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Printed Scholarly Books and E-book Reading Devices: A Comparative Life Cycle Assessment of Two Book Options

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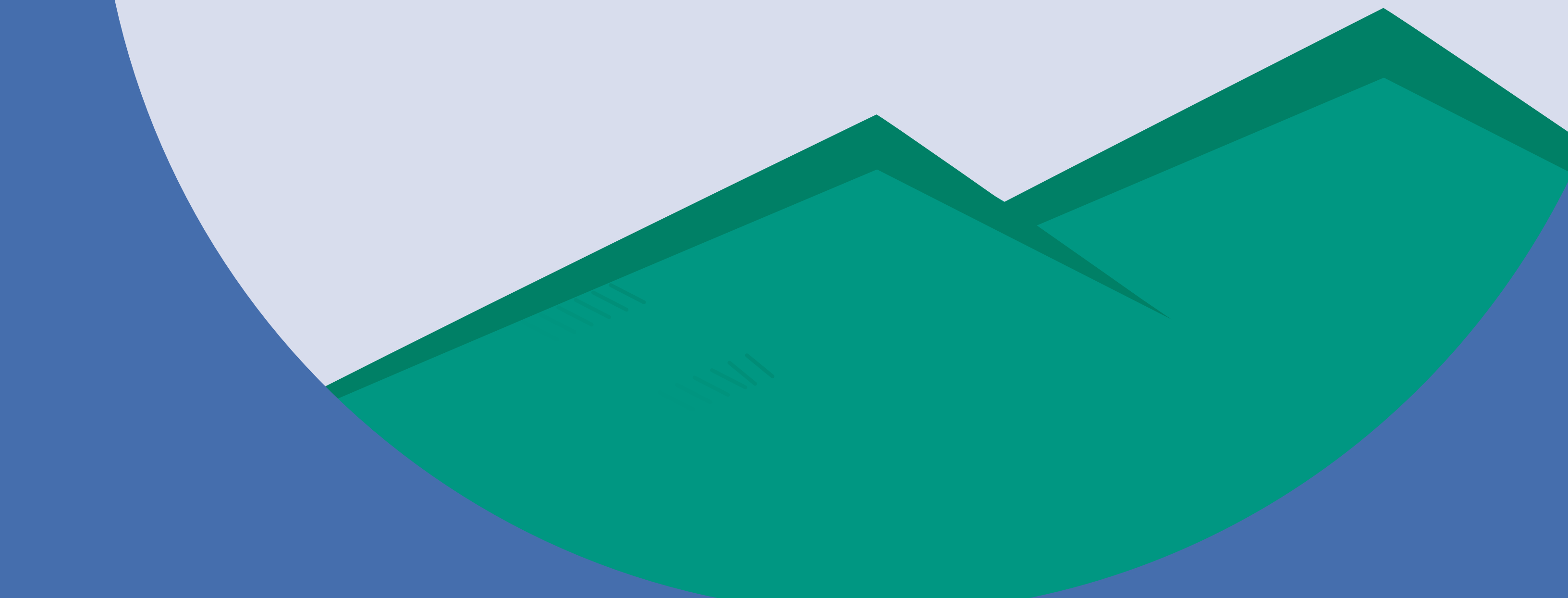

Printed Scholarly Books and E-book Reading Devices:
A Comparative Life Cycle Assessment of Two Book Options

By:

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ABSTRACT

Books have endured because they are remarkably well engineered; they are easy to use, portable, relatively cost-effective, and they require no instructions or manuals for their use. Despite their utility, however, conventional books published on paper have numerous limitations. Traditional, print-based books can be extremely costly to produce, store, ship, and sell. Less evident, however, are the environmental burdens associated with the infrastructure and activities necessary to produce and deliver the conventional book. With the advantage of being able to store thousands of pages of text and graphics in a single portable device, dedicated electronic reading devices (e-readers), on the other hand, are gaining in popularity. Several of these e-readers are now on the market and hold promise for the future of electronic publications in history, science and technology.

This paper presents the findings of a life-cycle assessment (LCA) of two different book options – electronic and print. The purpose of this study is two-fold: (1) to investigate the life cycle environmental aspects of e-publishing of scholarly books and e-book reading devices (i.e. e-readers); and (2) to apply the life cycle models to a variety of scholarly e-book applications and compare LCA results for traditional print based counterparts. This study compared the life-cycle burdens and impacts of a college student reading 40 scholarly books and the equivalent amount of digitized information (53.6-MB) using a dedicated e-book reading device. Total primary energy, material and water requirements, air and water pollutant emissions, and solid wastes for each system were evaluated. By comparing these two book options, this study provides industry, consumers, and policy makers with valuable information necessary to make environmentally informed decisions regarding e-book technologies.

E-reader critics have rightfully argued that e-readers are not conducive to long sessions of reading text from a screen, lack the tactile appeal and “atmosphere” of conventional books, and are inconvenient in the sense that they represent yet another device that the user must purchase and learn to use. However, from an environmental standpoint, it is difficult to argue against the integration of e-readers into a school’s curriculum, especially if the original user chooses to retain rather than resell the book or if the utility of owning the book expires (i.e. the book is discarded). The most notable observations gleaned from this study are as follows:

- Environmental burdens associated with electronic book storage (i.e. server storage) are small when compared to the physical storage of books (i.e. bookstore).
- E-readers eliminate personal transportation-related burdens since they allow for instant accessibility to digitized texts (i.e. anywhere there is Internet access).
- E-readers are more compact and are less material intensive than the equivalent number of printed books.
- Although the most significant contributor to the e-reader’s LCA results, electricity generation for e-reader use had less of an environmental impact than did paper production for the conventional book system.

The intention of this study is not discourage the use of the printed book. Rather, this paper provides industry, consumers, and policy makers with a better understanding of the potential environmental impacts associated with traditional and electronic book systems. Further, this study also provides another case study examining the relationship between information technology and the environment that can contribute to product design improvements and the development of more sustainable technologies.

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1 INTRODUCTION

1.1 Origins of Study

1.1.1 Electronic Publishing, E-books, and Their Impacts

When the father of the printing press, Johann Gutenburg, looked towards the future, he could never have dreamed that one small invention could revolutionize the world. The gift of publishing provided authors with an effective and efficient mechanism by which to communicate ideas, observations, commentary, plays, poetry, science, mathematics, and so on. Although there have been many significant technological advances since the invention of the Gutenburg printing press in 1450, the book industry remained essentially unchanged until the advent of the Internet and electronic commerce. Now, with the widespread availability of computers and the Internet (over 830 million users worldwide[1]), we stand at the crossroads of a literary revolution.

With the aforementioned technology in place, electronic publishing is primed to revolutionize the world, by giving every individual the ability to self-publish their ideas, stories, and books, without the prohibitive costs associated with conventional publishing. The Internet serves as a new medium for publishing, at zero or next to zero cost, and provides the possibility of broadcasting content to tens, perhaps hundreds of millions of potential readers. Thanks to recent technology advances in information processing and the explosive growth of information technology (IT), commercial electronic publishing has been made a reality.

Conventional approaches to book production have involved either manual or mechanical binding of sheets of paper in order to form an organized, structured, composite entity. New publication media now offer many alternative approaches to the creation of books and the ways in which they can be disseminated and used. The most recent trend in the publishing industry is the development of electronic books (e-books), which has the potential to be the most far-reaching change since Gutenburg's invention. E-books have recently been characterized as "a meteor striking the scholarly publication world" (Flowers 1999) and during the last few years, e-books have become one of the new frontiers for digitization in the publishing and library communities (Machovec 2002).

Fifteen years ago, e-book content was pretty much limited to self published science fiction, libertarian manifestos and works in the public domain. Since the mid-1990s, however, nearly all books published in nearly all countries have been typeset from digital files, which can be transmitted worldwide and downloaded in readable form on screens or as books printed on demand (Epstein 2001). Moreover, many older titles, some of them long out of print and with expired copyrights have now been digitized. Additionally, many scholarly, technical, and scientific books as well as scientific papers, journals, corporate documents, publications of non-governmental organizations, and government documents, can now be delivered electronically. In recent years, several major book and

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[1] www.netsizer.com, accessed December 13, 2002.

periodical publishers including, Random House, McGraw-Hill, MacMillan, Newsweek, and The Wall Street Journal, have jumped on the e-book bandwagon. With major players such as Microsoft, the world's largest software developer, and Barnes & Noble, the world's largest book retailer, joining forces and contributing substantial resources, e-books are rapidly moving out of realm of the research laboratory and into the practical marketplace as a viable consumer product (Hawkins 2000). In light of this, the Association of American Publishers predicts that 28 million people will be using electronic devices to read books by the year 2005 (Basch 2000).

Electronic books can be downloaded from the web, and then read using special devices, known as e-readers. An e-reader allows you to store several books at once, and is portable, just like a traditional book. E-readers are not only being used by the general public but also by specific groups of people for their own special purposes, and the available banks of digital texts are constantly growing. These specific groups include college and high school students, mobile professionals, and people with vision problems.

What are the potential consequences of this displacement of printed text with digitized text? Although digital technologies have been recognized for their potential to facilitate communication, simplify everyday life, and improve environmental conditions, there can be negative unintended consequences associated with the proliferation of these technologies. On the other hand, as numerous examples testify, unintended consequences can just as often be for the good. The Internet, for instance, which all but the most technophobic would agree is a terrific innovation, grew more or less accidentally out of obscure military research (Whitman 1996). As such, the present study was undertaken to more fully investigate the long-term consequences of this prodigious shift from printed text to digitized text.

1.1.2 Focus on E-readers

Due to the enormous complexity of the e-publishing network, it was necessary to narrow the focus of this investigation to a manageable scope. Given the prediction that future textbooks, reference books, and manuals could be mainly digital (Levy 2000) and the fact that electronic reading devices are one of the emerging digital options, e-readers were chosen as the focus of this research.

1.2 Significance of Topic

1.2.1 Impact of Disruptive Technologies

History has shown repeatedly that technology is never neutral, and the benefits and deficits of new technology are not distributed equally - there are winners, and there are losers, and it's not always clear who the winners are until the losers are vanquished (Postman 1993). If we accept this as true, we ought to be very careful about introducing new technologies without first studying their potential effects. When a new technology comes along that seems to change everything, the ultimate implications are not always readily apparent. For example, the invention of the transistor and then the integrated circuit made information processing far cheaper and faster than ever before. The eventual result: the Internet Age. Other examples of disruptive technologies include railroads, the telephone, electric power, and the automobile. Due to the fact that technological innovations always interact with complex social structures in unexpected ways (Guedon 1994), it is necessary to study them to expose these unforeseeable consequences before they can have a potentially damaging effect.

1.2.2 Growth in Interest over E-books

The recent spate of high-profile e-publishing bankruptcies, such as netLibrary and Reciprocal, and disappointing sales of devices and content have led some to declare the e-book movement moribund. However, a number of publishers and distributors are optimistic and quick to report rising sales and even profits (Reid 2002). E-book publisher, Palm Digital Media, for example, reported selling more than 180,000 e-book downloads in 2001, representing a 40% increase in unit volume from the previous year. Another e-book publisher, Fictionwise.com, sold more than 100,000 e-book downloads, tripled its membership to 33,000 members, and reported a 400% increase in revenue in 2001. Furthermore, Forrester Research, Inc. predicts this trend to continue for many in the e-publishing industry, forecasting that e-book sales will rise to $7.8 billion by 2005 (Evans 2001).

Although many readers and educators have a powerful psychological and sociological attachment to the conventional book, pilot projects and quiet adoption of various e-book systems have been occurring throughout higher education and the health professions, among other arenas. Several universities have begun to integrate handheld, portable e-book devices into their classrooms and libraries. The Electronic Text Center at the University of Virginia, for example, ran a pilot project in which two courses were provided with Pocket PCs pre-loaded with the course material in e-book format. Overall, an overwhelming majority of the students who participated in this study enjoyed reading on these devices, despite some technological and functional limitations (Ruotolo 2002). As another sign of growth in the e-publishing industry, Culturecom Holdings, a Hong Kong listed e-publisher, plans to launch its electronic textbook, or e-textbook, product in September of 2002. Ten schools from nine provinces, covering 600 secondary school students, will be involved in the project.

Academic libraries are also riding the digital wave. Academic libraries and university presses at Big Ten universities and the University of Chicago have teamed up in an electronic publishing venture that aims to put hundreds of scholarly books in digital form (Young 2002). The goal of this project is to enable these university presses to offer all of their books in electronic form. Additionally, the University of Michigan is participating in a five year project (1999-2004) which is supported through a $3-million grant from The Andrew W. Mellon Foundation. This project, known as the History E-Book Project, is intended to foster broader acceptance by the scholarly community of e-books by creating electronic books of high quality, to develop publishing processes that will help streamline production, and to establish the viability of scholarly publishing in electronic format. The University of Michigan Press is one of ten publishers participating in this project. Of more than 40,000 books published in the U.S. each year, one out of ten bears the imprint of a university press. Thus, this project represents a significant impact for e-books. The History E-Book Project plans to convert 500 backlist titles to electronic format and to publish 85 completely new electronic titles.

Finally, many scholarly, technical, and scientific books as well as scientific papers, journals, corporate documents, and government documents, can now be delivered electronically. As discussed previously, several major book and periodical publishers including, Random House, McGraw-Hill, MacMillan, Newsweek, and The Wall Street Journal, have jumped on the e-book bandwagon.

1.3 Method of Inquiry

Due to the enormous complexity of the e-publishing network and Internet-related systems, life-cycle assessment (LCA), a comprehensive environmental evaluation tool that looks at the full life cycle of a product, was considered appropriate for this study. Moreover, studies by Caudill (2000) and Zurkirch and Reichart (2000), which investigate the indirect effects of Internet-related systems, are excellent examples where LCA has been applied successfully. LCA, which is increasingly being used by industry professionals, is particularly useful for exposing unintended environmental consequences of a product system. This investigation will follow the International Organization for Standardization (ISO) 14000 methods for life cycle assessment. Section 3 discusses the LCA research methodology.

1.4 Organization of Report

This report is divided into eight sections. These sections are briefly discussed below.

Section 1: Discusses the study’s wider context and importance.
Section 2: Provides background information about e-publishing and e-books.
Section 3: Discusses LCA methodology.
Section 4: Discusses the study’s purpose and scope
Section 5: Describes the modeling process and provides LCI results for individual system elements.
Section 6: Provides LCIA results for each product system.
Section 7: Examines each product system’s sensitivity to various inputs.
Section 8: Provides conclusions, recommendations, and possibilities for future research.

2 AN OVERVIEW OF ELECTRONIC PUBLISHING AND E-BOOKS

This section introduces basic terminology and concepts relating to e-publishing and e-books. Readers who are already familiar with e-books and e-book readers should feel comfortable moving directly to Section 3.

2.1 What is Electronic Publishing?

Electronic publishing (e-publishing) is the process of creating and disseminating information via electronic means including email and via the Web. Electronically published materials may originate as traditional paper publishing or may be created specifically for electronic transfer[2].

2.2 What are E-books?

It is essential to distinguish between the different types of e-books since imprecise terminology has been a major source of confusion in this area. E-books are generally found in one of four applications discussed below:

Downloadable e-books
The contents of a book are available on a Web site for downloading to the end user's PC. The user does not have to purchase any special reading device and can employ standard and well-known Web techniques to obtain the book.

Dedicated e-book reading devices (e-readers)
A dedicated hardware device, which has a high-quality screen and special capabilities for reading downloadable e-books.

Web-accessible e-books
E-books that remain on a provider's Web site that can usually be accessed for free.

Print-on-Demand (POD) e-books
The contents of a book are stored on a computer system connected to a printer, from which printed and bound copies are produced on demand.

2.3 E-book Niches

The college classroom is an obvious target for e-book implementation because college students typically embrace new technologies and also purchase a high volume of expensive, cumbersome and rapidly discarded books. There are many who believe that the new generation of learners, what Dan Tapscott calls the Net Generation, or N-Gen, are much more accustomed to reading and learning from a screen. In his book *Growing Up Digital*, Tapscott (1998) writes, "Kids look at computers the same way boomers look at TV. This shift from broadcast medium (television) to interactive medium (the Net) signals a 'generation lap' in which the N-Gen is lapping its parents on the 'info-track.'"

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[2] www.desktoppub.about.com, accessed August 14, 2002.

Dedicated readers could have a substantial market for textbooks. Apparently, the electronic textbook (e-textbook) market is growing fast and e-textbooks are becoming quite popular in educational institutions (Hawkins 2001). Some professors have encouraged students to purchase e-textbooks for their courses, and others are currently working with publishers and vendors to help them develop electronic versions of textbooks for their classes. Metatext, Inc., for example, provides a service that allows professors to customize college-level textbooks and reading lists. Students are also favorable to the idea of carrying a single, lightweight handheld e-reader that contains the contents of several texts over the alternative of carrying a heavy backpack containing several large textbooks. Further, most e-textbooks offer enhanced and powerful capabilities of electronic information searching, annotating, highlighting, and customizing the user interface.

Other specific genres that have had success in electronic form include bibliographies, abstracting and indexing guides, dictionaries, encyclopedias, directories, cookbooks, product catalogs, and maintenance manuals. These genres share certain properties in that their readers want to find and then read relatively short chunks of specific text, they are frequently updated, and in some cases, they can be greatly enriched by multimedia and expanded content (Lynch 1999).

2.4 General Benefits of E-books

Although the e-book is in its infancy, e-books offer several advantages over traditional print-based books. The general benefits associated with e-books include:

- Production costs for e-books are frequently much lower than printed books since there are potentially no printing, shipping, or storage costs associated with e-books
- Physical storage costs associated with e-books are minimized since digitized books occupy no shelf space. Thus, libraries can support users without the need of physical processing, physical maintenance, or physical storage and distribution. This may be especially useful in developing countries where bookstores and libraries are scarce.
- E-books can remain in print and in stock as long as digital storage devices survive.
- E-books can potentially eliminate shipping costs since digital texts can be transmitted directly to consumers via the Internet. Thus, e-books can be sold for much less than conventional books that are shipped physically from printers in Boston or London to wholesalers' warehouses and finally to thousands of retail bookstores from which, after a few months, unsold copies are returned to their publishers and destroyed.
- E-books do not wear out with repeated use, which is especially relevant in a library environment.
- E-books enable virtually anyone to self-publish without paying outrageous fees from vanity publishers, or getting rejection letters from regular publishers.
- Digital information is available on demand (i.e. anywhere there is Internet access). Therefore, e-books save the user a trip to the bookstore or library and have the potential of catering to the need for instant gratification.

- Many titles can now be published or republished that wouldn't have had a chance before e-publishing since publishing e-books isn't as costly as publishing printed books. These include the following:
    - Niche books that don't attract a large audience
    - Mid-list titles (i.e. quality books that aren't destined to be best sellers)
    - Out-of-print books
    - Textbooks customized for a specific course
    - Digital books that take advantage of interactive elements like hyperlinks and media clips.
- Electronic content can be readily updated so that the user can have access to the most recent edition. Electronic media have a much more rapid turnaround time than print materials, allowing electronic versions of reference works to remain more current.
- The electronic edition of a book may well be available before the printed copy appears since updating a printed book is usually a very long process.
- The Internet transcends international boundaries. Thus, it may be difficult to impose government regulations (i.e. banning).
- User can add bookmarks without damaging the book.
- E-books incorporate links to a dictionary, thesaurus, etc.
- E-books have potential environmental benefits, which this thesis plans to investigate.

2.5 E-reader Advantages

In addition to the general benefits of e-books discussed above, e-readers provide the following advantages:

- Have the ability to store multiple books on a single device.
- Compact and lighter in weight than the equivalent number of printed books.
- Tremendous versatility and instant accessibility. Convenient to carry, easy to learn to use, and some have backlit screens so they can be used anywhere, even in the dark.
- Have capabilities useful for book reading such as the ability to electronically bookmark a page, highlight passages, and search for words or phrases.

2.6 General Limitations of E-books

Critics have identified the following limitations of e-books:

- PCs are not conducive to long sessions of reading text from a screen.
- Lack tactile appeal and "atmosphere" of conventional books.
- Limited number of titles available.
- Security and copyright considerations.

2.7 E-reader Limitations

In addition to the general limitations of e-books discussed above, potential weaknesses of e-readers include the following:

- Inconvenient in the sense that e-readers represent yet another device that the user must purchase and learn to use.
- Standards for e-books are still in development, so an e-book for one type or brand of e-reader may not be readable on another.
- Question of obsolescence.
- Potential need for technical support.
- Readability factor.
- Must buy replacement if device breaks.
- Battery life/cost issues.
- Potential environmental burdens associated with electricity use.
- Users find some e-readers awkward and uncomfortable to use because the screen images scroll up and down instead of left to right like a conventional book.

3 METHODOLOGY

Due to the growing interests in environmental protection and increased awareness of the adverse impacts associated with manufacturing processes and consumption patterns, several methods/tools have been developed to better understand and reduce these impacts. One of the techniques being developed for this purpose is Life Cycle Assessment (LCA). LCA is a primary analytical tool of industrial ecology, which constitutes the systematic view of local, regional, and global uses and flows associated with products, processes, and industrial and economic sectors. LCA, which is increasingly being used by industry professionals, allows for a comprehensive analysis of the environmental consequences of a product system over its entire life. The LCA concept is one in which an industrial system is viewed not in isolation from its surrounding systems but in concert with them (Jelinski 1991). LCA has already proven itself to be a useful tool for examining the impacts of like cases (e.g. networks, digital libraries) from a systems perspective (Gard 2001). The current study will also employ the LCA approach. This investigation followed the International Organization for Standardization (ISO) 14000 methods for LCA.

LCA establishes an environmental profile of a product system by quantifying and clarifying the environmental aspects (i.e. energy consumption, material consumption, solid waste generation, etc.) associated with the product system. These results may then be used to evaluate the associated ecological and human impacts. LCAs evaluate the environmental impacts from each of the following major life-cycle stages:

- Raw material extraction/acquisition;
- Material processing;
- Product manufacturing;
- Product use, maintenance, and repair; and
- Final disposition/end-of-life.

These stages can be divided further into sub-stages. Material production, for example, can be divided into raw material acquisition (mining, drilling for petroleum, harvesting) and material processing (smelting, polymerization), while manufacturing can be split into part and component fabrication processes and system assembly (EPA 1992). The inputs (e.g. resources and energy) and outputs (e.g. products, emissions, and waste) within each life-cycle stage, as well as the interaction between each stage (e.g. transportation) are also evaluated within the LCA framework. A generic product system comprising the five life cycle stages is shown below (Figure 3-1).

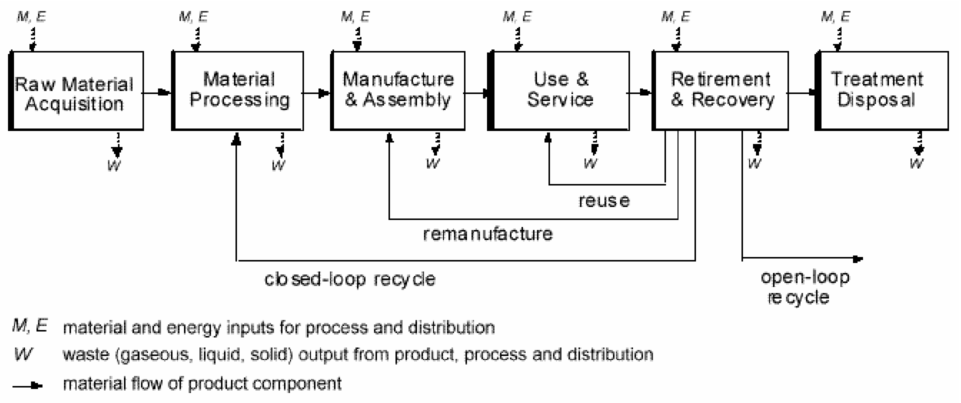

Figure 3-1: Life Cycle of a Generic Product System

3.1 LCA Components

The international standard, ISO 14040, has defined the four major components of an LCA as: (1) goal definition and scope; (2) inventory analysis; (3) impact assessment; and (4) interpretation of results. These components are briefly described below:

3.1.1 Goal Definition and Scope

This LCA component lays out why the LCA is being conducted and its intended use, considers for whom the results are intended, and determines the system and data categories to be studied. Section 4 discusses this LCA component, as it relates to this study, in greater detail.

3.1.2 Inventory Analysis

The inventory analysis component identifies and quantifies the material and energy resource inputs as well as the emissions and product outputs from the unit processes in the life cycle of the product system. This analysis, known as life-cycle inventory (LCI), is discussed in Section 5.

3.1.3 Impact Assessment

This LCA component characterizes the effects of the inputs and outputs on the environment and human and ecological health. According to the EPA's life-cycle impact assessment framework (1995), impact assessment includes three sub-components: (1) Classification – the process of assignment and initial aggregation of data from inventory studies into various impact categories; (2) Characterization – applying impact assessment tools to analyze and quantify potential ecological health, human health, and resource depletion impacts; (3) Valuation – integrating across impact categories using weights or other approaches enabling decision makers to assimilate and consider the full range of relevant outcomes. Section 6 discusses this LCA component, as it relates to this study, in greater detail.

3.1.4 Life Cycle Interpretation

Interpretation involves using findings from the analysis to identify and evaluate opportunities for reducing life-cycle environmental impacts. This LCA component also summarizes the conclusions of the study and makes recommendations for improvement to decision-makers regarding design or policy issues. Life cycle interpretation is presented in Section 8.

3.2 LCA Benefits

The general benefits associated with the LCA approach include:

- Opportunities to improve the environmental aspects of products at various points in their life cycle are identified.
- Results for different product systems may be compared, provided that the assumptions and context of each study are the same.
- LCA models have the potential of exposing unforeseeable consequences.
- A holistic perspective can facilitate understanding of complex relationships and is particularly useful when examining still-evolving technologies (Gard 2001), such as electronic reading devices.

3.3 LCA Limitations

Although considered by many industry professionals as a powerful investigation tool, the LCA approach is viewed by critics as inherently limited in its capabilities. Critics have identified the following LCA limitations:

- Difficulty in obtaining accurate data. The accuracy of LCA studies may be limited by accessibility or availability of relevant data or data quality.
- Time constraints and limited resources jeopardize LCA completeness and comprehensiveness. In light of this, the current study was conducted within the context and time frame of a Masters thesis project.
- The choices and assumptions made in LCA (i.e. system boundaries and results interpretation) are subjective by nature.

4 GOAL DEFINITION AND SCOPE

4.1 Introduction

This section presents the goal and scope of this study, including its purpose, previous research, descriptions of the product systems being evaluated, unit of analysis (i.e. functional unit), and the system boundaries. Goal and scope definition is the first phase of LCA and is important because it determines why the LCA is being conducted and its intended use, as well as the system and data categories to be studied.

4.1.1 Purpose of Study

This case study is a comparative LCA of two different book options – electronic and print – available to the average consumer in the marketplace. Given the expected market growth of e-books (Evans 2001), the prediction that future textbooks, reference books, and manuals could be mainly digital (Levy 2000), and the fact that the relative life-cycle environmental impacts of e-books and e-readers have not been scientifically established to date, there is a need for a quantitative environmental LCA of e-book technologies.

The purpose of this study is two-fold: (1) to investigate the life cycle environmental aspects of e-publishing of scholarly books and e-book reading devices (i.e. e-readers); and (2) to apply the life cycle models to a variety of scholarly e-book applications and compare LCA results for traditional print based counterparts. By comparing these two options, this thesis provides industry and consumers with valuable information necessary to make environmentally informed decisions regarding e-book technology and subsequently enable them to consider the relative environmental trade-offs associated with each book system (i.e. electronic vs. print). This study is designed to provide the electronics and e-publishing industries with information needed to improve the environmental attributes of e-books and e-readers. Further, when considering which book system to invest in, consumers and companies can refer to the results of this study to assist them in making environmentally informed decisions. This study will enable consumers to formulate a more educated decision about which book system has the least environmental burden. More specifically, this study documents the raw material mass requirements, energy requirements, and environmental impacts created throughout the life cycle of each product.

4.1.2 Previous Research

Although previous research has investigated the environmental impacts of digital libraries, IT equipment, e-publishing, and electronic journals, there has not been a quantitative LCA that addresses e-books and e-readers. Moreover, few studies have evaluated the environmental impacts of e-publishing and e-book technologies, such as that conducted by Gard (2001), which evaluated the environmental performance of an electronic journal collection. However, the study's scope was limited in that only life-cycle energy consumption was addressed. Finally, although there is a growing body of e-book related research, most of these studies have focused on user preferences and the effects of the new technology on reading practices and have only qualitatively discussed environmental issues related to e-book technologies.

4.1.3 Intended Audience and Use of Study

The primary targets for this study include the electronics and e-publishing industries, policy makers, and consumers in the marketplace. The expected value of this study to these groups is highlighted below.

Electronics and e-publishing industry

- Provide industry with an analysis that evaluates the life-cycle environmental impacts of e-book and e-reader technologies.
- Provide guidance for improving design and use of these technologies.
- Assist manufacturers in evaluating alternative products and processes that reduce releases of toxic chemicals and reduce risks to human health and the environment in addition to optimizing traditional parameters, such as cost and performance.
- Enable electronics and e-publishing industry to make environmentally informed decisions when assessing changes in product and product design, raw material use, industrial processing, and waste management.
- Provide specific data for communicating the environmental benefits of e-book systems to clients, consumers, and colleagues.

Policy Makers

- Provide a scientific reference for evaluating e-book and e-reader technologies
- Provide a basis for developing regulatory and economic instruments that encourage more sustainable practices in regards to traditional and electronic book systems.

Consumers in the Marketplace

- Enable consumers to make a more educated decision about which book system has the least environmental burden.
- Provide consumers with an analysis that evaluates the trade-offs associated with each book system.

4.2 System Boundaries

This LCA focuses on the U.S. e-book reader and printed book markets. Therefore, the geographic boundary for the use, distribution, and disposition stages of the two systems is limited to the United States. However, geographic boundaries for raw material extraction, material processing, and product manufacture are assumed worldwide, particularly for IT equipment. Primary energy calculations were based on the average U.S. grid efficiency for electricity production.

In terms of temporal boundaries, this study covers a period from 2002-2006 (4 years). It is believed that this time frame balances two competing needs in that it is 1) long enough to uncover the primary environmental effects associated with each book system, but also 2) short enough to realistically deal with the rapidly changing nature of e-book technologies.

4.3 General Assumptions

To facilitate a comparison of the life cycles of the two book systems, several general assumptions were made and are detailed below.

- The document creation for the electronic and traditional book systems is virtually identical. Therefore, it has been mutually excluded from this analysis.
- Although digital media enable information to be presented in a variety of formats including tables, graphs, pictures, rotateable 3-D images, audio and video footage, and hypertext linking, these specific modes of communication are not considered in the present study. Hence, only printed and digital texts are considered to make an equivalent comparison between the electronic and traditional book systems.
- Product Selection: The REB 1100 dedicated e-book reader (REB 1100) from RCA was chosen as the e-book reader model to be investigated in this study. The device, licensed from Gemstar® and based on the popular Rocket eBook, runs on its own proprietary e-book format. A brief description of the REB 1100 is provided below.

  - Approximate price = $300
  - Weight = 18.0 ounces
  - Dimensions = 5.0” x 7.0” x 1.5”
  - Useful life = 5 years
  - Screen type = 5.5” monochrome LCD
  - Screen Resolution/Size = 320 x 480
  - Battery Type/Life = rechargeable lithium ion / ~30 hours
  - RAM = 8 MB with 72 MB expandable memory
  - Built-in 33.6 Kbps modem

- Although the REB 1100 contains an internal Li-Ion rechargeable battery, which allows for portable use, this study will investigate the case where the device is plugged into an outlet. This scenario represents an upper limit for energy consumption during use of the e-book reader (see Section 5.3.4.7 for a more detailed description.

4.4 Functional Unit

The functional unit is a measure of the performance of the functional outputs of the product system and is necessary to ensure comparability of LCA results (ISO 14040 1997). Before defining the functional unit, it is helpful to establish a user profile. This study’s user profile, which summarizes the user’s most noteworthy characteristics and use patterns, is presented below.

- The “user” is defined as a typical college student in the United States.
- The user owns a dedicated e-book reading device (e.g. REB 1100)
- The student is enrolled in a generic, 4-year Bachelor of Arts (B.A.) program. The program’s curriculum requires each student to enroll in 5 classes per semester. Assuming 2 semesters per year, the student enrolls in 40 total classes over 4 years.
- It is assumed that the student must purchase one scholarly book per class (40 textbooks over 4 years).
- Assuming that the texts are available at a university bookstore, the user will purchase five books per visit to the bookstore, thus requiring a total of 8 trips to the bookstore.
- This study assumes that the book(s) in question will maintain its physical integrity over the 4-year time frame of this analysis and that the user will choose to retain rather than resell the book.

Although simplified, the user profile serves as a reasonable basis for this investigation. For this study, the function is defined as the actual process of a college student reading 40 scholarly e-books one time each using a dedicated e-book reading device. With this in mind, the digital system’s functional unit (FU) was then determined to be forty scholarly e-books, which are to be downloaded and viewed using the REB 1100 e-reader. In an LCA, product systems are evaluated on a functionally equivalent basis. Therefore, the print-based FU equivalent is forty printed scholarly books.

For the traditional print-based system, the length of the average scholarly book was assumed to be 500 pages with a standard-sized 7” x 10” high-end print run. This standard book unit (i.e. 500 page, 7” x 10” scholarly book) is represented in the digital system as the file size of an equivalent e-book. In order to determine this equivalency, the total file size (in kilobytes per word) was calculated from a selection of five random e-books, which might comprise a reading list for a standard college-level B.A. course. Assuming 1” (top and bottom) and 1.25” (left and right) margins with a font size of 10 and single line spacing, these results were averaged and multiplied by the average number of words per standard textbook (267,000 words)[3] to determine the number of kilobytes (kB) per textbook. It should be noted that these calculations exclude any pictures/images and only consider the words within the main body of the text. Further, file size is based on Gemstar’s unique operating system. The results are presented in Table 4-1 shown below.

Table 4-1: File Size for an E-book System.

Source	File Size (kB)	Words in body of text	kB/Words
The Origin of Species by Charles Darwin	429	208,327	0.0021
Alice in Wonderland by Lewis Carrol	350	26,695	0.013
Jane Eyre by Charlotte Bronte	595	134,259	0.0044

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[3] Words per page determined using a standard word processing program (Microsoft Word) and adjusting the margins, line spacing and font size appropriately.

The Three Musketeers By Alexandre Dumas	759	229,877	0.0033
Great Expectations by Charles Dickens	546	186,341	0.0029

Source: http://www.textlibrary.com/
http://www.powells.com/

Average File Size (per word) = 0.00514 kB/word

Average words per standard book unit (i.e. a 500 page 7” x 10” book)

= 534 words/page = 267,000 words

Average File Size (per standard book unit) = **1,372 kB**

Thus, this study assumes that 40 scholarly books will have a file size of approximately 54,895 kB (53.6 MB[4]) when using the Gemstar operating system. Since the REB 1100 has 8 MB of memory, it is assumed that the student will erase the previous semester’s e-books from the device before proceeding to download the next set. Table 4-2 summarizes the FU equivalencies for each product system.

Table 4-2: Functional Unit Equivalencies

Product System	Functional Unit
Printed Scholarly Book	Forty 500 page, 7” x 10” scholarly books
E-Reader	40 scholarly e-books (1,372 kB/e-book)

Sensitivity analyses (Section 7) were conducted to explore the effect of re-reading material and studying using the e-reader.

4.5 System Descriptions

As discussed earlier, the two product systems being analyzed in this study include the e-book reading devices used in a classroom setting and their traditional print-based counterparts. Typical LCAs investigate environmental impacts across several life cycle stages. For example, an LCA of a conventional product manufactured in a plant may include the following life cycle stages: raw material acquisition; material processing; component production; product manufacture and assembly; use, maintenance and repair; reuse and recycling; and final disposal. However, the boundaries of these life cycle stages can be modified/adjusted to facilitate modeling. Thus, the current study adopted a slightly different scheme that investigates five separate life cycle stages: material production, manufacturing, product distribution, use, and end-of-life management. Separate life cycles models were developed for each system and are included in Figures 4-1 and 4-2, which can be found at the end of this section. A description of each product system is discussed below.

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[4] 1 MB = 1,024 kB

4.5.1 Traditional Book System

As discussed earlier, this cradle-to-grave LCA includes five life-cycle stages: (1) material production; (2) product manufacturing; (3) product distribution; (4) product use; and (5) end-of-life management. Also included in this LCA model are the activities necessary to move materials between stages (i.e. transport of raw materials) in addition to the product distribution stage. The process flow diagram and model elements for a traditional book system are depicted in Figure 4-1. Each box in the diagram represents an individual model element. A brief description of each life cycle stage, and associated model elements (shown in italics), is presented below.

4.5.1.1 Material Production Stage

In general, printed books are comprised of paper and ink components. These components are derived from various natural resource stocks (*Ink Production, Paper Production*).

4.5.1.2 Manufacturing Stage

The manufacturing phase for the traditional book system begins immediately following publishing activities (*Document Creation)*. The document is then printed, assembled, and bound *(Book Printing Operations*) whereupon it is ready for delivery.

4.5.1.3 Distribution Stage

After the book printing operations, the finished product is shipped (*Textbook Delivery*) from the printer to a wholesaler's warehouse and finally to a retail bookstore or library. Additional environmental burdens are associated with the production and disposition of the book's packaging (*Packaging Production, Packaging Disposition*).

4.5.1.4 Use Stage

After receipt at the bookstore, each book is processed and managed *(Book Storage*). Bookstores have operating systems (*Facility Infrastructure*) in place to help support these activities. A student who does not own a particular copy of a book may wish to travel to the bookstore (*Personal Transportation*) in order to purchase the book for future use (*Book Retrieval and Viewing*).

4.5.1.5 End of Life Stage

When the physical integrity of a book is damaged beyond use or the utility of owning the book expires, the student will usually choose to dispose of the book (*Book Disposition*) or resell the book.

4.5.2 E-book System

Figure 4-2 depicts the boundaries and model elements for the e-book system over each life cycle stage. Each box in the diagram represents an individual model element. A brief description of each life cycle stage, and associated model elements (shown in italics), is presented below.

4.5.2.1 Material Production Stage

In general, e-readers are comprised of several plastic, rubber, metal, and glass components. These components are derived from various natural resource stocks (*E-Reader Materials Processing*).

4.5.2.2 Manufacturing Stage

The manufacturing phase for the electronic book system involves several manufacturing processes *(E-Reader Manufacturing, Battery Manufacturing, Cable Manufacturing*), whereupon the device is assembled and ready for delivery.

4.5.2.3 Distribution Stage

Following e-reader assembly, the finished product is shipped (*E-Reader Delivery*) from the manufacturer to a wholesaler's warehouse and finally to a retail bookstore or library. Additional environmental burdens are associated with the production and disposition of the e-reader's packaging (*Packaging Production, Packaging Disposition*).

4.5.2.4 Use Stage

After receipt at a retail bookstore or library, each e-reader is processed and managed *(E-Book Storage*). The user may wish to travel to a bookstore (*Personal Transportation*) and purchase an e-reader device. Additional building-related functions (*Facility Infrastructure*) are necessary to support the maintenance and storage of these devices.

The next use phase element deals with the creation of the e-book itself. A web-accessible e-book begins as a digital file where it then goes through a series of standard publishing steps (*Document Creation*). Following the creation of a scholarly e-textbook, the data file is stored electronically on a server (*Data Storage*). Additional burdens are associated with manufacturing the server equipment (*Server Production*) and end-of-life management (*Serve Disposition*). When a user wishes to access/download an e-book, the data file must travel through a communications network (*Electronic File Transfer*). Additional environmental burdens are associated with the manufacturing and disposition of the networking equipment (*Network Equipment Production, Network Equipment Disposition*). After the e-book is downloaded, it is read directly using the e-reader device (*E-Reader Use*).

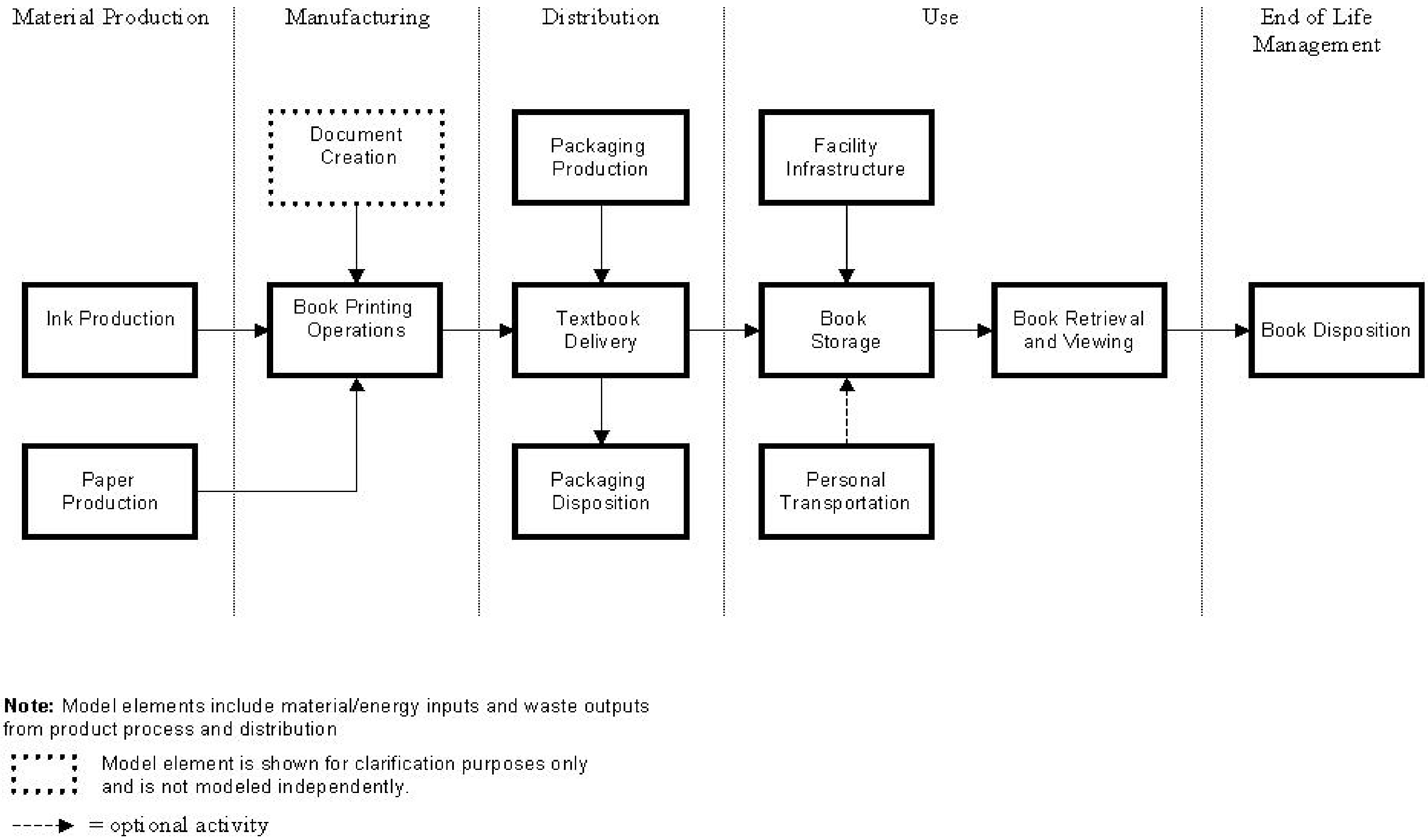
It should be noted that all server and network-related components are processes that support the use of the e-reader. Therefore, all server and network-related environmental burdens have been assigned to the e-reader system's overall Use Phase (see Figure 4-2).

4.5.2.5 End of Life Stage

End-of-life burdens include disposing of the used e-reader device (*E-Reader Disposition*).

LCI data was collected for individual model elements for both systems. Section 5 describes the methods for collecting LCI data and presents LCI results for each product system.

Figure 4-1: Life Cycle Process Flow Diagram – Conventional Book System

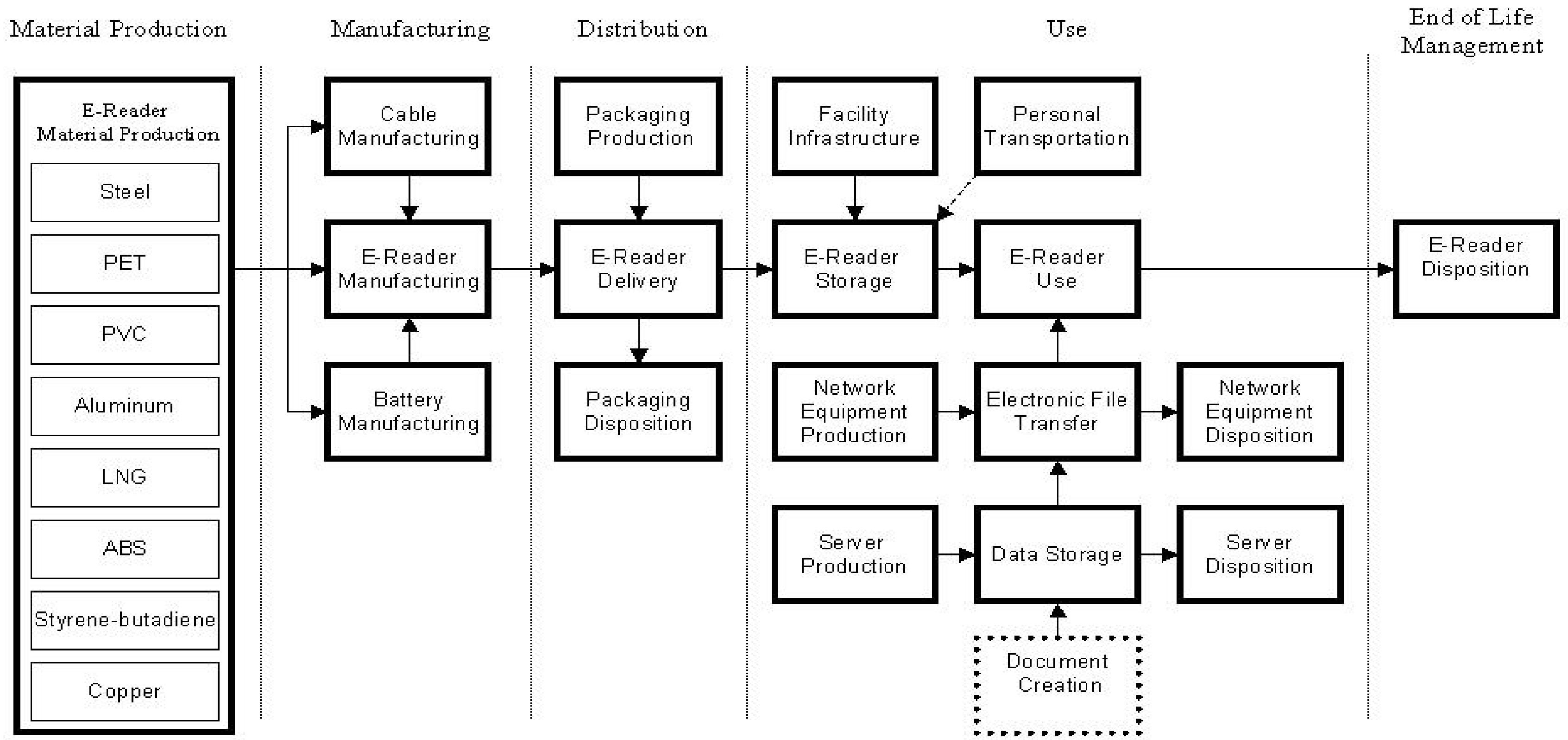


Note: Model elements include material/energy inputs and waste outputs from product process and distribution

⬚ Model element is shown for clarification purposes only and is not modeled independently.

----▶ = optional activity

Figure 4-2: Life Cycle Process Flow Diagram – E-Reader System



Note: Model elements include material/energy inputs and waste outputs from product process and distribution. Additionally, not all e-reader raw materials are shown.

Model element is shown for clarification purposes only and is not modeled independently.

----► = optional activity

Acronyms
PET = polyethylene terephthalate
PVC = polyvinyl chloride
LNG = liquefied natural gas
ABS = Acrylonitrile Butadiene Styrene

5 LIFE-CYCLE INVENTORY

Life-cycle inventory (LCI) involves the compilation and quantification of the material and resource inputs and outputs for a given product system throughout its life cycle. LCI is a “cradle to grave” accounting of the environmentally significant inputs and outputs of a system. The environmental burdens measured in this case study include material input requirements, total energy consumed, air and water emissions released, and total solid wastes associated with the product’s life-cycle. As shown in Figures 4-1 and 4-2, each product system is comprised of several unit processes/model elements. A conceptual diagram depicting the inventory described above for a given unit process is shown in Figure 5-1 below.

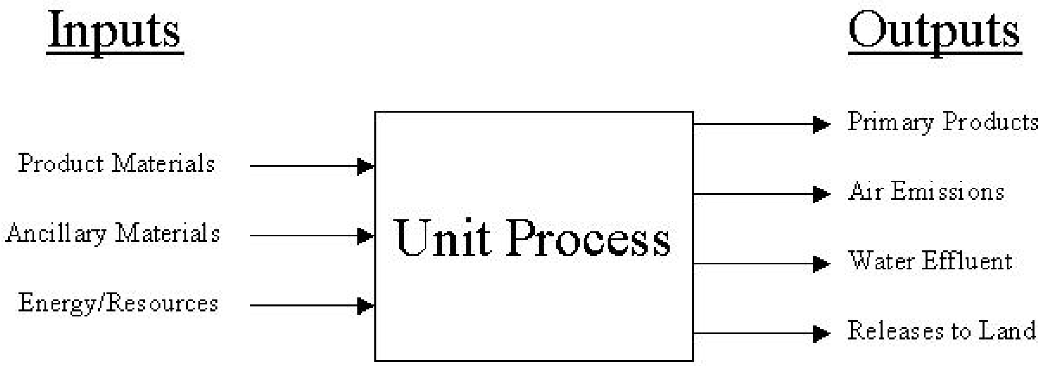


Figure 5-1: Life Cycle Unit Process Inventory

The purpose of this section is to describe the methods for collecting LCI data and present LCI results for each product system. LCI data were normalized with respect to the study’s functional unit, user profile, and 4-year time frame.

Section 5.1 presents general methodologies for LCI data collection. Model elements for each system are discussed sequentially, beginning with the conventional print-based book system (Section 5.2) followed by the e-reader system (Section 5.3). Where applicable, Sections 5.2 and 5.3 present 1) specific methodologies, 2) data sources and quality, and 3) limitations and uncertainties for each product system’s individual model elements. Section 5.4 then concludes with combined LCI data for each product system.

5.1 General Methodology

This section describes the data categories evaluated in this LCI, the evaluative decision rules employed in this study, and data collection sources.

Data Categories

Data categories for which inventory data were collected include material inputs, primary energy inputs, water consumption, pollutant emissions to air and water, and solid waste generation. Inventory data were normalized to mass per functional unit (in the case of material/resource inputs and emission/solid waste outputs) and megajoules (MJ) per functional unit (in the case of energy inputs). Recall that the digital system's FU is 40 scholarly e-books, which are to be downloaded and viewed using the REB 1100 e-reader. The printed book system's FU equivalent is forty 500 page, 7"x10" scholarly books.

Decision Rules

The collection and aggregation of appropriate data for a given product system remains a challenge for LCA practitioners. This study employed several decision rules as to which materials or components should be included in the overall modeled life-cycle of each product. Material inputs that account for more than one percent (1%) of the total mass of each product were given top priority for data collection. Similarly, materials or components that were known or suspected of having significant associated environmental and energy burdens were included in this analysis. Recognizing the time constraints and resource limitations of this study, materials or components that account for less than one percent of total mass for each system were excluded from this analysis.

Data Collection Sources

LCI data were collected from both primary and secondary sources. Primary data includes data that is directly accessible, plant-specific, and/or measurable from the field. Secondary data, on the other hand, includes data from literature resources or other LCAs, but may be applicable to the product of interest. Data was also obtained through visits to retail establishments and phone interviews with representatives of book/e-book manufacturers, distributors, and retailers.

5.2 Traditional Book System

This section presents a detailed description of the model elements for the traditional book system. The order of discussion follows the product's life-cycle stages from material production to end-of-life management, as shown in Figure 4-1.

5.2.1 Material Production Phase

A printed book's primary components (i.e. paper and ink) are generally derived from harvested wood and petroleum stocks. LCI data for paper and ink production represent environmental burdens associated with all aspects of raw material extraction. Consequently, this study's analysis of the traditional book system combines the environmental burdens from raw material extraction with material processing. Therefore, any activities attributable to petroleum production and wood harvesting have been incorporated into the *Ink Production* and *Paper Production* model element descriptions and are presented in the following sections.

5.2.1.1 Paper Production

Introduction

Paper is the primary component of a scholarly book. Present-day paper production steps, as described by The Institute of Paper Science and Technology (2000), are discussed below.

1. *Timber Preparation:* After delivery by truck or rail, the raw logs are soaked in water, debarked, and fed into a chipper.

2. *Pulping:* This process involves removing lignin, the substance that holds wood together, and other components of wood from the cellulose fibers used to make paper. The lignin is removed by the action of sodium hydroxide and sodium sulfate under heat and pressure. These cooking chemicals, otherwise known as white liquor, are combined with wood chips and fed into a digester. The lignin is dissolved and the cellulose fibers are released as pulp. Once "digestion" is complete, the pulp is separated from the spent chemicals (black liquor) and rinsed.

3. *Bleaching:* The rinsed pulp, which is too dark to use for most grades of paper, is then treated with several bleaching agents including chlorine, chlorine dioxide, ozone, and peroxide. Although chlorine provides the best bleaching results and does the least amount of damage to the fibers, concerns arise about its dioxin containing byproducts.

4. *Refining:* The bleached pulp is beaten with a series of rotating serrated, metal disks in order to flatten and fray the pulp's individual cellulose fibers. This process facilitates the paper web formation by assisting the cellulose fibers to bond together.

5. *Sheet Forming:* The refined pulp is then rinsed and diluted with water where it is subsequently mixed with clay or talc "fillers." The pulp/water mixture is dispensed onto a moving continuous mesh belt. Once the water drains away, the cellulose fibers trapped on the mesh belt adhere to one another to form a paper web. The paper web then moves to the "press section" rollers, which remove any remaining water.

6. *Coating, Drying, Calendering*: After leaving the press section, the sheet is dried and may be coated with pigments, latex mixtures, or many other substances to give it a higher gloss or other characteristic. Before being collected on a take-up roll and removed from the paper machine, the sheet is pressed smooth by a series of polished, close-stacked metal rollers known as a calender.

7. *Cutting and Packaging*: The new paper roll is either simply rewound on a new core and shipped directly to the customer upon inspection or it is cut, boxed, and wrapped for delivery.

The production of two types of paper - textbook paper and corrugated paperboard - was modeled for this study. Model descriptions and results for each paper type are presented below.

Textbook Paper Model Description and Results

Textbook paper production is the first model element to be considered. This model utilized life cycle model components developed by Gard (2001). As discussed earlier, LCI data for textbook paper represent environmental burdens associated with all aspects of wood harvesting, transporting the logs to the mill, debarking and chipping, and manufacturing. Therefore, a clear distinction between raw material extraction and material processing in terms of environmental impacts could not be determined. Consequently, this study's analyses combine environmental burdens from raw material extraction with environmental burdens from material processing with respect to textbook paper.

LCI data for the production of one-ton primary (i.e. 0% secondary content), uncoated groundwood textbook paper was used for this model (EPA 2000). The boundaries for the textbook paper production LCI profile include harvesting of trees, transportation of logs to the mill, debarking and chipping, and manufacture of pulp and paper using primary fiber. The U.S. EPA life-cycle inventory data for primary textbook paper did not include LCI data for raw material requirements. Instead, raw material requirements were determined using the Database for Environmental Analysis and Management (DEAM) developed by the Ecobilan Group[5] (Ecobilan 1999) for the production of paper bleached with sulfate.

To calculate the FU mass of primary textbook paper required for forty 500-page scholarly books, four parameters were defined:

1. Sheet size – An industry term that refers to the frontal surface area of the bound textbook. It should be noted that this study uses the term "sheet" to refer to a single piece of paper and the term "page" as one side of one sheet. Thus, there are two pages per sheet. Although scholarly books are produced in a variety of sheet sizes, this study assumes a sheet size of 7" x 10", which is a common sheet size for "high-end" textbooks (Schultz 2002).

2. Basis weight – Refers to the weight of a ream (500 standard units of paper). A basis weight of 60 pounds is suitable for coated textbook grade paper (Schultz 2002) and is assumed here. This model variable is adjustable using the Model Inputs spreadsheet in Appendix A.

3. Unit Size – Refers to the size of standard paper units. "High-end" textbook printing grades come in standard units of 29" x 41".

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[5] Otherwise known as Ecobalance in the U.S.

4. Sheets per textbook – This study assumes the average length of a scholarly textbook to be 500 pages, or 250 double-sided sheets per textbook. This model variable is adjustable using the Model Inputs spreadsheet in Appendix A.

Assumptions pertaining to non-text material including end sheets, title pages and publisher information, preface, acknowledgements, table of contents, and appendixes are based on conversations with Steve Schultz (2002) of Edwards Brothers, Inc. and are included in Table 5-1. These variables can be adjusted using the Model Inputs spreadsheet in Appendix A.

Table 5-1: Non-Text Material used in Scholarly Textbooks

Description	Pages per Textbook	Sheets per Textbook
End Sheets	4	2
Title Pages and Publisher Information	6	3
Preface	2	1
Table of Contents	4	2
Appendices	20	10
Total	36	**18**

Thus, the total number of sheets per textbook is:

Text material + non-text material = 250 + 18 = 268 sheets.

The textbook's paper mass was determined using the parameter calculations shown below:

$$\text{Standard Unit Mass} = \frac{60\text{ lbs}}{500\text{ units}} \times \frac{\text{kg}}{2.2\text{ lbs}} = 0.054\text{ kg}$$

$$\text{Sheet Mass} = (0.054\text{ kg})\text{ x }\left(\frac{7''\text{ x }10''}{29''\text{ x }41''}\right) = 0.0032\text{ kg/sheet}$$

Textbook Paper Mass = (0.0032 kg) x (268 sheets per textbook) = 0.86 kg

Paperboard Model Description and Results

The *Paper Production* model includes the production of materials necessary for a textbook case. This study assumes that the textbook paper and case materials are produced at the same facility. The textbook case material is comprised of paperboard, generally referred to as 80 point board or 98 point board depending on the dimensions of the book. Paperboard is generally comprised of recycled fibers instead of virgin material and is produced in a similar manner as paper except that paperboard is much thicker and has higher strength characteristics. A 7" x 10" scholarly textbook will generally employ a 7.25" x 10.25" 80 point board case (Schultz 2002). Paperboard is a three dimensional material with a uniform thickness. The measurement of this thickness is called the caliper of the paperboard. Caliper is measured in one thousandth of an inch, 0.001 inch increments. Each 0.001 inch is also called a point. Thus, the 80 point paperboard used in this study measures out to be 0.08 inches thick.

During book assembly, nylon coated, 80 pound paper (referred to as C-1S), which includes information about the book (i.e. title, author, etc.), is pressed and glued to the paperboard for aesthetic purposes, thereby forming a case. LCI data for the production of one-ton virgin liner and medium for corrugated containers (EPA 2000) was used to represent the environmental burdens associated with the production of the paperboard and paper cover. The boundaries for the corrugated paper LCI profiles include harvesting of trees, wood residue production, sodium sulfate mining and processing, soda ash production, corn starch manufacturing, manufacture of virgin unbleached and semichemical paperboard, and transportation of rolls to corrugated box plants. The U.S. EPA life-cycle inventory data, however, did not include LCI data for raw material requirements. Therefore, raw material requirements were determined using Ecobalance's DEAM life cycle assessment software for the production of 1000 kg of corrugated cardboard.

As discussed above, a textbook's "glossy" characteristic is created by a nylon coating and a glue/adhesive is used to form the C-1S paper to the paperboard. However, environmental burdens associated with nylon and glue production were excluded from this analysis since their masses represent less than one percent of a textbook's total mass.

Using a standard balance scale, the mass of a 7.25 x 10.25" case, constructed in a similar manner as described above, is:

$$\text{Case Mass} = 0.192 \text{ kg}$$

Combining the paper mass with the case mass yields the total textbook mass:

$$\text{Mass}_{\text{Total}} = 1.052 \text{ kg}$$

Thus, the total FU mass for the printed book system is:

$$\text{Mass}_{\text{FU}} = (1.052 \text{ kg}) \times (40) = 42.08 \text{ kg}$$

The model elements for *Textbook Paper Production* include logistics from the paper production facility to book printing facility. The following assumptions were made to facilitate transportation calculations.

- After completion of textbook paper and case production steps, the textbook paper and case are shipped directly from the production facility to the book printing facility. Thus, intermediate warehousing is excluded from this analysis.
- A single heavy duty, class 8 diesel tractor-trailer is used for the duration of the trip.

- Since the predominant fuel is diesel, emissions will be calculated based on diesel combustion.

It should be noted that the weight of packaging materials used to transport the paper from the paper production facility to book printing facility was not considered in this analysis.

Textbook paper transportation model variables may be adjusted using the *Model Inputs* spreadsheet and are described below.

1. Travel Distance: Refers to the distance between the paper production facility and the printing facility. Although this model variable can be adjusted the *Model Inputs* spreadsheet, this study assumes an initial distance of 500 miles.

2. FU Mass: Originally calculated as 42.1 kg/FU (0.046 ton/FU).

3. Franklin Associates (2000) reported the average transportation fuel and energy requirements for a diesel tractor-trailer to be 9.4 gal/1,000 ton-mile and 1,465 Btu/ton-mile, respectively.

All energy and calculations are based on the following relationship:

Energy (MJ) =

FU mass (ton) x distance (mi) x energy intensity (Btu/ton-mile) x 0.001055 MJ/1Btu

LCI data and calculations for textbook paper production and textbook case production are included in Appendix B and C, respectively. The amount of energy consumed and emissions generated during transportation are calculated for the total textbook mass and are included in Appendix D. Appendix D also includes LCI production data (Ecobilan 1999) for the amount of diesel gasoline consumed during transportation. LCI data presented in Appendixes B, C, and D is summarized in the table below.

Table 5-2: LCI results – Paper production

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Paper Production	100	1,342	87	3,071	374	2
Paperboard Production	12	240	8	86	155	2
Paper Delivery*	1	71	3	17	32	0

*Includes diesel production data and combustion-related data

Data Sources and Quality

- The U.S. EPA life-cycle inventory data for primary textbook paper and office paper (EPA 2000) was compiled through a cooperative agreement between the Research Triangle Institute (RTI) and the U.S. EPA's Office of Research Development. Franklin Associates and Roy F. Weston developed the data in this report from primary and secondary sources in North America and Europe. Because the precision and completeness of this information were difficult to determine, EPA considers the LCI data to be of average quality.
- Standard information about bond weight and unit size for paper is readily available from a number of industry sources (Gard 2001), suggesting that the data is highly credible.
- Raw material requirements for the production of 1000 kg of corrugated cardboard and sulfate-bleached paper, as well as LCI data for the production of diesel gasoline, were compiled from Ecobalance, Inc.'s TEAM life cycle assessment software and associated DEAM database. DEAM inputs and outputs are given in terms of mass or other appropriate unit (e.g. kg or MJ) per unit mass of material. DEAM has been used by more than one hundred organizations worldwide across many industries and is considered to be of sound quality. Users include Ford, General Motors, Chrysler, Volkswagen, BMW, Hewlett-Packard, Xerox, Dow Corning, British Steel, and the National Renewable Energy Laboratory (US Department of Energy).
- Life cycle data on transportation energy and emissions were taken from a report provided by Franklin Associates, Ltd. of Prairie Village, KS (Franklin 2000). The energy usage for combination tractor-trailers weighing greater than 14,000 pounds was calculated based on the following data:

    - Average miles per gallon for tractor-trailer = 5.9 miles per gallon
    - A fully loaded tractor-trailer carries a maximum of 45,000 pounds

  Quality of this data (per pollutant emitted) ranged from excellent to poor. For example, fossil fuel carbon dioxide emissions data was assigned a data quality indicator (DQI) of A, suggesting that it is of the highest quality possible. This data represents recent industrial data collected by experts and is based on verified measurements. Antimony emissions data, on the other hand, was assigned a DQI of E, suggesting that it is of poor quality. This data represents older, non-qualified estimates from a sample that is incomplete or whose representativeness is unknown (Franklin 2000). Due to this variability in data quality, this study considers the LCI data to be of average quality.

Limitations and Uncertainties

- The average length of a scholarly textbook may vary significantly between disciplines. Therefore, the FU of 500 pages was simply used as a baseline for this model.
- The U.S. EPA life-cycle inventory data for primary textbook paper encompassed manufacturing to the point of one-ton paper rolls. Due to a lack of data availability,

processes associated with cutting, stacking and packaging were excluded from the analysis. However, it should be noted that these aforementioned processes are considered less energy intensive when compared to upstream activities such as raw material acquisition, heating, mixing, rinsing, rolling, and drying.

- Although a large percentage of scholarly works are available in soft cover, most textbooks and scholarly books available to the average student are Smyth-type sewn case bound (Schultz 2002). Therefore, books analyzed in this study were assumed to employ a hardcover.
- The U.S. EPA life-cycle inventory data for primary textbook paper and paperboard did not include LCI data for raw material requirements. To account for this missing data, raw material requirements were determined using Ecobalance's DEAM database for the production of 1000 kg of corrugated cardboard and sulfate-bleached paper.
- Ecobalance inventories are derived from secondary sources. For example, some data comes from Europe, some from the United States, and some from both. Thus, the available inventories do not precisely meet the geographic and temporal boundaries outlined in Section 4 of this study. However, the material production data represents only one portion of the overall inventory of the printed book system. Further, Ecobalance inventories have been widely used throughout the world (Ecobilan 1999), which suggests that these limitations are not unique to this study, but common of other LCIs as well.
- Uncertainties arise due to selection of vehicle type. Printing companies and shippers alike may choose between several sizes of delivery vehicles. Obviously, smaller trucks consume less energy per mile and oftentimes produce fewer emissions. Unless competing delivery modes are considered, however, implications associated with the choice of delivery vehicle cannot be known.
- Ideally, printers and shippers would prefer to ship their trucks fully loaded. However, this is not always logistically feasible. Although this study assumes that a truck leaves the paper production facility fully loaded and remains so until final delivery, one could argue that as payload decreases the FU burden increases.

5.2.1.2 Ink Production

Introduction

The three primary components of lithographic inks include pigments, vehicles, and modifiers. A description of each ink component is presented below:

1. Pigment production – Pigments are not considered dyes, but are used to impart color to a printing ink. Once received by the ink manufacturer, the refined petroleum substance is chemically and physically treated through a series of synthesizing and finishing stages. In the final stages, the material is usually filtered and washed to remove impurities, where it is then converted into a form called a presscake, which has the appearance similar to a colored brick of moist, spongy clay. This substance consists of the pigment and water only. The presscake then goes through a process called "flushing." The flushing process involves combining the presscake with an oil-based liquid/varnish in an apparatus that resembles a large cement mixer.

Because the pigment tends to be oleophilic (i.e. has a greater affinity to oil than water), the pigment adheres to the varnish and the water is driven off, leaving behind an extremely dense paste.

2. Vehicles – Vehicles are used to produce the desired ink properties such as tack and viscosity. Vehicles are oil-based varnishes, which wet, carry, and bond the pigment (discussed above) to the paper and are produced prior to the ink manufacturing process.

3. Modifiers – Modifiers are used to modify the ink for press performance, or to modify the behavior of the ink as a dried film. Like vehicles, modifiers are derived from oil and are produced prior to the ink manufacturing process.

Ink manufacturers combine pigments, vehicles, and modifiers in a variety of ways to produce the desired result.

Model Description and Results

- An existing study investigating the life-cycle environmental impacts of printed communications (Juntunen and Lindqvist 1995) indicated that approximately 7.92 kg of ink and 1220 kg of paper are required per tonne of printed book material. Since ink represents less than 1% of the total weight of the system, environmental burdens associated with ink production were excluded from this analysis.

Data Sources and Quality

- Issues related to data quality of the 1995 LCA study (Juntunen and Lindqvist 1995) are discussed in more detail in Section 5.2.2.2.

Limitations and Uncertainties

- Paper and ink comprise the major components of a printed textbook. Although comprehensive production data was available for paper, similar data for ink was not available. Since ink represents less than 1% of the total weight of the system, this decision to exclude these burdens is assumed to have only a minor effect on the final results.

5.2.2 Manufacturing Phase

5.2.2.1 Document Creation

Process flow diagrams for both systems (Figures 4-1 and 4-2) feature this model element. This process involves several key steps (i.e. authoring, digital file storage, editing, etc.) necessary to create a scholarly textbook. All activities related to document creation have been allocated to the Manufacturing Phase of each book system. Because the *Document Creation* process is virtually identical to both systems, it has been mutually excluded from this analysis. Instead, this study intends to focus on processes that are truly different between the two systems.

5.2.2.2 Book Printing Operations

Introduction

Although there are several types of printing processes including gravure, engraving, flexography, and screen printing, offset lithography is the most commonly used type of scholarly book printing method (~99%) (Schultz 2002) and will be considered exclusively in this study. Offset lithography, simply stated, depends on the ink and water balance. Ink, being an oil-based substance, repels water, which keeps the non-image areas of the plate from accepting ink. This repelling action is what causes the ink to form on the image areas of the plate.

The basic printing process consist of three stages: pre-press, press, and post-press (How Stuff Works 2002). The stages are briefly discussed below.

1) *Pre-press production:* Text and images from film negatives, which are typically created from a digital file, are transferred to printing plates in much the same way that photographs are developed. A measured amount of light is allowed to pass through the film negatives, thereby exposing the printing plate. Exposing the printing plates to light incites a chemical reaction that allows an ink-receptive coating to be activated. This results in the transfer of the image from the negative to the printing plate. Printing plate material varies, although many consider aluminum the best, and most costly, plate material. Each of the primary colors -- black, cyan (blue), magenta (red), and yellow -- has a separate plate. Color control is assisted by use of computers.

2) *Press Run:* Paper is fed through the press as one continuous stream pulled from rolls of paper. Each roll can weigh as much as 1 ton. The paper is cut to size after printing. Offset lithography can also be done with pre-cut paper in sheetfed presses. Web presses print at very high speeds and use very large sheets of paper. Press speeds can reach up to 50,000 impressions per hour. An impression is equal to one full press sheet (38 inches x 22 and three-fourths inches). The press has to maintain a constant balance between the force required to move the paper forward and the amount of backpressure (resistance) that allows the paper to remain tight and flat while traveling through the equipment.

3) As stated before, the fact that oil and water do not mix is the underlying principle to offset lithography. Ink is distributed to the plates through a series of rollers (see Figure 5-2). The plate cylinders are first dampened by water rollers followed by ink rollers. Ink from the ink rollers adheres to the image area, whereas the water rollers repel ink, thereby protecting the non-image areas. Each plate then transfers its image to a rubber blanket that, in turn, transfers the image to the paper. The plate itself does not actually touch the paper; thus the term "offset" lithography. To prevent smudging,

the paper is fed through an oven to facilitate drying and then through a series of "chill rollers" that cool the paper down instantly and set the ink into the paper.

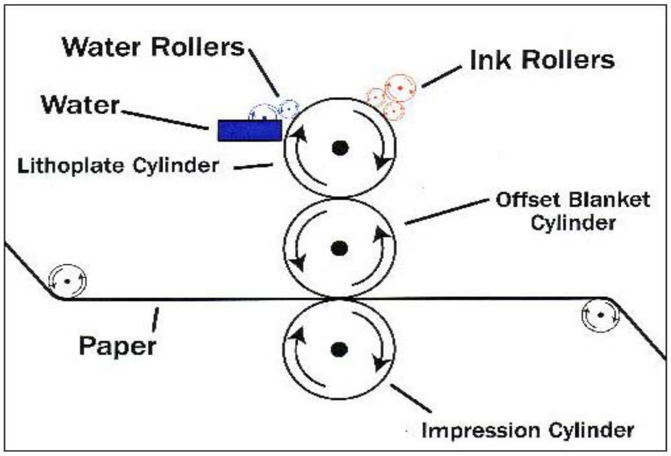

Figure 5-2: Offset Lithography

4) *Post-press production:* The rolls of now-printed paper are cut into sheets. These sheets are then assembled together so that the pages fall in the correct order, sewn, and bound together. Most textbooks are Smyth-type sewn case bound (Schultz 2002). This book sewing method involves a through-the-bind-edge stitch that attaches each signature to the adjacent one. Smyth-type sewing, which draws its name from a major equipment manufacturer in the field, provides a strong binding as well as good "layflat" characteristics necessary for many textbooks, lab books, teachers' editions, and reference books.

As discussed earlier, scholarly textbook case material is comprised of paperboard. Nylon coated paper (referred to as C-1S) that usually includes information about the book (i.e. title, author, etc.) is pressed and glued to the paperboard for aesthetic purposes.

After the post-press production process, the finished product is shipped from the printer to wholesalers' warehouses and finally to thousands of retail bookstores.

Model Description and Results

An existing study investigating the life-cycle environmental burdens of printed communications provided LCI data for several categories of printed material (Juntunen and Lindqvist 1995). Based on the results of this study, the on-site energy burden distribution for printing a scholarly textbook was determined to be 0.77 MWh/tonne for electricity, 0.72 MWh/tonne for heavy fuel oil, and 1.19 MWh/tonne for remote heat supplied by a public utility via natural gas combustion (Lindqvist 2002)[6]. It should be noted that these electricity, fuel oil, and natural gas requirements are for on-site use only

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[6] This distribution was not originally reported in the Finnish study, but is based on recent conversations with the author of the journal article (Lindqvist 2002).

(i.e. running equipment, heating the facilities, lighting, etc.). Again, these model variables are adjustable using the Model Inputs spreadsheet in Appendix A.

As discussed earlier, the FU paper mass was determined to be 34.4 kg. Thus, the on-site electricity required to print forty 500 page scholarly books was calculated using the following relationship:

$$\text{Electricity} \quad = \frac{0.77\ \text{MWh}}{\text{tonne}} \times \frac{34.4\ \text{kg}}{\text{FU}} \times \frac{1\ \text{tonne}}{1000\ \text{kg}} \times \frac{3600\ \text{MJ}}{1\ \text{MWh}}$$

$$= \mathbf{95.4\ MJ/FU}$$

Assuming a higher heating value of 153,600 Btu/gal and a density of 8.25 lbs/gal (Energy Solutions Center 2002), the on-site heavy fuel oil requirement (in kg) was calculated using the following relationship:

$$\text{Fuel Oil} \quad = \frac{0.72\ \text{MWh}}{\text{tonne}} \times \frac{34.4\ \text{kg}}{\text{FU}} \times \frac{1\ \text{tonne}}{1000\ \text{kg}} \times \frac{3{,}412{,}142\ \text{BTU}}{1\ \text{MWh}} \times \frac{1\ \text{gallon}}{153{,}600\ \text{BTU}}$$

$$= 0.55\ \text{gallons} = 4.53\ \text{lbs} = \mathbf{2.05\ kg/FU}$$

Similarly, the on-site heavy fuel oil requirement (MJ equivalency) was calculated using the following relationship:

$$\text{Fuel Oil} \quad = \frac{0.72\ \text{MWh}}{\text{tonne}} \times \frac{34.4\ \text{kg}}{\text{FU}} \times \frac{1\ \text{tonne}}{1000\ \text{kg}} \times \frac{3{,}412{,}142\ \text{BTU}}{1\ \text{MWh}} \times \frac{1\ \text{MJ}}{947.8\ \text{BTU}}$$

$$= \mathbf{89.2\ MJ/FU}$$

Assuming an approximate heat content of 1,019 Btu/ft^3, the on-site natural gas requirement (in kg) was calculated using the following relationship:

$$\text{Natural Gas} \quad = \frac{1.19\ \text{MWh}}{\text{tonne}} \times \frac{34.4\ \text{kg}}{\text{FU}} \times \frac{1\ \text{tonne}}{1000\ \text{kg}} \times \frac{3{,}412{,}142\ \text{BTU}}{1\ \text{MWh}} \times \frac{1\ \text{cubic foot}}{1{,}019\ \text{BTU}}$$

$$= 137.08\ \text{ft}^3/\text{FU} = \mathbf{2.52\ kg/FU}^{7}$$

Similarly, the on-site natural gas requirement (MJ equivalency) was calculated using the following relationship:

$$\text{Natural Gas} \quad = \frac{1.19\ \text{MWh}}{\text{tonne}} \times \frac{34.4\ \text{kg}}{\text{FU}} \times \frac{1\ \text{tonne}}{1000\ \text{kg}} \times \frac{3{,}412{,}142\ \text{BTU}}{1\ \text{MWh}} \times \frac{1\ \text{MJ}}{947.8\ \text{BTU}}$$

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[7] According to the European Natural Gas Vehicle Association (2002), 1 kg of natural gas = 54.44 ft^3 of natural gas.

= **147 MJ/FU**

As discussed earlier, the electricity, fuel oil, and natural gas requirements determined above are for on-site use. Total fuel cycle LCI data, including upstream environmental burdens, for scholarly textbook printing is included in Appendix E. These LCI models were constructed using Ecobalance, Inc.'s DEAM life cycle assessment software for conventional electricity generation, heavy fuel oil production and combustion, and natural gas production and combustion. LCI data presented in Appendix E is summarized in the table below.

Table 5-3: LCI results – Book printing operations

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Printing Electricity	16	464	37	6	10	74
Heavy fuel oil*	2	99	7	20	77	0
Remote Heat**	3	162	20	0	0	0

* Includes heavy fuel oil production data and combustion-related data
**Includes natural gas production and combustion-related data

Data Sources and Quality

- The 1995 LCA study was part of the Finnish national research program for graphic arts (GAT) and utilized the Finnish KCL-ECO programming tool to assist with LCI data compilation. Data availability and resource constraints determined the selection of project scope and boundaries. All printing operations, including the conventional phases from text processing to the post press operations, were considered in this study. This LCA also included energy burdens associated with facility requirements (i.e. lighting, HVAC), while excluding burdens associated with production of printing equipment, raw material production, and transportation of materials and products. LCA results reportedly agree with industry field measurements, which suggests data of good quality.
- Inventory data on conventional electricity generation was compiled from Ecobalance, Inc.'s TEAM life cycle assessment software and associated DEAM database. Ecobalance's TEAM database software program included precombustion and combustion impacts and utilizes EPA AP-42 emission factors. TEAM electricity generation inventory data is grouped by NERC region and is from 1991. Each NERC region has its own unique profile of resource use and emissions per MJ (or kWh) generated based on the mix of generating technologies (i.e. coal, natural gas, heavy fuel oil, nuclear, hydro) in that specific region. Impacts due to electricity use were assigned based on the NERC ECAR region, the location of UM, which has the following mix of generating technologies:

- Coal (89.2%)
- Natural Gas (0.3%)
- Heavy Fuel Oil (0.3 %)
- Nuclear (9.7%)
- Hydroelectricity (0.5%)

Additionally, LCI data for the production of 1 kg of heavy fuel oil and natural gas were compiled from Ecobalance, Inc.'s TEAM life cycle assessment software and associated DEAM database. Finally, emissions data for the combustion of residual fuel oil in industrial boilers and the combustion of natural gas in utility boilers were taken from Ecobalance's DEAM database. TEAM is now widely used throughout the world across many industries and is considered to be of sound quality.

Limitations and Uncertainties

- As discussed earlier, this model element utilized printing data from a Finnish LCA. Clearly, there are differences between European and North American printing industries including energy mixes and grid efficiencies.
- Newer electronic printing technologies, such as computer-to-plate and digital printing, are rapidly gaining acceptance in the marketplace. Further, these electronic publishing activities have made Pre-press printing activities less energy intensive (Juntunen and Lindqvist 1995). However, these technologies were not considered in this study due to a lack of data.
- The TEAM inventory data for electricity generation account for losses in transmission and distribution (~7.03% according to DOE/EIA (1991)), but do not include the environmental impacts associated with constructing the electricity generating power plants. These impacts are considered to be small in comparison with the environmental impacts from the combustion of fossil fuels over the plant's lifetime.
- The emissions from the combustion of residual oil in industrial boilers may vary depending on the composition of the fuel type, type of boiler, and the firing practices used.

5.2.3 Product Distribution Phase

5.2.3.1 Textbook Delivery

The first and only Distribution Phase activity considered involves the delivery of the printed scholarly textbook to a storage facility. Since this study centers on the use of these textbooks in a university setting, we will assume that the printed textbooks will be delivered to a university bookstore. The model spreadsheet for this process is provided in Appendix A. The following assumptions were made to facilitate model calculations.

- After the post-press production process, the textbook is shipped directly from the printing facility to the university bookstore. Given the large volume of material held in these facilities and relatively low energy intensity per footprint, environmental impacts associated with intermediate storage are expected to be small. Thus, intermediate warehousing is excluded from this analysis.

- A single heavy duty, class 8 diesel tractor-trailer is used for the duration of the trip.
- Since the predominant fuel is diesel, emissions will be calculated based on diesel combustion.
- The weight of packaging materials was not considered in this analysis. This is not to suggest that packaging is not important. Rather, the impacts associated with packaging (i.e. boxes, shrink wrap, etc.) are considered to be small in comparison with the environmental impacts associated with the textbook paper production and printing operations. Therefore, the *Packaging Production* and *Packaging Disposition* model elements are not modeled independently and are shown separately for clarification purposes only.

Textbook Transportation model variables may be adjusted using the *Model Inputs* spreadsheet and are described below.

1. Travel Distance: Refers to the distance between the printing facility and the university library. Although this model variable can be adjusted in the *Model Inputs* spreadsheet, this study assumes an initial distance of 1200 km (~746 miles). Mean transport distance between printing facility and local consumer were estimated to be 1200 km (Dalhielm & Axelsson 1995).

2. FU Mass: Originally calculated in Section 5.2.1.1 as 42.1 kg/FU (0.046 ton/FU).

3. Franklin Associates (2000) reported the average transportation fuel and energy requirements for a diesel tractor-trailer to be 9.4 gal/1,000 ton-mile and 1,465 Btu/ton-mile, respectively.

The amount of energy consumed and emissions generated during transportation are calculated for the total FU mass of the conventional book system and are included in Appendix F. Appendix F also includes LCI production data for the amount of diesel gasoline consumed during transportation. LCI data presented in Appendix F is summarized in the table below.

Table 5-4: LCI results – Textbook Delivery

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Textbook Delivery*	1	112	5	55	57	0

* Includes diesel production data and combustion-related data

<u>Data Sources and Quality</u>

- Life cycle data on transportation energy and emissions were taken from a report provided by Franklin Associates, Ltd. This data source is discussed in Section 5.2.1.1.

- Hauling distance assumptions were based on data found in a Swedish study (Dalhielm & Axelsson 1995).

Limitations and Uncertainties

- Conventional books are sometimes shipped physically from printers to wholesalers' warehouses and finally to thousands of retail bookstores and/or libraries. Since these intermediate warehouses have a relatively low energy intensity per footprint, energy burden associated with the brief storage of a scholarly textbook is expected to be small. Thus, warehousing was excluded from this LCI.
- All other limitations and uncertainties regarding transportation are discussed in Section 5.2.1.1.

5.2.4 Use Phase

5.2.4.1 Book Storage

As discussed earlier, *Book Storage* refers to the management activities necessary to maintain a collection of books. Although this model elements appears in the process flow diagram (Figure 4-1) for the traditional book system, this process is not modeled independently and is shown separately for clarification purposes only. Alternatively, all activities attributable to *Book Storage* have been included within the *Facility Infrastructure* model element description, which is presented below.

5.2.4.2 Facility Infrastructure

Energy consumption related to building infrastructure was modeled for the conventional book system. Although college level textbooks can be purchased on-line, the focus of the *Facility Infrastructure* model is limited to a campus bookstore. The average energy intensity for retail/commercial buildings was determined to be approximately 76,400 Btu/ft^2 (Energy Information Administration 1995). A breakdown of the electricity, natural gas and fuel oil consumption intensities is presented in the table below. It should be noted that these electricity, fuel oil, and natural gas requirements are for on-site use only (i.e. heating, lighting, etc.).

Table 5-5: Fuel Consumption Intensities for Retail/Commercial Buildings

Fuel Type	Consumption Intensity
Electricity	11.8 KWh/ft^2
Natural Gas	45.2 ft^3/ft^2
Fuel Oil (heavy)	0.14 gal/ft^2

Source: Energy Information Administration, 1995 Commercial Buildings Energy Consumption Survey

The direct footprint per textbook was then estimated. Bookshelf space per textbook was calculated in the following manner:

Shelf Area = (cover width) x (cover thickness + (sheet thickness x number of sheets))

$$\text{Shelf Area} = \left[(7.25'')\times\left((0.16'')+\left(\frac{0.005''}{\text{sheet}}\right)\times\left(\frac{268\text{ sheets}}{\text{textbook}}\right)\right)\right]\times\left(\frac{\text{sq. ft}}{144\text{ sq. in}}\right)$$

$$= .076\ \text{ft}^2/\text{textbook}$$

Thus, the total FU shelf area for the printed book system is:

$$\text{Shelf Area}_{\text{FU}} = \left(\frac{0.076\text{ ft2}}{\text{textbook}}\right) \text{ x (40 textbooks)} = 3.04\ \text{ft}^2$$

To account for empty shelf space between titles, a factor of two was applied as an adjustment:

$$\text{Area}_{\text{FU, Adjustment 1}} = 2 \text{ x } 3.04\ \text{ft}^2 = 6.08\ \text{ft}^2$$

Assuming that one-third of a bookstore’s total floor space is dedicated entirely to shelving space and four shelves per stack, the total amount of space allocated to the FU is:

$$\text{Area}_{\text{FU, Adjustment 2}} = \left(\frac{6.08\text{ sq. ft.}}{\text{FU}}\right)\times\left(\frac{1}{1/3}\right)\times\left(\frac{\text{stack}}{4\text{ shelves}}\right)$$

$$= 4.56\ \text{ft}^2/\text{FU}$$

Combining the adjusted FU area with the building’s annual average electricity consumption yields:

$$\text{Electricity} = \left(\frac{4.56\text{ sq. ft.}}{\text{FU}}\right)\left(\frac{11.8\text{ KWh/year}}{\text{sq. ft.}}\right)\times\left(\frac{3.6\text{ MJ}}{\text{KWh}}\right) = \mathbf{193.7\ MJ/year/FU}$$

Assuming a shelf life of one month, the total on-site electricity requirement was calculated using the following relationship:

$$\text{Electricity}_{\text{FU}} = \frac{193.7\text{ MJ/year}}{\text{FU}}\times\frac{1\text{ year}}{12\text{ months}}\times(1\text{ month shelf life})$$

$$= \mathbf{16.14\ MJ/FU}$$

Please note that facility infrastructure model variables, including book footprint, space ratio, shelf life, and shelves per stack, may be adjusted using the *Model Inputs* spreadsheet.

Assuming a density of 8.25 lbs/gal (Energy Solution Center 2002), the on-site heavy fuel oil requirement (in kg) was calculated using the following relationship:

$$\text{Fuel Oil} \quad = \frac{4.56\ \text{sq. ft.}}{\text{FU}} \times \frac{0.14\ \text{gal/year}}{\text{sq. ft.}}$$

$$= 0.64\ \text{gal/year/FU} = 5.27\ \text{lbs/year/FU} = \mathbf{2.39\ kg/year/FU}$$

Similarly, the on-site heavy fuel oil requirement (MJ equivalency) was calculated using the following relationship:

$$\text{Fuel Oil} \quad = \frac{4.56\ \text{sq. ft.}}{\text{FU}} \times \frac{0.14\ \text{gal/year}}{\text{sq. ft.}} \times \frac{153{,}600\ \text{BTU}}{\text{gal}} \times \frac{1\ \text{MJ}}{947.8\ \text{BTU}}$$

$$= \mathbf{103\ MJ/year/FU}$$

Assuming a shelf life of one month, the on-site fuel oil requirement (in kg and MJ) was calculated using the following relationships:

$$\text{Fuel Oil}_{\text{FU}} \quad = \frac{2.39\ \text{kg/year}}{\text{FU}} \times \frac{1\ \text{year}}{12\ \text{months}} \times (1\ \text{month}) = \mathbf{0.2\ kg/FU}$$

$$= \frac{103\ \text{MJ/year}}{\text{FU}} \times \frac{1\ \text{year}}{12\ \text{months}} \times (1\ \text{month}) = \mathbf{8.7\ MJ/FU}$$

Assuming an approximate heat content of 1,019 Btu/ft^3, the on-site natural gas requirement (in kg) was calculated using the following relationship:

$$\text{Natural Gas} \quad = \frac{4.56\ \text{sq. ft.}}{\text{FU}} \times \frac{45.2\ \text{cubic feet/year}}{\text{sq. ft.}}$$

$$= 206.11\ \text{ft}^3\text{/year/FU} = \mathbf{3.79\ kg/year/FU}^{\mathbf{8}}$$

Similarly, the on-site natural gas requirement (MJ equivalency) was calculated using the following relationship:

$$\text{Natural Gas} \quad = \frac{4.56\ \text{sq. ft.}}{\text{FU}} \times \frac{45.2\ \text{cubic feet/year}}{\text{sq. ft.}} \times \frac{1{,}019\ \text{BTU}}{\text{cubic feet}} \times \frac{1\ \text{MJ}}{947.8\ \text{BTU}}$$

$$= \mathbf{221.6\ MJ/year/FU}$$

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[8] According to the European Natural Gas Vehicle Association (2002), 1 kg of natural gas = 54.44 ft^3 of natural gas.

Assuming a shelf life of one month, the on-site natural gas requirement (in kg and MJ) was calculated using the following relationships:

$$\text{Natural Gas}_{\text{FU}} = \frac{3.79\ \text{kg/year}}{\text{FU}} \times \frac{1\ \text{year}}{12\ \text{months}} \times (1\ \text{month}) = \mathbf{0.32\ kg/FU}$$

$$= \frac{221.6\ \text{MJ/year}}{\text{FU}} \times \frac{1\ \text{year}}{12\ \text{months}} \times (1\ \text{month}) = \mathbf{18.47\ MJ/FU}$$

As discussed earlier, the electricity, fuel oil, and natural gas requirements determined above are for on-site use only. Total fuel cycle LCI data, including upstream environmental burdens, for book infrastructure burdens is included in Appendix G. These LCI models were constructed using Ecobalance, Inc.'s DEAM life cycle assessment software for conventional electricity generation, heavy fuel oil production and combustion, and natural gas production and combustion. LCI data presented in Appendix G is summarized in the table below.

Table 5-6: LCI results – Facility Infrastructure

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Electricity	3	78	7	1	2	13
Fuel oil*	0	10	1	2	7	0
Natural Gas**	0	20	3	0	0	0

* Includes fuel oil production data and combustion-related data
**Includes natural gas production and combustion-related data

Data Sources and Quality

- Building energy intensity data for retail buildings was taken from the 1995 Commercial Buildings Energy Consumption Survey, a national probability sample survey of commercial buildings, sponsored by the Energy Information Administration. The data were collected from a sample of 6,639 buildings representing 4.6 million commercial buildings and 58.8 billion square feet of commercial floor space in the United States. Although this data is nearly seven years old and does not reflect any changes in utility plant performance since 1995, it is considered to be of good quality.
- Sheet thickness was determined by dividing the thickness of a stack of standard office paper by the quantity of sheets. This data is assumed to be of good quality.
- The estimated ratio of book shelving space to total floor space was based on conversations with a local university bookstore manager (Hall 2003).
- Issues related to data quality of Ecobalance's DEAM software program are discussed in Sections 5.2.1.1 and 5.2.2.2.

Limitations and Uncertainties

- One could argue that there are additional energy burdens associated with storing the books in a dorm room or an apartment. However, the impacts associated with personal storage are considered to be small in comparison with the environmental impacts associated with paper production and printing operations. Therefore, personal storage was not considered in this analysis. Environmental burdens would become significant, however, if the study compared a much larger personal collection in the hard copy and digital formats.
- All building energy burdens were allocated based on book-related activities. This is appropriate since most university bookstores deal primarily with the collection and maintenance of books.
- As discussed above, sheet thickness was determined by dividing the thickness of a stack of standard office paper by the quantity of sheets. Typically, office paper has a bond weight of 50 pounds as opposed to 60 pounds for textbook paper. This is not expected to have a significant effect on shelf area calculation determined above, however (Schultz 2002).
- Issues related to the limitations and uncertainties of Ecobalance's TEAM software program are discussed in Sections 5.2.1.1 and 5.2.2.2.

5.2.4.3 Personal Transportation

Environmental burdens associated with bookstore-related travel are considered in this section. This model assumes the mode of transport to be automotive. This model element may be excluded from the combined analysis if a non-automotive (non-emitting) mode of transport is selected instead.

The *Personal Transportation* model includes three variables (i.e. distance, fuel efficiency, and number of trips) that may be adjusted using the *Model Inputs* spreadsheet provided in Appendix A. These variable include:

1. Distance - Refers to the vehicle miles traveled (roundtrip) during a visit to the bookstore, initially assumed to be 10 miles.
2. Fuel Efficiency – Refers to the fuel consumption of an automobile in miles per gallon (mpg). An average fuel efficiency of 23 mpg was determined based on information published by the Department of Energy (1995) and is assumed here.
3. Number of Trips – Refers to the number of visits the user takes to the bookstore over the time period of the study. As determined in the user profile (Section 4.4), the user will purchase five books per visit to the bookstore, thus requiring a total of 8 trips to the bookstore.

The amount of energy consumed and emissions generated during transportation are calculated for total trip distance and are included in Appendix H. Appendix H also includes LCI production data for the amount of gasoline consumed during transportation. LCI data presented in Appendix H is summarized in the table below.

Table 5-7: LCI results – Personal Transportation

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Personal Transportation*	12	1,196	44	497	514	3

* Includes gasoline production data and combustion-related data

All energy and emissions calculations were adjusted to account for the 10 mile roundtrip to the bookstore. For example, according to the U.S. Automotive Material Partnership (1999), life cycle energy data indicated that one mid-sized car consumes 995,089 MJ (total life-cycle) of life cycle energy over the course of 120,000 miles. Combining this data with distance (i.e. 10 miles) yielded the total trip-related energy consumption per FU.

$$\text{Energy}_{\text{TRIP}} = (995{,}089 \text{ MJ}/120{,}000 \text{ miles}) \times (10 \text{ miles/trip})$$

$$= 82.92 \text{ MJ/trip}$$

Thus, 82.92 MJ of life cycle energy are consumed each time a patron wishes to purchase five books from the university bookstore. This calculation assumes the following:

- The student must purchase one book per class and the student is enrolled in five classes per semester;
- The texts are available at the student's university bookstore and are not sold out;
- The trip does not involve non-bookstore activities. Therefore, all energy and environmental burdens are allocated exclusively to the FU;

<u>Data Sources and Quality</u>

- Life cycle energy and emission data was taken from the U.S. Automotive Material Partnership (U.S. AMP 1999) report Life Cycle Inventory Analysis of a Generic Vehicle, written in conjunction with Ecobalance and UM. The study considered a generic, mid-size family sedan in the United States. The energy usage for this vehicle was calculated based on the following data:
  1. Combined average fuel economy of 23 mpg
  2. Useful life of 11 years, and 120,000 miles
  3. Vehicle can potentially carry up to 6 passengers (3 front and 3 rear)

  For credibility purposes, a "Peer Review" panel independently reviewed the report. Review comments are included within the report. Although slightly dated, this report is considered to be the most comprehensive LCIA conducted on the automobile to date.
- Travel distance was assigned an initial value of ten miles based on personal experience and observation. This initial distance of 10 miles (roundtrip) may overestimate student travel distance, especially in Ann Arbor. Therefore, sensitivity to this parameter is examined in Section 7.

Limitations and Uncertainties

- The generic vehicle, by its very name, is not indicative of a specific library patron's ownership patterns.
- The U.S. AMP "use phase" data did not include energy usage associated with infrastructure, delivery to the dealership, sales, and vehicle storage.
- Although several bookstore patrons utilize motorcycles, buses, and other forms of transportation, these other modes of transportation were excluded from this analysis due to a lack of LCI data.
- This study assumed one vehicle occupant and does not recognize weight differences of occupants.

5.2.4.4 Book Retrieval and Viewing

The final Use Phase activity considered involves reading the book, itself. For simplification purposes, this process is not modeled independently and is shown separately in Figure 4-2 for clarification purposes, although one could argue that an artificial light source used specifically for reading purposes consumes energy. However, due to constraints of time and resources, an investigation of reading-related environmental impacts was not explored.

5.2.5 End-of-Life Phase

5.2.5.1 Textbook Disposition

The first and only End-of-Life (EOL) Phase activity considered involves the disposition of a printed scholarly textbook. This study assumes that a book is purchased with the intent of keeping it forever. According to Zachary (2002), books made from sound materials that do not receive unwonted abuse can easily survive 400 years or more and it is not uncommon to find books surviving from the 1400s and earlier. Although books printed on acidic paper start to break down in about 30-50 years, many can survive much longer than that if they are not physically stressed. In light of these findings, environmental burdens associated with textbook disposition were excluded from this analysis.

Data Quality and Sources

- Information pertaining to book life was taken from data provided by UM's library conservation services department (Zachary 2002) and is considered to be highly credible.

Limitations and Uncertainties

- The time it takes for a book to reach a state of damage beyond use depends on many variables: amount of use, special damaging events (i.e. fire, flood, vandals), storage environment, and the quality of the paper and other materials from which it is made. When the physical integrity of a book is damaged beyond use or the practicality of owning the book expires, a book owner may make one of two decisions: 1) dispose of the book; or 2) resell the book. However, to keep the scope of this project realistic, this study assumes that the book in question will maintain its physical integrity over the 4-year time frame of this analysis and that the book owner will choose to retain rather than resell the book. It should be noted, however, that a sensitivity analysis testing the resell and disposal options is presented in Section 7.

5.3 E-Reader System

This section presents a detailed description of the model elements for the e-reader system. Before proceeding with a discussion of the product's life cycle, as shown in Figure 4-2, a brief introduction to e-reader technology is presented.

Introduction to E-reader Technology

E-readers are similar to personal digital assistants (PDAs) in that they utilize liquid crystal display (LCD) technology and rely on stylus/touch-screen technology and handwriting recognition programs for data entry. All e-readers, regardless of brand, share the following features: (1) microprocessor, (2) operating system, (3) memory, (4) batteries, (5) LCD technology, (6) input device (i.e. buttons in combination with touch screen), (7) input/output ports, and (8) desktop PC software. A brief description of each of these features is presented below.

1. *Microprocessor*: A microprocessor coordinates all of the e-reader's functions according to a set of programmed instructions. Unlike desktop PCs and portable laptop computers, e-readers use smaller, cheaper microprocessors, which tend to be slower than their PC counterparts (16-75 MHz, compared with up to 1,000 MHz in PCs). The REB 1100 utilizes an ARM-720T general purpose 32-bit microprocessor.

2. *Operating System*: The operating system contains the pre-programmed instructions that tell the microprocessor what to do. The operating systems used by e-readers are not as complex as those used by PCs, generally have fewer instructions, and take up less memory. Examples of different e-reader operating systems include Palm OS and Pocket PC. The REB 1100 employs the Gemstar eBook Reader operating system.

3. *Memory*: All e-readers have memory. Unlike PCs, e-readers do not have a hard drive. Alternatively, e-readers store basic programs (memo pad, operating system, etc.) in a read-only memory (ROM) chip, which remains intact even when the device shuts down. Data and any programs added later are stored in the device's random-access memory (RAM) chip. The REB 1100 has 8 MB of memory with 72 MB expandable memory. In contrast, a PC commonly found at a university library could have anywhere between 128 and 512 MB of RAM.

4. *Batteries*: All e-readers are powered by batteries. Some models use alkaline (AAA) batteries, while others use rechargeable batteries (lithium ion, nickel-cadmium or

nickel-metal hydride). E-readers also come with AC adapters to run off household electric current.

5. *LCD Technology*: Although several major categories of flat panel displays (FPDs) are available to consumers in the marketplace, liquid crystal displays (LCDs) comprise approximately 87% of the FPD market (OTA 1995). Further, virtually all e-readers employ some type of LCD display screen. In general, a LCD is comprised of two glass plates surrounding a liquid crystal material that filters external light. Unlike the LCD screens for desktop or laptop computers, which are used solely as output devices, e-readers use their screens for output and input.

6. *Input Device*: E-readers vary in how the user can input data and commands, but most e-readers, like the REB 1100, typically use a “stylus” and touch screen exclusively, with a few buttons to bring up screens or applications. As described above, the e-reader’s screen displays information with a LCD. Atop the LCD sits a touch screen that allows the user launch programs by tapping on the screen with a pen-like stylus.

7. *Input/Output Ports:* Most e-readers are designed to work in tandem with a desktop or laptop. Communication between e-reader and PC is referred to as “data synchronization” or “syncing” and is typically done through a serial or universal serial bus (USB) port on the e-reader device. In addition to communicating through a cable, many PDA/e-readers combination devices have an infrared communications port that uses infrared (IR) light to beam information to a PC or another PDA. Some PDA/e-reader combination devices also offer wireless methods to transfer data to and from a PC/PC network through a wireless e-mail/Internet service provider like those available on new models of cell phones. Finally, some e-readers, like the REB 1100, offer telephone modem accessories to transfer files to and from a PC network.

8. *Desktop PC Software:* Although most e-readers can work independently of PCs (i.e. they have built in modems), some users may wish to download e-books using a PC. This is accomplished by installing synchronization software, which allows communication between the e-reader and PC.

Product Description

The REB 1100 dedicated e-book reader (REB 1100) from RCA, shown in Figure 5-3 on the following page, was chosen as the e-book reader model to be investigated in this study. Along with the REB 1200, the REB 1100 is currently RCA’s standard e-reader module and is the most directly comparable with other manufacturer’s products. Recall that the REB-1100’s dimensions are 5.0” x 7.0” x 1.5”.

Figure 5-3: REB 1100 E-book Reader from RCA

The major components of the REB 1100 dedicated e-book reader (REB 1100) and mass of each component are presented in Table 5-8.

Table 5-8: Preliminary List of REB 1100 Components

Component	Mass (g)	Weight %
RCA REB 1100 E-book (excluding internal battery)	416.54	24.97
Internal Lithium Ion Battery	91.89	5.51
AC Adapter	385.61	23.12
Telephone Cable	41.18	2.47
USB Cable	47.84	2.87
Screen Cleaning Cloth	7.18	0.43
Synthetic Leather Slip Case	52.6	3.15
Quick Start Guide*	38.28	2.30
E-book Librarian CD ROM	15.37	0.92
Inner Packaging*	278.59	16.71
Outer Packaging*	292.51	17.54
Total (includes packaging)	**1667.59**	
Total (excludes packaging)	**1005.61**	

*Denotes packaging element

Based on disassembly of the e-reader, information taken from existing life-cycle studies (Socolof 2001; DOE 2001), and conversations with industry specialists, a summary of the e-reader's bill of materials (BOM) is presented in Table 5-9. The last column of Table 5-9 indicates the life-cycle stage in which a material or component was included.

Table 5-9: E-reader Bill of Primary Material Inputs

Component		Material	Mass (g)	Mass (g)	Weight (%) of total	Weight (%) of total	Included in analysis as:
	Subcomponent						
Frame [a]	------------------->	Zinc	23.63		2.35%		Material Production Stage
Screws [a]	------------------->	Steel	5.00		0.50%		Material Production Stage
Housing Assembly [b]			177.96		17.70%		
	Cover	ABS		118.1		11.74%	Material Production Stage
	Rubber Tabs	Styrene-butadiene copolymer		31.42		3.12%	Material Production Stage
	Buttons	PVC		28.44		2.83%	Material Production Stage
CD-ROM disc	------------------->	Metals (Ni, Ag)	15.37		1.53%		Not included in analysis
Screen cleaning cloth	------------------->	Cotton Fibers	7.18		0.71%		Not included in analysis, <1% total mass
LCD Assembly [c]			125.62		12.49%		
	Glass [d]	Soda lime or borosilicate		114.31		11.37%	Glass Manufacturing Process
	Color Filter Pigment [d]	Resins		7.75		0.77%	Panel Component Manufacturing Process
	Polarizer [d]	Polyvinyl alcohol		1.93		0.19%	Panel Component Manufacturing Process
	Liquid Crystals [d]	Phenylcyclohexanes biphenyls		0.44		0.04%	Panel Component Manufacturing Process
	Transistor [d]	Metals (e.g. Si, Mo, Al, etc.)		0.36		0.04%	Module Manufacturing Process
	Electrode [d]	Indium Tin Oxide (ITO)		0.097		0.01%	Module Manufacturing Process
	Alignment layer [d]	Polymide		0.097		0.01%	Module Manufacturing Process
	Other (adhesives, spacers, misc) [d]	Miscellaneous		0.59		0.06%	Module Manufacturing Process
Printed Wiring Board Assembly [c]			82.33		8.19%		
	PWB [d]	Misc. (Se, Cu, etc.)		74.29		7.39%	PWB Manufacturing Process
	Solder [d]	60% tin, 40% lead		8.03		0.80%	PWB Manufacturing Process
Backlight Lamp [c]	------------------->	Misc. (glass, phosphor, Hg)	2.00		0.20%		Backlight Manufacturing Process
USB Cable [a,b]			47.84		4.76%		
	Wiring	Copper		23		2.29%	Material Production Stage, Cable Manufacturing
	Casing/Sheath	PVC		24.84		2.47%	Material Production Stage, Cable Manufacturing
Phone Cable [a,b]			41.18		4.10%		
	Wiring	Copper		7.38		0.73%	Material Production Stage, Cable Manufacturing
	Casing/Sheath	PVC		33.8		3.36%	Material Production Stage, Cable Manufacturing
AC Adapter [a,b]			385.61		38.35%		
	Wiring	Copper		38.56		3.83%	Material Production Stage, Cable Manufacturing
	Core	Iron		231.36		23.01%	Material Production Stage, Cable Manufacturing
	Other (adhesives, misc)	Misc.		9.64		0.96%	Not included in analysis, <1% total mass
	Casing/Sheath	PVC		106.04		10.54%	Material Production Stage, Cable Manufacturing
Internal Li-Ion Battery [e]			91.89		9.14%		
		Graphite [f]		3.45		0.34%	Not included in analysis, <1% total mass
		Carbon Black [f]		0.15		0.01%	Not included in analysis, <1% total mass
		Copper [f]		13.31		1.32%	Material Production Stage
		Manganese [f]		11.17		1.11%	Material Production Stage
		Magnesium [f]		0.71		0.07%	Not included in analysis, <1% total mass
		Carbon [f]		1.85		0.18%	Not included in analysis, <1% total mass
		Aluminum [f]		29.01		2.88%	Material Production Stage
		Carbon dioxide [f]		5.95		0.59%	Not included in analysis, <1% total mass
		Ethylene oxide [f]		5.95		0.59%	Not included in analysis, <1% total mass
		Steel [f]		8.84		0.88%	Material Production Stage
		PET [f]		4.44		0.44%	Not included in analysis, <1% total mass
		PE [f]		2.25		0.22%	Not included in analysis, <1% total mass
		PP [f]		2.25		0.22%	Not included in analysis, <1% total mass
		PVC [f]		0.33		0.03%	Material Production Stage
		Circuit Boards [f]		2.22		0.22%	Not included in analysis, <1% total mass
TOTAL			1005.61		100%		

a: mass directly measured; material identified via communication with material specialist (Filisko, 2002; Andrae, 2003) and energy dispersive spectrometry;
b: mass directly measured; material identified via communication with material specialists (Filisko, 2002; Andrae, 2003) and infrared spectrometry;
c: material composition based on EPA's CDP study (see explanation below);
d: mass estimated using EPA's CDP study (see explanation below);
e: material composition based on DOE's PNGV study (see explanation below);
f: mass estimated using DOE's PNGV study (see explanation below);
Note: BOM excludes the device's packaging components. This component will be modeled separately.
This life-cycle stage allocation scheme follows the same framework outlined in the CDP life-cycle.

As indicated in Table 5-9, the e-reader's LCD assembly is comprised of several subcomponents including glass**,** color filter pigment**,** polarizers**,** liquid crystals**,** transistors, electrodes**,** alignment layers**,** and other miscellaneous subcomponents. Since these subcomponents could not be readily separated and identified, subcomponent mass was estimated using an existing life cycle study produced as part of the U.S. EPA's Design for the Environment Computer Display Project (CDP) (Socolof 2001). The CDP study used LCA to investigate the life-cycle environmental impacts of LCD and cathode ray tube (CRT) technologies that can be used for desktop computer displays. According to CDP life-cycle study, the computer display's LCD assembly mass is 0.6483 kg[9], whereas the e-reader's LCD assembly mass is 125.62g. Table 5-10 presents the weight percentage of each computer display LCD assembly subcomponent.

Table 5-10: Computer Display LCD Subcomponent Weight Percent of Total LCD Assembly Mass

Computer Display LCD Subcomponent	Mass (kg)	Weight %
Glass	0.59	91 %
Color filter pigment	0.04	6.17 %
Polarizer	0.01	1.54 %
Liquid crystal	0.0023	0.35 %
Transistor	0.0019	0.29 %
Electrode	0.0005	0.077 %
Alignment layer	0.0005	0.077 %
Other	0.0031	0.47 %
Total	**0.6483**	**100 %**

Source: Socolof, 2001

Thus, the mass of each e-reader LCD subcomponent was estimated by combining the total mass of the e-reader's LCD assembly (125.62 g) with the weight percentages determined above. For example, according to the CDP study, glass comprises 91% of the total mass of the computer display LCD (see table above). Therefore, the glass component of the e-reader's LCD was assumed to weigh approximately 114 g (i.e. 91% of 125.62 g).

As with the LCD assembly, the e-reader's printed wiring board (PWB) assembly subcomponents could not be readily separated and identified. Instead, subcomponent mass was estimated using the EPA's CDP referenced above. According to CDP life-cycle study, the computer display's PWB assembly mass is 0.41 kg[10], whereas the e-reader's PWB assembly mass is 82.33 g. Table 5-11 presents the weight percentage of each computer display PWB assembly subcomponent.

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[9] Determined by adding the mass of each LCD subcomponent together.

[10] Determined by adding the mass of each PWB subcomponent together.

Table 5-11: Computer Display PWB Subcomponent Weight Percent of Total PWB Assembly Mass

Computer Display LCD Subcomponent	Mass (kg)	Weight %
PWB	0.37	90 %
Solder	0.04	10 %
Total	**0.41**	**100 %**

Source: Socolof, 2001

Thus, the mass of each e-reader PWB subcomponent was estimated by combining the total mass of the e-reader's PWB assembly (82.33 g) with the weight percentages determined above. For example, according to the CDP study, solder comprises 9.7 % of the total mass of the computer display PWB (see table above). Therefore, the solder component of the e-reader's PWB was assumed to weigh approximately 8.03 g (i.e. 9.7% of 82.33 g).

The e-reader's internal Lithium Ion (Li-Ion) battery is comprised of several materials, which could not be readily separated and weighed. Material composition information, therefore, was taken from a U.S. Department of Energy (DOE 2001) report developed under the Partnership for a New Generation of Vehicles (PNGV) program. This study involved a comparative assessment of the potential life-cycle environmental impacts of Li-Ion batteries for use in hybrid electric vehicles (HEVs). According to the DOE's PNGV study, the HEV's Li-Ion battery mass is 35.84 kg, whereas the e-reader's Li-Ion battery mass is 91.89 g. Table 5-12 presents a material breakdown for the HEV's Li-Ion battery.

Table 5-12: HEV Li-Ion Materials Breakdown

Material	Mass (kg)	Weight %
Graphite	1.347	3.76 %
Carbon Black	0.057	0.16 %
Copper	5.191	14.48 %
Manganese	4.357	12.16 %
Magnesium	0.275	0.77 %
Carbon	0.72	2.01 %
Aluminum	11.316	31.57 %
Carbon dioxide	2.321	6.48 %
Ethylene oxide	2.321	6.48 %
Steel	3.448	9.62 %
PET	1.733	4.84 %
PE	0.878	2.45 %
PP	0.878	2.45 %
PVC	0.13	0.36 %
Circuit Boards	0.867	2.42 %
Total	**35.84**	100 %

Source: DOE, 2001

Thus, the mass of each Li-Ion battery material for the e-reader was estimated by combining the total mass of the e-reader's battery (91.89 g) with the weight percentages determined above. For example, according to the PNGV study, aluminum comprises 31.57 % of the total mass of the HEV's Li-Ion battery (see table above). Therefore, the aluminum component of the e-reader's Li-Ion battery was assumed to weigh approximately 29 g (i.e. 31.57% of 91.89 g).

Data Sources and Quality

- For e-reader materials that could not be readily separated and identified, material composition and weights were estimated using data taken from an existing life cycle study (Socolof 2001) produced as part of the U.S. EPA's Design for the Environment (DfE) Computer Display Project (CDP). The CDP study used LCA to investigate the life-cycle environmental impacts of liquid crystal display (LCD) and cathode ray tube (CRT) technologies that can be used for desktop computer displays. Data were collected from both primary and secondary data. Where primary and secondary data were lacking, various assumptions and modeling served as defaults. The CDP study employed a critical review process in which a project Core Group and Technical Work Group, consisting of representatives from industry, academia, and government provided critical reviews of the assessment. Therefore, this data is considered to be of high quality. Other CDP data quality issues, where applicable, are explained in further detail in the sections that follow.
- Separable plastic components (i.e. cover, tabs, etc.) were identified via infrared spectrometry and personal communication with material specialists within UM's Department of Material Sciences and Engineering (Filisko 2002). Figure 5-4 provides an example of an infrared spectrum "fingerprint." This spectrum indicates that the device's inner packaging material is comparable to polyurethane. Vertical differences between the two graphs can be attributed to material thickness (Filisko 2002).

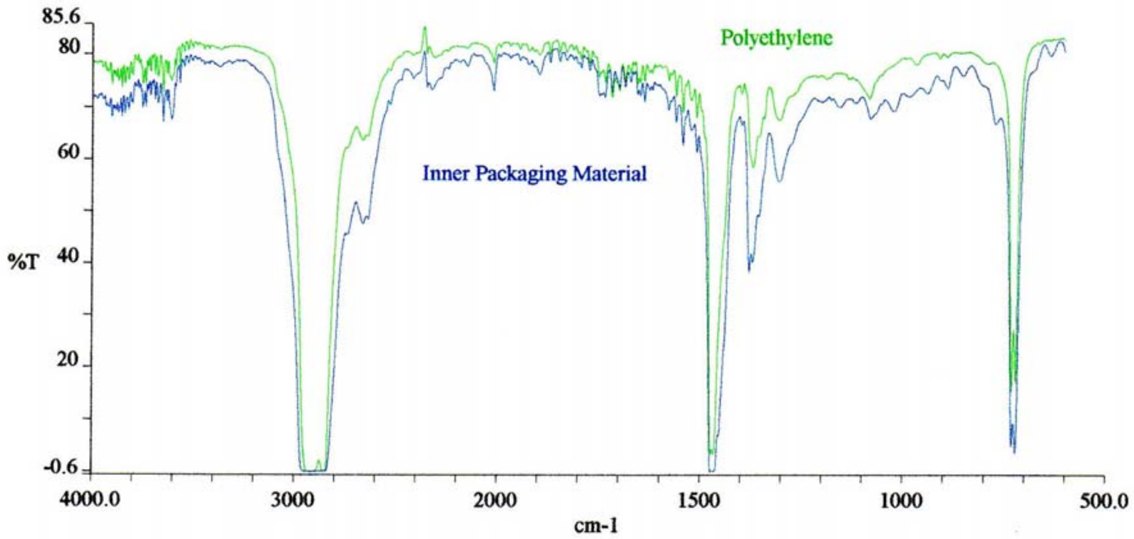

Figure 5-4: Inner Packaging Infrared Spectrum Fingerprint

- Separable metallic components (i.e. frame, screws, etc.) were identified via energy dispersive spectrometry and personal communication with material specialists within UM's Department of Geological Sciences (Skomurski 2003). Figure 5-5 provides an example of an energy spectrum "fingerprint." This spectrum indicates that the e-reader's frame is comprised almost entirely of zinc with trace amounts of carbon, oxygen and silica.

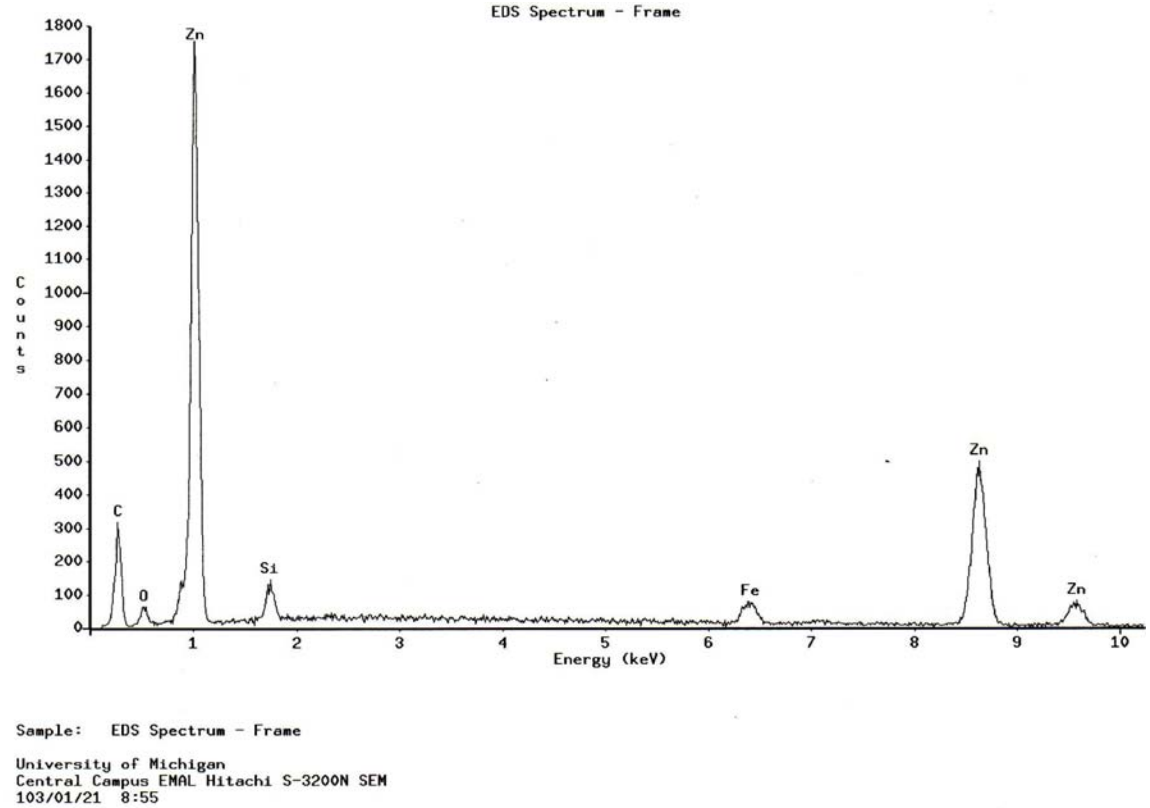

Figure 5-5: Frame Energy Spectrum Fingerprint

- Separable plastic and metallic components were weighed directly using a standard digital scale.
- Li-Ion battery material inventory data were taken from a U.S. Department of Energy (DOE 2001) report entitled, Environmental Evaluation of New Generation Vehicles and Vehicle Components, developed under the Partnership for a New Generation of Vehicles (PNGV) program. This study involved a comparative assessment of the potential life-cycle environmental impacts of Li-Ion batteries for use in hybrid electric vehicles (HEVs). According to the PNGV study, material composition data were collected from secondary sources. Where data were not available, other materials were picked as surrogates, or that material was left out. Consequently, the final percentage of the total battery mass accounted for was 89.6%. Because the precision and completeness of this information were difficult to determine, it is considered to be of average quality.
- AC adapter, USB cable and telephone cable material composition and mass percentages were derived via personal communication with material and industry specialists (Filisko 2002; Andrae 2003).

Limitations and Uncertainties

- For the CDP life-cycle study, the functional unit was one LCD desktop computer display over its lifespan. The functional unit specifications for this LCD desktop computer display versus the REB 1100 e-reader are presented in the following table.

Table 5-13: FU Comparison between a LCD Desktop Computer Display and REB 1100

Specification	LCD Desktop Computer Display	REB 1100 E-Reader
Mass	5.73 kg	.417 kg *
Diagonal Viewing Area	15”	5.5”
Resolution	1024 x 768 color pixels	320 x 480 pixels

* E-reader mass excludes the internal Li-Ion battery, AC adapter, USB cable, telephone cable, CD-ROM, screen cleaning cloth, and all packaging elements since these items do not actually comprise the e-reader, itself.

Although a computer desktop display and an e-reader have distinct performance characteristics and are used in different applications, both display devices employ LCD technologies. Therefore, to facilitate modeling of the REB 1100’s materials processing and manufacturing, this study assumes that the LCD desktop computer display modeled in the CDP life-cycle study and the REB 1100 device are comparable (i.e. material composition and material processing) except for the following key dissimilarities.

1) The LCD computer desktop display has a greater mass and diagonal viewing area than the REB 1100.

2) The REB 1100 contains a 91.9 g Li-Ion rechargeable battery. Additionally, several cables and accessories accompany the REB 1100, including the device’s AC adapter, USB cable, telephone cable, CD-ROM, and screen cleaning cloth. As indicated in the table above, the e-reader FU mass (416.54 g) excludes the mass of these accessories (474.63 g).

- The PNGV study used LCA to investigate the potential life-cycle environmental impacts of Li-Ion batteries for use in a hybrid electric vehicle. Although a hybrid vehicle’s battery and an e-reader’s internal battery have distinct performance characteristics and are used in different applications, both batteries employ Li-Ion technologies. Therefore, to facilitate modeling of the REB 1100’s materials processing and manufacturing, this study assumes that the Li-Ion battery modeled in the PNGV life-cycle study and the e-reader’s Li-Ion battery are comparable (i.e. material composition and material processing) except for a difference in total mass.

5.3.1 Material Production Phase

5.3.1.1 E-Reader Material Production

Introduction

An e-reader's primary components are generally derived from metallic minerals, natural gas, and petroleum stocks. This study's analysis of the e-reader system combines the environmental burdens from raw material extraction with environmental burdens from material processing. Therefore, activities attributable to the extraction of metallic minerals, natural gas, and petroleum have been incorporated into the *E-Reader Production* model element. Material processing involves the processing of natural resources by reaction, separation, purification, and alteration steps to yield engineered materials. Material processing also includes transporting those processed materials to the product manufacturing facilities.

Model Description and Results

The materials included in the Material Production stage for which inventory data were obtained are presented in Table 5-14. As explained in Table 5-9, the e-reader life-cycle stage allocation scheme follows the same framework outlined in the CDP life-cycle study, such that environmental burdens associated with the production of the metals and polymers used in the computer display were included in the upstream life-cycle stage (i.e. materials extraction and materials processing). Similarly, environmental burdens associated with all other computer desktop LCD display materials (e.g. PWB, liquid crystals, etc.) were included in the manufacturing stages, which again follows the framework outlined in the CDP life-cycle study. Table 5-14 also summarizes the data source, data quality information, and whether or not transport data was included in the inventories.

Table 5-14: Materials included in the material production stage and data sources

Material	Mass (g)	Transport included?	Source (year)
METALS			
Zinc	23.63	Y[b]	Ecobalance DEAM Database (1996)
Copper	82.25	Y[b]	Ecobalance DEAM Database (1996)
Aluminum	29.01	Y[b]	Ecobalance DEAM Database (1996)
Iron	231.36	N	U.S. AMP (1998)
Steel	13.84	Y[b]	Ecobalance DEAM Database (1990)
Manganese	11.17	N	Ecobalance DEAM Database (1996)
POLYMERS			
Acrylonitrile-butadiene styrene (ABS)	118.1	N	Ecobalance DEAM Database (1997)
Styrene-butadiene copolymer [a]	31.42	N	Ecobalance DEAM Database (1997)
Polyvinyl Chloride (PVC)	193.45	N	Ecobalance DEAM Database (1997)

a: The styrene-butadiene process is the 50/50 average of the styrene and butadiene processes.

b: Data set addresses transportation; however, the extent to which it is included in a particular process inventory is uncertain.

LCI data and calculations for e-reader materials processing are included in Appendix I. As indicated in the table above, transportation data is not included in 5 of 9 data sets. To account for this missing data, the amount of energy consumed and emissions generated during transportation are calculated for those materials where transportation is omitted and are included in Appendix J. Appendix J also includes LCI production data for the amount of diesel gasoline consumed during transportation. Environmental burdens associated with transportation were calculated in the same manner described in Section 5.2.1.1. LCI data presented in Appendixes I and J is summarized in the table below.

Table 5-15: LCI results – Materials production

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Materials Processing	3	46	2	28	26	0
Material Delivery*	0.01	1.05	0.71	0.51	0.53	0

* Includes diesel production data and combustion-related data

Data Quality and Sources

- LCI data for the production of steel, copper, aluminum, manganese, ABS and PVC were compiled from Ecobalance's TEAM life cycle assessment software and associated DEAM database. Ecobalance's DEAM databases are derived from a variety of sources, including European and U.S. data sources. Additionally, the temporal boundaries of the data vary. Further, transportation data (e.g. from material production to the manufacturing facility) is not included in each data set, thereby creating a data gap for those particular data sets. In light of these factors, inconsistencies among data sets are created and reduce the data quality when used for the purposes of this study. However, this is a common difficulty with LCA, which often uses data from secondary sources for upstream processes to avoid the tremendous amount of time and resources required to collect all the needed data (Socolof 2001).
- Life cycle data on transportation energy and emissions were taken from a report provided by Franklin Associates, Ltd. This data source is discussed in Section 5.2.1.1. It should be noted that for those materials where transportation information is omitted, an initial travel distance of 500 miles is assumed.

Uncertainties and Limitations

- Ecobilan inventories are derived from secondary sources. For example, some data comes from Europe, some from the United States, and some from both. Thus, the available inventories do not precisely meet the geographic and temporal boundaries outlined in Section 4 of this study. However, the material processing data represents only one portion of the overall inventory of the e-reader system. Further, Ecobilan inventories listed in Table 5-14 have been widely used throughout the world (Ecobilan 1999), which suggests that these limitations are not unique to this project, but common of other LCIs as well.

- Issues related to limitations and uncertainties regarding transportation are discussed in Section 5.2.1.1.

5.3.2 Manufacturing Phase

Three separate model elements for the manufacturing of the e-reader, itself, the e-reader's internal lithium-ion battery, and e-reader cabling were constructed and are presented below.

5.3.2.1 E-Reader Manufacturing

Activities associated with the *E-Reader Manufacturing* model element include further processing of the e-reader's various components and assembly of the e-reader device, whereupon it is ready for delivery. E-reader manufacturing involves the following manufacturing processes:

- Cold cathode fluorescent lamp (CCFL) manufacturing;
- Backlight light guide manufacturing;
- Polarizer manufacturing;
- Liquid crystal manufacturing;
- LCD glass manufacturing;
- Front glass color filter patterning;
- LCD panel and module manufacturing;
- Printed wiring board manufacturing; and,
- E-reader assembly

Based on the assumption that the LCD desktop computer display modeled in the CDP life-cycle study and the REB 1100 device are comparable in terms of material composition and material processing, LCI manufacturing data for a LCD desktop computer display (Socolof 2001) was scaled down for an e-reader using relative mass (5.73 kg vs. 0.417 kg). It should be noted that this e-reader mass excludes the internal Li-Ion battery, AC adapter, USB cable, telephone cable, CD-ROM, screen cleaning cloth, and all packaging elements since these items do not actually comprise the e-reader, itself.

The CDP life-cycle study categorizes certain manufacturing sub-processes. For example, the CDP life-cycle study includes separate LCI data for glass and PWB manufacturing. In this case, the e-reader LCI data is scaled down using relative mass for those respective components. For example, CDP glass weighs 590 g vs. 114 g for the e-reader, thereby requiring an adjustment factor of 0.19. Similarly, the CDP PWB weighs 370 g vs. 82.3 g for the e-reader, thereby requiring an adjustment factor of 0.22. As expected, LCI data for other manufacturing processes (e.g. product assembly) was scaled down using relative total mass (5.73 kg vs. 0.89 kg). LCI results for e-reader manufacturing are presented in Appendix K and summarized in the table below.

Table 5-16: LCI results – E-Reader Manufacturing

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
E-Reader Manufacturing	21	203	5	0	122	1

Data Sources and Quality

- LCI e-reader manufacturing data was taken from an existing life cycle study (Socolof 2001) produced as part of the U.S. EPA's Design for the Environment (DfE) Computer Display Project (CDP). LCD manufacturing data from Japanese, Korean, American manufacturers of desktop computer monitors were collected using data collection questionnaires. Follow-up communication with these companies was conducted to verify data gaps or discrepancies. Participating companies provided information about their manufacturing process and inventory of process inputs and outputs. Where data could not be confirmed, additional literature research and discussions with other industry experts were conducted (Socolof 2001). Some of the companies that participated in this study included Samsung Electronics, Toshiba Display Technology Co., Ltd., and Harison Electric Co., Ltd. The data collection phase of the CDP project began in 1997 and extended through 2000. In the data collection questionnaires, companies identified whether the quantity of each inventory item was measured, calculated, or estimated. The questionnaires indicated that 33% of the data was measured, 30% calculated, 23% estimated, and 14% not classified. The reader is referred to the CDP life-cycle study for additional data quality issues.

Limitations and Uncertainties

- The primary limitations and uncertainties associated with the CDP study's manufacturing analysis are related to 1) material exclusions 2) data availability 3) data collection process 4) data uncertainties. These issues are discussed below:

  1) Material Exclusions - Although major LCD components were included in the CDP analysis, certain components, most notably the column and row driver ICs, were excluded from the analysis. Back-of-the-envelope calculations suggest that this exclusion is not expected to have a significant impact on the inventory results due to the small size of the drivers (Socolof 2001).
  2) Data Availability – Companies were not willing to provide information regarding LCD glass manufacturing. Instead, CRT glass manufacturing data was modified to represent LCD glass manufacturing.
  3) Data Collection Process – Companies supplying data for this project were self-selected. Because some environmentally progressive companies may be more willing to supply data than those that are less progressive, the possibility of selection bias exists. Further, the data were supplied by companies whose vested

interest is to have their product look more desirable, which could result in biased data being provided (Socolof 2001). To help reduce or identify any such bias, a peer review process was employed. Finally, verification of data was difficult due to obvious language barriers, although the use of the Asian Technology Information Program (ATIP) as a liaison helped reduce this limitation.

4) Data Uncertainties – Additional limitations are related to large data ranges (i.e. wide variability in data) provided by LCD manufacturers.

The reader is referred to the CDP life-cycle study for more information on additional limitations and uncertainties.

- LCD panel manufacturing is an ever evolving and rapidly advancing process. Thus, this study's analysis is viewed as a "snapshot" in time and reflects environmental burdens associated with LCD manufacturing from 1997 through 2000.
- Recent industrial ecology analyses provide evidence that far more energy and chemicals than previously suspected are required to produce semiconductors and that the U.S. Toxics Release Inventory (TRI) significantly underestimate emissions associated with the production of semiconductors (Betts 2003). These studies indicate that the embodied energy and materials necessary for semiconductor production and operation inflate the weight of a 2 gram chip by 630-fold. Further, the Electronics Industry Association of Japan's emissions value for semiconductor production and operation is 10 times that of the TRI estimates. The CDP study did not treat semiconductors as a separate entity. Rather, environmental burdens associated with the semiconductor were rolled in with the PWB data. Thus, it is difficult to determine if the CDP LCI data for the PWB component accurately reflects these amplified impacts discussed above. Due to the small size/mass of these semiconductors, however, it is expected that the potential exclusion of these enlarged environmental impacts may not significantly influence this study's results.
- This study assumes that the LCD desktop computer display modeled in the CDP life-cycle study and the REB 1100 device are comparable in terms of manufacturing processes. Although both display devices employ LCD technologies, e-readers are unique in that they often utilize components/technologies that are not generally incorporated into LCD desktop computer displays. For example, some e-readers employ RAM chips, styluses, CD-ROMs, and screen cleaning cloths. The manufacturing of these components may be energy intensive and use various process chemicals that degrade the environment. However, due to the small size of these components, it is assumed that treating LCD desktop computer displays and the REB 1100 device as identical will not significantly impact this study's results.

5.3.2.2 Cable Manufacturing

Activities associated with the *Cable Manufacturing* model element include processing and assembly of the e-reader's AC adapter, USB cable and telephone cable. E-reader cable manufacturing involves the following manufacturing steps:

- Receipt of raw materials;

- Wire drawing;
- Wire inspection;
- Electrolytic tinning;
- Insulation;
- Stranding;
- Sheathing;
- Testing;
- Quality Control Inspection; and,
- Marking and Packaging

An existing study investigating the environmental impacts of computer cable manufacturing was used for this model (Andrae 2003). Based on the results of this study, the on-site energy burden for computer cable manufacturing/assembly was determined to be 0.83 Wh/gram (electricity)[11]. This model variable may be adjusted using the Model Inputs spreadsheet in Appendix A.

As discussed earlier, the total cable mass was determined to be 474.63 g. Thus, the electricity required to manufacture the e-reader's cabling was calculated using the following relationship:

$$\text{Electricity}_{\text{Cabling}} = \frac{0.83\ \text{Wh}}{\text{gram}} \times \frac{474.63\ \text{g}}{\text{FU}} \times \frac{1\ \text{kWh}}{1000\ \text{Wh}} \times \frac{3.6\ \text{MJ}}{1\ \text{kWh}}$$

$$= \mathbf{1.41\ MJ/FU}$$

Total fuel cycle LCI data, including upstream environmental burdens, for e-reader cable manufacturing is included in Appendix L and was constructed using Ecobalance, Inc.'s DEAM life cycle assessment software for conventional electricity generation (NERC ECAR region).

The model element for *Cable Manufacturing* includes logistics from the cable manufacturing facility to e-book manufacturing facility. The following assumptions were made to facilitate transportation calculations.

- After completion of the cable manufacturing steps, the cables are shipped directly from the cable manufacturing facility to e-book manufacturing facility. Thus, intermediate warehousing is excluded from this analysis.
- A single heavy duty, class 8 diesel tractor-trailer is used for the duration of the trip.
- Since the predominant fuel is diesel, emissions will be calculated based on diesel combustion.
- The weight of packaging materials is considered negligible.

The amount of energy consumed and emissions generated during transportation are calculated for the total cable mass (474.63 g) and are included in Appendix L as well.

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[11] Energy for heating of factory was not included in this analysis.

Appendix L also includes LCI production data for the amount of diesel fuel consumed during transportation. LCI data presented in Appendix L is summarized in the table below.

Table 5-17: LCI results – Cable Manufacturing

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Cable Manufacturing	0.23	6.89	0.92	0.09	0.15	1.11
Cable Delivery*	0.01	0.85	0.71	0.41	0.43	1.11

* Includes diesel production data and combustion-related data

Data Quality and Sources

- LCI cable manufacturing data was taken from an unpublished Swedish report compiled by Ericsson, Inc. (Andrae 2003) that utilized LCA methodology to determine the environmental impacts associated with computer cabling. Cable manufacturing data from Swedish manufacturers of installation and switchboard cabling were collected using LCI data collection questionnaires. This LCA provided electricity requirements associated with facility operations (i.e. lighting, assembly), while excluding burdens associated with heating the facility and transportation of materials and products. LCA results reportedly agree with industry field measurements, which suggests data of good quality.
- Issues related to data quality of Ecobalance's TEAM software program for conventional electricity generation are discussed in Section 5.2.2.2.
- Life cycle data on transportation energy and emissions were taken from a report provided by Franklin Associates, Ltd. This data source is discussed in Section 5.2.1.1. An initial travel distance of 500 miles is assumed.

Limitations and Uncertainties

- As discussed earlier, this model element utilized manufacturing data from a Swedish LCA. Clearly, there are differences between Swedish and North American cable manufacturing industries.
- To facilitate modeling of the e-reader's AC adapter, USB cable, and telephone cable processing and manufacturing, this study assumes that the cable modeled in the Ericsson life-cycle study and the e-reader's cabling are identical (i.e. material composition and material processing). One could argue that manufacturing of these different cables may vary due to their distinct performance requirements and applications. Similarly, the Swedish life-cycle study did not include energy burdens associated with heating the facility. However, the cable manufacturing data represents only one portion of the overall inventory of the e-reader system and is therefore, not expected to have a significant impact on the results of this study.
- Issues related to limitations and uncertainties regarding transportation are discussed in Section 5.2.1.1.

5.3.2.3 Battery Manufacturing

Activities associated with the Li-Ion battery's material production are included in Section 5.3.1.1. Activities associated with the *Battery Manufacturing* model element include processing and assembly of the e-reader's internal Li-Ion Battery. An existing study investigating the environmental impacts of industrial 2V lead/acid battery manufacturing was used as a surrogate for this model (Andrae 2003). According to this study, lead/acid battery manufacturing involves the following manufacturing steps:

- Receipt of raw materials;
- Lead cylinder casting;
- Lead oxide production;
- Paste production;
- Grid production;
- Casting TTW connectors (of brass);
- Grid pasting;
- Grid curing;
- Plate forming;
- Plate washing;
- Plate drying;
- Plate partitioning;
- Assembly;
- Welding of elements;
- On/off-line shrinking;
- TTW welding;
- Cover welding;
- (Thioxy) gluing cover;
- Terminal post assembly;
- Leak testing;
- Filling and first charge;
- Further leak testing;
- High rate discharge testing; and,
- Storage and shipping.

Based on the results of the Andrae (2003) study, the on-site energy burden for battery manufacturing/assembly was determined to be 10.59 kWh/pair (electricity)[12]. A pair of 2V batteries weighs approximately 7 kg (Andrae 2003). Therefore, the energy burden for battery manufacturing/assembly is assumed to be 1.51 kWh/kg. This model variable may be adjusted using the Model Inputs spreadsheet in Appendix A.

As discussed earlier, the Li-Ion battery mass was determined to be 91.89 g. Thus, the electricity required to manufacture the e-reader's battery was calculated using the following relationship:

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[12] Energy for heating of factory was not included in this analysis.

$$\text{Electricity}_{\text{Battery}} = \frac{1.51\,\text{kWh}}{\text{kg}} \times \frac{1\,\text{kg}}{1000\,\text{g}} \times \frac{91.89\,\text{g}}{\text{FU}} \times \frac{3.6\,\text{MJ}}{1\,\text{kWh}}$$

$$= \mathbf{0.499\ MJ/FU}$$

Total fuel cycle LCI data, including upstream environmental burdens, for e-reader battery manufacturing is included in Appendix M and was constructed using Ecobalance, Inc.'s DEAM life cycle assessment software for conventional electricity generation (NERC ECAR region).

The model element for *Battery Manufacturing* includes logistics from the battery manufacturing facility to e-book manufacturing facility. Environmental burdens associated with transportation were calculated in the same manner described for the e-reader cabling above. The amount of energy consumed and emissions generated during transportation are calculated for the total battery mass (91.89 g) and are included in Appendix M as well. Appendix M also includes LCI production data for the amount of diesel gasoline consumed during transportation. LCI data presented in Appendix M is summarized in the table below.

Table 5-18: LCI results – Battery Manufacturing

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Battery Manufacturing	0.08	2.43	0.57	0.00	0.05	0.39
Battery Delivery*	0.00	0.16	0.68	0.08	0.08	0.00

* Includes diesel production data and combustion-related data

Data Sources and Quality

- LCI battery manufacturing data was taken from an unpublished Swedish report compiled by Ericsson, Inc. (Andrae 2003) that utilized LCA methodology to determine the environmental impacts associated with a 7 kg 2V lead/acid battery. Manufacturing data from Swedish manufacturers of lead/acid batteries were collected using LCI data collection questionnaires. This LCA provided electricity requirements associated with facility operations (i.e. lighting, assembly), while excluding burdens associated with heating the facility and transportation of materials and products. LCA results reportedly agree with industry field measurements, which suggests data of good quality.
- Issues related to data quality of Ecobalance's TEAM software program for conventional electricity generation are discussed in Section 5.2.2.2.
- Life cycle data on transportation energy and emissions were taken from a report provided by Franklin Associates, Ltd. This data source is discussed in Section 5.2.1.1. An initial travel distance of 500 miles is assumed.

Limitations and Uncertainties

- As with the cable manufacturing data, this model element utilized manufacturing data from a Swedish LCA. Clearly, there are differences between Swedish and North American battery manufacturing industries.
- Due to a lack of data regarding Li-Ion battery manufacturing, this study assumes that the 2V lead/acid battery modeled in the Ericsson life-cycle study and the e-reader's battery are comparable in terms of manufacturing. However, manufacturing energy intensities for different battery types (e.g. Li-Ion vs. lead/acid) may vary due to their distinct performance requirements and applications. Additionally, the Swedish life-cycle study did not include energy burdens associated with heating the facility.
- Issues related to limitations and uncertainties regarding Ecobalance's TEAM software program for conventional electricity generation are discussed in Section 5.2.2.2.
- Issues related to limitations and uncertainties regarding transportation are discussed in Section 5.2.1.1.

5.3.3 Product Distribution Phase

5.3.3.1 Packaging Production

Introduction

Following product assembly, the REB 1100 device is housed in a 13" x 8.25" x 4.5" box, which contains a number of separate compartments that house the individual e-reader components. The packaging described above is comprised of 100% virgin corrugated paper. Also, several items including additional inner packaging and the device's instructions manual are comprised of office paper. Finally, several individual e-reader components (e.g. AC adapter, telephone cable) and the e-reader, itself, are packaged in plastic. A summary of all packaging components associated with the REB 1100 and materials that make up those components is included in Table 5-19.

Table 5-19: REB 1100 Packaging Bill of Materials

Component	Material	Mass (g)
Outer Box	Corrugated Paper	292.51
Inner Packaging (i.e. compartments)	Corrugated Paper	259.08
CD-ROM slip cover	Office Paper	4.07
Screen Cleaning Cloth Packaging	Office Paper	1.4
REB 1100 Instructions Manual	Office Paper	38.28
Synthetic leather slip case	Calendered PVC	52.6
Inner Packaging (i.e. plastic bags)	Polyethylene	14.03
Total		**661.97**

All activities related to the e-reader's packaging have been allocated to the Distribution Phase of the E-book system (see Figure 4-2). Data was collected for the following packaging elements: 1) paper and plastic packaging production; and 2) packaging disposition. It should be noted that this study's analysis of the e-reader system combines the environmental burdens from material extraction with environmental burdens from production. Therefore, any activities attributable to wood harvesting for paper or petroleum drilling for plastic, for example, have been incorporated into the *Packaging Production* model element description.

Paper Packaging and Instruction Manual

As stated above, several items including the device's outer box (~292.51 g) and inner packaging (~259.08 g) are comprised of corrugated paper. LCI data for the production of one-ton linerboard and medium for corrugated containers (EPA 2000) was used to determine the environmental burdens associated with the production of the corrugated paper outer box and inner packaging.

Corrugated containers are made by combining three paper board layers—a kraft or recycled paperboard inner liner and outer liner and a semichemical or recycled fluted paperboard medium—using a starch-based adhesive to adhere all three layers (EPA 2000). The resulting containerboard is then cut and folded to form the finished box. It should be noted that the starch adhesive and finished box are not included in the EPA profile.

The boundaries for the corrugated paper LCI profiles include harvesting of trees, wood residue production, sodium sulfate mining and processing, soda ash production, corn starch manufacturing, manufacture of virgin unbleached and semichemical paperboard, and transportation of rolls to corrugated box plants. The U.S. EPA life-cycle inventory data did not include LCI data for raw material requirements. Therefore, raw material requirements were determined using Ecobalance, Inc.'s TEAM life cycle assessment software for the production of 1000 kg of corrugated cardboard. LCI data and calculations for the REB 1100's corrugated paper packaging production are included in Appendix N.

As discussed earlier, several items including additional inner packaging (~5.47 g) and the device's instruction manual (~38.28 g) are comprised of office paper. LCI data for the production of 100 percent virgin office paper was used for this model (EPA 2000). The data for virgin office paper profile represent uncoated freesheet bleached paper produced in an alkaline papermaking process using bleached kraft pulp. The product consists of 78 percent pulp, 16 percent filler, and 6 percent moisture. The boundaries for the office paper LCI profiles include harvesting of trees, transportation of logs to the mill, debarking and chipping, and manufacture of pulp and paper using primary fiber. Again, the U.S. EPA life-cycle inventory data did not include LCI data for raw material requirements. Therefore, raw material requirements were determined using Ecobalance, Inc.'s TEAM life cycle assessment software for the production of 1000 kg kraft (bleached) from pulp bleached with sulfate. LCI data and calculations for the device's inner packaging and manual office paper production are also included in Appendix N.

Plastic Packaging

As discussed earlier, several individual e-reader components (e.g. AC adapter, telephone cable) are packaged in plastic. Infrared spectrometry indicated that this plastic material is comprised of polyethylene (PE). LCI data was produced using Ecobalance's DEAM database for the production of 1 kg of PE (all grades) and is included in Appendix N along with the LCI data for paper production. The boundaries for PE production include extraction of raw materials, (crude oil, natural gas, etc.), processing crude oil and natural gas, petroleum refining, and ethylene polymerization and separation of polyethylene. Transport of the finished product is not included in the DEAM database.

According to Table 5-19, the e-reader is housed in a synthetic leather slipcase. Synthetic leather carrying cases, such as this, are typically constructed with a calendered polyvinyl chloride (PVC) material (Sommers 2002). Therefore, this study assumes that the e-reader's slipcase is constructed of 100% calendered PVC. LCI data was produced using Ecobalance's DEAM database for the production of 1 kg of PVC and is included in Appendix N. The boundaries for this system include extraction of raw materials, production of the polymer resin, transport of the resin to the converter, the conversion process itself, and the packaging of the finished component for onward dispatch. Transport of the finished PVC product to the e-reader manufacturing facility is not included in this DEAM database.

Transportation

The model element for *Packaging Production* includes logistics from the packaging production facility to the e-reader manufacturing facility. Environmental burdens associated with transportation were calculated in the same manner described in Section 5.2.1.1. The packaging transportation model variables may be adjusted using the *Model Inputs* spreadsheet. LCI data and calculations for the REB 1100's packaging transportation are included in Appendix O. Appendix O also includes LCI production data for the amount of diesel gasoline consumed during transportation.

LCI data presented in Appendixes N and O is summarized in the table below.

Table 5-20: LCI results – Packaging Production

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Packaging Production	1.02	23.37	0.80	11.11	14.08	0.15
Packaging Delivery*	0.01	1.18	0.72	0.58	0.60	0

* Includes diesel production data and combustion-related data

Data Quality and Sources

- The U.S. EPA life-cycle inventory data for corrugated linerboard and medium and office paper (2000) was compiled through a cooperative agreement between the Research Triangle Institute (RTI) and the U.S. EPA's Office of Research Development. The LCI data for corrugated linerboard and medium is considered to be of very good quality. However, because the precision and completeness of information were difficult to determine, EPA considers the LCI data for office paper to be of average quality.
- Issues related to data quality of Ecobalance's TEAM software program are discussed in Section 5.2.1.1. and 5.3.1.1.
- Life cycle data on transportation energy and emissions were taken from a report provided by Franklin Associates, Ltd. This data source is discussed in Section 5.2.1.1. An initial travel distance of 500 miles is assumed.

Limitations and Uncertainties

- Issues related to the limitations and uncertainties of data presented in the U.S. EPA life-cycle inventory data for linerboard, medium for corrugated containers, and office paper are present in 5.2.1.1.
- Limitations and uncertainties associated with Ecobalance's TEAM software program are discussed in Section 5.2.1.1 and 5.3.1.1
- Issues related to limitations and uncertainties related to transportation are discussed in Section 5.2.1.1.

5.3.3.2 Packaging Disposition

The next Distribution Phase activity considered involves the disposition of the e-reader's packaging. This study assumed that all packaging is disposed of at a landfill. Environmental burdens related to collection and landfill processing activities was taken from a report published by Keep America Beautiful, Inc. and conducted by Franklin Associates, Ltd. (2000). LCI data for packaging disposition is included in Appendix P and is summarized in the table below.

Table 5-21: LCI results – Packaging Disposal

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Disposal	0.00	0.40	0.15	0.00	0.11	0.66

Data Quality and Sources

- Landfill disposal data was acquired from a study conducted by Franklin Associates and published by Keep America Beautiful, Inc. This study reports the energy and environmental emissions related to the collection vehicle and landfill equipment for handling MSW (Franklin 2000).

Limitations and Uncertainties

- The study assumes that all packaging associated with the e-reader is landfilled. However, the user may wish to retain the device's packaging for other uses (e.g. storage). Given the relatively small FU burden (0.66 kg) associated with the e-reader's packaging landfill disposition, this decision was not expected to have a significant impact on the results of this study.

5.3.3.3 E-Reader Delivery

The final Distribution Phase activity considered involves the delivery of the e-reader to the end user. Since this study centers on the use of these e-readers in a university setting, we will assume that the device will be delivered to a college student's home. The following assumptions were made to facilitate model calculations.

- After the post-press production process, the e-reader is shipped directly from the manufacturing facility to the student's home. Thus, intermediate warehousing is excluded from this analysis.
- A single heavy duty, class 8 diesel tractor-trailer is used for the duration of the trip.

E-Reader Transportation model variables may be adjusted using the *Model Inputs* spreadsheet in Appendix A and are described below.

1. Travel Distance: Refers to the distance between the e-reader manufacturing facility and the student's home. This study assumes an initial distance of 500 miles.
2. FU Mass: Including packaging, the e-reader's FU mass was determined to be 1.67 kg/FU (0.0018 ton/FU).
3. Franklin Associates (2000) reported the average transportation fuel and energy requirements for a diesel tractor-trailer to be 9.4 gal/1,000 ton-mile and 1,465 Btu/ton-mile, respectively.

All energy and calculations are based on the following relationship:

Energy (MJ) =

FU mass (ton) x distance (mi) x energy consumption rate (Btu/ton-mile) x 0.001055 MJ/1Btu

The amount of energy consumed and emissions generated during e-reader transportation are calculated for the total FU mass and are included in Appendix Q. Appendix Q also includes LCI production data for the amount of diesel gasoline consumed during transportation. LCI data presented in Appendix Q is summarized in the table below.

Table 5-22: LCI results – E-Reader Delivery

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
E-Reader Delivery*	0.04	2.99	0.79	1.46	1.51	0.01

* Includes diesel production data and combustion-related data

Data Sources and Quality

- Life cycle data on transportation energy and emissions were taken from a report provided by Franklin Associates, Ltd. This data source is discussed in Section 5.2.1.1.

Limitations and Uncertainties

- E-readers are sometimes shipped physically from the manufacturer to wholesalers' warehouses and finally to thousands of retail bookstores and/or libraries. Since these intermediate warehouses have a relatively low energy intensity per footprint, energy burden associated with the brief storage of an e-reader is expected to be small. Thus, warehousing was excluded from this LCI.
- All other limitations and uncertainties regarding transportation are discussed in Section 5.2.1.1.

5.3.4 Use Phase

5.3.4.1 E-Reader Storage

As discussed earlier, *E-Reader Storage* refers to the management activities necessary to maintain an e-reader. Although this model element appears in the process flow diagram (Figure 4-2) for the e-reader system, this process is not modeled independently and is shown separately for clarification purposes only. Alternatively, all activities attributable to *E-Reader Storage* have been included within the *Facility Infrastructure* model element description, which is presented below.

5.3.4.2 Facility Infrastructure

This model element investigates the environmental burdens related to the building infrastructure necessary to maintain the integrity of the e-reader. The case for the traditional book system was discussed in Section 5.2.4.2. Since an e-reader and a print-based book are comparable in size, an e-reader's storage burden is assumed to be equal to the storage burden of one scholarly book. However, the impacts associated with building infrastructure are considered to be small in comparison with the environmental impacts associated with the use of the e-reader over the device's lifetime. Therefore, this element is not modeled independently and is shown separately in Figure 4-2 for clarification purposes only.

5.3.4.3 Personal Transportation

This model investigates the environmental burdens associated with consumer-related travel. Preliminary findings suggest that that many e-book devices are delivered directly to customers. Therefore, it is assumed that the e-reader device is shipped directly from the manufacturer to the user. Environmental burdens associated with e-reader delivery were discussed in Section 5.3.3.3.

5.3.4.4 Document Creation

This process involves several key steps (i.e. authoring, digital file storage, editing, etc.) necessary to create a scholarly e-textbook. Process flow diagrams for both systems (Figures 4-1 and 4-2) feature this model element. However, as discussed in Section 5.2.2.1, the *Document Creation* process is virtually identical to both systems and has, therefore, been mutually excluded from this analysis.

5.3.4.5 Server Computer and Data Storage

Introduction

The next Use Phase activity considered involves the digital storage of web accessible e-textbooks. Following the creation of a scholarly e-textbook, the data file is stored electronically on a server. In general, a server is a computer/device that provides information or services to computers on a network. Servers tend to be powerful computers that have large storage capacities and the ability to communicate over a network (Noerr 2000). Three server-related components were modeled for this study: 1) data storage; 2) server production; and 3) server disposition. In this study, these server-related components are processes that support the use of the e-reader. Therefore, all server-related environmental burdens have been assigned to the e-reader system's overall Use Phase (see Figure 4-2).

Data Storage Model Description and Results

The *Data Storage* model utilized life cycle model components developed by Gard (2001). The following baseline assumptions were made to facilitate model calculations:

- The network server was assumed to have a design life of 4 years and operates continuously.
- E-book files are stored on the server's internal hard drive.
- The Sun Fire 4800 Server, considered by industry professionals as an appropriate choice for internal storage of e-books data files (Lutter 2003), was chosen to represent a network server for this study. This particular server model has a power rating of 3,040 Watts.

Electricity requirements related to data storage were calculated using the following steps:

1. Calculate total server energy over the project's life (4 years)

Assuming that this server operates continuously at 3,040 Watts, the total lifetime energy consumption is:

$$\text{Energy}_{\text{Server}} = \frac{3{,}040 \text{ Watts}}{1} \times \frac{1 \text{ kW}}{1{,}000 \text{ Watts}} \times \frac{4 \text{ years}}{1} \times \frac{8760 \text{ hrs}}{\text{year}} = 106{,}521 \text{ kWh}$$

2. Calculate memory requirements for storing the FU data file

As discussed in Section 4.4, this study assumes that forty scholarly textbooks will have a file size of approximately 54,895 kB (~53.6 MB[13]) when using the Gemstar operating system. According to Noerr (2000), however, there are additional storage requirements associated with the data file's supporting functions. Table 5-23 summarizes Noerr's (2000) allocation scheme for total data storage requirements.

Table 5-23: FU Data File Storage Requirements

Support Function	Allocation Rule	Storage Requirement
Raw Data File	-	53.6 MB
Structural Overhead	20% of raw data	10.72 MB
Indexing Overhead	100% of raw data	53.6 MB
Bibliographic Overhead	-	.002 MB
Redundant Array Storage	33% of current subtotal	38.9 MB
	Total Storage Requirement	**156.83 MB**

Thus, forty e-textbooks require approximately 157 MB of storage capacity. Since the REB 1100 has only up 72 MB of memory, it is assumed that the student will erase the previous semester's e-books from the device before proceeding to download the next set.

3. Determine the server's total storage capacity.

According to manufacturer specifications, the Sun Fire 4800 server has up to 96 GB of storage capacity. This storage capacity is capable of storing over 25,000 e-textbooks.

4. Calculate the data file allocation ratio for the network server.

Combining the server's storage capacity and the FU data file storage requirements from Table 5-23 yields the following allocation ratio:

$$\text{Allocation Ratio}_{\text{Data File}} = \frac{156.83 \text{ MB}}{98{,}304 \text{ MB}} = 0.0016^{14}$$

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[13] 1 MB=1,024 kB

[14] This calculation uses the convention that 1MB = 1,024 kB

This assumes that all forty e-books are electronically stored on the server's hard drive over the duration of this study (4 years).

5. Determine number of additional users.

   For simplification purposes, it is assumed that 29 additional students attend class (i.e. 30 total students per class) with the user and therefore must access the same required digital books. Although other students and/or consumers in the marketplace may wish to download the same scholarly e-books, this scenario simply represents a lower bound. A sensitivity analysis exploring the effect of adjusting this parameter (i.e. number of users accessing the same e-books) is tested and reported in Section 7.

6. Calculate the server's total electricity requirements.

   Storage energy allocated to the server was calculated by applying the allocation ratios determined above to the server's total electricity consumption:

$$\text{Electricity}_{\text{Server}} = (0.0016) \text{ x } (106{,}521 \text{ kWh}) / 30 = 5.68 \text{ kWh}$$

   Converting this electricity consumption into megajoules yields:

$$\text{Electricity}_{\text{Server}} = \frac{5.68 \text{ kWh}}{1} \times \frac{3.6 \text{ MJ}}{\text{kWh}} = 20.45 \text{ MJ}$$

   A previous study by Mitchell-Jackson (2001) determined that support equipment consumes approximately 1.06 times the server's actual computing energy. Thus, a factor of 1.06 was applied to account for auxiliary energy related to support and HVAC equipment:

$$\text{Total Electricity}_{\text{Server}} = (20.45 \text{ MJ}) + [(1.06) \times (20.45 \text{ MJ})] = 42 \text{ MJ}$$

Total fuel cycle LCI data, including upstream environmental burdens, for conventional electricity generation associated with server data storage is included in Appendix R and was constructed using Ecobalance, Inc.'s TEAM life cycle assessment software for conventional electricity generation (NERC ECAR region).

Server Production Model Description and Results

Because production data for server equipment was not available, LCI data for the production of a standard desktop computer was used instead. LCI production data, taken from a study conducted by Atlantic Consulting (Atlantic 1998), is included in Appendix S. LCI data related to desktop computer production (includes material production, manufacturing and distribution) was scaled up using the relative server and desktop computer power ratings (3,040 Watts vs. 160 Watts) and subsequently adjusted using the server storage capacity allocation ratio (0.0016) and user ratio (1/30) calculated above.

Server Disposition Model Description and Results

Again, due to a lack of data for server equipment, LCI disposition data was taken from the study conducted by Atlantic Consulting (Atlantic 1998) on generic personal computers. LCI data related to desktop disposition, included in Appendix T, was scaled up using the relative server and desktop computer power ratings (484 Watts vs. 160 Watts) and subsequently adjusted using the server storage capacity allocation ratio (0.0016) and user ratio (1/30) calculated above.

LCI computer and data storage results are summarized in the table below.

Table 5-24: LCI results – Computer and Data Storage

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Data Storage	6.89	204.21	16.40	2.52	4.44	32.79
Server Production	1.43	3.68	0.18	0.00	0.18	1.42
Server Disposal	0.03	-0.01	0.00	0.00	0.03	0.04

Data Sources and Quality

- Server power rating and storage capacity data were taken directly from the SUN Microsystems, Inc.'s web site (www.sun.com) and are considered to be of good quality. To examine the effects of using other server equipment, the power rating and storage capacity variables may be adjusted using the Model Inputs spreadsheet in Appendix A.
- The scheme for calculating server's data file storage requirements was taken from a report written by Dr. Peter Noerr (Noerr 2000), which examines the establishment/creation of digital library systems. Dr. Noerr, a private consultant and system design specialist, is considered an expert in the areas of digital libraries, multiple character set handling, information modeling, search system and interfaces, and systems architecture and design.
- Auxiliary energy requirements associated with support and HVAC equipment was adopted from a report by Mitchell-Jackson (2001). Completed as a thesis at the UC-Berkeley and supported by researchers at the Lawrence Berkeley National Laboratory, Mitchell-Jackson's report explored the energy consumption of a typical Internet data center.
- Conducted by Atlantic Consulting and IPU for the Ecolabel Unit of the European Commission, the 1998 LCA study of personal computers sought to identify the most significant environmental burdens associated with personal computers and identify ways of reducing the burden through improvement analysis. A number of public, semi-public, and private information sources (including the Danish Environmental

Protection Agency, Battelle Laboratories, and Microelectronics and Computer Technology Corporation) were used for input/output data. The functional unit for this LCA was a generic desktop PC with a 200 MHz processor, 16 MB RAM, 3.2 GB hard disc, 15-inch monitor, and standard keyboard. This base case PC has no energy saving facilitates and consumes 160 Watts when turned on. Critics have argued that this report contains several discrepancies (Williams & Sasaski 2001). Whether these discrepancies are due to misprint, unclear communication, or incorrect data is not known.
- Issues related to data quality of Ecobalance's TEAM software program for conventional electricity generation are discussed in Section 5.2.2.2.

Limitations and Uncertainties

- Although the scaling up of LCI production and disposition data using the relative server and desktop computer power ratings may seem crude, this scheme is necessary in that it provides a way in which to estimate parameters for which no data exists (Gard 2001). Further, most high-powered computers (i.e. servers) tend to utilize more storage space requiring more energy-intensive semiconductor chips. The heightened production energy necessary to manufacturing these semiconductor chips enhances the soundness of this allocation scheme.
- 1998 LCA study of personal computers assumed that 63% of the servers and associated packaging were sent to landfills, 22% to incineration, and 15% to recycling and is based on disposal routes of general household waste in England, Wales, Germany, France, and Spain. Clearly, there are differences between European and North American waste handling operations including disposal options, energy mixes, and grid efficiencies.
- Limitations and uncertainties associated with Ecobalance's TEAM software program for conventional electricity generation are discussed in Section 5.2.2.2.
- This study assumes that the server employs no energy saving facilities, which reduce energy consumption during periods of inactivity. Of course, a server could experience lower traffic levels during off-peak hours. However, since server files may be accessed globally, it is assumed that any period of complete inactivity is unlikely.
- For simplification purposes, this study assumed a 4-year design life for the server, although a server's components may degrade at significantly different rates (e.g. CPU vs. hard drive) However, given a controlled environment and regular maintenance, a 4-year design life is a reasonable assumption (Lutter 2003).
- A generic desktop computer and a server have distinct performance characteristics and are used in different applications. However, to facilitate modeling of the server's materials processing and manufacturing, this study assumes that the generic desktop computer modeled in the Atlantic (1998) life-cycle study and the server are identical (i.e. material composition and material processing) except for the following key dissimilarities.

    1) The generic desktop PC is comprised of a control unit (10.73 kg), monitor (13.87 kg), and a keyboard 1.48 kg). The Sun 4800 server, on the other hand, is a single unit weighing approximately 72.5 kg.

2) The generic desktop PC consumes 160 Watts when turned on, whereas the Sun 4800 server consumes 3,040 Watts.

5.3.4.6 Computer Network

Introduction

Following the creation of a scholarly e-textbook, the data file is made available via a communications network (i.e. the Internet). The RCA REB 1100, like most e-readers on the market, comes with a built in 33.6K modem that can connect to any analog telephone line and summon/download the data file through the network. For this study, all network-related environmental burdens have been assigned to the e-book system's Use Phase. Three network-related components were modeled for this study: 1) electronic file transfer; 2) network equipment production; and 3) network equipment disposition. Like the server-related components modeled in the previous section, these network-related components are processes that support the use of the e-reader and become relevant only when an e-book is requested and sent through the network. Therefore, all network-related environmental burdens have been assigned to the e-reader system's overall Use Phase (see Figure 4-2).

Electronic File Transfer Model Description and Results

The *Electronic File Transfer* model utilized life cycle model components developed by Gard (2001). Energy consumption related to the electronic file transfer through networking equipment was calculated using the following steps:

1. Determine the total amount of data transferred

As discussed in Section 4.4, forty scholarly e-textbooks will have a file size of approximately 54,895 kB (~4.49 x 10^8 bits of information) when using the Gemstar operating system. However, when a data file is transferred over a network, the amount of data transferred is greater than the actual file size. This is attributed to the splitting of a data file into separate elements called packets. Packets are comprised of three parts:

1) Header: Contains instructions about the data carried by the packet (e.g. destination address)
2) Payload: Contains the actual data that the packet is delivering to the destination.
3) Trailer: Contains information that tells the receiving device that it has reached the end of the packet

Networks typically use fixed-length packets of 1,024 bits. The header of each packet is 96 bits long and the trailer is 32 bits long, leaving 896 bits for the payload (How Stuff Works 2002).

The total number of packets required for sending the article was determined by dividing the actual data being delivered (i.e. total file size) by the payload size:

$$\text{Number of Packets} = \frac{54{,}895\ \text{kB}}{1} \times \frac{1000\ \text{bytes}}{1\ \text{kB}} \times \frac{8\ \text{bits}}{1\ \text{byte}} \times \frac{\text{packets}}{896\ \text{bits}}$$

$$= 490{,}133\ \text{packets/FU}$$

Combining the number of packets with the packet size (i.e. header, footer, and payload combined) yields the total amount of data transferred over the network:

$$\text{Total Data Transfer} = \frac{490{,}133\ \text{packets}}{\text{FU}} \times \frac{1024\ \text{bits}}{\text{packet}} \times \frac{\text{byte}}{8\ \text{bits}} \times \frac{\text{kB}}{1000\ \text{bytes}}$$

$$= 62{,}737\ \text{kB}$$

2. Calculate the total electricity consumption of networking equipment

Utilizing network life cycle model components developed by Gard (2001), a network resembling UM's may consist of 15 routers, 2 switches, and 2 hubs. Relevant network parameters and performance requirements are presented below.

Table 5-25: Network Parameters and Specifications

Equipment Type	Quantity	Make/Model	Capacity (MB/sec)	Average Utilization (0<U<1)	Power (Watts)	Electricity Consumption (kWh/MB)
Hubs	2	Cisco 800	10	0.20	20	0.0000056
Switches	2	Cisco Catalyst 1700	10	0.30	30	0.0000056
LAN Routers	2	Cisco 3620	25	0.40	60	0.0000033
PoP Routers	4	Cisco 7505	1,067	0.40	600	0.0000016
Backbone Routers	3	Cisco 10008	51,200	0.50	600	0.00000002
NAP Routers	6	Cisco 12016	80,000	0.50	1,617	0.000000067
					TOTAL	0.000016187

Source: Gard 2002

From above, LAN or local area network is a computer network (or data communications network) which is confined in a limited geographical area. Similarly, PoP or point of presence is an access point to the Internet. Finally, a NAP or network access point is one of several major Internet interconnection points that serve to tie all the Internet access providers together[15].

According to Table 5-25, total electricity consumption (kWh/MB) for the networking equipment shown above was determined to be 1.62 x 10^{-5} kWh/MB. Electricity consumption was calculated using the following relationship:

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[15] LAN, PoP, and NAP definitions found at http://www.networksearch.com.

Electricity $_{\text{Device}}$ = [(Power Rating)/ (Traffic Capacity)] x Utilization x Quantity

$$= \frac{\text{kW}}{1} \times \frac{\text{MB}}{\text{second}} \times \frac{3600\ \text{seconds}}{\text{hour}} \text{ x Utilization x Quantity}$$

= kWh/MB

3. Allocate energy to the FU for each piece of networking equipment.

Combining the on-site electricity consumption of the networking equipment with the total amount of data transferred over the network yields the amount of network electricity allocated to the FU:

$$\text{Electricity}_{\text{Network}} = \frac{0.0000162\ \text{kWh}}{\text{MB}} \times \frac{62{,}737\ \text{kB}}{1} \times \frac{1\ \text{MB}}{1{,}024\ \text{kB}} \times \frac{3.6\ \text{MJ}}{1\ \text{kWh}}$$

= 0.0036 MJ/FU

4. Adjust electricity burden to account for auxiliary equipment

A previous study by Mitchell-Jackson (2001) determined that support equipment consumes approximately 1.06 times the network's actual routing energy. Thus, a factor of 1.06 was applied to account for auxiliary energy related to support and HVAC equipment:

$$\text{Adjusted Electricity}_{\text{Network}} = (0.0036\ \text{MJ}) + [(1.06) \times (0.0036\ \text{MJ})] = \mathbf{0.0074\ MJ}$$

Total fuel cycle LCI data, including upstream environmental burdens, for conventional electricity generation associated with electronic data file transfer is included in Appendix U and was constructed using Ecobalance, Inc.'s TEAM life cycle assessment software for conventional electricity generation (NERC ECAR region). LCI data presented in Appendix U is summarized in the table below.

Table 5-26: LCI results – Electronic File Transfer

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Electricity Requirement	0.00	0.04	0.38	0.13	0.04	0.01

Network Equipment Production Model Description and Results

Life cycle burdens for the production of routers, hubs, and switches were not available. Instead, LCI data for the production of a standard desktop computer was used (Atlantic

1998). LCI production data related to desktop computer production (including material production, manufacturing and distribution) was scaled up using a similar approach taken for server production (Section 5.3.4.5).

1) The relative power rating for each type of equipment as compared to a standard desktop computer was multiplied by equipment quantities.
2) A final allocation ratio was then determined by combining the previous ratios, FU file size, equipment capacity, utilization, and an assumed design life of 4 years.

As a sample calculation, the allocation ratio for the number of hubs utilized by UM's network system is presented below.

$$\text{Allocation Ratio}_{\text{Hubs}} = 2\text{ hubs} \times \left(\frac{20\text{ Watts}}{150\text{ Watts}}\right) \times \left(\frac{62{,}737\text{ kB}}{\text{FU}}\right) \times (0.20) \times \left(\frac{\text{second}}{10\text{ MB}}\right) \times \left(\frac{\text{year}}{31.5\text{ Msecs}}\right) \times \left(\frac{1}{4\text{ years}}\right)$$

$$= \mathbf{2.69 \times 10^{-6}}$$

Assuming a file size of 62,737 kB and a design life of 4 years, allocation ratios for the equipment utilized by UM's network system is presented in the table below:

Table 5-27: Network Equipment Allocation Ratios

Equipment Type	Quantity	Make/Model	Capacity (MB/sec)	Average Utilization (0<U<1)	Power (Watts)	Allocation Ratio
Hubs	2	Cisco 800	10	0.20	20	2.69×10^{-6}
Switches	2	Cisco Catalyst 1700	10	0.30	30	5.968×10^{-6}
LAN Routers	2	Cisco 3620	25	0.40	60	5.366×10^{-6}
PoP Routers	4	Cisco 7505	1,067	0.40	600	2.983×10^{-6}
Backbone Routers	3	Cisco 10008	51,200	0.50	600	4.828×10^{-8}
NAP Routers	6	Cisco 12016	80,000	0.50	1,617	2.01×10^{-7}

Due to the extremely small allocation ratios calculated above, LCI data for the production of network equipment are not expected to have a significant impact on the results of this study and were thus, excluded from the analysis.

Network Equipment Disposal Model Description and Results

Again, due to a lack of data for server equipment, LCI disposition data was taken from the life-cycle study conducted by Atlantic Consulting (Atlantic 1998) on generic personal computers. LCI data related to desktop disposition was scaled down using the allocation ratios calculated above (Table 5-27). However, due to the extremely small allocation ratios calculated in Table 5-27, LCI data for the disposal of network equipment are not expected to have a significant impact on the results of this study and were thus, excluded from the analysis.

Data Sources and Quality

- FU file size was determined from the analysis presented in Section 5.3.4.5.
- Information regarding standard packet size and control data were obtained from an online source, (howstuffworks.com). Standard information about packet size and control data is readily available from a number of industry sources, suggesting that the data is highly credible.
- Information regarding UM's network architecture and utilization rates was taken from Gard (2001). Gard obtained this information through a series of interviews with support staff at UM's Library and Information Technology and Communications department, and the MichNet group.
- Network equipment model information, power ratings, and data flow capacities were taken directly from the Cisco Systems, Inc.'s web site (www.cisco.com) and are considered to be of excellent quality.
- Auxiliary energy requirements associated with support and HVAC equipment was adopted from a report by Mitchell-Jackson (2001) and are discussed in Section 5.3.4.5.
- Issues related to data quality of Ecobalance's DEAM database for conventional electricity generation are discussed in Section 5.2.2.2.

Limitations and Uncertainties

- Due to the ever-evolving nature of the Internet and IT networks, modeling the Internet is inherently problematic. Thus, this study's analysis is viewed as a "snapshot" in time and reflects environmental burdens associated with network systems from 2001 through 2002.
- Uncertainty associated with auxiliary and support equipment arises because buildings that house networking equipment may vary in age, overall function (i.e. network equipment space is shared with other functions) and size. For simplification purposes, environmental burdens associated with auxiliary equipment production and disposal were excluded from this analysis.
- As discussed earlier, IT networks, by nature, are difficult to model. For example, two separate files transmitted via the Internet between two computers are likely to follow vastly different paths. Gard (2001) examined the effect on energy consumption of adjusting three network-related variables: 1) Adjusting the number of Internet backbone routers by 50% and 200%; 2) Utilization of network equipment was altered by the same two factors; and 3) equipment power ratings were reduced by 50% to simulate technological improvements. Sensitivity results indicated that none of these adjustments had a significant effect on overall energy consumption ($\leq 0.2\%$). Similarly, other sensitivity analyses performed by Gard indicate that changes in network-related parameters have very little effect on energy consumption.
- According to Gard (2001), satellite connections are seldom used for high-speed Internet, and therefore only hard links were considered. Similarly, network filters and

amplifiers were omitted from the analysis due to difficulty in assessing the quantity of these devices and because these devices generally consume far less energy than other network equipment (i.e. routing and switching equipment). The reader is referred to Gard's (2001) life-cycle study for more information on additional limitations and uncertainties regarding network modeling.

- Finally, since power grid efficiency varies regionally and networks are scattered throughout the world, complications arise in assuming a single grid efficiency (NERC ECAR region in this case). Therefore, a sensitivity analysis on grid efficiency was tested and is reported in Section 7.

5.3.4.7 E-Reader Use

The final Use Phase element involves the actual use of the e-reader. Two components were modeled with respect to e-reader use: 1) file transfer and 2) on-screen viewing. Recall from Section 4.3 that e-reader use modeled in this study represents the case where the device is plugged into an outlet. Since e-readers are not capable of printing downloadable e-books, environmental burdens associated with laser printing an e-book were not considered.

File Transfer

Using a standard phone jack, an e-book file may be transferred (i.e. downloaded) from the Internet to the e-reader. As discussed earlier, the REB 1100 e-reader utilizes a 33.6 kilobits per second (kbps) internal modem. Given that 8 bits are equal to one byte[16], the time necessary to download a standard e-textbook (1,372 kB) can be calculated in the following manner:

$$\text{Download Time} = \frac{1372\text{ kB}}{1} \times \frac{1000\text{ bytes}}{1\text{ kB}} \times \frac{8\text{ bits}}{1\text{ byte}} \times \frac{\text{kb}}{1000\text{ bits}} \times \frac{\text{sec}}{33.6\text{ kb}} \times \frac{\text{min}}{60\text{ s}}$$

$$= 5.44\text{ minutes per download}^{17}$$

Combining the study's FU (40 e-book downloads) with the device's power rating when in use (11 Watts) yields the amount of electricity required to download 40 e-textbooks:

$$\text{Electricity}_{\text{Download}} = 40\text{ downloads} \times \frac{5.44\text{ min}}{\text{download}} \times \frac{1\text{ hour}}{60\text{ min}} \times \frac{11\text{ Watts}}{1} \times \frac{\text{kW}}{1000\text{ Watts}} \times \frac{3.6\text{ MJ}}{\text{kWh}}$$

$$= 0.14\text{ MJ}$$

It should be noted that the electricity requirement determined above represents the case where the device is plugged into an outlet.

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[16] http://www.cyberwizardpit.net/calc.htm, accessed January 22, 2003.

[17] Download speeds may vary depending on network traffic.

To account for increased download times due to internet congestion as well as predicted technology improvements, the device's download speed (kilobits per second) and power rating may be adjusted using the *Model Inputs* spreadsheet provided in Appendix A.

On-screen Viewing

Once the e-book is downloaded, it is read directly using the e-reader. Research has shown that average reading speeds range between 200-250 words per minute when reading from paper. However, experiments indicate that reading from a computer screen is approximately 30% slower than reading from paper (Gould 1987). Although improvements in computer screen readability abound, this study assumes that the average reading speed from an e-reader is 140 words per minute (i.e. 200 wpm x 70%). To account for improvements in computer screen readability, this variable may be adjusted using the *Model Inputs* spreadsheet provided in Appendix A. As determined in Section 4.4, the average 500 page scholarly text contains 267,000 words. The electricity requirements for on-screen viewing was determined by combining the variables from above with the e-reader's power rating[18].

$$\text{Electricity}_{\text{Reading}} =$$

$$40\text{ texts} \times \frac{267{,}000\text{ words}}{\text{text}} \times \frac{\text{min}}{140\text{ words}} \times \frac{\text{hour}}{60\text{ min}} \times \frac{11\text{ Watts}}{1} \times \frac{\text{kW}}{1000\text{ Watts}} \times \frac{3.6\text{ MJ}}{\text{kWh}}$$

$$= 50.34\text{ MJ}$$

Again, the electricity requirement determined above represents the case where the device is plugged into an outlet.

Total Use-related Energy Consumption

Total electricity requirements for reading 40 e-books over the study's 4-year time frame was calculated by adding the e-reader's individual use-related components:

$$\text{Electricity}_{\text{Total}} = \text{Electricity}_{\text{Download}} + \text{Electricity}_{\text{Reading}}$$

$$= 0.14\text{ MJ} + 50.34\text{ MJ} = \mathbf{50.48\text{ MJ}}$$

After determining the use-related electricity requirements, total fuel cycle LCI data, including upstream environmental burdens, for e-reader use was developed and is included in Appendix V. The LCI models were constructed using Ecobalance, Inc.'s TEAM life cycle assessment software for conventional electricity generation (NERC ECAR region). LCI data presented in Appendix V is summarized in the table below.

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[18] Power rating determined using a line logger (i.e. energy meter).

Table 5-28: LCI results – E-reader Use

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Electricity Requirement	8	245	20	3	292	39

Data Sources and Quality

- The e-reader's power rating was determined using an energy meter. Energy output readings provided by the energy meter are considered to be of good quality.
- Using the energy meter, the device's power rating during charging and normal use (i.e. plugged into an outlet) was found to be the same. The commonness of this occurrence was corroborated via personal communication with electronic specialists within the University of Michigan's Department of Chemistry (George 2003). According to manufacturer specifications, the battery is completely charged after 3 hours of continuous charging. Once fully charged, the device has a battery life of approximately 10-20 hours depending on contrast and brightness settings. Therefore, 10-20 hours of use with the battery requires 33 watt-hours of electricity (i.e. 3 hrs $_{\text{Charging}}$ x 11 Watts). Alternatively, the same usage for the case where the device is plugged in ranges from 110 to 210 watt-hours (i.e. 10-20 hrs $_{\text{Use}}$ x 11 Watts). Thus, the case modeled in this study represents an upper limit to energy use.
- The e-reader's download capability (33.6 kbps) was taken directly from the device's manufacturer specifications. Therefore, this information is considered to be current and accurate.
- Standard information about the range of average reading speeds from paper is readily available from a number of industry and internet sources, suggesting that the data is highly credible.
- Data regarding reading speed from a computer screen was taken from a report published by the IBM Research Center (Gould 1987). This report, which summarizes a series of experiments, attempts to explain why people read more slowly from CRT displays than from paper. This report is considered to be of sound quality.
- Issues related to data quality of Ecobalance's DEAM database for conventional electricity generation are discussed in Section 5.2.2.2.

Limitations and Uncertainties

- This study excludes the possibility of increased download times due to network congestion. Since on-screen viewing time (~76,286 minutes[19]) dwarfs the time required to download 40 e-textbooks (~5.4 minutes), this decision is not expected to have a significant effect on the results of this study.

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[19] Calculated using the following relationship: (40 e-textbooks) x (267,000 words per e-textbook) x (140 words per minute) = 76,286 minutes (~1,271 hours)

- The IBM Research Center report used to determine the average reading speed from a computer screen focused primarily on reading from cathode-ray tube displays. The e-reader, however, utilizes LCD technology. Compared to the CRT, the LCD provides, among other things, better on-screen readability (Koch and Keoleian 1995). A sensitivity analysis, included in Section 7, was conducted to determine the effect of screen readability (i.e. number of words read per minute) on the results of this study.
- Issues related to the limitations and uncertainties of Ecobalance's DEAM database for conventional electricity generation are discussed in Section 5.2.2.2.

5.3.5 End of Life Phase

5.3.5.1 E-Reader Disposition

The only EOL Phase activity considered involves the disposition of e-reader device. Environmental burdens related to collection and landfill processing activities were taken from a report published by Keep America Beautiful, Inc. and conducted by Franklin Associates, Ltd. (2000). This study assumes that the e-reader, itself, and all accessories (e.g. AC adapter, CD-ROM, etc.) associated with the e-reader are landfilled. Thus, recycling is excluded from this analysis. LCI data for e-reader disposition is included in Appendix W and summarized in the table below.

Table 5-29: LCI results – E-reader Disposal

Component	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Disposal	0.00	0.62	0.22	0.00	0.17	1.01

Data Quality and Sources

- Landfill disposal data was acquired from a study conducted by Franklin Associates and published by Keep America Beautiful, Inc. This study reports environmental burdens related to the collection vehicle and landfill equipment for handling MSW (Franklin 2000).

Limitations and Uncertainties

- The study assumes that all accessories (e.g. AC adapter, CD-ROM, etc.) associated with the e-reader are landfilled. Given the relatively small FU burden (0.61 kg) associated with the e-reader's accessory landfill disposition, this decision was not expected to have a significant impact on the results of this study.

5.4 SUMMARY OF LIFE-CYCLE INVENTORY RESULTS

This section presents the total life-cycle inventory results for two different book options – electronic and print – available to the average consumer in the marketplace. It should be noted that life-cycle inventory results reflect the base case scenario outlined in previous sections. Recall that the base case assumed the following:

- The user must purchase one scholarly book per class (40 books over 4 years).
- The average scholarly book has the following attributes:
  - 500 pages in length
  - Standard-sized 7" x 10" high-end print run with a basis weight of 60 pounds.
  - 1" (top and bottom) and 1.25" (left and right) margins with a font size of 10.
- 40 scholarly books will have a file size of approximately 54,895 kB (53.6 MB) when using the Gemstar operating system.
- Assuming that the texts are available at a university bookstore, the user will purchase five books per visit to the bookstore, thus requiring a total of 8 trips to the bookstore.
- E-reader use is based primarily on the effect of reading each e-book once. Thus, the effect of studying is not considered.
- 29 additional students attend class (i.e. 30 total students per class) with the user and therefore must access the same required digital books from a storage server.
- After four years, the user decides to retain rather than resell or dispose of the purchased books. Thus, there is only one user per book and no burdens associated with disposal.
- Impacts due to electricity use were assigned based on the NERC ECAR region grid efficiency.

Overall, the conventional book system required more raw materials and water inputs, consumed more energy, and produced more air and water emissions and solid wastes than the e-reader system. Table 5-30 presents results for total cumulative primary energy, material inputs, emissions to air, emissions to water and solid waste generation for each product system. Additionally, the total LCI for each system is shown graphically in Figures 5-6.

Table 5-30: Life-Cycle Comparison Summary

System Category	Material Inputs (kg)	Primary Energy (MJ)	Air Emissions (kg)	Water Consumption (l)	Water Emissions (g)	Solid Waste (kg)
Printed Book	151	3,794	222	3,754	1,229	94
E-Reader	42	742	50	48	463	77

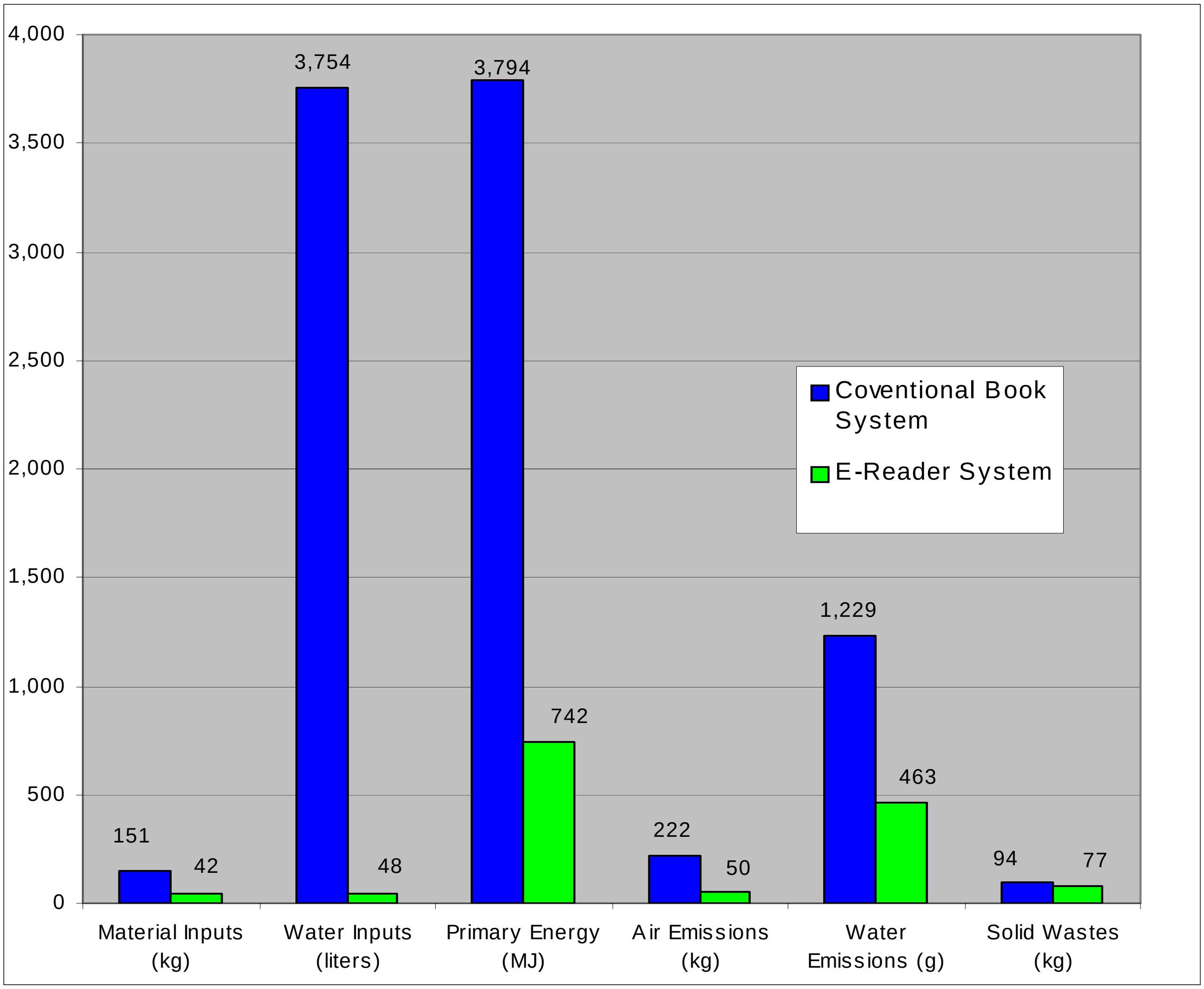

Figure 5-6: Total Life Cycle Comparison

Inventory totals for the each book system on a per life-cycle stage basis are presented in Tables 5-31 and 5-32.

Table 5-31: Conventional book system inventory by life-cycle stage

	Material Production	Manufacturing	Distribution	Use	End of Life Management	TOTAL
Material Inputs (kg)	113	21	1	15	0	**151**
Water Consumption (L)	3,174	26	55	500	0	**3,754**
Process Energy (MJ)	1,653	724	112	1,305	0	**3,794**
Air Emissions (g)	99	64	5	55	0	**222**
Water Emissions (g)	562	87	57	523	0	**1,229**
Solid Waste (kg)	4	75	0	16	0	**94**

Table 5-32: E-Reader System Inventory by Life-Cycle Stage

	Material Production	Manufacturing	Distribution	Use	End of Life Management	TOTAL
Material Inputs (kg)	3	21	1	17	0	**42**
Water Consumption (L)	28	1	13	6	0	**48**
Process Energy (MJ)	47	214	28	453	1	**742**
Air Emissions (g)	3	8	2	37	0	**50**
Water Emissions (g)	26	123	16	297	0	**463**
Solid Waste (kg)	0	3	1	72	1	**77**

5.4.1 Discussion of Baseline LCI Results

Conventional Book System

Beginning with the material inputs, Table 5-31 indicates that most materials are from the material production life-cycle stage. As shown in Appendix B and C, the largest material contributor is wood, which accounts for approximately 55% of all material inputs. Similarly, nearly 85% of the water inputs are from the material production stage. Process energy requirements are dominated by the material production and use life-cycle stages. However, it should be noted that nearly 92% of the primary energy from the use stage is attributed to personal transportation. In terms of primary energy, the manufacturing stage is also a significant contributor, accounting for 19% of the total energy requirements. Air emissions totals are driven by the material production, manufacturing and use life-cycle stages, which account for 45%, 29%, and 25% of the total, respectively. Not surprisingly, textbook paper production is the largest air emissions contributor in the material production stage, accounting for more than 88% of the total. Similarly, infrastructure related electricity requirements account for more than 58% of the total air emissions from the manufacturing stage. Finally, water emissions and solid wastes generated are dominated by the use stage. Again, though, most of these emissions are related to personal transportation.

E-reader System

Not surprisingly, the e-reader's life-cycle inventory results are driven by the use of the e-reader, itself. Beginning with the material inputs, Table 5-32 indicates that most materials are from the manufacturing and use life-cycle stage, accounting for approximately 50% and 40% of the total, respectively. The largest material contributor in the manufacturing life-cycle is LNG (~14.1 kg), which is an ancillary material. The largest material contributors in the use life-cycle stage are natural gas, coal, and petroleum, which are used to generate electricity required for on-screen viewing. On the other hand, the majority of water inputs (~58%) are from the material production stage. In terms of process energy, the use stage is the most significant contributor, accounting for 61% of the total energy requirements, and again may be attributed to the electricity generated for on-screen viewing. Finally, water emissions and solid wastes generated are dominated by the use stage.

6 LIFE-CYCLE IMPACT ASSESSMENT

Life-cycle Impact Assessment (LCIA) involves the translation of the environmental burdens identified in the LCI into environmental impacts. Section 6.1 presents this study's LCIA methodology and discusses data sources, data quality, and the limitations and uncertainties associated with LCIA methodology.

6.1 Methodology

The three major phases of LCIA as defined by the Society of Environmental Toxicology and Chemistry (SETAC) (Fava *et al*. 1993) are described below:

1) Classification – the process of assignment and initial aggregation of data from inventory studies into various impact categories (e.g. ecosystem, human health, and natural resources).
2) Characterization – the qualitative and/or quantitative estimation of potential impacts for each impact category, generally derived using specific impact assessment models.
3) Valuation – The assignment of relative values and/or weights to impacts.

According to the ISO 14042 (ISO 1996) methods for life cycle assessment, the classification and characterization phases are considered the only mandatory elements of LCIA. Further, although widely practiced in the LCA community, the valuation stage is the least developed of the three impact assessment stages (EPA 1995). Therefore, the methodologies for life-cycle impact classification and characterization are utilized and presented below.

6.1.1 Classification

The classification phase of impact assessment provides a preliminary link between inventory items and potential impacts (EPA 1995). The impact categories to be included in this LCIA focus on abiotic ecosystem impacts. These include global warming, stratospheric ozone depletion, and acidification. Once impact categories are selected, it is necessary to classify inventory items within impact categories. The following table presents the chemical/physical properties for classifying inventory items into the impact categories listed above.

Table 6-1: Classification of inventory items into impact categories

Emission Type	Chemical Property	Impact Category
Air	global warming gases (e.g. CO_2, N_2O, CH_4, etc.)	global warming
Air	ozone depleting substance (e.g. CFCs, halons, etc.)	stratospheric ozone depletion
Air	substances that react to form hydrogen ions (H+)	acidification

6.1.2 Characterization

The characterization step of LCIA involves quantifying the magnitude of potential impacts. To characterize these impacts, this study utilizes an equivalency approach in which an equivalency factor, usually based on a reference chemical, is used to relate an inventory output amount to some impact category. For example, global warming potential (GWP) equivalency factors, which are estimates of a chemical's radiative forcing potential compared to the reference chemical (i.e. CO_2), are used to relate an atmospheric release to the global warming impact category. The methodologies used to quantify the global warming, stratospheric ozone depletion and acidification impact categories are presented below.

Global Warming Impacts

The greenhouse effect results when atmospheric trace gases permit incoming solar radiation to reach the surface of the Earth unhindered but restrict the outward flow of infrared radiation. These atmospheric trace gases are referred to as greenhouse gases. They absorb and reradiate this outgoing radiation, effectively storing some of the heat in the atmosphere, thus producing a net warming of the surface. The process is called the "greenhouse effect."

Global warming potentials (GWPs), an index used to compare the relative radiative forcing of different gases, are calculated as the ratio of the radiative forcing resulting from one kg emission of various greenhouse gases (GHGs) to one kg of CO_2 over a fixed period of time. A comparison of the different GHG substances covered in this study and their associated GWPs is presented in the table below.

Table 6-2: Global warming potentials

Chemical	GWP*
Carbon dioxide (CO_2)	1
Methane (CH_4)	23
Carbon tetrafluoride (perfluormethane)	5,700
Nitrous oxide (N_2O)	296
Sulfur hexafluoride	22,200
HFC-23	12,000
HFC-125	3,400
HFC-134a	1,300
HFC-143a	4,300
HFC-152a	120
HFC-227ea	3,500
HFC-236fa	9,400
Perfluoroethane (C_2F_6)	11,900

* Based on Intergovernmental Panel on Climate Change (IPCC) 2001 GWP estimates, 100-year time horizon.

The total impact due to global warming was calculated using the following formula:

$$GWP_{total} = \Sigma\, m_i \times GWP_i$$

where:

GWP_{total} = total global warming impact score (kg of CO_2 equivalents) for all greenhouse gases released to the air per functional unit
m_i = mass (kg) of greenhouse gas, i, released to the air per functional unit
GWP_i = GWP equivalency factor (kg of CO_2 equivalents/kg of greenhouse gas, i) - 100 year time horizon

Stratospheric Ozone Depletion

Stratospheric ozone depletion, caused by chemicals such as chlorofluorocarbons, is a concern because the ozone layer in the stratosphere prevents 95-99% of the sun's ultraviolet radiation from striking the earth. Negative consequences resulting from increased levels of UV (ultraviolet) radiation striking the earth include genetic damage, skin cancer and eye damage (http://www.nas.nasa.gov/About/Education/Ozone/).

The ozone depletion potential (ODP) is the ratio of the impact on the ozone of a chemical compared to the impact of a similar mass of CFC-11. Thus, the ODP of CFC-11 is defined to be 1.0. A comparison of the different ozone depleting substances covered in this study and their associated ODPs is presented in the table below.

Table 6-3: Ozone depletion potentials

Chemical	ODP*
1,1,1-trichloroethane (methyl chloroform)	0.1
CFC-12 (dichlorodifluoromethane)	1
CFC-13 (chlorotrifluoromethane)	1
Carbon tetrachloride (tetrachloromethane)	1.1
HALON-1301	10
HCFC-225ca	0.025
HCFC-225cb	0.033
Bromomethane (methylbromide)	0.7

*Source: Title IV of the 1990 Clean Air Act Amendments (CAAA)

The total impact due to stratospheric ozone depletion was calculated using the following formula:

$$ODP_{total} = \Sigma\ m_i \times ODP_i$$

where:

ODP_{total} = total ozone depletion impact score (kg of CFC-11 equivalents) for all ozone depleting chemicals released to the air per functional unit

m_i = mass (kg) of ozone depleting chemical, i, released to the air per functional unit

ODP_i = ODP equivalency factor (kg CFC-11 equivalents/kg ozone depleting chemical, i.)

Acidification

Acidification is the process whereby air pollution – mainly ammonia, sulphur dioxide and nitrogen oxides – is converted into acid substances. Negative consequences resulting from acidification included widespread damage to plant and animal life, eutrophication, and the release of heavy metals into the groundwater.

The acidification potential (AP) is the ratio of hydrogen ions that can be formed per unit mass of the pollutant released compared to sulfur dioxide (SO_2). AP values that will be used as the basis of calculating acidification impacts are presented in the table below.

Table 6-4: Acidification potentials

Chemical	AP*
Ammonia (NH_4)	1.88[a]
Hydrochloric acid (HCl)	0.88[a]
Hydrofluoric acid (HF)	1.6[a]
Nitric oxide (NO)	1.07[a]
Nitrogen dioxide (NO_2)	0.7[a]
Nitrogen oxides (NOx)	0.7[a]
Sulfur dioxide (SO_2)	1[a]
Sulfur oxides (SOx)	1[a]
Sulfur trioxide (SO_3)	0.8[b]
Nitric acid (HNO_3)	0.51[b]
Sulfuric acid (H_2SO_4)	0.65[b]
Phosphoric acid (H_3O_4P)	0.98[b]
Hydrogen sulfide (H_2S)	1.88[b]

[a] Source: Heijungs et al. 1992

[b] Source: Hauschild and Wenzel, 1997

The total impact due to acidification was calculated using the following formula:

$$AP_{total} = \Sigma m_i \text{ x } AP_i$$

where:

AP_{total} = total acidification impact score (kg of SO_2 equivalents) for all acidification chemicals released per functional unit
m_i = mass (kg) of acidification chemical, i, released per functional unit
AP_i = AP equivalency factor (kg SO_2 equivalents/ kg acidification chemical, i.)

Data Sources and Quality

- As discussed above, LCIA calculations and results were determined using equivalency factors and LCI results from Section 5. Data sources and data quality of LCI data used to calculate impact scores were discussed in Section 5 of this report. The sources and quality of data for each impact category (i.e. global warming, ozone depletion, and acidification) are discussed further in the following section.

Limitations and Uncertainties

- Uncertainties are inherent in GWP, ODP, and AP equivalency factors and the reader is referred to each source for more information on associated uncertainties.
- Specific limitations and uncertainties associated with each impact category are discussed in the following section.

6.2 LCIA Baseline Results

This section presents the LCIA results using the impact assessment methodology outlined in Section 6.1. A summary of the life-cycle impact category indicator results for each product system and a breakdown of the impact categories on a per life-cycle stage basis are presented in Sections 6.2.1 and 6.2.2, respectively.

6.2.1 Summary of LCIA Results

LCIA results for each product system are summarized in Table 6-5 and detailed in the following sections. The results presented in this table were obtained by converting LCI results to common units and aggregating them within an impact category.

Table 6-5: LCIA Results

Impact Category	Units	Traditional book system	E-reader system
Global warming	kg-CO_2 equivalents	218	60
Ozone depletion	kg-CFC-11 equivalents	1.04E-06[a]	1.14E-06[a]
Acidification	kg-SO_2 equivalents	1.09	0.39

a: Several of the substances included in this category are Class I ozone depleting substances and therefore were phased out of production in 1996. Eliminating these phased out substances from the analysis reveals that the life-cycle ozone depletion total for the conventional book system should be reduced to 9.59E –07 kg of CFC-11 equivalents and 7.85E –07 kg of CFC-11 equivalents for the e-reader system.

Under baseline conditions, the conventional book system is far worse in terms of global warming emissions, emitting almost four times the amount of GHGs than the e-reader system. Similarly, the conventional book system emitted larger quantities of ozone depleting substances (when Class I ozone depleting substances are eliminated) and chemicals associated with acidification.

6.2.2 Discussion of Impact Category Results

6.2.2.1 Global Warming

Figure 6-1 presents the LCIA results for the global warming impact category based on the impact assessment methodology outlined in Section 6.1.

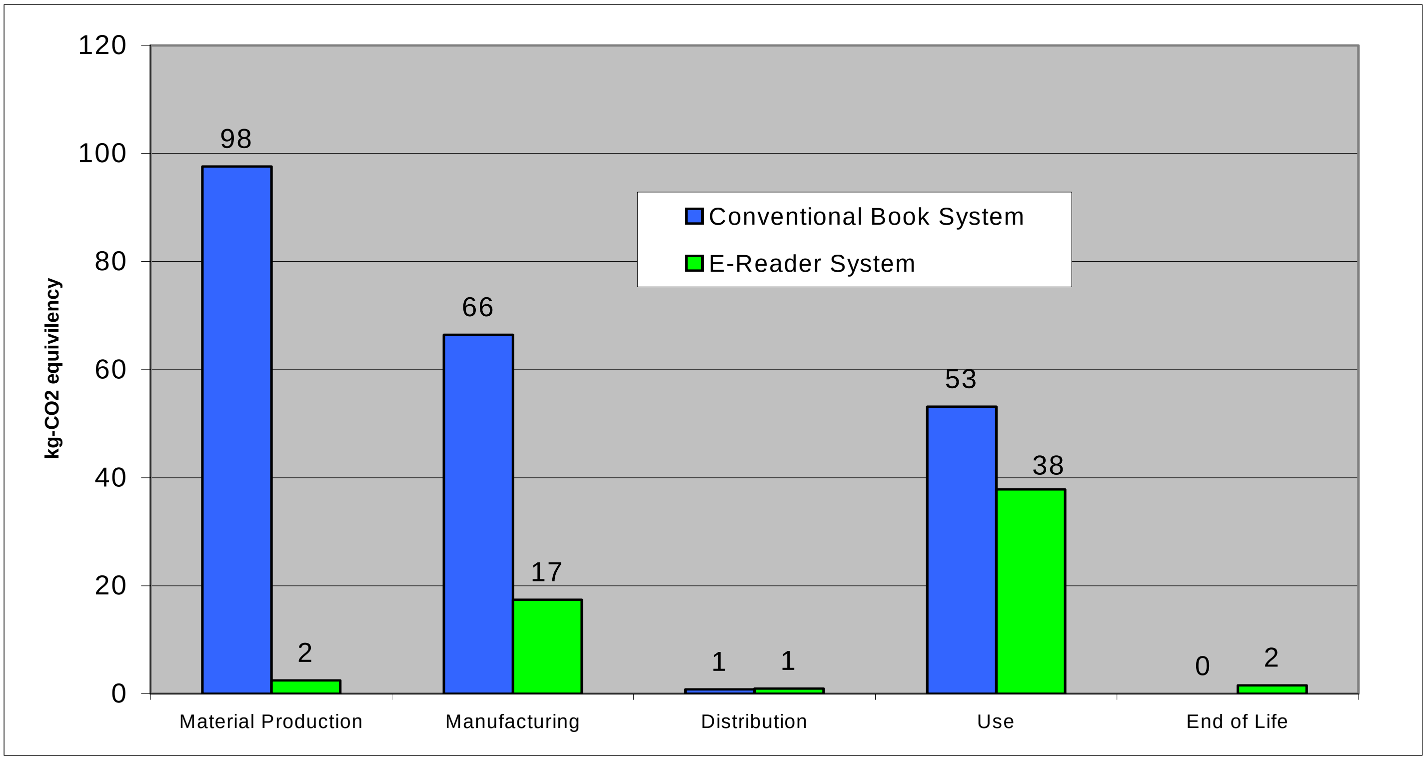

Figure 6-1: Global Warming Impacts Comparison by Life-Cycle Stage

Conventional Book System

Table 6-6 lists the complete global warming results on a per life-cycle stage basis for the conventional book system.

Table 6-6: Conventional Book System Global Warming Impacts

	CO_2 (g)	Methane (g)	N_2O (g)	Carbon tetrafluoride (g)	Sulfur hexafluoride (g)	CO_2 equivalents (kg)	Contribution to Impact Score
Material Production	97,071	21	0.10	0	0	97.58	45%
Manufacturing	62,273	112	5.28	0	0	66.42	30%
Distribution	691	3	0.06	0	0	0.79	0%
Use	50,924	78	1.37	0	0	53.13	24%
End of Life	0	0	0.00	0	0	0.00	0%
TOTAL	210,959	215	7	0	0	**218**	**100%**

Table 6-6 indicates that the life-cycle global warming total for the conventional book system was 218 kg of CO_2 equivalents. The conventional book system global warming indicators are driven by the material production and manufacturing stages, which contribute approximately 45% and 30% of the total, respectively. The use stage is also a significant global warming contributor, accounting for 24% of the total. As expected, the distribution of global warming impacts across each life-cycle stage mirrors those of energy consumption due to the large CO_2 emissions associated electricity generation. Most of the CO_2 emissions from the material production and use life-cycle stages can be attributed to emissions from electricity generation or transportation-related fuel combustion.

E-Reader System

Table 6-7 lists the complete global warming results on a per life-cycle stage basis for the e-reader system.

Table 6-7: E-Reader System Global Warming Impacts

	CO_2 (g)	Methane (g)	N_2O (g)	Carbon tetrafluoride (g)	Sulfur hexafluoride (g)	CO_2 equivalents (kg)	Contribution to Impact Score
Material Production	2,282	5	0.06	0.01	0.00	2.47	4%
Manufacturing	5,308	10	0.16	0.00	0.53	17.38	29%
Distribution	958	1	0.00	0.00	0.00	0.99	2%
Use	35,024	61	4.76	0.00	0.00	37.84	63%
End of Life	159	62	0.00	0.00	0.00	1.58	3%
TOTAL	**43,732**	**139**	**5**	**0.01**	**0.5**	**60.27**	**100%**

Table 6-7 indicates that the life-cycle global warming total for the e-reader system was 60 kg of CO_2 equivalents as compared with 218 kg of CO_2 equivalents for the conventional book system. As expected, the e-reader system global warming impacts have the greatest contribution from the use life-cycle stage, which accounts for approximately 63% of the total. Most of the CO_2 emissions occur due to electricity generation necessary for operation of the e-reader.

Limitations and Uncertainties

As is a common LCA limitation, electric grid inventories embedded in material production inventories often have differing geographic and temporal boundaries or may not be representative of older technologies (Socolof 2001). Therefore, actual greenhouse gas emissions may be higher or lower than report in this study. Additionally, LCI data for many of the primary contributors to the global warming impact category are derived from existing LCI databases. Limitations and uncertainties associated with these databases have been discussed extensively in previous sections and pertain here.

6.2.2.2 Ozone Depletion

Figure 6-2 presents the LCIA results for the stratospheric ozone depletion impact category based on the impact assessment methodology outlined in Section 6.1.

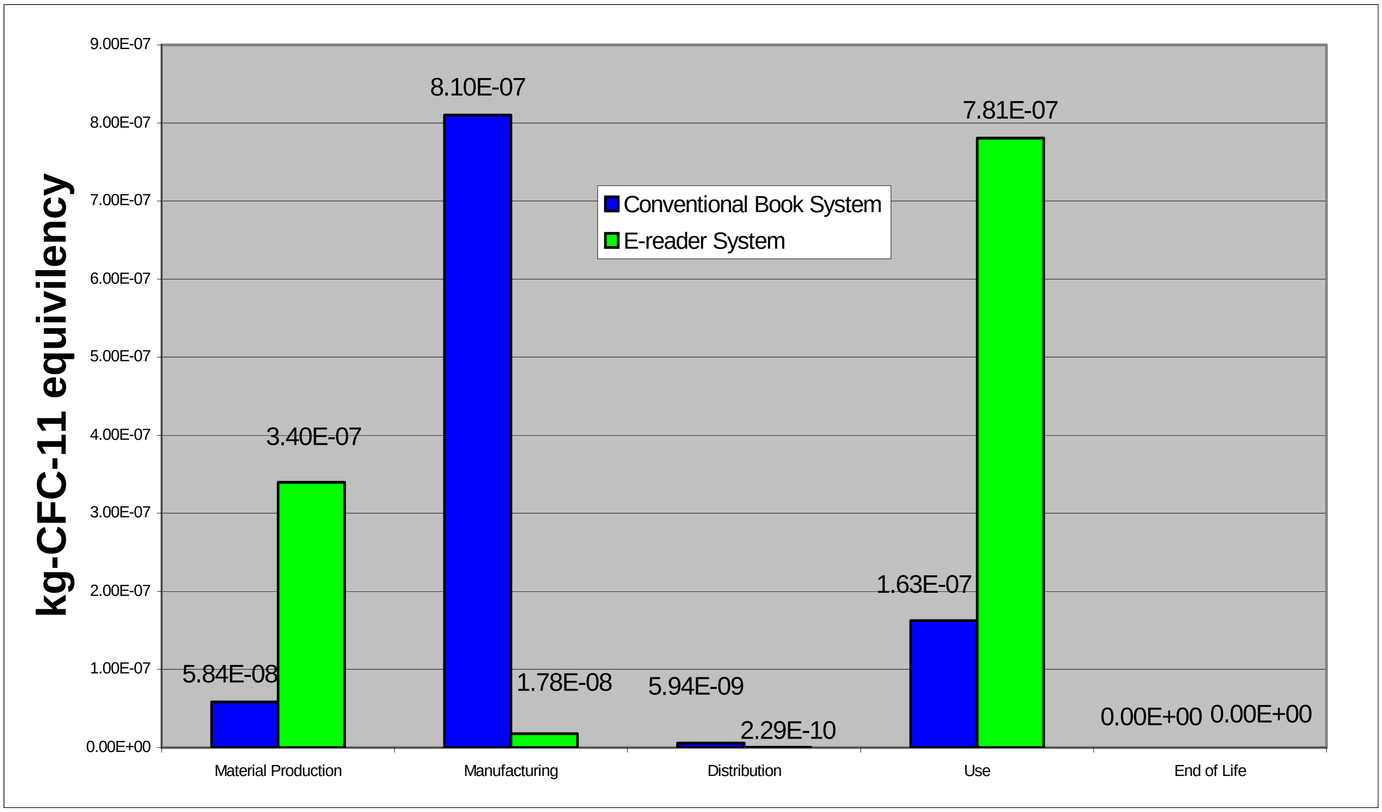

Figure 6-2: Ozone Depletion Impact Comparison by Life-Cycle Stage

Conventional Book System

Table 6-8 lists the LCIA results for the stratospheric ozone depletion impact category on a per life-cycle stage basis for the conventional book system.

Table 6-8: Conventional Book System LCIA Results for Stratospheric Ozone Depletion

	Material Production	Manufacturing	Distribution	Use	End of Life	TOTAL
1,1,1-trichloroethane (g)	2.47E-07	1.42E-04	4.96E-07	2.85E-05	0.00E+00	**1.71E-04**
Carbon tetrachloride (g)	5.18E-05	0.00E+00	2.80E-06	0.00E+00	0.00E+00	**5.46E-05**
HALON-1301 (g)	9.29E-10	1.24E-09	2.68E-09	2.44E-08	0.00E+00	**2.92E-08**
HCFC-225ca (g)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**
HCFC-225cb (g)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**
Bromomethane (g)	1.97E-06	1.14E-03	3.97E-06	2.28E-04	0.00E+00	**1.37E-03**
Ozone Depletion (kg CFC-11 Equivalents)	5.84E-08	8.10E-07	5.94E-09	1.63E-07	0.00E+00	**1.04E-06**
Contribution to Impact Score	6%	78%	0.57%	16%	0%	**100%**

Table 6-8 indicates that the life-cycle ozone depletion total for the conventional book system was 1.04E -06 kg of CFC-11 equivalents. The conventional book system ozone depletion results are driven by the manufacturing stage, which contributes approximately 78% of the total. Bromomethane emissions from electricity generation and fuel oil and natural gas production are the single largest contributor in this stage. Most of the other materials in the table are emitted from material production or are related to infrastructure.

E-reader System

Table 6-9 lists the LCIA results for the stratospheric ozone depletion impact category on a per life-cycle stage basis for the e-reader system.

Table 6-9: E-reader System LCIA Results for Stratospheric Ozone Depletion

	Material Production	Manufacturing	Distribution	Use	End of Life	TOTAL
1,1,1-trichloroethane (g)	3.70E-08	2.84E-06	1.84E-08	1.37E-04	0.00E+00	**1.40E-04**
Carbon tetrachloride (g)	2.61E-08	2.53E-08	1.12E-07	0.00E+00	0.00E+00	**1.63E-07**
HALON-1301 (g)	3.39E-05	2.95E-11	9.94E-11	2.60E-10	0.00E+00	**3.39E-05**
HCFC-225ca (g)	0.00E+00	2.71E-05	0.00E+00	0.00E+00	0.00E+00	**2.71E-05**
HCFC-225cb (g)	0.00E+00	2.71E-05	0.00E+00	0.00E+00	0.00E+00	**2.71E-05**
Bromomethane (g)	2.96E-07	2.28E-05	1.47E-07	1.10E-03	0.00E+00	**1.12E-03**
Ozone Depletion (kg CFC-11 Equivalents)	3.40E-07	1.78E-08	2.29E-10	7.81E-07	0.00E+00	**1.14E-06**
Contribution to Impact Score	30%	2%	0.01%	69%	0%	**100%**

Table 6-9 indicates that the life-cycle ozone depletion total for the conventional book system was 1.14E -06 kg of CFC-11 equivalents as compared to 1.04E -06 kg of CFC equivalents for the conventional book system. E-reader system ozone depletion results are driven by the material production and use life-cycle stages, which contribute approximately 30% and 69% of the total, respectively. Bromomethane emissions from electricity generation in the use phase and halon emissions from e-reader material production are among the top contributors.

Limitations and Uncertainties

It should be noted that most materials, with the exception bromomethane, HCFC-225ca and HCFC-225cb, listed in Tables 6-8 and 6-9 are Class I ozone depleting substances and therefore were phased out of production in 1996 (EPA 2002), which suggests that data is not representative of current conditions. Bromomethane, although a Class I ozone depleting substance, has not yet been phased out of production. Eliminating these Class I substances from the analysis reveals that the life-cycle ozone depletion total for the conventional book system should be reduced to 9.59E -07 kg of CFC-11 equivalents and 7.85E –07 kg of CFC-11 equivalents for the e-reader system. Additionally, Socolof (2001) indicates that most of the Class I substance emissions data are of below average quality and therefore, life-cycle stratospheric ozone depletion results are highly uncertain. Finally, LCI data for many of the primary contributors to the ozone depletion impact category are derived from existing LCI databases. Limitations and uncertainties associated with these databases have been discussed extensively in previous sections and pertain here.

6.2.2.3 Acidification

Figure 6-3 presents the LCIA results for the acidification impact category based on the impact assessment methodology outlined in Section 6.1.

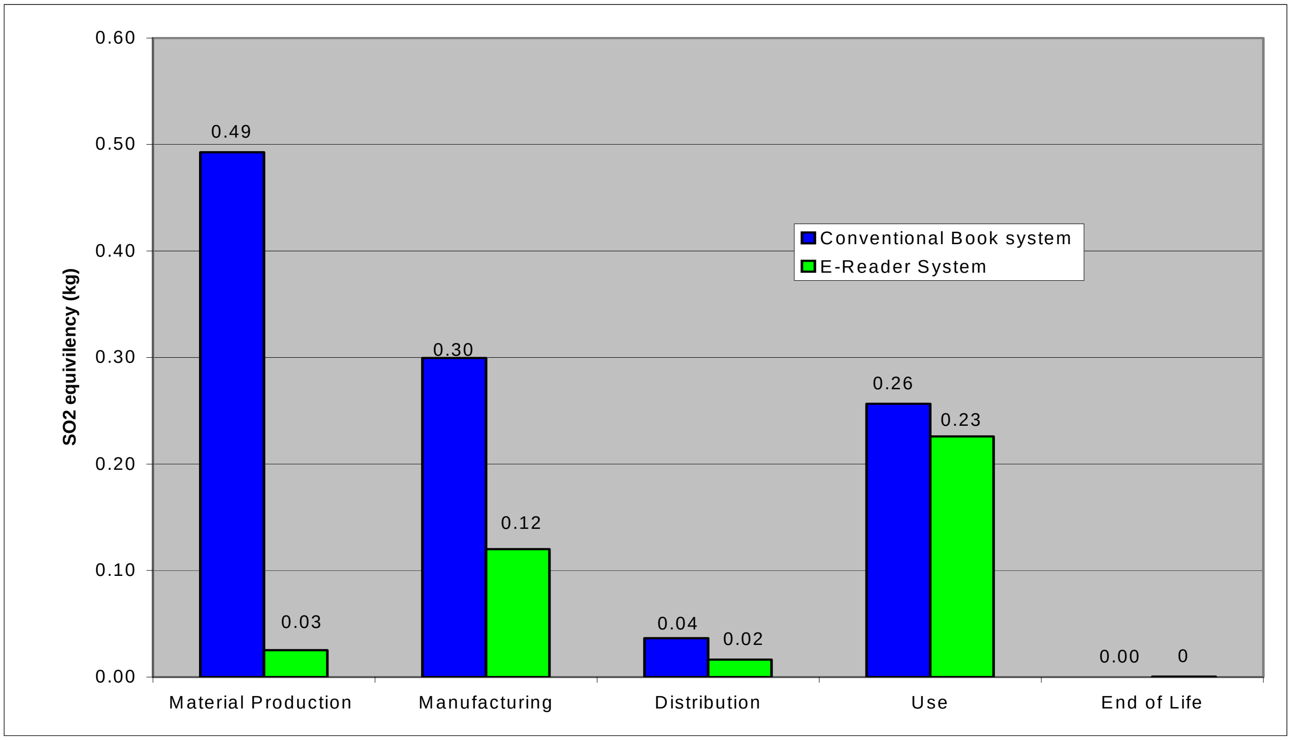

Figure 6-3: Acidification Impacts by Life-Cycle Stage

Conventional Book System

Table 6-10 lists the LCIA results for the acidification impact category on a per life-cycle stage basis for the conventional book system.

Table 6-10: Conventional Book System LCIA Results for Acidification

	Material Production	Manufacturing	Distribution	Use	End of Life	TOTAL
Ammonia (NH_4) (g)	2.34	0.28	0.02	0.13	0	**2.76**
Hydrochloric acid (HCl) (g)	6.90	8.53	0.03	1.99	0	**17.44**
Hydrofluoric acid (HF) (g)	0.86	1.07	0.00	0.25	0	**2.18**
Nitrogen oxides (NOx) (g)	454.63	170.62	34.48	201.48	0	**861.22**
Sulfur oxides (SOx) (g)	162.75	170.42	12.45	113.16	0	**458.78**
Nitric acid (HNO_3) (g)	0	0	0	0	0	**0.00**
Sulfuric acid ($H2SO_4$) (g)	0	0	0	0	0	**0.00**
Hydrogen sulfide (H_2S) (g)	0.01	0.02	0.01	0.08	0	**0.12**
Acidification (kg SO_2 equivalents)	0.49	0.30	0.04	0.26	0.00	**1.09**
Contribution to Impact Score	45.4%	27.6%	3.4%	23.6%	0.0%	**100.0%**

Table 6-10 indicates that the life-cycle acidification total for the conventional book system was 1.09 kg of SO_2 equivalents. Conventional book system acidification results are driven by material production and the manufacturing stage, which contribute approximately 45% and 28% of the total, respectively. SO_2 and NO_x emissions from paper production and transportation-related fuel consumption are among the top contributors in material production stage. On the other hand, SO_2 and NO_x emissions from paper from electricity generation and fuel oil and natural gas production are the largest contributor in material production stage.

E-reader System

Table 6-11 lists the LCIA results for the acidification impact category on a per life-cycle stage basis for the e-reader system.

Table 6-11: E-Reader System LCIA Results for Acidification

	Material Production	Manufacturing	Distribution	Use	End of Life	TOTAL
Ammonia (NH_4) (g)	0.01	4.53	0.04	0	0	**4.59**
Hydrochloric acid (HCl) (g)	0.16	4.93	0.02	8.24	0	**13.36**
Hydrofluoric acid (HF) (g)	0.01	3.81	0.00	1.03	0	**4.85**
Nitrogen oxides (NOx) (g)	7.56	105.75	8.40	130.33	0.51	**252.54**
Sulfur oxides (SOx) (g)	19.93	27.12	10.34	125.96	0.07	**183.42**
Nitric acid (HNO_3) (g)	0	0.02	0	0	0	**0.02**
Sulfuric acid ($H2SO_4$) (g)	0.0001	0	0	0	0	**0.00**
Hydrogen sulfide (H_2S) (g)	0.0017	0.0001	0.0003	0.0029	0	**0.01**
Acidification (kg SO_2 equivalents)	0.03	0.12	0.02	0.23	0	**0.39**
Contribution to Impact Score	6.5%	30.9%	4.2%	58.2%	0.1%	**100.0%**

Table 6-11 indicates that the life-cycle acidification total for the e-reader system was 0.39 kg of SO_2 equivalents as compared to 1.09 kg of SO_2 equivalents for the conventional book system. E-reader system acidification results are driven by the manufacturing and use life-cycle stages, which contribute approximately 31% and 58% of the total, respectively. SO_2 and NO_x emissions from electricity generation are among the top contributors in these two stages.

Limitations and Uncertainties

LCI data for many of the primary contributors to the acidification impact category are derived from existing LCI databases. Limitations and uncertainties associated with these databases have been discussed extensively in previous sections and pertain here.

7 SENSITIVITY ANALYSES

7.1 Introduction

A sensitivity analysis was conducted to identify parameters and assumptions that had the largest effects on the results of the study. Each parameter was changed independently of all others so that the magnitude of its effect on the base case could be assessed. Recall that the base case assumed the following:

- The user must purchase one scholarly book per class (40 books over 4 years).
- The average scholarly book has the following attributes:
  - 500 pages in length
  - Standard-sized 7” x 10” high-end print run with a basis weight of 60 pounds.
  - 1” (top and bottom) and 1.25” (left and right) margins with a font size of 10.
- 40 scholarly books will have a file size of approximately 54,895 kB (53.6 MB) when using the Gemstar operating system.
- Assuming that the texts are available at a university bookstore, the user will purchase five books per visit to the bookstore, thus requiring a total of 8 trips to the bookstore.
- E-reader use is based primarily on the effect of reading each e-book once. Thus, the effect of studying is not considered.
- 29 additional students attend class (i.e. 30 total students per class) with the user and therefore must access the same required digital books from a storage server.
- After four years, the user decides to retain rather than resell or dispose of the purchased books. Thus, there is only one user per book and no burdens associated with disposal.
- Impacts due to electricity use were assigned based on the NERC ECAR region grid efficiency.

A total of 8 variables were selected on which to conduct a series of sensitivity analyses and are discussed below. It should be noted that those variables that had little effect on the LCA results were not included for discussion. Section 7.3 presents a summary of the effects on several environmental categories relative to the base case for each parameter varied.

7.2 Input Variables

Number of Users per Book

Recall that the base case assumed that after four years, the user decides to retain rather than resell the book. Typically, however, when the utility of owning a book expires (i.e. the student no longer needs the text for class), the student will sell the book back to the bookstore from which he or she purchased it or to another student at a reduced cost. This parameter was tested at values of 2 and 3. This provides results for a scenario in which the books are resold once (i.e. 2 users) and another scenario in which the second user sells the book to a third student (i.e. 3 users). Although the number of different users could be increased further, this study assumes that a non-library book typically would not have more than three users, especially in a college setting. It should be noted that varying this parameter has no effect on the e-reader system since an e-book cannot be transferred from one e-reader to another. Although arguments could be made that more than one student could utilize the same e-reader (i.e. the e-reader is shared), this scenario is highly impractical, especially in a college setting, and was therefore not considered in this analysis.

Book Length

Recall that for the traditional print-based system, the length of the average scholarly book was assumed to be 500 pages. Since the average length of a scholarly textbook may vary significantly between disciplines, this parameter was tested at values of 250 and 1000 pages. Non-text material, reading time, and file size are assumed to be proportional to book length.

Personal Transportation Parameters

Recall that for the conventional book system, the vehicle miles traveled (roundtrip) during a visit to the bookstore was initially assumed to be 10 miles. The initial distance of 10 miles was adjusted to values of 20 and 0 (i.e. a non-emitting mode of transport is selected).

Book Disposition

Recall that this study assumes that a book is purchased with the intent of keeping it forever. Thus, environmental burdens associated with textbook disposition were excluded. However, since the physical integrity of a book is sometimes breached, this option of book disposal was investigated. This parameter was tested for the disposal of 20 and all 40 books. Environmental burdens associated with EOL management were calculated in the same manner as described in Section 5.3.5.1.

Number of Users Accessing E-book

Recall that this study assumes that 29 additional students attend class (i.e. 30 total students per class) with the user and therefore must access the same required digital books. However, one might argue that other students and/or consumers in the marketplace may wish to download the same scholarly e-books. Further, private academic institutions sometimes have class enrollments smaller than 30. Thus, this parameter was tested at values of 15 and 100.

Study Parameters

Recall that for this study, the function is defined as the actual process of a college student reading 40 scholarly e-books one time using a dedicated e-book reading device. However, it is likely that a student may wish to utilize the e-reader for the purposes of studying or to reference previously viewed e-material. Thus, the environmental burdens associated with additional e-reader use were explored by adjusting the number of study hours per week. This parameter was tested at values of 1 hour/week for each class (640 hours total) and 3 hours/week for each class (2,688 hours total)[20].

On-screen Readability

Research has shown that average reading speeds range between 200-250 words per minute when reading from paper. Although improvements in computer screen readability abound, this study assumed that the average reading speed from an e-reader is 140 words per minute (i.e. 30% slower than 200 words per minute). To examine the effects of improvements in screen readability, reading speed from an e-reader was tested at values of 175 and 200 words per minute.

Power Grid Efficiencies

Finally, impacts due to electricity use were assigned based on the NERC ECAR region grid efficiency. Since grid efficiency varies regionally, complications arise in assuming a single grid efficiency. Therefore, this parameter was adjusted using U.S. average grid efficiency (24.8%) and the ECAR WSCC region grid efficiency (33.8%)[21].

A summary of each sensitivity case is presented in the table below (Table 7-1).

Table 7-1: Sensitivity Analysis Cases

Parameter	**Base Case**	**Lower Case**	**Case Letter**	**% change from base case**	**Upper Case**	**Case Letter**	**% change from base case**
Number of Users per Book	**1**	2	A	100%	3	B	200%
Book Length (pages, MB memory)	**500 (1.34 MB)**	250 (0.67 MB)	C	-50%	1000 (2.68 MB)	D	100%
Personal Transportation (round trip VMT)	**10**	0	E	-100%	20	F	100%
Book Disposal	**Not considered**	Considered (20 books)	G	-	Considered (40 books)	H	-
Number of Users Accessing E-book	**30**	15	I	-50%	100	J	233%
Total Study Hours	**0**	640	K	-	2,688	L	-
On-Screen Readability (words/min)	**140**	175	M	25%	200	N	43%
Grid Efficiency (%)	**20.57**	24.8	O	21%	33.8	P	64%

Note: Case letters correspond to the letters in Table 7-2 presented in the following section.

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[20] This assumes 5 classes per semester, 8 semesters over the study's time frame, and 16 week long semesters.

[21] Grid efficiencies account for losses in transmission and distribution (~7.03%)

7.3 Sensitivity of Results to Input Variations

A summary of the effects on resource consumption, energy requirements, major emissions, and environmental impact categories relative to the base case for each parameter varied is shown in Table 7-2 at the end of this section. The percentages shown represent the deviation from the base case values. The positive numbers indicate a percent increase while the negative numbers signify a decrease.

Number of Users per Book

As discussed earlier, varying this parameter had no effect on the e-reader system since an e-book cannot be transferred from one e-reader to another. The conventional book system, on the other hand was very sensitive to this variable. Before proceeding, it is important to note that burdens associated with paper/ink production and shipment, book printing operations, book delivery, facility infrastructure, and book disposal are all fixed. Thus, these burdens are allocated to the FU according to the number of users per book. Results indicate that each environmental category falls dramatically as the number of users and/or readings increases. In terms of energy consumption, considered a useful proxy for significant impact categories, equivalency between the two systems is never reached (Figure 7-1). This may be attributed to the fact that personal transportation burdens in the conventional book system's use life-cycle stage dwarfs all other effects when fixed-cost allocations are small (i.e. many users/readings per book).

Figure 7-1: Sensitivity Results for Increased Number of Users per Book

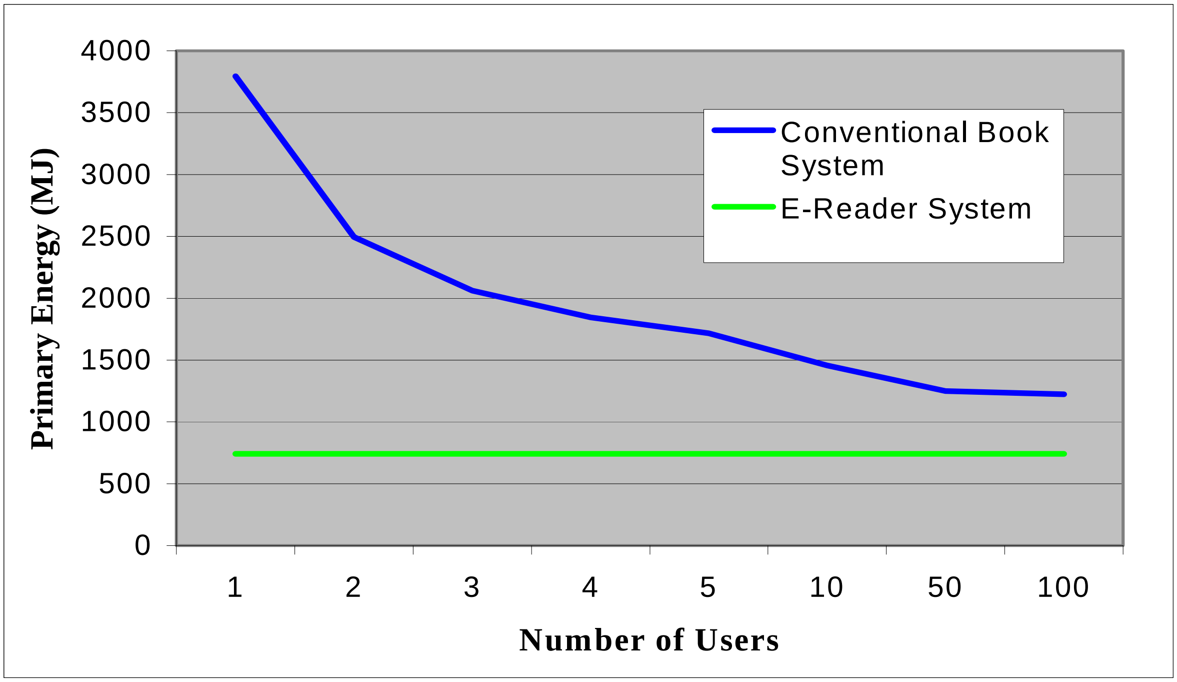


Table 7-2: Sensitivity Analysis Condensed Results

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Conventional Book System																
Material Inputs (kg)	-45.9%	-61.3%	-38.0%	75.9%	-8.1%	8.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-4.3%	-8.2%
Water Requirements (liters)	-43.4%	-57.8%	-39.2%	78.4%	-13.2%	13.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-1.5%	-1.5%
Total Primary Energy (MJ)	-34.2%	-45.6%	-27.2%	54.5%	-31.5%	31.5%	0.3%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-4.0%	-7.1%
Air Emissions (kg)	-40.0%	-53.4%	-32.8%	65.6%	-19.6%	19.6%	2.1%	4.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-6.5%	-11.4%
Water Emissions (g)	-29.1%	-38.8%	-20.3%	40.6%	-41.8%	41.8%	0.3%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-3.9%	-4.7%
Solid Wastes (kg)	-48.4%	-64.5%	-37.9%	75.8%	-3.2%	3.2%	22.3%	44.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-33.5%	-55.7%
GWP (kg-CO_2 equivalents)	-59.0%	-70.2%	-33.4%	66.9%	-19.9%	19.9%	15.2%	30.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-6.8%	-12.1%
Acidification (kg-SO_2 equivalents)	-40.3%	-53.8%	-27.6%	55.1%	-19.4%	19.4%	0.8%	1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-8.9%	-15.2%
E-reader System																
Material Inputs (kg)	0.0%	0.0%	-20.0%	40.0%	0.0%	0.0%	0.0%	0.0%	16.7%	-11.7%	10.0%	30.0%	-4.0%	-6.0%	-12.2%	-21.5%
Water Requirements (liters)	0.0%	0.0%	-6.0%	12.0%	0.0%	0.0%	0.0%	0.0%	5.5%	-3.8%	3.3%	9.9%	-1.3%	-2.0%	-0.5%	-7.1%
Total Primary Energy (MJ)	0.0%	0.0%	-30.5%	61.1%	0.0%	0.0%	0.0%	0.0%	28.0%	-19.6%	16.6%	49.8%	-6.6%	-9.9%	-10.6%	-24.3%
Air Emissions (kg)	0.0%	0.0%	-35.5%	71.0%	0.0%	0.0%	0.0%	0.0%	32.4%	-22.7%	19.4%	58.1%	-7.7%	-11.5%	-24.5%	-43.5%
Water Emissions (g)	0.0%	0.0%	-31.4%	62.8%	0.0%	0.0%	0.0%	0.0%	1.0%	-0.7%	31.1%	93.2%	-12.3%	-18.5%	-60.3%	-62.4%
Solid Wastes (kg)	0.0%	0.0%	-46.9%	93.8%	0.0%	0.0%	0.0%	0.0%	42.7%	-29.9%	25.7%	77.1%	-10.2%	-15.3%	-34.9%	-57.8%
GWP (kg-CO_2 equivalents)	0.0%	0.0%	-31.4%	62.8%	0.0%	0.0%	0.0%	0.0%	28.7%	-20.1%	17.1%	51.3%	-6.8%	-10.2%	-20.7%	-50.1%
Acidification (kg-SO_2 equivalents)	0.0%	0.0%	-29.1%	58.2%	0.0%	0.0%	0.0%	0.0%	26.6%	-18.6%	15.8%	47.5%	-6.3%	-9.5%	-20.1%	-35.2%

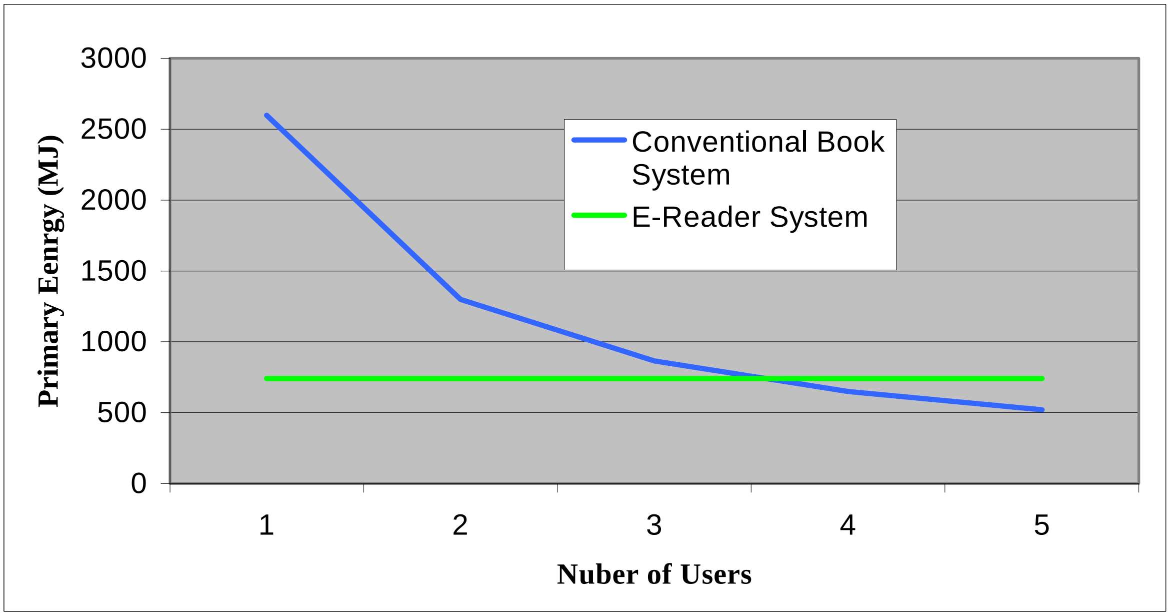
Case Letter	
A	2 users per book
B	3 users per book
C	250 page book (0.67 MB e-book)
D	1000 page book (2.68 MB e-book)
E	0 mile round trip (personal transportation)
F	20 mile round trip (personal transportation)
G	20 books landfilled
H	40 books landfilled
I	15 users accessing e-book from server
J	100 users accessing e-book from server
K	640 total study hours
L	2,688 total study hours
M	onscreen readability = 175 words/min
N	onscreen readability = 200 wrods/min
O	US average electric grid efficiency (24.8%)
P	ECAR WSCC electric grid efficiency (33.8%)

Note: Grid efficiencies for case letters O and P account for losses in transmission and distribution (~7.03%).

Stratospheric Ozone Depletion responses not included in sensitivity analysis due to the large uncertainties associated with Class I substance emissions.

When transportation is eliminated from the analysis, energy equivalency between the tow systems is reached at approximately 4 users per book (Figure 7-2).

Figure7-2: Sensitivity Results for Increased Number of Users per Book (excluding personal transportation)



Book Length

As expected, results for each system were highly sensitive to this variable. In terms of energy consumption, the e-reader was slightly more sensitive to adjusting book length.

Personal Transportation Parameters

As discussed earlier, transportation clearly has a dominant effect on the outcome of the results for each system. Even when personal transportation is eliminated from the conventional book system analysis, however, results indicate that the e-reader system is superior in practically every environmental performance category when assuming single person ownership of the book(s).

Book Disposition

Varying the number of books landfilled had a significant effect on solid wastes generated and global warming emission for the conventional book system. However, this variable had very little effect on all other environmental categories.

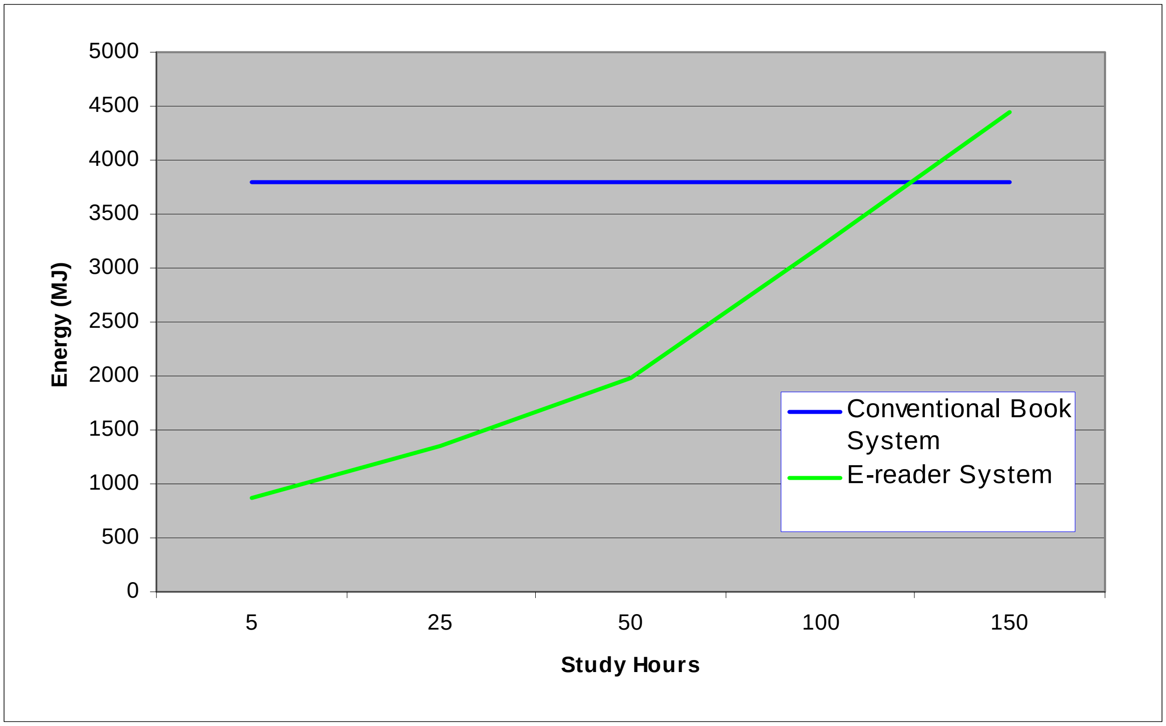
Number of Users Accessing E-book

It is important to note that burdens associated with server production, transportation and disposal are fixed. Thus, these burdens are allocated to the FU according to the number of users accessing the e-book from the server. Similar to varying the number of users per book in the conventional book system, adjusting this parameter had a dramatic effect on the e-reader system's LCA results. Sensitivity results indicate that the e-reader system is preferable in terms of energy consumption as long as at least one other person accesses the e-book(s) from the server.

Study Parameters

Sensitivity analyses revealed that utilizing the e-reader for the purposes of studying or to reference previously viewed e-material had a significant effect on the results of this study. Results indicate that each environmental category increased dramatically as the number of study hours increases. In terms of energy consumption, equivalency between the two systems is reached at approximately 128 study hours per week (Figure 7-3), which suggests that the student would need to study more than 25 hours/week for each class.

Figure 7-3: Sensitivity Results – Increased Number of Study Hours



On-screen Readability

As expected, LCA results for e-reader system were highly sensitive to this variable. Varying the reading rate (words/min) had more of an effect on air and water emissions and solid wastes generated than on all other environmental categories.

Power Grid Efficiencies

Understandably, the effect of changing power grid efficiency had a greater effect on the e-reader system since most environmental burdens associated with the e-reader are a result of electricity generation necessary for operation of the e-reader.

8 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was two-fold: (1) to investigate the life cycle environmental aspects of e-publishing of scholarly books and e-readers; and (2) to apply the life cycle models to a variety of scholarly e-book applications and compare LCA results for traditional print based counterparts. By comparing these two options, this thesis enables industry and consumers to consider the relative environmental trade-offs associated with each book system (i.e. electronic vs. print) and provides them with valuable information necessary to make environmentally informed decisions regarding e-book technology. Further, this study is also designed to provide the electronics and e-publishing industries with information needed to improve the environmental attributes of e-books and e-readers.

8.1 Conclusions

This section briefly summarizes the results of this study and draws conclusions based on those results.

8.1.1 Baseline LCI Results

Overall, the conventional book system required more raw materials and water inputs, consumed more energy, and produced more air and water emissions and solid wastes than the e-reader system under baseline conditions. Major conclusions from the baseline LCI are as follows:

- For the conventional book system, LCI results were largely driven by three factors: (1) textbook paper production, (2) the relatively large amount of electricity consumed during book printing operations, and (3) personal transportation.
- For the e-reader system, LCI results were driven by the electricity generated for on-screen viewing.

8.1.2 Baseline LCIA Results

Under baseline conditions, the conventional book system is far worse in terms of global warming emissions, emitting almost four times the amount of GHGs (as kg of CO_2 equivalents) than the e-reader system. Similarly, the conventional book system emitted larger quantities of ozone depleting substances and chemicals associated with acidification. Again, the conventional book system's impacts were driven by textbook paper production, electricity generation for book printing operations, and personal transportation. Similarly, for the e-reader system, many of the impacts were driven by the relatively large amount of electricity consumed during the use stage.

8.1.3 Sensitivity Analysis Results

A sensitivity analysis was conducted to identify parameters and assumptions that had the largest effects on the results of the study. Results indicated that environmental burdens were highly dependent upon scenario assumptions and input values. Major conclusions drawn from this analysis are as follows:

1) The conventional book system was very sensitive to the number of users per book. On the other hand, varying this parameter had no effect on the e-reader system since an e-book cannot be transferred from one e-reader to another[22]. In terms of energy consumption, equivalency between the two systems is never reached. However, when eliminating personal transportation from the analysis, energy equivalency between the two systems is reached at approximately 4 users per book.
2) Varying the length of the average scholarly book had nearly an equally proportionate effect on both book systems.
3) Environmental burdens associated with personal transportation dominate in situations where fixed-cost allocations are small. Even when personal transportation is eliminated from the conventional book system analysis, however, results indicate that the e-reader system is superior in practically every environmental performance category when assuming single person ownership of the book(s).
4) Similar to varying the number of users per book in the conventional book system, adjusting the number of users accessing the e-books from the server had a dramatic effect on the e-reader system's LCA results. Sensitivity results indicate that the e-reader system is preferable in terms of energy consumption as long as at least one other person accesses the e-book(s) from the server.
5) Results indicate that aside from reading each e-book, utilizing the e-reader for the purposes of studying or to reference previously viewed e-material had a significant effect on the results of this study. In terms of energy consumption, equivalency between the two systems is reached at approximately 128 study hours per week using the e-reader. Acknowledging that there are only 168 hours in a week emphasizes the impracticality of studying 128 hours per week. In this case, the student would need to study more than 25 hours/week for each class.
6) As expected, LCA results for e-reader system were highly sensitive to improvements in on-screen readability whereby reading speed from the e-reader screen increases.
7) Changes in grid efficiency had a greater effect on the e-reader system since most environmental burdens associated with the e-reader are a result of electricity generation necessary for operation of the e-reader.

8.2 Discussion

E-reader critics have rightfully argued that e-readers are not conducive to long sessions of reading text from a screen, lack the tactile appeal and "atmosphere" of conventional books, and are inconvenient in the sense that they represent yet another device that the user must purchase and learn to use. However, from an environmental standpoint, it is difficult to argue against the integration of e-readers into a school's curriculum,

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[22] Although arguments could be made that more than one student could utilize the same e-reader (i.e. the e-reader is shared), this scenario is highly impractical, especially in a college setting, and was therefore not considered in this analysis.

especially if the original user chooses to retain rather than resell the book or if the utility of owning the book expires (i.e. the book is discarded). The most notable observations gleaned from this study are as follows:

- Environmental burdens associated with electronic book storage (i.e. server storage) are small when compared to the physical storage of books (i.e. bookstore).
- E-readers eliminate personal transportation-related burdens since they allow for instant accessibility to digitized texts (i.e. anywhere there is Internet access).
- E-readers are more compact and are less material intensive than the equivalent number of printed books.
- Although the most significant contributor to the e-reader's LCA results, electricity generation for e-reader use had less of an environmental impact than did paper production for the conventional book system.

E-readers are not for everyone. However, reports have shown that the electronic textbook (e-textbook) market is growing fast and e-textbooks are becoming quite popular in educational institutions (Hawkins 2001). Other specific genres that have had success in electronic form include bibliographies, abstracting and indexing guides, dictionaries, encyclopedias, directories, cookbooks, product catalogs, and maintenance manuals. These genres share certain properties in that their readers want to find and then read relatively short chunks of specific text, they are frequently updated, and in some cases, they can be greatly enriched by multimedia and expanded content (Lynch 1999).

The intention of this study is not discourage the use of the printed book. Rather, this paper provides industry, consumers, and policy makers with a better understanding of the potential environmental impacts associated with traditional and electronic book systems. Further, this study also provides another case study examining the relationship between information technology and the environment that can contribute to product design improvements and the development of more sustainable technologies.

8.3 Suggestions for Future Research

As with most LCAs, this study was not an all-inclusive or exhaustive investigation. In light of this, areas where future research could be conducted to refine the results in this study include:

- Apply LCI and LCIA methodology to other e-reader brands and systems. Several IT companies, including Franklin and Nuvomedia, have developed their own e-reader devices and e-book software. Studying a variety of other e-readers could reveal which product design has the least environmental impact.
- Examine the effects of increasing the time frame of this study. Many printed books can survive for hundreds of years if they are not physically stressed. On the other hand, e-readers are expected to have a design life under 5 years.
- Conduct more research on EOL options for e-readers and print-based books. In terms of book resale, several issues should be addressed such as transportation back to the

bookstore for both used book buyers and sellers and prevalence of resale between friends and acquaintances.

- Update e-reader component manufacturing data, especially for semiconductors, to reflect recent technology trends.
- Investigate the system costs associated with each book option. As discussed earlier, because there are potentially no printing, shipping, or physical storage costs associated with e-books, production costs for e-books are frequently much lower than printed books. Thus, e-books can be sold for much less than conventional books.

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APPENDIX A
MODEL INPUTS SPREADSHEET

Appendix A: Model Inputs Spreadsheet

Traditional Book System

I. Textbook Paper Variables

Variable Description	Quantity	Units
Basis Weight	60	Pounds
Textbook Length	500	Pages
Cover Weight	0.192	Kilograms
Non-text Material	18	Sheets / Textbook
Textbook Paper Mass	0.86	Kilograms
FU Mass (40 textbooks)	42.10	Kilograms
Different Users	1.00	

II. Textbook Paper Transportation Variables

Variable Description	Quantity	Units
FU Mass	42.10	Kilograms
Travel Distance	500	Miles
Fuel Efficiencey	9.4	gal/1000 ton-mile
Energy Consumption	1,465	Btu/ton-mile

III. Textbook Printing Variables

Variable Description	Quantity	Units
Electricity Burden	0.77	MWh/tonne
Required Fuel Oil	0.72	MWh/tonne
Required Natural Gas	1.19	MWh/tonne

IV. Textbook Delivery Variables

Variable Description	Quantity	Units
FU Mass	42.10	Kilograms
Travel Distance	746	Miles
Fuel Efficiencey	9.4	gal/1000 ton-mile
Energy Consumption	1,465	Btu/ton-mile

Appendix A (continued): Model Inputs Spreadsheet

V. Facility Infrastructure

	Quantity	Units
Electricity Burden	11.80	KWh/ft^2/year
Required Fuel Oil	0.14	gal/ft^2/year
Required Natural Gas	45.20	ft^3/ft^2/year
Book Footprint	3.04	ft^2
Space Ratio	0.33	
Adjustment factor for empty space	2.00	
Adjusted Book Footprint	18.24	ft^2
Book Shelf Life	1.00	month
Shelves per Stack	4.00	stacks

VI. Personal Transportation

Variable Description	Quantity	Units
Travel Distance per trip	10	Miles
Number of Trips	8	Trips
Total Travel Distance	80	Miles
Fuel Efficiencey	23	miles/gallon

VII. Book Disposal

Variable Description	Quantity	Units
Number of Books Disposed	0	Books

E-READER SYSTEM

I. Cable Manufacturing Variables

Variable Description	Quantity	Units
Electricity Requirment	0.83	Wh/g

II. Battery Manufacturing Variables

Variable Description	Quantity	Units
Electricity Requirment	1.51	kWh/kg

V. E-Reader Transportation Variables

Variable Description	Quantity	Units
FU Mass	1.67	Kilograms
Travel Distance	500	Miles
Fuel Efficiencey	9.4	gal/1000 ton-mile
Energy Consumption	1465	Btu/ton-mile

VI. Host Server Variables

Variable Description	Quantity	Units
Rated Power	3040	Watts
Memory Capacity	98304	MB
Equipment Design Life	4	years
FU File Size (40 e-books)	156.8	MB
Number of users accessing e-books	30	people

VII. E-Reader Use-related Variables

Variable Description	Quantity	Units
Download Speed	33.60	kbps
Device Power Rating	11	Watts
Average Reading Speed from LCD	140	words/minute
Words per e-book	267,000	words
E-book file size	1,372	kB
Study Frequency	0	hours/week per semester

APPENDIX B
LCI DATA
TEXTBOOK PAPER PRODUCTION

Appendix B: Textbook Paper Production

Assumptions:	FU textbook paper mass (40 textbooks)	34.42	kg
	Equivalent Mass	0.03795	tons
		Factor for 1,000 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	1.93E-02	6.64E-04
	(r) Clay (in ground)	6.46E+01	2.22E+00
	(r) Coal (in ground)	7.64E+01	2.63E+00
	(r) Iron (Fe, ore)	1.07E-02	3.68E-04
	(r) Lignite (in ground)	3.04E+01	1.05E+00
	(r) Limestone (CaCO3, in ground)	3.45E+01	1.19E+00
	(r) Natural Gas (in ground)	2.03E+02	7.00E+00
	(r) Oil (in ground)	7.81E+01	2.69E+00
	(r) Sand (in ground)	5.70E-03	1.96E-04
	(r) Sodium Chloride (NaCl, in ground or in sea)	3.67E+01	1.26E+00
	(r) Sulfur (S, in ground)	1.38E+01	4.73E-01
	(r) Uranium (U, ore)	1.83E-02	6.30E-04
	Wood	2.33E+03	8.03E+01
	Raw Materials (unspecified)	2.25E+01	7.73E-01
	Total (kg)		9.96E+01
Note: Raw material requirements exclude water usage, which equals		3.07E+03	liters
		Factor for 1 ton	Millions of BTUs
Combustion Process Energy	Electricity	1.07E+01	4.06E-01
	Natural Gas	9.03E+00	3.43E-01
	LPG	0.00E+00	0.00E+00
	Coal	7.07E+00	2.68E-01
	Distilate Oil	0.00E+00	0.00E+00
	Residual Oil	3.31E+00	1.26E-01
	Gasoline	0.00E+00	0.00E+00
	Diesel	0.00E+00	0.00E+00
	Wood	8.64E-01	3.28E-02
	Black Liquor	2.34E+00	8.88E-02
Precombustion Process Energy	Natural Gas	1.35E-01	5.12E-03
	Residual Oil	2.22E-02	8.42E-04
	Distilate Oil	1.63E-02	6.19E-04
	Gasoline	7.49E-03	2.84E-04
	LPG	3.51E-04	1.33E-05
	Coal	2.81E-03	1.07E-04
	Nuclear	2.17E-03	8.23E-05
	Hydropower	6.81E-03	2.58E-04
	Other	6.03E-03	2.29E-04
Total Energy (mmBtu)			1.27E+00
Total Energy (MJ)			1.34E+03
Air Emissions	Ammonia (lb)	1.74E-04	6.60E-06
	Carbon Monoxide (lb)	2.04E+00	7.74E-02
	CO2 (lb)	5.04E+03	1.91E+02
	Hydrocarbons-non CH4 (lb)	6.01E+00	2.28E-01
	Hydrochloric acid (lb)	1.95E-03	7.40E-05
	Lead (lb)	6.56E-06	2.49E-07
	Methane (lb)	2.96E-01	1.12E-02
	Nitrogen Oxides (lb)	2.06E+01	7.82E-01
	Particulates (lb)	1.23E+01	4.67E-01
	Sulfur Oxides (lb)	2.10E+00	7.97E-02
	Total (lb)		1.93E+02
	Total (g)		8.74E+04
Water Emissions	Dissolved solids (lb)	1.97E+00	7.48E-02
	Suspended solids (lb)	3.10E+00	1.18E-01
	BOD (lb)	1.64E+00	6.22E-02
	COD (lb)	1.50E+01	5.69E-01
	Oil (lb)	3.55E-02	1.35E-03
	Sulfuric Acid (lb)	4.63E-04	1.76E-05
	Iron (lb)	1.41E-03	5.35E-05
	Ammonia (lb)	6.56E-04	2.49E-05
	Copper (lb)	0.00E+00	0.00E+00
	Cadmium (lb)	9.08E-05	3.45E-06
	Arsenic (lb)	0.00E+00	0.00E+00
	Mercury (lb)	7.05E-09	2.68E-10
	Phosphate (lb)	2.33E-04	8.84E-06
	Selenium (lb)	0.00E+00	0.00E+00
	Chromium (lb)	9.08E-05	3.45E-06
	Lead (lb)	1.71E-08	1.71E-08
	Zinc (lb)	3.09E-05	1.17E-06
	Total (lb)		8.25E-01
	Total (g)		3.74E+02
Solid Waste	Solid Waste #1 (lb)	0.00E+00	0.00E+00
	Ash (lb)	3.05E+00	1.16E-01
	Sludge (lb)	0.00E+00	0.00E+00
	Scrap (lb)	0.00E+00	0.00E+00
	Unspecified (lb)	9.01E+01	3.42E+00
	Total (lb)		3.53E+00
	Total (kg)		1.60E+00

APPENDIX C
LCI DATA
TEXTBOOK COVER PRODUCTION

Appendix C: Textbook Cover Production

Assumptions and Variables:	FU cover mass (40 textbooks)	7.68	kg
	Equivalent Mass	0.0085	tons

		Factor for 1000 kg	kg
Raw Materials	Bauxite (Al2O3, ore)	1.02E+00	7.83E-03
	Clay (in ground)	5.54E+00	4.25E-02
	Coal (in ground)	1.93E+01	1.48E-01
	Iron (Fe, ore)	1.10E-03	8.45E-06
	Lignite (in ground)	1.65E+01	1.27E-01
	Limestone (CaCO3, in ground)	4.47E+00	3.43E-02
	Natural Gas (in ground)	1.02E+02	7.80E-01
	Oil (in ground)	5.55E+01	4.26E-01
	Sand (in ground)	5.00E-04	3.84E-06
	Sodium Chloride (NaCl, in ground or in sea)	1.41E+00	1.08E-02
	Sulfur (S, in ground)	1.85E+00	1.42E-02
	Uranium (U, ore)	1.25E-02	9.60E-05
	Borax (B4Na2O7)	3.40E-01	2.61E-03
	Maize	6.49E+01	4.98E-01
	Potatoes	1.39E+01	1.07E-01
	Raw Materials (unspecified)	7.74E+01	5.95E-01
	Urea (H2NCONH2)	2.76E+00	2.12E-02
	Wastepaper	8.30E+02	6.37E+00
	Wood	3.82E+02	2.93E+00
	Total (kg)	1.58E+03	1.21E+01
Note: Raw material requirements	exclude water usage, which equals	8.60E+01	liters

		Factor for 1 ton	Millions of BTUs
Combustion Process Energy	Electricity	3.74E+00	3.17E-02
	Natural Gas	1.81E+00	1.53E-02
	LPG	1.70E-04	1.44E-06
	Coal	4.18E+00	3.54E-02
	Distilate Oil	4.50E-03	3.81E-05
	Residual Oil	1.31E-01	1.10E-03
	Gasoline	3.10E-04	2.62E-06
	Diesel	1.58E+00	1.34E-02
	Wood	1.54E+01	1.30E-01
	Black Liquor	0.00E+00	0.00E+00
Precombustion Process Energy	Natural Gas	5.40E-02	4.57E-04
	Residual Oil	1.00E-02	8.47E-05
	Distilate Oil	2.60E-03	2.20E-05
	Gasoline	2.70E-03	2.29E-05
	LPG	1.78E-04	1.51E-06
	Coal	4.42E-06	3.74E-08
	Nuclear	1.90E-03	1.61E-05
	Hydropower	2.77E-04	2.34E-06
	Other	2.68E-04	2.27E-06
Total Energy (mmBtu)			2.28E-01
Total Energy (MJ)			2.40E+02

			Pounds (lbs)
		Factor for 1 ton	lbs
Air Emissions	Acreolin	7.00E-06	5.93E-08
	Aldehydes	1.06E-01	8.97E-04
	Ammonia	1.61E-01	1.36E-03
	Antimony	6.40E-06	5.42E-08
	Arsenic	5.00E-04	4.23E-06
	Benzene	6.30E-03	5.33E-05
	Beryllium	4.10E-05	3.47E-07
	Cadmium	1.20E-04	1.02E-06
	Carbon Monoxide	3.77E+01	3.19E-01
	Carbon Tetrachloride	1.30E-05	1.10E-07
	Chlorine	1.30E-02	1.10E-04
	Chromium	7.70E-04	6.52E-06
	Cobalt	1.90E-05	1.61E-07
	Dioxins	4.00E-11	3.39E-13
	Fossil Carbon Dioxide	1.98E+03	1.68E+01
	Hydrocarbons	2.50E+00	2.12E-02
	Hydrochloric acid	3.60E-02	3.05E-04
	Hydrogen Fluoride	5.00E-03	4.23E-05
	Kerosene	1.80E-04	1.52E-06
	Lead	2.10E-03	1.78E-05
	Manganese	1.70E-02	1.44E-04
	Mercury	1.63E-04	1.38E-06
	Metals	1.46E+00	1.24E-02
	Methane	3.65E+00	3.09E-02
	Methylene Chloride	3.20E-05	2.71E-07
	Napthalene	4.00E-03	3.39E-05
	Nickel	1.60E-03	1.35E-05
	Nitrogen oxides	2.02E+01	1.71E-01
	Nitrous Oxide	1.90E-02	1.61E-04
	n-Nitrosodimethylamine	1.50E-06	1.27E-08
	Other Organics	1.35E+00	1.14E-02
	Particulates	4.98E+00	4.22E-02
	Perchloroethylene	6.90E-06	5.84E-08
	Phenols	6.60E-02	5.59E-04
	Selenium	5.50E-05	4.66E-07
	Sulfur Oxides	3.10E+01	2.62E-01
	Total Reduced Sulfur	7.90E-02	6.69E-04
	Trichloroethylene	6.80E-06	5.76E-08
	Total (lb)	2.08E+03	1.76E+01
	Total (g)		8.00E+03

		Factor for 1 ton	lbs
Water Emissions	Dissolved solids (lb)	7.78E+00	6.59E-02
	Suspended solids (lb)	6.00E+00	5.08E-02
	BOD (lb)	3.82E+00	3.23E-02
	COD (lb)	2.09E+01	1.77E-01
	Phenol (lb)	8.04E-06	6.81E-08
	Sulfides (lb)	1.60E-05	1.35E-07
	Oil (lb)	1.40E-01	1.19E-03
	Sulfuric Acid (lb)	1.30E-02	1.10E-04
	Iron (lb)	7.20E-02	6.10E-04
	Ammonia (lb)	5.86E-02	4.96E-04
	Cyanide (lb)	6.02E-07	5.10E-09
	Cadmium (lb)	3.50E-04	2.96E-06
	Aluminum (lb)	1.50E-01	1.27E-03
	Mercury (lb)	2.70E-08	2.29E-10
	Phosphates (lb)	1.37E-01	1.16E-03
	Phosphorus (lb)	8.80E-02	7.45E-04
	Selenium (lb)	0.00E+00	0.00E+00
	Nitrogen (lb)	3.10E-02	2.62E-04
	Nitrates (lb)	3.37E-03	2.85E-05
	Chromium (lb)	3.50E-04	2.96E-06
	Lead (lb)	2.00E-07	1.69E-09
	Chloride (lb)	3.50E-01	2.96E-03
	Sodium (lb)	2.80E-04	2.37E-06
	Calcium (lb)	1.50E-04	1.27E-06
	Sulfates (lb)	3.50E-01	2.96E-03
	Manganese (lb)	4.50E-02	3.81E-04
	Fluorides (lb)	7.00E-04	5.93E-06
	Boron (lb)	5.30E-02	4.49E-04
	Other Organics (lb)	3.20E-02	2.71E-04
	Chromates (lb)	1.50E-05	1.27E-07
	Metal Ion (lb)	2.40E-03	2.03E-05
	Acid (lb)	2.50E-03	2.12E-05
	Zinc (lb)	3.50E-01	2.96E-03
	Total (lb)		3.42E-01
	Total (g)		1.55E+02

		Factor for 1 Ton	lbs
Solid Waste	Sludge (lb)	5.06E+01	4.28E-01
	Unspecified (lb)	6.23E+01	5.27E-01
	Ash (lb)	4.24E+02	3.59E+00
	Total (lb)		4.55E+00
	Total (kg)		2.06E+00

APPENDIX D
LCI DATA
TEXTBOOK PAPER AND CASE DELIVERY

1) Energy consumed and emissions generated
2) Diesel fuel production

Appendix D: Textbook paper and cover delivery – Energy consumed and emissions generated

Assumptions and Variables

Total Trip Distance:	500	miles
FU Mass (40 textbooks	42.10	kg
FU Mass equivilency:	0.04641	tons
Fuel Efficiency	9.4	gal/1000 ton-miles
Energy Consumption:	1,465	Btu/ton-mile

From	To	Distance (mi)	Conveyance	Fuel	Fuel Eff. (gal/1000 ton.mi)	Mass (ton)	Energy Rate (Btu/ton.mi)	Energy consumed (MJ)	Fuel consumed (gal)
Paper Manufacturing Facility	Book Printing Facility	500	Tractor-trailer	diesel	9.4	0.0464	1,465	35.87	0.21814

Air Pollution due to Transportation

Compound	Emissions (lbs/1000 gal)	Mass Released (lbs)
Acreolin	4.70E-06	1.03E-09
Ammonia	4.00E-02	8.73E-06
Antimony	3.80E-05	8.29E-09
Arsenic	7.90E-05	1.72E-08
Benzene	1.50E-05	3.27E-09
Beryllium	5.50E-06	1.20E-09
Cadmium	1.20E-04	2.62E-08
Carbon Tetrachloride	1.90E-05	4.14E-09
Chlorine	1.50E-03	3.27E-07
Chromium	9.00E-05	1.96E-08
CO	2.15E+02	4.69E-02
CO2 (total)	2.54E+04	5.55E+00
Cobalt	1.10E-04	2.40E-08
Dioxins	2.50E-10	5.45E-14
Formaldehyde	2.10E-05	4.58E-09
HC	8.79E+01	1.92E-02
HCl	2.50E-02	5.45E-06
HF	3.30E-03	7.20E-07
Kerosene	1.00E-04	2.18E-08
Lead	1.40E-04	3.05E-08
Manganese	1.10E-04	2.40E-08
Mercury	2.60E-05	5.67E-09
Metals	2.50E-03	5.45E-07
Methane	4.05E+00	8.83E-04
Methylene Chloride	2.10E-05	4.58E-09
Naphthalene	7.00E-06	1.53E-09
Nickel	1.70E-03	3.71E-07
Nitrous Oxide	2.80E-03	6.11E-07
n-nitrodimethylamine	9.90E-07	2.16E-10
Nox	2.18E+02	4.76E-02
Other Aldehydes	5.97E+00	1.30E-03
Other Organics	1.16E+02	2.53E-02
Particulates	3.15E+01	6.87E-03
Perchloroethylene	4.60E-06	1.00E-09
Phenols	1.20E-04	2.62E-08
Radionuclides (Ci)	8.70E-05	1.90E-08
Selenium	7.20E-05	1.57E-08
Sox	6.20E+01	1.35E-02
TCE	4.40E-06	9.60E-10
		5.71E+00
Total (g)		2.59E+03

Water Pollution due to Transportation

Waterborne Emmission	Emissions (lbs/1000 gal)	Mass Released (lb)
Acid	8.40E-06	1.83E-09
Metal Ion	1.80E-01	3.93E-05
Dissolved Solids	3.48E+01	7.59E-03
Suspended Soli	7.90E-01	1.72E-04
BOD	1.30E-01	2.84E-05
COD	8.70E-01	1.90E-04
Phenol	5.80E-04	1.27E-07
Oil	8.10E-01	1.77E-04
Sufuric Acid	6.90E-03	1.51E-06
iron	1.90E-02	4.14E-06
Ammonia	1.40E-02	3.05E-06
Chromium	1.30E-03	2.84E-07
Lead	1.50E-05	3.27E-09
Zinc	6.50E-04	1.42E-07
Chlorides	1.28E+00	2.79E-04
Sodium	1.60E-04	3.49E-08
Calcium	9.00E-05	1.96E-08
Sulfates	1.03E+00	2.25E-04
Manganese	9.20E-03	2.01E-06
Fluorides	4.10E-04	8.94E-08
Nitrates	3.90E-05	8.51E-09
Phosphates	3.50E-03	7.63E-07
Boron	2.80E-02	6.11E-06
Other organics	8.50E-02	1.85E-05
Chromates	9.80E-05	2.14E-08
Cyanide	1.90E-06	4.14E-10
Mercury	9.80E-08	2.14E-11
Cadmium	1.30E-03	2.84E-07
Total (lb)		8.74E-03
Total (g)		3.96E+00

Solid Waste Due To Transportation

Category	Emission (lb/1000 gal)	Mass (lb)	Mass (kg)
Solid Waste	133	2.90E-02	1.32E-02

Appendix D (continued): Textbook paper and cover delivery - Diesel production

Assumptions and Variables:	Diesel Requirement:	0.22	gal
	Diesel Equivilancy:	0.68	kg

Note: This assumes that the density of diesel = 0.827 g/ml

		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	1.07E-04	7.34E-05
	(r) Coal (in ground)	3.62E-02	2.47E-02
	(r) Limestone (CaCO3, in ground)	2.87E-03	1.96E-03
	(r) Natural Gas (in ground)	1.17E-01	8.00E-02
	(r) Oil (in ground)	1.06E+00	7.27E-01
	(r) Sand (in ground)	6.58E-05	4.50E-05
	(r) Sodium Chloride (NaCl, in ground or in sea)	3.02E-05	2.06E-05
	(r) Uranium (U, ore)	6.10E-07	4.16E-07
	Total		8.34E-01

Note: Raw material requirements exclude water usage, which equals 1.72E+01 liters

		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.44E+01	3.03E+01
	E Fuel Energy	7.44E+00	5.08E+00
	E Non Renewable Energy	5.18E+01	3.53E+01
	E Renewable Energy	4.90E-02	3.34E-02
	E Total Primary Energy	5.18E+01	3.54E+01

		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	2.39E-07	1.63E-07
	(w) Aluminum (Al3+)	3.42E-04	2.34E-04
	(w) Ammonia (NH4+, NH3, as N)	6.54E-02	4.46E-02
	(w) AOX (Adsorbable Organic Halogens)	9.02E-10	6.16E-10
	(w) Aromatic Hydrocarbons (unspecified)	2.11E-07	1.44E-07
	(w) Barium (Ba++)	6.77E-07	4.62E-07
	(w) BOD5 (Biochemical Oxygen Demand)	4.53E-01	3.09E-01
	(w) Cadmium (Cd++)	7.05E-10	4.81E-10
	(w) Chlorides (Cl-)	1.53E+01	1.05E+01
	(w) Chromium (Cr III, Cr VI)	9.14E-08	6.24E-08
	(w) COD (Chemical Oxygen Demand)	3.83E+00	2.62E+00
	(w) Copper (Cu+, Cu++)	1.41E-08	9.63E-09
	(w) Cyanide (CN-)	9.87E-10	6.74E-10
	(w) Dissolved Matter (unspecified)	1.05E-03	7.15E-04
	(w) Fluorides (F-)	9.20E-05	6.28E-05
	(w) Halogenated Matter (organic)	2.82E-10	1.93E-10
	(w) Hydrocarbons (unspecified)	9.86E-04	6.73E-04
	(w) Iron (Fe++, Fe3+)	8.69E-07	5.93E-07
	(w) Lead (Pb++, Pb4+)	2.82E-09	1.93E-09
	(w) Mercury (Hg+, Hg++)	3.24E-12	2.21E-12
	(w) Metals (unspecified)	2.64E-02	1.80E-02
	(w) Nickel (Ni++, Ni3+)	1.41E-09	9.63E-10
	(w) Nitrate (NO3-)	1.49E-04	1.02E-04
	(w) Nitrogenous Matter (unspecified, as N)	3.81E-08	2.60E-08
	(w) Oils (unspecified)	2.53E-01	1.73E-01
	(w) Organic Matter (unspecified)	6.22E-07	4.24E-07
	(w) Phenol (C6H5OH)	8.71E-03	5.95E-03
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	1.40E-06	9.59E-07
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	3.38E-09	2.31E-09
	(w) Salts (unspecified)	3.90E-03	2.66E-03
	(w) Sodium (Na+)	1.97E+01	1.35E+01
	(w) Sulfate (SO4--)	2.18E-04	1.49E-04
	(w) Sulfide (S--)	1.39E-07	9.51E-08
	(w) Suspended Matter (unspecified)	2.06E+00	1.40E+00
	(w) TOC (Total Organic Carbon)	2.11E-06	1.44E-06
	(w) Toluene (C6H5CH3)	3.10E-08	2.12E-08
	(w) Zinc (Zn++)	2.92E-08	1.99E-08
	Total (g)		2.85E+01

Note: Water emissions exclude chemically polluted water, which equals 1.67E+00 liters

		Factor for 1 kg	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	1.37E-08	9.36E-09
	(a) Acenaphthylene (C12H8)	5.71E-09	3.90E-09
	(a) Acetaldehyde (CH3CHO)	1.03E-05	7.03E-06
	(a) Acetophenone (C8H8O)	2.71E-07	1.85E-07
	(a) Acrolein (CH2CHCHO)	5.24E-06	3.58E-06
	(a) Aldehyde (unspecified)	3.82E-03	2.61E-03
	(a) Aluminum (Al)	5.55E-05	3.79E-05
	(a) Ammonia (NH3)	5.52E-03	3.77E-03
	(a) Anthracene (C14H10)	5.53E-09	3.77E-09
	(a) Antimony (Sb)	1.60E-06	1.09E-06
	(a) Aromatic Hydrocarbons (unspecified)	1.27E-07	8.66E-08
	(a) Arsenic (As)	3.77E-05	2.58E-05
	(a) Barium (Ba)	8.34E-07	5.70E-07
	(a) Benzene (C6H6)	3.67E-02	2.51E-02
	(a) Benzo(a)anthracene	3.23E-09	2.21E-09
	(a) Benzo(a)pyrene (C20H12)	1.82E-09	1.24E-09
	(a) Benzo(b)fluoranthene	1.27E-09	8.67E-10
	(a) Benzo(bjk)fluoranthene	1.99E-09	1.36E-09
	(a) Benzo(ghi)perylene	1.44E-09	9.80E-10
	(a) Benzo(k)fluoranthene	1.27E-09	8.67E-10
	(a) Benzyl Chloride (C7H7Cl)	1.27E-05	8.64E-06
	(a) Beryllium (Be)	3.79E-06	2.58E-06
	(a) Bromoform (CHBr3)	7.05E-07	4.81E-07
	(a) Butane (C4H10)	1.34E-03	9.18E-04
	(a) Cadmium (Cd)	2.18E-06	1.49E-06
	(a) Calcium (Ca)	4.81E-05	3.28E-05
	(a) Carbon Dioxide (CO2, biomass)	1.80E-04	1.23E-04
	(a) Carbon Dioxide (CO2, fossil)	3.86E+02	2.63E+02
	(a) Carbon Disulfide (CS2)	2.35E-06	1.60E-06
	(a) Carbon Monoxide (CO)	1.07E+00	7.33E-01
	(a) Chlorides (Cl-)	8.44E-05	5.76E-05
	(a) Chlorine (Cl2)	1.34E-08	9.14E-09

		Factor for 1 kg	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	1.27E-07	8.64E-08
	(a) Chlorobenzene (C6H5Cl)	3.98E-07	2.72E-07
	(a) Chloroform (CHCl3, HC-20)	1.07E-06	7.28E-07
	(a) Chromium (Cr III, Cr VI)	5.72E-05	3.90E-05
	(a) Chrysene (C18H12)	3.15E-09	2.15E-09
	(a) Cobalt (Co)	6.84E-06	4.67E-06
	(a) Copper (Cu)	4.29E-06	2.93E-06
	(a) Cumene (C9H12)	9.58E-08	6.54E-08
	(a) Cyanide (CN-)	4.52E-05	3.09E-05
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	1.32E-06	9.01E-07
	(a) Dibenzo(a,h)anthracene	9.01E-10	6.15E-10
	(a) Dichlorobenzene (1,4-C6H4Cl2)	7.68E-07	5.25E-07
	(a) Dimethyl Benzanthracene (7,12-C20H16)	9.61E-09	6.56E-09
	(a) Dimethyl Sulfate (C2H6O4S)	8.68E-07	5.92E-07
	(a) Dinitrotoluene (2,4-C7H6N2O4)	5.06E-09	3.46E-09
	(a) Dioxins (unspecified)	2.93E-10	2.00E-10
	(a) Diphenyl ((C6H5)2)	3.07E-08	2.10E-08
	(a) Ethane (C2H6)	1.98E-03	1.36E-03
	(a) Ethyl Benzene (C6H5C2H5)	1.71E-06	1.17E-06
	(a) Ethyl Chloride (C2H5Cl)	7.59E-07	5.18E-07
	(a) Ethylene Dibromide (C2H4Br2)	2.17E-08	1.48E-08
	(a) Ethylene Dichloride (C2H4Cl2)	7.23E-07	4.94E-07
	(a) Fluoranthene	1.51E-08	1.03E-08
	(a) Fluorene (C13H10)	1.86E-08	1.27E-08
	(a) Fluorides (F-)	9.56E-06	6.53E-06
	(a) Formaldehyde (CH2O)	3.31E-03	2.26E-03
	(a) Furan (C4H4O)	1.36E-09	9.29E-10
	(a) Halogenated Hydrocarbons (unspecified)	7.05E-13	4.81E-13
	(a) Halon 1301 (CF3Br)	1.23E-09	8.38E-10
	(a) Hexane (C6H14)	1.15E-03	7.88E-04
	(a) Hydrocarbons (except methane)	2.90E-01	1.98E-01
	(a) Hydrocarbons (unspecified)	4.27E-01	2.91E-01
	(a) Hydrogen Chloride (HCl)	2.17E-02	1.48E-02
	(a) Hydrogen Fluoride (HF)	2.71E-03	1.85E-03
	(a) Hydrogen Sulfide (H2S)	8.71E-03	5.95E-03
	(a) Indeno (1,2,3,c,d) Pyrene	2.42E-09	1.66E-09
	(a) Iron (Fe)	1.07E-04	7.32E-05
	(a) Isophorone	1.05E-05	7.16E-06
	(a) Lead (Pb)	3.34E-05	2.28E-05
	(a) Magnesium (Mg)	1.99E-04	1.36E-04
	(a) Manganese (Mn)	6.02E-05	4.11E-05
	(a) Mercury (Hg)	2.34E-06	1.60E-06
	(a) Metals (unspecified)	7.57E-07	5.17E-07
	(a) Methane (CH4)	2.21E+00	1.51E+00
	(a) Methyl Bromide (CH3Br)	2.89E-06	1.97E-06
	(a) Methyl Chloride (CH3Cl)	9.58E-06	6.54E-06
	(a) Methyl Cholanthrene (3-C21H16)	1.15E-09	7.87E-10
	(a) Methyl Chrysene (5-C19H15)	3.98E-10	2.72E-10
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	7.05E-06	4.81E-06
	(a) Methyl Hydrazine (CH6N2)	3.07E-06	2.10E-06
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	3.61E-07	2.47E-07
	(a) Methyl Naphthalene (2-C11H10)	1.54E-08	1.05E-08
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	6.33E-07	4.32E-07
	(a) Methylene Chloride (CH2Cl2, HC-130)	5.24E-06	3.58E-06
	(a) Molybdenum (Mo)	5.40E-06	3.69E-06
	(a) Naphthalene (C10H8)	9.00E-07	6.15E-07
	(a) Nickel (Ni)	3.41E-04	2.33E-04
	(a) Nitrogen Oxides (NOx as NO2)	1.51E+00	1.03E+00
	(a) Nitrous Oxide (N2O)	4.47E-02	3.05E-02
	(a) Organic Matter (unspecified)	1.82E-01	1.24E-01
	(a) Particulates (PM 10)	6.39E-04	4.37E-04
	(a) Particulates (unspecified)	3.41E-01	2.33E-01
	(a) Pentane (C5H12)	1.66E-03	1.14E-03
	(a) Phenanthrene (C14H10)	6.05E-08	4.13E-08
	(a) Phenol (C6H5OH)	2.89E-07	1.97E-07
	(a) Phosphorus (P)	3.48E-05	2.38E-05
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	1.41E-10	9.63E-11
	(a) Propane (C3H8)	4.50E-06	3.08E-06
	(a) Propionaldehyde (CH3CH2CHO)	6.87E-06	4.69E-06
	(a) Pyrene (C16H10)	9.50E-09	6.49E-09
	(a) Selenium (Se)	2.53E-05	1.73E-05
	(a) Silicon (Si)	4.81E-05	3.28E-05
	(a) Sodium (Na)	2.85E-04	1.94E-04
	(a) Styrene (C6H5CHCH2)	4.52E-07	3.09E-07
	(a) Sulfur Oxides (SOx as SO2)	2.09E+00	1.43E+00
	(a) Tetrachloroethylene (C2Cl4)	7.77E-07	5.31E-07
	(a) Toluene (C6H5CH3)	9.74E-06	6.65E-06
	(a) Trichloroethane (1,1,1-CH3CCl3)	3.61E-07	2.47E-07
	(a) Vanadium (V)	7.49E-04	5.11E-04
	(a) Vinyl Acetate (C4H6O2)	1.37E-07	9.38E-08
	(a) Xylene (C6H4(CH3)2)	2.67E-06	1.83E-06
	(a) Zinc (Zn)	2.57E-05	1.75E-05
	Total (g)		6.56E+02

		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	1.94E-01	1.33E-01

APPENDIX E
LCI DATA
BOOK PRINTING OPERATIONS

1) Electricity Production
2) Heavy Fuel Oil Production
3) Combustion of Residual Oil in Industrial Boilers
4) Natural Gas Production
5) Combustion of Natural Gas in a Utility Boiler

Appendix E: Book Printing Operations - Electricity Production

Assumptions and Variables:	Electricity Requirement:	95.43	MJ

		Factor for 1 MJ	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.46E-07	2.35E-05
	(r) Coal (in ground)	1.48E-01	1.42E+01
	(r) Limestone (CaCO3, in ground)	1.17E-02	1.12E+00
	(r) Natural Gas (in ground)	9.17E-04	8.75E-02
	(r) Oil (in ground)	2.99E-03	2.85E-01
	(r) Sand (in ground)	1.51E-07	1.44E-05
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.92E-08	6.60E-06
	(r) Uranium (U, ore)	7.17E-07	6.84E-05
	Total		1.57E+01

Note: Raw material requirements exclude water usage, which equals	5.72E+00	liters

		Factor for 1 MJ	MJ
Energy Burdens	E Feedstock Energy	3.94E-01	3.76E+01
	E Fuel Energy	4.47E+00	4.26E+02
	E Non Renewable Energy	4.85E+00	4.63E+02
	E Renewable Energy	7.96E-03	7.60E-01
	Electricity	1.50E-02	1.43E+00
	E Total Primary Energy	4.86E+00	4.64E+02

		Factor for 1 MJ	grams (g)
Water Emissions	(w) Acids (H+)	1.06E-09	1.01E-07
	(w) Aluminum (Al3+)	7.83E-07	7.48E-05
	(w) Ammonia (NH4+, NH3, as N)	1.89E-04	1.80E-02
	(w) AOX (Adsorbable Organic Halogens)	2.07E-12	1.97E-10
	(w) Aromatic Hydrocarbons (unspecified)	4.84E-10	4.62E-08
	(w) Barium (Ba++)	1.55E-09	1.48E-07
	(w) BOD5 (Biochemical Oxygen Demand)	1.04E-03	9.92E-02
	(w) Cadmium (Cd++)	1.61E-12	1.54E-10
	(w) Chlorides (Cl-)	3.75E-02	3.58E+00
	(w) Chromium (Cr III, Cr VI)	3.46E-10	3.30E-08
	(w) COD (Chemical Oxygen Demand)	8.78E-03	8.38E-01
	(w) Copper (Cu+, Cu++)	3.23E-11	3.08E-09
	(w) Cyanide (CN-)	2.26E-12	2.16E-10
	(w) Dissolved Matter (unspecified)	4.28E-03	4.08E-01
	(w) Fluorides (F-)	1.08E-04	1.03E-02
	(w) Halogenated Matter (organic)	6.46E-13	6.16E-11
	(w) Hydrocarbons (unspecified)	2.41E-06	2.30E-04
	(w) Iron (Fe++, Fe3+)	2.11E-07	2.01E-05
	(w) Lead (Pb++, Pb4+)	6.46E-12	6.16E-10
	(w) Mercury (Hg+, Hg++)	7.42E-15	7.08E-13
	(w) Metals (unspecified)	6.37E-05	6.08E-03
	(w) Nickel (Ni++, Ni3+)	3.23E-12	3.08E-10
	(w) Nitrate (NO3-)	2.59E-05	2.47E-03
	(w) Nitrogenous Matter (unspecified, as N)	8.71E-11	8.32E-09
	(w) Oils (unspecified)	6.61E-04	6.30E-02
	(w) Organic Matter (unspecified)	2.79E-09	2.66E-07
	(w) Phenol (C6H5OH)	1.99E-05	1.90E-03
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.22E-09	3.07E-07
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	7.75E-12	7.39E-10
	(w) Salts (unspecified)	8.92E-06	8.52E-04
	(w) Sodium (Na+)	4.83E-02	4.61E+00
	(w) Sulfate (SO4--)	2.33E-05	2.22E-03
	(w) Sulfide (S--)	6.02E-10	5.74E-08
	(w) Suspended Matter (unspecified)	4.74E-03	4.53E-01
	(w) TOC (Total Organic Carbon)	4.84E-09	4.62E-07
	(w) Toluene (C6H5CH3)	7.10E-11	6.78E-09
	(w) Zinc (Zn++)	9.93E-11	9.48E-09
	Total (g)		1.01E+01

Note: Water emissions exclude chemically polluted water, which equals	5.66E-01	liters

		Factor for 1 MJ	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	3.78E-08	3.60E-06
	(a) Acenaphthylene (C12H8)	1.85E-08	1.77E-06
	(a) Acetaldehyde (CH3CHO)	4.22E-05	4.03E-03
	(a) Acetophenone (C8H8O)	1.11E-06	1.06E-04
	(a) Acrolein (CH2CHCHO)	2.15E-05	2.05E-03
	(a) Aldehyde (unspecified)	7.58E-03	7.23E-01
	(a) Aluminum (Al)	1.36E-07	1.30E-05
	(a) Ammonia (NH3)	5.11E-05	4.88E-03
	(a) Anthracene (C14H10)	1.56E-08	1.48E-06
	(a) Antimony (Sb)	1.51E-06	1.44E-04
	(a) Aromatic Hydrocarbons (unspecified)	2.90E-10	2.77E-08
	(a) Arsenic (As)	1.30E-04	1.24E-02
	(a) Barium (Ba)	9.72E-08	9.28E-06
	(a) Benzene (C6H6)	2.59E-04	2.47E-02
	(a) Benzo(a)anthracene	5.93E-09	5.66E-07
	(a) Benzo(a)pyrene (C20H12)	2.82E-09	2.69E-07
	(a) Benzo(b)fluoranthene	3.86E-12	3.68E-10
	(a) Benzo(bjk)fluoranthene	8.14E-09	7.77E-07
	(a) Benzo(ghi)perylene	2.00E-09	1.91E-07
	(a) Benzo(k)fluoranthene	3.86E-12	3.68E-10
	(a) Benzyl Chloride (C7H7Cl)	5.18E-05	4.95E-03
	(a) Beryllium (Be)	1.49E-05	1.43E-03
	(a) Bromoform (CHBr3)	2.89E-06	2.76E-04
	(a) Butane (C4H10)	4.18E-06	3.99E-04
	(a) Cadmium (Cd)	8.42E-06	8.03E-04
	(a) Calcium (Ca)	1.18E-07	1.12E-05
	(a) Carbon Dioxide (CO2, biomass)	2.97E-05	2.84E-03
	(a) Carbon Dioxide (CO2, fossil)	3.77E+02	3.59E+04
	(a) Carbon Disulfide (CS2)	9.62E-06	9.18E-04
	(a) Carbon Monoxide (CO)	1.62E-01	1.55E+01
	(a) Chlorides (Cl-)	1.16E-05	1.11E-03
	(a) Chlorine (Cl2)	6.00E-11	5.72E-09

		Factor for 1 MJ	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	5.18E-07	4.95E-05
	(a) Chlorobenzene (C6H5Cl)	1.63E-06	1.55E-04
	(a) Chloroform (CHCl3, HC-20)	4.37E-06	4.17E-04
	(a) Chromium (Cr III, Cr VI)	2.17E-04	2.07E-02
	(a) Chrysene (C18H12)	7.41E-09	7.07E-07
	(a) Cobalt (Co)	7.61E-06	7.27E-04
	(a) Copper (Cu)	7.73E-08	7.38E-06
	(a) Cumene (C9H12)	3.92E-07	3.74E-05
	(a) Cyanide (CN-)	1.85E-04	1.77E-02
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	5.40E-06	5.16E-04
	(a) Dibenzo(a,h)anthracene	2.70E-12	2.58E-10
	(a) Dichlorobenzene (1,4-C6H4Cl2)	2.39E-09	2.28E-07
	(a) Dimethyl Benzanthracene (7,12-C20H16)	3.02E-11	2.88E-09
	(a) Dimethyl Sulfate (C2H6O4S)	3.55E-06	3.39E-04
	(a) Dinitrotoluene (2,4-C7H6N2O4)	2.07E-08	1.98E-06
	(a) Dioxins (unspecified)	1.20E-09	1.14E-07
	(a) Diphenyl ((C6H5)2)	1.26E-07	1.20E-05
	(a) Ethane (C2H6)	6.17E-06	5.89E-04
	(a) Ethyl Benzene (C6H5C2H5)	6.96E-06	6.64E-04
	(a) Ethyl Chloride (C2H5Cl)	3.11E-06	2.97E-04
	(a) Ethylene Dibromide (C2H4Br2)	8.88E-08	8.48E-06
	(a) Ethylene Dichloride (C2H4Cl2)	2.96E-06	2.83E-04
	(a) Fluoranthene	5.26E-08	5.02E-06
	(a) Fluorene (C13H10)	6.74E-08	6.43E-06
	(a) Fluorides (F-)	1.82E-06	1.74E-04
	(a) Formaldehyde (CH2O)	3.16E-05	3.02E-03
	(a) Furan (C4H4O)	5.57E-09	5.32E-07
	(a) Halogenated Hydrocarbons (unspecified)	1.61E-15	1.54E-13
	(a) Halon 1301 (CF3Br)	2.81E-12	2.68E-10
	(a) Hexane (C6H14)	8.54E-06	8.15E-04
	(a) Hydrocarbons (except methane)	1.39E-02	1.33E+00
	(a) Hydrocarbons (unspecified)	2.68E-02	2.56E+00
	(a) Hydrogen Chloride (HCl)	8.88E-02	8.48E+00
	(a) Hydrogen Fluoride (HF)	1.11E-02	1.06E+00
	(a) Hydrogen Sulfide (H2S)	2.13E-05	2.03E-03
	(a) Indeno (1,2,3,c,d) Pyrene	4.52E-09	4.31E-07
	(a) Iron (Fe)	2.62E-07	2.50E-05
	(a) Isophorone	4.29E-05	4.10E-03
	(a) Lead (Pb)	1.29E-04	1.23E-02
	(a) Magnesium (Mg)	8.14E-04	7.77E-02
	(a) Manganese (Mn)	2.42E-04	2.31E-02
	(a) Mercury (Hg)	8.08E-06	7.71E-04
	(a) Metals (unspecified)	1.76E-09	1.68E-07
	(a) Methane (CH4)	6.60E-01	6.30E+01
	(a) Methyl Bromide (CH3Br)	1.18E-05	1.13E-03
	(a) Methyl Chloride (CH3Cl)	3.92E-05	3.74E-03
	(a) Methyl Cholanthrene (3-C21H16)	3.58E-12	3.42E-10
	(a) Methyl Chrysene (5-C19H15)	1.63E-09	1.55E-07
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	2.89E-05	2.76E-03
	(a) Methyl Hydrazine (CH6N2)	1.26E-05	1.20E-03
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	1.48E-06	1.41E-04
	(a) Methyl Naphthalene (2-C11H10)	4.78E-11	4.56E-09
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	2.59E-06	2.47E-04
	(a) Methylene Chloride (CH2Cl2, HC-130)	2.15E-05	2.05E-03
	(a) Molybdenum (Mo)	4.80E-08	4.58E-06
	(a) Naphthalene (C10H8)	1.00E-06	9.56E-05
	(a) Nickel (Ni)	1.76E-04	1.68E-02
	(a) Nitrogen Oxides (NOx as NO2)	1.40E+00	1.34E+02
	(a) Nitrous Oxide (N2O)	5.14E-02	4.90E+00
	(a) Organic Matter (unspecified)	8.45E-04	8.06E-02
	(a) Particulates (PM 10)	1.56E-06	1.49E-04
	(a) Particulates (unspecified)	9.04E-01	8.63E+01
	(a) Pentane (C5H12)	5.18E-06	4.94E-04
	(a) Phenanthrene (C14H10)	2.00E-07	1.91E-05
	(a) Phenol (C6H5OH)	1.18E-06	1.13E-04
	(a) Phosphorus (P)	3.97E-07	3.79E-05
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	3.23E-13	3.08E-11
	(a) Propane (C3H8)	5.75E-07	5.49E-05
	(a) Propionaldehyde (CH3CH2CHO)	2.81E-05	2.68E-03
	(a) Pyrene (C16H10)	2.44E-08	2.33E-06
	(a) Selenium (Se)	9.63E-05	9.19E-03
	(a) Silicon (Si)	1.18E-07	1.12E-05
	(a) Sodium (Na)	6.97E-07	6.65E-05
	(a) Styrene (C6H5CHCH2)	1.85E-06	1.77E-04
	(a) Sulfur Oxides (SOx as SO2)	1.35E+00	1.29E+02
	(a) Tetrachloroethylene (C2Cl4)	3.18E-06	3.04E-04
	(a) Toluene (C6H5CH3)	1.81E-05	1.72E-03
	(a) Trichloroethane (1,1,1-CH3CCl3)	1.48E-06	1.41E-04
	(a) Vanadium (V)	2.88E-06	2.75E-04
	(a) Vinyl Acetate (C4H6O2)	5.63E-07	5.37E-05
	(a) Xylene (C6H4(CH3)2)	2.75E-06	2.63E-04
	(a) Zinc (Zn)	1.03E-06	9.86E-05
	Total (g)		3.68E+04

		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	7.81E-01	7.45E+01

Appendix E (continued): Book Printing Operations - Heavy Fuel Oil Production

Assumptions and Variables:	Heavy Fuel Oil Requirement:	0.55	gallons
	Equivilancy	2.06	kg
		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	4.08E-05	8.41E-05
	(r) Coal (in ground)	2.94E-02	6.05E-02
	(r) Limestone (CaCO3, in ground)	2.32E-03	4.79E-03
	(r) Natural Gas (in ground)	7.81E-02	1.61E-01
	(r) Oil (in ground)	1.05E+00	2.17E+00
	(r) Sand (in ground)	2.50E-05	5.15E-05
	(r) Sodium Chloride (NaCl, in ground or in sea)	1.15E-05	2.36E-05
	(r) Uranium (U, ore)	4.95E-07	1.02E-06
	Total		2.40E+00
Note: Raw material requirements exclude water usage, which equals		1.99E+01	liters
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.28E+01	8.83E+01
	E Fuel Energy	5.00E+00	1.03E+01
	E Non Renewable Energy	4.78E+01	9.85E+01
	E Renewable Energy	3.97E-02	8.18E-02
	E Total Primary Energy	4.78E+01	9.86E+01
		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	1.44E-07	2.97E-07
	(w) Aluminum (Al3+)	1.30E-04	2.68E-04
	(w) Ammonia (NH4+, NH3, as N)	2.47E-02	5.10E-02
	(w) AOX (Adsorbable Organic Halogens)	3.43E-10	7.06E-10
	(w) Aromatic Hydrocarbons (unspecified)	8.03E-08	1.66E-07
	(w) Barium (Ba++)	2.57E-07	5.30E-07
	(w) BOD5 (Biochemical Oxygen Demand)	1.72E-01	3.55E-01
	(w) Cadmium (Cd++)	2.68E-10	5.52E-10
	(w) Chlorides (Cl-)	1.52E+01	3.12E+01
	(w) Chromium (Cr III, Cr VI)	4.89E-08	1.01E-07
	(w) COD (Chemical Oxygen Demand)	1.46E+00	3.00E+00
	(w) Copper (Cu+, Cu++)	5.36E-09	1.10E-08
	(w) Cyanide (CN-)	3.75E-10	7.73E-10
	(w) Dissolved Matter (unspecified)	8.49E-04	1.75E-03
	(w) Fluorides (F-)	7.46E-05	1.54E-04
	(w) Halogenated Matter (organic)	1.07E-10	2.21E-10
	(w) Hydrocarbons (unspecified)	9.75E-04	2.01E-03
	(w) Iron (Fe++, Fe3+)	4.07E-07	8.38E-07
	(w) Lead (Pb++, Pb4+)	1.07E-09	2.21E-09
	(w) Mercury (Hg+, Hg++)	1.23E-12	2.54E-12
	(w) Metals (unspecified)	2.27E-02	4.68E-02
	(w) Nickel (Ni++, Ni3+)	5.36E-10	1.10E-09
	(w) Nitrate (NO3-)	6.59E-05	1.36E-04
	(w) Nitrogenous Matter (unspecified, as N)	1.45E-08	2.98E-08
	(w) Oils (unspecified)	1.44E-01	2.97E-01
	(w) Organic Matter (unspecified)	3.73E-07	7.68E-07
	(w) Phenol (C6H5OH)	3.31E-03	6.82E-03
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	5.34E-07	1.10E-06
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unsp.)	1.29E-09	2.65E-09
	(w) Salts (unspecified)	1.48E-03	3.05E-03
	(w) Sodium (Na+)	1.95E+01	4.02E+01
	(w) Sulfate (SO4--)	9.10E-05	1.88E-04
	(w) Sulfide (S--)	8.22E-08	1.69E-07
	(w) Suspended Matter (unspecified)	7.82E-01	1.61E+00
	(w) TOC (Total Organic Carbon)	8.03E-07	1.66E-06
	(w) Toluene (C6H5CH3)	1.18E-08	2.43E-08
	(w) Zinc (Zn++)	1.45E-08	2.98E-08
	Total (g)		7.68E+01
Note: Water emissions exclude chemically polluted water, which equals		4.55E+00	liters
		Factor for 1 kg	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	9.46E-09	1.95E-08
	(a) Acenaphthylene (C12H8)	4.38E-09	9.02E-09
	(a) Acetaldehyde (CH3CHO)	8.35E-06	1.72E-05
	(a) Acetophenone (C8H8O)	2.20E-07	4.53E-07
	(a) Acrolein (CH2CHCHO)	4.25E-06	8.75E-06
	(a) Aldehyde (unspecified)	2.31E-03	4.76E-03
	(a) Aluminum (Al)	5.49E-05	1.13E-04
	(a) Ammonia (NH3)	3.18E-03	6.55E-03
	(a) Anthracene (C14H10)	4.08E-09	8.41E-09
	(a) Antimony (Sb)	9.46E-07	1.95E-06
	(a) Aromatic Hydrocarbons (unspecified)	4.82E-08	9.93E-08
	(a) Arsenic (As)	3.15E-05	6.48E-05
	(a) Barium (Ba)	4.77E-07	9.84E-07
	(a) Benzene (C6H6)	2.22E-02	4.58E-02
	(a) Benzo(a)anthracene	2.12E-09	4.36E-09
	(a) Benzo(a)pyrene (C20H12)	1.38E-09	2.85E-09
	(a) Benzo(b)fluoranthene	7.44E-10	1.53E-09
	(a) Benzo(bjk)fluoranthene	1.61E-09	3.32E-09
	(a) Benzo(ghi)perylene	9.31E-10	1.92E-09
	(a) Benzo(k)fluoranthene	7.44E-10	1.53E-09
	(a) Benzyl Chloride (C7H7Cl)	1.03E-05	2.11E-05
	(a) Beryllium (Be)	3.04E-06	6.26E-06
	(a) Bromoform (CHBr3)	5.71E-07	1.18E-06
	(a) Butane (C4H10)	8.15E-04	1.68E-03
	(a) Cadmium (Cd)	1.73E-06	3.56E-06
	(a) Calcium (Ca)	4.76E-05	9.80E-05
	(a) Carbon Dioxide (CO2, biomass)	1.46E-04	3.00E-04
	(a) Carbon Dioxide (CO2, fossil)	2.31E+02	4.76E+02
	(a) Carbon Disulfide (CS2)	1.90E-06	3.92E-06
	(a) Carbon Monoxide (CO)	5.69E-01	1.17E+00
	(a) Chlorides (Cl-)	4.51E-05	9.28E-05
	(a) Chlorine (Cl2)	8.03E-09	1.65E-08
		Factor for 1 kg	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	1.03E-07	2.11E-07
	(a) Chlorobenzene (C6H5Cl)	3.22E-07	6.64E-07
	(a) Chloroform (CHCl3, HC-20)	8.64E-07	1.78E-06
	(a) Chromium (Cr III, Cr VI)	4.65E-05	9.59E-05
	(a) Chrysene (C18H12)	2.24E-09	4.61E-09
	(a) Cobalt (Co)	5.76E-06	1.19E-05
	(a) Copper (Cu)	3.83E-06	7.89E-06
	(a) Cumene (C9H12)	7.77E-08	1.60E-07
	(a) Cyanide (CN-)	3.66E-05	7.55E-05
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	1.07E-06	2.20E-06
	(a) Dibenzo(a,h)anthracene	5.17E-10	1.07E-09
	(a) Dichlorobenzene (1,4-C6H4Cl2)	4.66E-07	9.60E-07
	(a) Dimethyl Benzanthracene (7,12-C20H16)	5.82E-09	1.20E-08
	(a) Dimethyl Sulfate (C2H6O4S)	7.03E-07	1.45E-06
	(a) Dinitrotoluene (2,4-C7H6N2O4)	4.10E-09	8.45E-09
	(a) Dioxins (unspecified)	2.37E-10	4.89E-10
	(a) Diphenyl ((C6H5)2)	2.49E-08	5.13E-08
	(a) Ethane (C2H6)	1.20E-03	2.48E-03
	(a) Ethyl Benzene (C6H5C2H5)	1.39E-06	2.85E-06
	(a) Ethyl Chloride (C2H5Cl)	6.15E-07	1.27E-06
	(a) Ethylene Dibromide (C2H4Br2)	1.76E-08	3.62E-08
	(a) Ethylene Dichloride (C2H4Cl2)	5.86E-07	1.21E-06
	(a) Fluoranthene	1.17E-08	2.41E-08
	(a) Fluorene (C13H10)	1.46E-08	3.00E-08
	(a) Fluorides (F-)	5.24E-06	1.08E-05
	(a) Formaldehyde (CH2O)	3.24E-03	6.68E-03
	(a) Furan (C4H4O)	1.10E-09	2.27E-09
	(a) Halogenated Hydrocarbons (unspecified)	2.68E-13	5.52E-13
	(a) Halon 1301 (CF3Br)	4.66E-10	9.60E-10
	(a) Hexane (C6H14)	7.00E-04	1.44E-03
	(a) Hydrocarbons (except methane)	2.42E-01	4.99E-01
	(a) Hydrocarbons (unspecified)	3.66E-01	7.53E-01
	(a) Hydrogen Chloride (HCl)	1.76E-02	3.62E-02
	(a) Hydrogen Fluoride (HF)	2.20E-03	4.53E-03
	(a) Hydrogen Sulfide (H2S)	8.62E-03	1.78E-02
	(a) Indeno (1,2,3,c,d) Pyrene	1.66E-09	3.42E-09
	(a) Iron (Fe)	1.06E-04	2.19E-04
	(a) Isophorone	8.50E-06	1.75E-05
	(a) Lead (Pb)	2.71E-05	5.59E-05
	(a) Magnesium (Mg)	1.61E-04	3.32E-04
	(a) Manganese (Mn)	4.86E-05	1.00E-04
	(a) Mercury (Hg)	1.88E-06	3.88E-06
	(a) Metals (unspecified)	2.91E-07	5.99E-07
	(a) Methane (CH4)	1.60E+00	3.29E+00
	(a) Methyl Bromide (CH3Br)	2.34E-06	4.83E-06
	(a) Methyl Chloride (CH3Cl)	7.77E-06	1.60E-05
	(a) Methyl Cholanthrene (3-C21H16)	6.99E-10	1.44E-09
	(a) Methyl Chrysene (5-C19H15)	3.22E-10	6.64E-10
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	5.71E-06	1.18E-05
	(a) Methyl Hydrazine (CH6N2)	2.49E-06	5.13E-06
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	2.93E-07	6.04E-07
	(a) Methyl Naphthalene (2-C11H10)	9.32E-09	1.92E-08
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	5.13E-07	1.06E-06
	(a) Methylene Chloride (CH2Cl2, HC-130)	4.25E-06	8.75E-06
	(a) Molybdenum (Mo)	4.97E-06	1.02E-05
	(a) Naphthalene (C10H8)	5.74E-07	1.18E-06
	(a) Nickel (Ni)	3.20E-04	6.60E-04
	(a) Nitrogen Oxides (NOx as NO2)	1.11E+00	2.29E+00
	(a) Nitrous Oxide (N2O)	3.94E-02	8.12E-02
	(a) Organic Matter (unspecified)	1.10E-01	2.27E-01
	(a) Particulates (PM 10)	6.33E-04	1.30E-03
	(a) Particulates (unspecified)	2.51E-01	5.17E-01
	(a) Pentane (C5H12)	1.01E-03	2.08E-03
	(a) Phenanthrene (C14H10)	4.65E-08	9.58E-08
	(a) Phenol (C6H5OH)	2.34E-07	4.83E-07
	(a) Phosphorus (P)	3.34E-05	6.89E-05
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unsp.)	5.36E-11	1.10E-10
	(a) Propane (C3H8)	3.63E-06	7.48E-06
	(a) Propionaldehyde (CH3CH2CHO)	5.57E-06	1.15E-05
	(a) Pyrene (C16H10)	6.91E-09	1.42E-08
	(a) Selenium (Se)	2.08E-05	4.28E-05
	(a) Silicon (Si)	4.76E-05	9.80E-05
	(a) Sodium (Na)	2.82E-04	5.80E-04
	(a) Styrene (C6H5CHCH2)	3.66E-07	7.55E-07
	(a) Sulfur Oxides (SOx as SO2)	1.48E+00	3.06E+00
	(a) Tetrachloroethylene (C2Cl4)	6.30E-07	1.30E-06
	(a) Toluene (C6H5CH3)	6.80E-06	1.40E-05
	(a) Trichloroethane (1,1,1-CH3CCl3)	2.93E-07	6.04E-07
	(a) Vanadium (V)	7.37E-04	1.52E-03
	(a) Vinyl Acetate (C4H6O2)	1.11E-07	2.29E-07
	(a) Xylene (C6H4(CH3)2)	1.75E-06	3.60E-06
	(a) Zinc (Zn)	1.50E-05	3.10E-05
	Total (g)		7.19E+02
		Factor for 1 kg	kilograms (kg)
Solid Waste	Waste (total)	1.56E-01	3.21E-01

Note: Heavy fuel oil production includes:

Domestic and foreign crude oil production (onshore conventional, advanced, offshore conventional recovery)

Transportation to the refineries in the US.

Crude oil refining into heavy fuel oil.

Transportation from refinery to end-user.

Appendix E (cont.): Book Printing Operations - Combustion of Residual Oil in Industrial Boilers

Assumptions and Variables:	Heavy Fuel Oil Requirement:	89.23	MJ
		Factor for 1 MJ	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	6.05E-08	5.40E-06
	(a) Acenaphthylene (C12H8)	7.26E-10	6.48E-08
	(a) Anthracene (C14H10)	3.50E-09	3.12E-07
	(a) Antimony (Sb)	1.51E-05	1.34E-03
	(a) Arsenic (As)	3.79E-06	3.38E-04
	(a) Barium (Ba)	7.38E-06	6.58E-04
	(a) Benzene (C6H6)	6.14E-07	5.48E-05
	(a) Benzo(a)anthracene	1.15E-08	1.03E-06
	(a) Benzo(b)fluoranthene	2.12E-09	1.89E-07
	(a) Benzo(ghi)perylene	3.24E-09	2.89E-07
	(a) Benzo(k)fluoranthene	2.12E-09	1.89E-07
	(a) Beryllium (Be)	7.98E-08	7.12E-06
	(a) Cadmium (Cd)	1.14E-06	1.02E-04
	(a) Carbon Dioxide (CO2, fossil)	7.09E+01	6.32E+03
	(a) Carbon Monoxide (CO)	1.43E-02	1.28E+00
	(a) Chlorides (Cl-)	9.96E-04	8.89E-02
	(a) Chromium (Cr III, Cr VI)	3.14E-06	2.80E-04
	(a) Chrysene (C18H12)	3.41E-09	3.05E-07
	(a) Cobalt (Co)	1.73E-05	1.54E-03
	(a) Copper (Cu)	5.05E-06	4.51E-04
	(a) Dibenzo(a,h)anthracene	2.40E-09	2.14E-07
	(a) Ethyl Benzene (C6H5C2H5)	1.83E-07	1.63E-05
	(a) Fluoranthene	6.94E-09	6.20E-07
	(a) Fluorene (C13H10)	6.41E-09	5.72E-07
	(a) Fluorides (F-)	1.07E-04	9.55E-03
	(a) Formaldehyde (CH2O)	1.22E-04	1.09E-02
	(a) Hydrocarbons (except methane)	7.26E-04	6.48E-02
	(a) Indeno (1,2,3,c,d) Pyrene	3.07E-09	2.74E-07
	(a) Lead (Pb)	4.33E-06	3.87E-04
	(a) Manganese (Mn)	8.61E-06	7.68E-04
	(a) Mercury (Hg)	3.24E-07	2.89E-05
	(a) Methane (CH4)	1.96E-03	1.75E-01
	(a) Molybdenum (Mo)	2.26E-06	2.02E-04
	(a) Naphthalene (C10H8)	3.24E-06	2.89E-04
	(a) Nickel (Ni)	2.42E-04	2.16E-02
	(a) Nitrogen Oxides (NOx as NO2)	1.24E-01	1.11E+01
	(a) Nitrous Oxide (N2O)	3.16E-04	2.82E-02
	(a) Particulates (unspecified)	2.31E-01	2.06E+01
	(a) Phenanthrene (C14H10)	1.51E-08	1.34E-06
	(a) Phosphorus (P)	2.71E-05	2.42E-03
	(a) Pyrene (C16H10)	6.10E-09	5.44E-07
	(a) Selenium (Se)	1.96E-06	1.75E-04
	(a) Sulfur Oxides (SOx as SO2)	4.26E-01	3.80E+01
	(a) Toluene (C6H5CH3)	1.78E-05	1.59E-03
	(a) Vanadium (V)	9.13E-05	8.14E-03
	(a) Xylene (C6H4(CH3)2)	3.13E-07	2.79E-05
	(a) Zinc (Zn)	8.35E-05	7.45E-03
	Total (g)		6.40E+03

Note: Solid waste and water effluents were not considered in the DEAM database for combustion of heavy fuel oil in an an industrial boiler.

Appendix E (continued): Book Printing Operations – Natural Gas Production

Assumptions and Variables:	Natural Gas Requirement:	137.17	cubic feet
	Equivilancy	2.52	kg
		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	3.24E-07	8.15E-07
	(r) Coal (in ground)	8.39E-03	2.11E-02
	(r) Limestone (CaCO3, in ground)	6.62E-04	1.67E-03
	(r) Natural Gas (in ground)	1.22E+00	3.09E+00
	(r) Oil (in ground)	3.02E-03	7.61E-03
	(r) Sand (in ground)	1.98E-07	5.00E-07
	(r) Sodium Chloride (NaCl, in ground or in sea)	9.10E-08	2.29E-07
	(r) Uranium (U, ore)	1.44E-07	3.62E-07
	Total		3.12E+00
Note: Raw material requirements exclude water usage, which equals		1.92E-01	liters
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	5.28E+01	1.33E+02
	E Fuel Energy	1.13E+01	2.85E+01
	E Non Renewable Energy	6.41E+01	1.62E+02
	E Renewable Energy	1.13E-02	2.86E-02
	E Total Primary Energy	6.41E+01	1.62E+02
		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	2.99E-06	7.53E-06
	(w) Aluminum (Al3+)	1.03E-06	2.60E-06
	(w) Ammonia (NH4+, NH3, as N)	1.21E-04	3.05E-04
	(w) AOX (Adsorbable Organic Halogens)	2.72E-12	6.85E-12
	(w) Aromatic Hydrocarbons (unspecified)	6.37E-10	1.60E-09
	(w) Barium (Ba++)	2.04E-09	5.14E-09
	(w) BOD5 (Biochemical Oxygen Demand)	1.44E-03	3.63E-03
	(w) Cadmium (Cd++)	2.12E-12	5.35E-12
	(w) Chlorides (Cl-)	4.26E-02	1.07E-01
	(w) Chromium (Cr III, Cr VI)	7.91E-07	1.99E-06
	(w) COD (Chemical Oxygen Demand)	1.17E-02	2.95E-02
	(w) Copper (Cu+, Cu++)	4.25E-11	1.07E-10
	(w) Cyanide (CN-)	2.97E-12	7.49E-12
	(w) Dissolved Matter (unspecified)	2.65E-04	6.67E-04
	(w) Fluorides (F-)	2.15E-05	5.41E-05
	(w) Halogenated Matter (organic)	8.49E-13	2.14E-12
	(w) Hydrocarbons (unspecified)	3.12E-06	7.86E-06
	(w) Iron (Fe++, Fe3+)	4.52E-08	1.14E-07
	(w) Lead (Pb++, Pb4+)	8.49E-12	2.14E-11
	(w) Mercury (Hg+, Hg++)	9.77E-15	2.46E-14
	(w) Metals (unspecified)	7.49E-05	1.89E-04
	(w) Nickel (Ni++, Ni3+)	4.25E-12	1.07E-11
	(w) Nitrate (NO3-)	5.42E-06	1.36E-05
	(w) Nitrogenous Matter (unspecified, as N)	1.15E-10	2.89E-10
	(w) Oils (unspecified)	7.48E-04	1.88E-03
	(w) Organic Matter (unspecified)	7.91E-06	1.99E-05
	(w) Phenol (C6H5OH)	2.64E-05	6.66E-05
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	2.42E-08	6.09E-08
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	1.02E-11	2.57E-11
	(w) Salts (unspecified)	1.17E-05	2.96E-05
	(w) Sodium (Na+)	5.48E-02	1.38E-01
	(w) Sulfate (SO4--)	5.09E-06	1.28E-05
	(w) Sulfide (S--)	1.64E-06	4.14E-06
	(w) Suspended Matter (unspecified)	6.21E-03	1.56E-02
	(w) TOC (Total Organic Carbon)	6.37E-09	1.60E-08
	(w) Toluene (C6H5CH3)	9.34E-11	2.35E-10
	(w) Zinc (Zn++)	1.89E-07	4.75E-07
	Total (g)		2.98E-01
Note: Water emissions exclude chemically polluted water, which equals		1.73E-02	liters
		Factor for 1 kg	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	4.77E-09	1.20E-08
	(a) Acenaphthylene (C12H8)	2.52E-09	6.35E-09
	(a) Acetaldehyde (CH3CHO)	2.38E-06	6.00E-06
	(a) Acetophenone (C8H8O)	6.27E-08	1.58E-07
	(a) Acrolein (CH2CHCHO)	1.21E-06	3.05E-06
	(a) Aldehyde (unspecified)	3.88E-03	9.77E-03
	(a) Aluminum (Al)	1.54E-07	3.89E-07
	(a) Ammonia (NH3)	5.64E-02	1.42E-01
	(a) Anthracene (C14H10)	2.89E-09	7.29E-09
	(a) Antimony (Sb)	4.71E-07	1.19E-06
	(a) Aromatic Hydrocarbons (unspecified)	3.82E-10	9.63E-10
	(a) Arsenic (As)	7.62E-06	1.92E-05
	(a) Barium (Ba)	3.75E-07	9.44E-07
	(a) Benzene (C6H6)	4.56E-01	1.15E+00
	(a) Benzo(a)anthracene	2.02E-09	5.08E-09
	(a) Benzo(a)pyrene (C20H12)	1.13E-09	2.86E-09
	(a) Benzo(b)fluoranthene	1.50E-09	3.78E-09
	(a) Benzo(bjk)fluoranthene	4.60E-10	1.16E-09
	(a) Benzo(ghi)perylene	1.15E-09	2.90E-09
	(a) Benzo(k)fluoranthene	1.50E-09	3.78E-09
	(a) Benzyl Chloride (C7H7Cl)	2.92E-06	7.37E-06
	(a) Beryllium (Be)	1.01E-06	2.54E-06
	(a) Bromoform (CHBr3)	1.63E-07	4.11E-07
	(a) Butane (C4H10)	1.70E-03	4.29E-03
	(a) Cadmium (Cd)	5.05E-07	1.27E-06
	(a) Calcium (Ca)	1.34E-07	3.37E-07
	(a) Carbon Dioxide (CO2, biomass)	4.03E-05	1.02E-04
	(a) Carbon Dioxide (CO2, fossil)	4.76E+02	1.20E+03
	(a) Carbon Disulfide (CS2)	5.43E-07	1.37E-06
	(a) Carbon Monoxide (CO)	1.83E+00	4.62E+00
	(a) Chlorides (Cl-)	2.61E-05	6.58E-05
	(a) Chlorine (Cl2)	1.70E-07	4.29E-07

		Factor for 1 kg	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	2.92E-08	7.37E-08
	(a) Chlorobenzene (C6H5Cl)	9.19E-08	2.32E-07
	(a) Chloroform (CHCl3, HC-20)	2.46E-07	6.21E-07
	(a) Chromium (Cr III, Cr VI)	1.35E-05	3.41E-05
	(a) Chrysene (C18H12)	1.94E-09	4.90E-09
	(a) Cobalt (Co)	9.51E-07	2.40E-06
	(a) Copper (Cu)	8.46E-07	2.13E-06
	(a) Cumene (C9H12)	2.21E-08	5.58E-08
	(a) Cyanide (CN-)	1.04E-05	2.63E-05
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	3.05E-07	7.69E-07
	(a) Dibenzo(a,h)anthracene	1.02E-09	2.57E-09
	(a) Dichlorobenzene (1,4-C6H4Cl2)	9.74E-07	2.45E-06
	(a) Dimethyl Benzanthracene (7,12-C20H16)	1.22E-08	3.07E-08
	(a) Dimethyl Sulfate (C2H6O4S)	2.01E-07	5.05E-07
	(a) Dinitrotoluene (2,4-C7H6N2O4)	1.17E-09	2.95E-09
	(a) Dioxins (unspecified)	6.76E-11	1.70E-10
	(a) Diphenyl ((C6H5)2)	7.10E-09	1.79E-08
	(a) Ethane (C2H6)	2.51E-03	6.34E-03
	(a) Ethyl Benzene (C6H5C2H5)	3.98E-07	1.00E-06
	(a) Ethyl Chloride (C2H5Cl)	1.75E-07	4.42E-07
	(a) Ethylene Dibromide (C2H4Br2)	5.01E-09	1.26E-08
	(a) Ethylene Dichloride (C2H4Cl2)	1.67E-07	4.21E-07
	(a) Fluoranthene	5.53E-09	1.39E-08
	(a) Fluorene (C13H10)	6.20E-09	1.56E-08
	(a) Fluorides (F-)	3.09E-06	7.79E-06
	(a) Formaldehyde (CH2O)	8.71E-05	2.19E-04
	(a) Furan (C4H4O)	3.14E-10	7.92E-10
	(a) Halogenated Hydrocarbons (unspecified)	2.12E-15	5.35E-15
	(a) Halon 1301 (CF3Br)	3.69E-12	9.31E-12
	(a) Hexane (C6H14)	1.46E-03	3.68E-03
	(a) Hydrocarbons (except methane)	8.15E-01	2.05E+00
	(a) Hydrocarbons (unspecified)	2.24E-02	5.65E-02
	(a) Hydrogen Chloride (HCl)	5.02E-03	1.27E-02
	(a) Hydrogen Fluoride (HF)	6.27E-04	1.58E-03
	(a) Hydrogen Sulfide (H2S)	2.42E-05	6.10E-05
	(a) Indeno (1,2,3,c,d) Pyrene	1.77E-09	4.47E-09
	(a) Iron (Fe)	2.98E-07	7.51E-07
	(a) Isophorone	2.42E-06	6.11E-06
	(a) Lead (Pb)	7.80E-06	1.97E-05
	(a) Magnesium (Mg)	4.60E-05	1.16E-04
	(a) Manganese (Mn)	1.42E-05	3.59E-05
	(a) Mercury (Hg)	6.78E-07	1.71E-06
	(a) Metals (unspecified)	1.73E-07	4.35E-07
	(a) Methane (CH4)	1.81E+01	4.55E+01
	(a) Methyl Bromide (CH3Br)	6.68E-07	1.68E-06
	(a) Methyl Chloride (CH3Cl)	2.21E-06	5.58E-06
	(a) Methyl Cholanthrene (3-C21H16)	1.46E-09	3.68E-09
	(a) Methyl Chrysene (5-C19H15)	9.19E-11	2.32E-10
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	1.63E-06	4.11E-06
	(a) Methyl Hydrazine (CH6N2)	7.10E-07	1.79E-06
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	8.36E-08	2.11E-07
	(a) Methyl Naphthalene (2-C11H10)	1.95E-08	4.91E-08
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	1.46E-07	3.68E-07
	(a) Methylene Chloride (CH2Cl2, HC-130)	1.21E-06	3.05E-06
	(a) Molybdenum (Mo)	9.79E-07	2.47E-06
	(a) Naphthalene (C10H8)	6.34E-07	1.60E-06
	(a) Nickel (Ni)	1.86E-05	4.68E-05
	(a) Nitrogen Oxides (NOx as NO2)	3.36E+00	8.46E+00
	(a) Nitrous Oxide (N2O)	4.16E-03	1.05E-02
	(a) Organic Matter (unspecified)	2.28E+00	5.74E+00
	(a) Particulates (PM 10)	1.78E-06	4.48E-06
	(a) Particulates (unspecified)	1.49E-01	3.76E-01
	(a) Pentane (C5H12)	2.11E-03	5.32E-03
	(a) Phenanthrene (C14H10)	2.54E-08	6.39E-08
	(a) Phenol (C6H5OH)	6.68E-08	1.68E-07
	(a) Phosphorus (P)	8.03E-07	2.02E-06
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspd.)	4.25E-13	1.07E-12
	(a) Propane (C3H8)	1.15E-06	2.89E-06
	(a) Propionaldehyde (CH3CH2CHO)	1.59E-06	4.00E-06
	(a) Pyrene (C16H10)	5.55E-09	1.40E-08
	(a) Selenium (Se)	5.51E-06	1.39E-05
	(a) Silicon (Si)	1.34E-07	3.37E-07
	(a) Sodium (Na)	7.92E-07	1.99E-06
	(a) Styrene (C6H5CHCH2)	1.04E-07	2.63E-07
	(a) Sulfur Oxides (SOx as SO2)	9.92E-02	2.50E-01
	(a) Tetrachloroethylene (C2Cl4)	1.80E-07	4.53E-07
	(a) Toluene (C6H5CH3)	1.86E-05	4.68E-05
	(a) Trichloroethane (1,1,1-CH3CCl3)	8.36E-08	2.11E-07
	(a) Vanadium (V)	6.32E-06	1.59E-05
	(a) Vinyl Acetate (C4H6O2)	3.18E-08	8.00E-08
	(a) Xylene (C6H4(CH3)2)	2.49E-05	6.28E-05
	(a) Zinc (Zn)	2.57E-05	6.48E-05
	Total (g)		1.75E+03
		Factor for 1 kg	kilograms (kg)
Solid Waste	Waste (total)	4.22E-04	1.06E-03
Note: Production process includes:			
Recovery of raw natural gas.			
Glycol dehydration.			
Gas sweetening using the amine process .			
Pipeline transport to utilities (use of natural gas as pipeline fuel and electricity, including compressor station energy.			

Appendix E (continued): Book Printing Operations - Combustion of Natural Gas in a Utility Boiler

Assumptions and Variables:	**Natural Gas Requirement:**	**147.48**	**MJ**
		Factor for 1 MJ	**grams (g)**
Air Emissions	**(a) Acenaphthene (C12H10)**	**1.64E-09**	**2.42E-07**
	(a) Acenaphthylene (C12H8)	**1.64E-09**	**2.42E-07**
	(a) Ammonia (NH3)	**8.81E-04**	**1.30E-01**
	(a) Anthracene (C14H10)	**2.19E-09**	**3.23E-07**
	(a) Arsenic (As)	**1.42E-07**	**2.09E-05**
	(a) Barium (Ba)	**2.81E-06**	**4.14E-04**
	(a) Benzene (C6H6)	**1.48E-06**	**2.19E-04**
	(a) Benzo(a)anthracene	**1.64E-09**	**2.42E-07**
	(a) Benzo(a)pyrene (C20H12)	**1.10E-09**	**1.62E-07**
	(a) Benzo(b)fluoranthene	**1.64E-09**	**2.42E-07**
	(a) Benzo(ghi)perylene	**1.10E-09**	**1.62E-07**
	(a) Benzo(k)fluoranthene	**1.64E-09**	**2.42E-07**
	(a) Beryllium (Be)	**1.10E-08**	**1.62E-06**
	(a) Butane (C4H10)	**1.92E-03**	**2.83E-01**
	(a) Cadmium (Cd)	**5.11E-07**	**7.53E-05**
	(a) Carbon Dioxide (CO2, fossil)	**1.24E+02**	**1.83E+04**
	(a) Carbon Monoxide (CO)	**5.77E-02**	**8.51E+00**
	(a) Chromium (Cr III, Cr VI)	**9.65E-07**	**1.42E-04**
	(a) Chrysene (C18H12)	**1.64E-09**	**2.42E-07**
	(a) Cobalt (Co)	**9.58E-08**	**1.41E-05**
	(a) Copper (Cu)	**8.51E-07**	**1.25E-04**
	(a) Dibenzo(a,h)anthracene	**1.10E-09**	**1.62E-07**
	(a) Dichlorobenzene (1,4-C6H4Cl2)	**1.10E-06**	**1.62E-04**
	(a) Dimethyl Benzanthracene (7,12-C20H16)	**1.46E-08**	**2.15E-06**
	(a) Ethane (C2H6)	**2.83E-03**	**4.17E-01**
	(a) Fluoranthene	**2.74E-09**	**4.04E-07**
	(a) Fluorene (C13H10)	**2.56E-09**	**3.77E-07**
	(a) Formaldehyde (CH2O)	**2.21E-04**	**3.25E-02**
	(a) Hexane (C6H14)	**1.64E-03**	**2.42E-01**
	(a) Hydrocarbons (except methane)	**4.34E-04**	**6.40E-02**
	(a) Indeno (1,2,3,c,d) Pyrene	**1.64E-09**	**2.42E-07**
	(a) Lead (Pb)	**3.58E-07**	**5.28E-05**
	(a) Manganese (Mn)	**5.36E-07**	**7.91E-05**
	(a) Mercury (Hg)	**2.88E-07**	**4.24E-05**
	(a) Methane (CH4)	**3.29E-03**	**4.85E-01**
	(a) Methyl Cholanthrene (3-C21H16)	**1.64E-09**	**2.42E-07**
	(a) Methyl Naphthalene (2-C11H10)	**2.19E-08**	**3.23E-06**
	(a) Molybdenum (Mo)	**1.05E-06**	**1.56E-04**
	(a) Naphthalene (C10H8)	**5.57E-07**	**8.21E-05**
	(a) Nickel (Ni)	**1.48E-06**	**2.18E-04**
	(a) Nitrogen Oxides (NOx as NO2)	**1.02E-01**	**1.50E+01**
	(a) Nitrous Oxide (N2O)	**1.70E-03**	**2.51E-01**
	(a) Particulates (unspecified)	**1.26E-02**	**1.86E+00**
	(a) Pentane (C5H12)	**2.37E-03**	**3.50E-01**
	(a) Phenanthrene (C14H10)	**1.55E-08**	**2.29E-06**
	(a) Propane (C3H8)	**1.46E-03**	**2.15E-01**
	(a) Pyrene (C16H10)	**4.56E-09**	**6.73E-07**
	(a) Selenium (Se)	**2.19E-08**	**3.23E-06**
	(a) Sulfur Oxides (SOx as SO2)	**6.75E-04**	**9.96E-02**
	(a) Toluene (C6H5CH3)	**5.86E-06**	**8.64E-04**
	(a) Vanadium (V)	**1.37E-06**	**2.02E-04**
	(a) Zinc (Zn)	**2.65E-05**	**3.90E-03**
	Total (g)		**1.84E+04**

Note: Solid waste and water effluents were not considered in the DEAM database for the combustion of natural gas in a utility boiler.

APPENDIX F
TEXTBOOK DELIVERY

1) Energy Consumed and Emissions Generated
2) Diesel Fuel Production

Appendix F: Textbook Delivery – Energy Consumed and Emissions Generated

Assumptions and Variables

Total Trip Distance:	746	miles
FU Mass (40 textbooks):	42.10	kg
FU Mass equivilency:	0.04641	tons
Fuel Efficiency	9.4	gal/1000 ton-miles
Energy Consumption:	1,465	Btu/ton-mile

From	To	Distance (mi)	Conveyance	Fuel	Fuel Eff. (gal/1000 ton.mi)	Mass (ton)	Energy Rate (Btu/ton.mi)	Energy consumed (MJ)	Fuel consumed (gal)
Book Printing Facility	University Library	746	Tractor-trailer	diesel	9.4	0.0464	1,465	53.51	0.32546

Air Pollution due to Transportation

Compound	Emissions (lbs/1000 gal)	Mass Released (lbs)
Particulates	3.15E+01	1.03E-02
Nox	2.18E+02	7.10E-02
HC	8.79E+01	2.86E-02
Sox	6.20E+01	2.02E-02
CO	2.15E+02	7.00E-02
CO2 (total)	2.54E+04	8.28E+00
Formaldehyde	2.10E-05	6.83E-09
Other Aldehydes	5.97E+00	1.94E-03
Other Organics	1.16E+02	3.78E-02
Ammonia	4.00E-02	1.30E-05
Lead	1.40E-04	4.56E-08
Methane	4.05E+00	1.32E-03
Kerosene	1.00E-04	3.25E-08
Chlorine	1.50E-03	4.88E-07
HCl	2.50E-02	8.14E-06
HF	3.30E-03	1.07E-06
Metals	2.50E-03	8.14E-07
Antimony	3.80E-05	1.24E-08
Arsenic	7.90E-05	2.57E-08
Beryllium	5.50E-06	1.79E-09
Cadmium	1.20E-04	3.91E-08
Chromium	9.00E-05	2.93E-08
Cobalt	1.10E-04	3.58E-08
Manganese	1.10E-04	3.58E-08
Mercury	2.60E-05	8.46E-09
Nickel	1.70E-03	5.53E-07
Selenium	7.20E-05	2.34E-08
Acreolin	4.70E-06	1.53E-09
Nitrous Oxide	2.80E-03	9.11E-07
Benzene	1.50E-05	4.88E-09
Perchloroethylene	4.60E-06	1.50E-09
TCE	4.40E-06	1.43E-09
Methylene Chloride	2.10E-05	6.83E-09
Carbon Tetrachloride	1.90E-05	6.18E-09
Phenols	1.20E-04	3.91E-08
Naphthalene	7.00E-06	2.28E-09
Dioxins	2.50E-10	8.14E-14
n-nitrodimethylamine	9.90E-07	3.22E-10
Radionuclides (Ci)	8.70E-05	2.83E-08
		8.52E+00
Total (g)		3.86E+03

Water Pollution due to Transportation

Waterborne Emmission	Emissions (lbs/1000 gal)	Mass Released (lb)
Acid	8.40E-06	2.73E-09
Metal Ion	1.80E-01	5.86E-05
Dissolved Solids	3.48E+01	1.13E-02
Suspended Solic	7.90E-01	2.57E-04
BOD	1.30E-01	4.23E-05
COD	8.70E-01	2.83E-04
Phenol	5.80E-04	1.89E-07
Oil	8.10E-01	2.64E-04
Sufuric Acid	6.90E-03	2.25E-06
iron	1.90E-02	6.18E-06
Ammonia	1.40E-02	4.56E-06
Chromium	1.30E-03	4.23E-07
Lead	1.50E-05	4.88E-09
Zinc	6.50E-04	2.12E-07
Chlorides	1.28E+00	4.17E-04
Sodium	1.60E-04	5.21E-08
Calcium	9.00E-05	2.93E-08
Sulfates	1.03E+00	3.35E-04
Manganese	9.20E-03	2.99E-06
Fluorides	4.10E-04	1.33E-07
Nitrates	3.90E-05	1.27E-08
Phosphates	3.50E-03	1.14E-06
Boron	2.80E-02	9.11E-06
Other organics	8.50E-02	2.77E-05
Chromates	9.80E-05	3.19E-08
Cyanide	1.90E-06	6.18E-10
Mercury	9.80E-08	3.19E-11
Cadmium	1.30E-03	4.23E-07
Total (lb)		1.30E-02
Total (g)		5.91E+00

Solid Waste Due To Transportation

Category	Emission (lb/1000 gal)	Mass (lb)	Mass (kg)
Solid Waste	1.33E+02	4.33E-02	1.96E-02

Appendix F (continued): Textbook Delivery – Diesel Fuel Production

Assumptions and Variables:	Diesel Requirement:	0.33	gal	
	Diesel Equivilancy:	1.02	kg	Note: This assumes that the density of diesel = 0.827 g/ml

		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.30E-04	2.35E-04
	(r) Coal (in ground)	4.88E-02	4.97E-02
	(r) Limestone (CaCO3, in ground)	3.88E-03	3.95E-03
	(r) Natural Gas (in ground)	1.89E-01	1.92E-01
	(r) Oil (in ground)	1.08E+00	1.10E+00
	(r) Sand (in ground)	1.41E-04	1.44E-04
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.48E-05	6.60E-05
	(r) Uranium (U, ore)	8.21E-07	8.36E-07
	Total		1.35E+00

Note: Raw material requirements exclude water usage, which equals	5.49E+01	liters

		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.59E+01	4.68E+01
	E Fuel Energy	1.19E+01	1.22E+01
	E Non Renewable Energy	5.78E+01	5.88E+01
	E Renewable Energy	6.59E-02	6.71E-02
	E Total Primary Energy	5.78E+01	5.89E+01

		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	4.13E-07	4.21E-07
	(w) Aluminum (Al3+)	7.33E-04	7.47E-04
	(w) Ammonia (NH4+, NH3, as N)	1.42E-01	1.45E-01
	(w) AOX (Adsorbable Organic Halogens)	1.93E-09	1.97E-09
	(w) Aromatic Hydrocarbons (unspecified)	4.53E-07	4.62E-07
	(w) Barium (Ba++)	1.45E-06	1.48E-06
	(w) BOD5 (Biochemical Oxygen Demand)	9.71E-01	9.89E-01
	(w) Cadmium (Cd++)	1.51E-09	1.54E-09
	(w) Chlorides (Cl-)	1.56E+01	1.58E+01
	(w) Chromium (Cr III, Cr VI)	1.70E-07	1.73E-07
	(w) COD (Chemical Oxygen Demand)	8.22E+00	8.37E+00
	(w) Copper (Cu+, Cu++)	3.02E-08	3.08E-08
	(w) Cyanide (CN-)	2.12E-09	2.16E-09
	(w) Dissolved Matter (unspecified)	1.41E-03	1.44E-03
	(w) Fluorides (F-)	1.24E-04	1.26E-04
	(w) Halogenated Matter (organic)	6.04E-10	6.16E-10
	(w) Hydrocarbons (unspecified)	1.00E-03	1.02E-03
	(w) Iron (Fe++, Fe3+)	1.72E-06	1.75E-06
	(w) Lead (Pb++, Pb4+)	6.04E-09	6.16E-09
	(w) Mercury (Hg+, Hg++)	6.95E-12	7.08E-12
	(w) Metals (unspecified)	3.31E-02	3.37E-02
	(w) Nickel (Ni++, Ni3+)	3.02E-09	3.08E-09
	(w) Nitrate (NO3-)	3.01E-04	3.07E-04
	(w) Nitrogenous Matter (unspecified, as N)	8.16E-08	8.31E-08
	(w) Oils (unspecified)	4.53E-01	4.62E-01
	(w) Organic Matter (unspecified)	1.09E-06	1.11E-06
	(w) Phenol (C6H5OH)	1.87E-02	1.90E-02
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.01E-06	3.07E-06
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	7.25E-09	7.39E-09
	(w) Salts (unspecified)	8.36E-03	8.51E-03
	(w) Sodium (Na+)	2.00E+01	2.04E+01
	(w) Sulfate (SO4--)	4.51E-04	4.59E-04
	(w) Sulfide (S--)	2.44E-07	2.49E-07
	(w) Suspended Matter (unspecified)	4.41E+00	4.49E+00
	(w) TOC (Total Organic Carbon)	4.53E-06	4.62E-06
	(w) Toluene (C6H5CH3)	6.65E-08	6.77E-08
	(w) Zinc (Zn++)	5.63E-08	5.74E-08
	Total (g)		5.08E+01

Note: Water emissions exclude chemically polluted water, which equals	2.93E+00	liters

		Factor for 1 kg	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	2.15E-08	2.19E-08
	(a) Acenaphthylene (C12H8)	8.16E-09	8.31E-09
	(a) Acetaldehyde (CH3CHO)	1.39E-05	1.41E-05
	(a) Acetophenone (C8H8O)	3.65E-07	3.72E-07
	(a) Acrolein (CH2CHCHO)	7.06E-06	7.19E-06
	(a) Aldehyde (unspecified)	6.60E-03	6.72E-03
	(a) Aluminum (Al)	5.63E-05	5.74E-05
	(a) Ammonia (NH3)	9.84E-03	1.00E-02
	(a) Anthracene (C14H10)	8.17E-09	8.33E-09
	(a) Antimony (Sb)	2.81E-06	2.86E-06
	(a) Aromatic Hydrocarbons (unspecified)	2.72E-07	2.77E-07
	(a) Arsenic (As)	4.92E-05	5.01E-05
	(a) Barium (Ba)	1.49E-06	1.52E-06
	(a) Benzene (C6H6)	6.33E-02	6.45E-02
	(a) Benzo(a)anthracene	5.29E-09	5.39E-09
	(a) Benzo(a)pyrene (C20H12)	2.62E-09	2.67E-09
	(a) Benzo(b)fluoranthene	2.24E-09	2.28E-09
	(a) Benzo(bjk)fluoranthene	2.68E-09	2.73E-09
	(a) Benzo(ghi)perylene	2.36E-09	2.41E-09
	(a) Benzo(k)fluoranthene	2.24E-09	2.28E-09
	(a) Benzyl Chloride (C7H7Cl)	1.70E-05	1.74E-05
	(a) Beryllium (Be)	5.15E-06	5.25E-06
	(a) Bromoform (CHBr3)	9.49E-07	9.67E-07
	(a) Butane (C4H10)	2.32E-03	2.36E-03
	(a) Cadmium (Cd)	3.00E-06	3.06E-06
	(a) Calcium (Ca)	4.88E-05	4.97E-05
	(a) Carbon Dioxide (CO2, biomass)	2.46E-04	2.51E-04
	(a) Carbon Dioxide (CO2, fossil)	6.70E+02	6.83E+02
	(a) Carbon Disulfide (CS2)	3.16E-06	3.22E-06
	(a) Carbon Monoxide (CO)	2.00E+00	2.04E+00
	(a) Chlorides (Cl-)	1.57E-04	1.60E-04
	(a) Chlorine (Cl2)	2.35E-08	2.40E-08

		Factor for 1 kg	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	1.70E-07	1.74E-07
	(a) Chlorobenzene (C6H5Cl)	5.36E-07	5.46E-07
	(a) Chloroform (CHCl3, HC-20)	1.44E-06	1.46E-06
	(a) Chromium (Cr III, Cr VI)	7.66E-05	7.81E-05
	(a) Chrysene (C18H12)	4.82E-09	4.91E-09
	(a) Cobalt (Co)	8.82E-06	8.99E-06
	(a) Copper (Cu)	5.13E-06	5.22E-06
	(a) Cumene (C9H12)	1.29E-07	1.31E-07
	(a) Cyanide (CN-)	6.09E-05	6.20E-05
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	1.78E-06	1.81E-06
	(a) Dibenzo(a,h)anthracene	1.61E-09	1.64E-09
	(a) Dichlorobenzene (1,4-C6H4Cl2)	1.32E-06	1.35E-06
	(a) Dimethyl Benzanthracene (7,12-C20H16)	1.66E-08	1.69E-08
	(a) Dimethyl Sulfate (C2H6O4S)	1.17E-06	1.19E-06
	(a) Dinitrotoluene (2,4-C7H6N2O4)	6.82E-09	6.94E-09
	(a) Dioxins (unspecified)	3.94E-10	4.02E-10
	(a) Diphenyl ((C6H5)2)	4.14E-08	4.22E-08
	(a) Ethane (C2H6)	3.42E-03	3.49E-03
	(a) Ethyl Benzene (C6H5C2H5)	2.32E-06	2.36E-06
	(a) Ethyl Chloride (C2H5Cl)	1.02E-06	1.04E-06
	(a) Ethylene Dibromide (C2H4Br2)	2.92E-08	2.98E-08
	(a) Ethylene Dichloride (C2H4Cl2)	9.74E-07	9.92E-07
	(a) Fluoranthene	2.14E-08	2.18E-08
	(a) Fluorene (C13H10)	2.60E-08	2.65E-08
	(a) Fluorides (F-)	1.75E-05	1.79E-05
	(a) Formaldehyde (CH2O)	3.43E-03	3.50E-03
	(a) Furan (C4H4O)	1.83E-09	1.87E-09
	(a) Halogenated Hydrocarbons (unspecified)	1.51E-12	1.54E-12
	(a) Halon 1301 (CF3Br)	2.63E-09	2.68E-09
	(a) Hexane (C6H14)	1.99E-03	2.03E-03
	(a) Hydrocarbons (except methane)	3.77E-01	3.84E-01
	(a) Hydrocarbons (unspecified)	5.40E-01	5.50E-01
	(a) Hydrogen Chloride (HCl)	2.92E-02	2.98E-02
	(a) Hydrogen Fluoride (HF)	3.65E-03	3.72E-03
	(a) Hydrogen Sulfide (H2S)	8.84E-03	9.01E-03
	(a) Indeno (1,2,3,c,d) Pyrene	3.83E-09	3.91E-09
	(a) Iron (Fe)	1.09E-04	1.11E-04
	(a) Isophorone	1.41E-05	1.44E-05
	(a) Lead (Pb)	4.49E-05	4.57E-05
	(a) Magnesium (Mg)	2.68E-04	2.73E-04
	(a) Manganese (Mn)	8.16E-05	8.31E-05
	(a) Mercury (Hg)	3.18E-06	3.24E-06
	(a) Metals (unspecified)	1.62E-06	1.65E-06
	(a) Methane (CH4)	3.34E+00	3.40E+00
	(a) Methyl Bromide (CH3Br)	3.89E-06	3.97E-06
	(a) Methyl Chloride (CH3Cl)	1.29E-05	1.31E-05
	(a) Methyl Cholanthrene (3-C21H16)	1.99E-09	2.02E-09
	(a) Methyl Chrysene (5-C19H15)	5.36E-10	5.46E-10
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	9.49E-06	9.67E-06
	(a) Methyl Hydrazine (CH6N2)	4.14E-06	4.22E-06
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	4.87E-07	4.96E-07
	(a) Methyl Naphthalene (2-C11H10)	2.65E-08	2.70E-08
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	8.52E-07	8.68E-07
	(a) Methylene Chloride (CH2Cl2, HC-130)	7.06E-06	7.19E-06
	(a) Molybdenum (Mo)	6.16E-06	6.28E-06
	(a) Naphthalene (C10H8)	1.50E-06	1.53E-06
	(a) Nickel (Ni)	3.79E-04	3.86E-04
	(a) Nitrogen Oxides (NOx as NO2)	2.26E+00	2.30E+00
	(a) Nitrous Oxide (N2O)	5.43E-02	5.53E-02
	(a) Organic Matter (unspecified)	3.15E-01	3.21E-01
	(a) Particulates (PM 10)	6.49E-04	6.61E-04
	(a) Particulates (unspecified)	5.07E-01	5.16E-01
	(a) Pentane (C5H12)	2.87E-03	2.92E-03
	(a) Phenanthrene (C14H10)	8.63E-08	8.79E-08
	(a) Phenol (C6H5OH)	3.89E-07	3.97E-07
	(a) Phosphorus (P)	3.73E-05	3.80E-05
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unsp.)	3.02E-10	3.08E-10
	(a) Propane (C3H8)	6.10E-06	6.22E-06
	(a) Propionaldehyde (CH3CH2CHO)	9.25E-06	9.42E-06
	(a) Pyrene (C16H10)	1.43E-08	1.45E-08
	(a) Selenium (Se)	3.36E-05	3.43E-05
	(a) Silicon (Si)	4.88E-05	4.97E-05
	(a) Sodium (Na)	2.89E-04	2.94E-04
	(a) Styrene (C6H5CHCH2)	6.09E-07	6.20E-07
	(a) Sulfur Oxides (SOx as SO2)	3.24E+00	3.30E+00
	(a) Tetrachloroethylene (C2Cl4)	1.05E-06	1.07E-06
	(a) Toluene (C6H5CH3)	1.51E-05	1.54E-05
	(a) Trichloroethane (1,1,1-CH3CCl3)	4.87E-07	4.96E-07
	(a) Vanadium (V)	7.68E-04	7.82E-04
	(a) Vinyl Acetate (C4H6O2)	1.85E-07	1.88E-07
	(a) Xylene (C6H4(CH3)2)	4.37E-06	4.45E-06
	(a) Zinc (Zn)	4.52E-05	4.60E-05
	Total (g)		1.37E+03

		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	2.65E-01	2.70E-01

APPENDIX G
LCI DATA
FACILITY INFRASTRUCTURE

1) Electricity Production
2) Heavy Fuel Oil Production
3) Combustion of Residual Oil in Industrial Boilers
4) Natural Gas Production
5) Combustion of Natural Gas in a Utility Boiler

Appendix G: Facility Infrastructure – Electricity Production

Assumptions and Variables:	Electricity Requirement:	16.14	MJ
		Factor for 1 MJ	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.46E-07	3.97E-06
	(r) Coal (in ground)	1.48E-01	2.40E+00
	(r) Limestone (CaCO3, in ground)	1.17E-02	1.89E-01
	(r) Natural Gas (in ground)	9.17E-04	1.48E-02
	(r) Oil (in ground)	2.99E-03	4.82E-02
	(r) Sand (in ground)	1.51E-07	2.43E-06
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.92E-08	1.12E-06
	(r) Uranium (U, ore)	7.17E-07	1.16E-05
	Total		2.65E+00
Note: Raw material requirements exclude water usage, which equals		9.68E-01	liters
		Factor for 1 MJ	MJ
Energy Burdens	E Feedstock Energy	3.94E-01	6.36E+00
	E Fuel Energy	4.47E+00	7.21E+01
	E Non Renewable Energy	4.85E+00	7.83E+01
	E Renewable Energy	7.96E-03	1.28E-01
	Electricity	1.50E-02	2.42E-01
	E Total Primary Energy	4.86E+00	7.85E+01
		Factor for 1 MJ	grams (g)
Water Emissions	(w) Acids (H+)	1.06E-09	1.71E-08
	(w) Aluminum (Al3+)	7.83E-07	1.26E-05
	(w) Ammonia (NH4+, NH3, as N)	1.89E-04	3.04E-03
	(w) AOX (Adsorbable Organic Halogens)	2.07E-12	3.33E-11
	(w) Aromatic Hydrocarbons (unspecified)	4.84E-10	7.82E-09
	(w) Barium (Ba++)	1.55E-09	2.50E-08
	(w) BOD5 (Biochemical Oxygen Demand)	1.04E-03	1.68E-02
	(w) Cadmium (Cd++)	1.61E-12	2.61E-11
	(w) Chlorides (Cl-)	3.75E-02	6.05E-01
	(w) Chromium (Cr III, Cr VI)	3.46E-10	5.58E-09
	(w) COD (Chemical Oxygen Demand)	8.78E-03	1.42E-01
	(w) Copper (Cu+, Cu++)	3.23E-11	5.21E-10
	(w) Cyanide (CN-)	2.26E-12	3.65E-11
	(w) Dissolved Matter (unspecified)	4.28E-03	6.91E-02
	(w) Fluorides (F-)	1.08E-04	1.75E-03
	(w) Halogenated Matter (organic)	6.46E-13	1.04E-11
	(w) Hydrocarbons (unspecified)	2.41E-06	3.90E-05
	(w) Iron (Fe++, Fe3+)	2.11E-07	3.40E-06
	(w) Lead (Pb++, Pb4+)	6.46E-12	1.04E-10
	(w) Mercury (Hg+, Hg++)	7.42E-15	1.20E-13
	(w) Metals (unspecified)	6.37E-05	1.03E-03
	(w) Nickel (Ni++, Ni3+)	3.23E-12	5.21E-11
	(w) Nitrate (NO3-)	2.59E-05	4.18E-04
	(w) Nitrogenous Matter (unspecified, as N)	8.71E-11	1.41E-09
	(w) Oils (unspecified)	6.61E-04	1.07E-02
	(w) Organic Matter (unspecified)	2.79E-09	4.50E-08
	(w) Phenol (C6H5OH)	1.99E-05	3.22E-04
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.22E-09	5.20E-08
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	7.75E-12	1.25E-10
	(w) Salts (unspecified)	8.92E-06	1.44E-04
	(w) Sodium (Na+)	4.83E-02	7.79E-01
	(w) Sulfate (SO4--)	2.33E-05	3.76E-04
	(w) Sulfide (S--)	6.02E-10	9.72E-09
	(w) Suspended Matter (unspecified)	4.74E-03	7.66E-02
	(w) TOC (Total Organic Carbon)	4.84E-09	7.82E-08
	(w) Toluene (C6H5CH3)	7.10E-11	1.15E-09
	(w) Zinc (Zn++)	9.93E-11	1.60E-09
	Total (g)		1.71E+00
Note: Water emissions exclude chemically polluted water, which equals		9.58E-02	liters
		Factor for 1 MJ	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	3.78E-08	6.10E-07
	(a) Acenaphthylene (C12H8)	1.85E-08	2.99E-07
	(a) Acetaldehyde (CH3CHO)	4.22E-05	6.81E-04
	(a) Acetophenone (C8H8O)	1.11E-06	1.79E-05
	(a) Acrolein (CH2CHCHO)	2.15E-05	3.47E-04
	(a) Aldehyde (unspecified)	7.58E-03	1.22E-01
	(a) Aluminum (Al)	1.36E-07	2.19E-06
	(a) Ammonia (NH3)	5.11E-05	8.25E-04
	(a) Anthracene (C14H10)	1.56E-08	2.51E-07
	(a) Antimony (Sb)	1.51E-06	2.44E-05
	(a) Aromatic Hydrocarbons (unspecified)	2.90E-10	4.69E-09
	(a) Arsenic (As)	1.30E-04	2.10E-03
	(a) Barium (Ba)	9.72E-08	1.57E-06
	(a) Benzene (C6H6)	2.59E-04	4.18E-03
	(a) Benzo(a)anthracene	5.93E-09	9.57E-08
	(a) Benzo(a)pyrene (C20H12)	2.82E-09	4.55E-08
	(a) Benzo(b)fluoranthene	3.86E-12	6.23E-11
	(a) Benzo(bjk)fluoranthene	8.14E-09	1.31E-07
	(a) Benzo(ghi)perylene	2.00E-09	3.23E-08
	(a) Benzo(k)fluoranthene	3.86E-12	6.23E-11
	(a) Benzyl Chloride (C7H7Cl)	5.18E-05	8.37E-04
	(a) Beryllium (Be)	1.49E-05	2.41E-04
	(a) Bromoform (CHBr3)	2.89E-06	4.66E-05
	(a) Butane (C4H10)	4.18E-06	6.75E-05
	(a) Cadmium (Cd)	8.42E-06	1.36E-04
	(a) Calcium (Ca)	1.18E-07	1.90E-06
	(a) Carbon Dioxide (CO2, biomass)	2.97E-05	4.80E-04
	(a) Carbon Dioxide (CO2, fossil)	3.77E+02	6.08E+03
	(a) Carbon Disulfide (CS2)	9.62E-06	1.55E-04
	(a) Carbon Monoxide (CO)	1.62E-01	2.61E+00
	(a) Chlorides (Cl-)	1.16E-05	1.88E-04
	(a) Chlorine (Cl2)	6.00E-11	9.69E-10

		Factor for 1 MJ	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	5.18E-07	8.37E-06
	(a) Chlorobenzene (C6H5Cl)	1.63E-06	2.63E-05
	(a) Chloroform (CHCl3, HC-20)	4.37E-06	7.05E-05
	(a) Chromium (Cr III, Cr VI)	2.17E-04	3.51E-03
	(a) Chrysene (C18H12)	7.41E-09	1.20E-07
	(a) Cobalt (Co)	7.61E-06	1.23E-04
	(a) Copper (Cu)	7.73E-08	1.25E-06
	(a) Cumene (C9H12)	3.92E-07	6.33E-06
	(a) Cyanide (CN-)	1.85E-04	2.99E-03
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	5.40E-06	8.72E-05
	(a) Dibenzo(a,h)anthracene	2.70E-12	4.36E-11
	(a) Dichlorobenzene (1,4-C6H4Cl2)	2.39E-09	3.86E-08
	(a) Dimethyl Benzanthracene (7,12-C20H16)	3.02E-11	4.88E-10
	(a) Dimethyl Sulfate (C2H6O4S)	3.55E-06	5.74E-05
	(a) Dinitrotoluene (2,4-C7H6N2O4)	2.07E-08	3.35E-07
	(a) Dioxins (unspecified)	1.20E-09	1.93E-08
	(a) Diphenyl ((C6H5)2)	1.26E-07	2.03E-06
	(a) Ethane (C2H6)	6.17E-06	9.97E-05
	(a) Ethyl Benzene (C6H5C2H5)	6.96E-06	1.12E-04
	(a) Ethyl Chloride (C2H5Cl)	3.11E-06	5.02E-05
	(a) Ethylene Dibromide (C2H4Br2)	8.88E-08	1.43E-06
	(a) Ethylene Dichloride (C2H4Cl2)	2.96E-06	4.78E-05
	(a) Fluoranthene	5.26E-08	8.49E-07
	(a) Fluorene (C13H10)	6.74E-08	1.09E-06
	(a) Fluorides (F-)	1.82E-06	2.94E-05
	(a) Formaldehyde (CH2O)	3.16E-05	5.10E-04
	(a) Furan (C4H4O)	5.57E-09	9.00E-08
	(a) Halogenated Hydrocarbons (unspecified)	1.61E-15	2.61E-14
	(a) Halon 1301 (CF3Br)	2.81E-12	4.53E-11
	(a) Hexane (C6H14)	8.54E-06	1.38E-04
	(a) Hydrocarbons (except methane)	1.39E-02	2.24E-01
	(a) Hydrocarbons (unspecified)	2.68E-02	4.33E-01
	(a) Hydrogen Chloride (HCl)	8.88E-02	1.43E+00
	(a) Hydrogen Fluoride (HF)	1.11E-02	1.79E-01
	(a) Hydrogen Sulfide (H2S)	2.13E-05	3.44E-04
	(a) Indeno (1,2,3,c,d) Pyrene	4.52E-09	7.30E-08
	(a) Iron (Fe)	2.62E-07	4.24E-06
	(a) Isophorone	4.29E-05	6.93E-04
	(a) Lead (Pb)	1.29E-04	2.08E-03
	(a) Magnesium (Mg)	8.14E-04	1.31E-02
	(a) Manganese (Mn)	2.42E-04	3.91E-03
	(a) Mercury (Hg)	8.08E-06	1.30E-04
	(a) Metals (unspecified)	1.76E-09	2.85E-08
	(a) Methane (CH4)	6.60E-01	1.07E+01
	(a) Methyl Bromide (CH3Br)	1.18E-05	1.91E-04
	(a) Methyl Chloride (CH3Cl)	3.92E-05	6.33E-04
	(a) Methyl Cholanthrene (3-C21H16)	3.58E-12	5.79E-11
	(a) Methyl Chrysene (5-C19H15)	1.63E-09	2.63E-08
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	2.89E-05	4.66E-04
	(a) Methyl Hydrazine (CH6N2)	1.26E-05	2.03E-04
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	1.48E-06	2.39E-05
	(a) Methyl Naphthalene (2-C11H10)	4.78E-11	7.72E-10
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	2.59E-06	4.18E-05
	(a) Methylene Chloride (CH2Cl2, HC-130)	2.15E-05	3.47E-04
	(a) Molybdenum (Mo)	4.80E-08	7.74E-07
	(a) Naphthalene (C10H8)	1.00E-06	1.62E-05
	(a) Nickel (Ni)	1.76E-04	2.84E-03
	(a) Nitrogen Oxides (NOx as NO2)	1.40E+00	2.26E+01
	(a) Nitrous Oxide (N2O)	5.14E-02	8.30E-01
	(a) Organic Matter (unspecified)	8.45E-04	1.36E-02
	(a) Particulates (PM 10)	1.56E-06	2.53E-05
	(a) Particulates (unspecified)	9.04E-01	1.46E+01
	(a) Pentane (C5H12)	5.18E-06	8.36E-05
	(a) Phenanthrene (C14H10)	2.00E-07	3.23E-06
	(a) Phenol (C6H5OH)	1.18E-06	1.91E-05
	(a) Phosphorus (P)	3.97E-07	6.41E-06
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	3.23E-13	5.21E-12
	(a) Propane (C3H8)	5.75E-07	9.28E-06
	(a) Propionaldehyde (CH3CH2CHO)	2.81E-05	4.54E-04
	(a) Pyrene (C16H10)	2.44E-08	3.95E-07
	(a) Selenium (Se)	9.63E-05	1.55E-03
	(a) Silicon (Si)	1.18E-07	1.90E-06
	(a) Sodium (Na)	6.97E-07	1.12E-05
	(a) Styrene (C6H5CHCH2)	1.85E-06	2.99E-05
	(a) Sulfur Oxides (SOx as SO2)	1.35E+00	2.18E+01
	(a) Tetrachloroethylene (C2Cl4)	3.18E-06	5.14E-05
	(a) Toluene (C6H5CH3)	1.81E-05	2.92E-04
	(a) Trichloroethane (1,1,1-CH3CCl3)	1.48E-06	2.39E-05
	(a) Vanadium (V)	2.88E-06	4.65E-05
	(a) Vinyl Acetate (C4H6O2)	5.63E-07	9.08E-06
	(a) Xylene (C6H4(CH3)2)	2.75E-06	4.44E-05
	(a) Zinc (Zn)	1.03E-06	1.67E-05
	Total (g)		6.53E+03
		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	7.81E-01	1.26E+01

Appendix G (continued): Facility Infrastructure – Heavy Fuel Oil Production

Assumptions and Variables:	**Heavy Fuel Oil Requirement:**	**0.20**	**kg/FU**
		Factor for 1 kg	**kilograms (kg)**
Raw Materials	**(r) Bauxite (Al2O3, ore)**	**4.08E-05**	**8.13E-06**
	(r) Coal (in ground)	**2.94E-02**	**5.85E-03**
	(r) Limestone (CaCO3, in ground)	**2.32E-03**	**4.63E-04**
	(r) Natural Gas (in ground)	**7.81E-02**	**1.55E-02**
	(r) Oil (in ground)	**1.05E+00**	**2.10E-01**
	(r) Sand (in ground)	**2.50E-05**	**4.98E-06**
	(r) Sodium Chloride (NaCl, in ground or in sea)	**1.15E-05**	**2.29E-06**
	(r) Uranium (U, ore)	**4.95E-07**	**9.85E-08**
	Total		**2.32E-01**
Note: Raw material requirements exclude water usage, which equals		**1.92E+00**	**liters**
		Factor for 1 kg	**MJ**
Energy Burdens	**E Feedstock Energy**	**4.28E+01**	**8.53E+00**
	E Fuel Energy	**5.00E+00**	**9.95E-01**
	E Non Renewable Energy	**4.78E+01**	**9.52E+00**
	E Renewable Energy	**3.97E-02**	**7.91E-03**
	E Total Primary Energy	**4.78E+01**	**9.52E+00**
		Factor for 1 kg	**grams (g)**
Water Emissions	**(w) Acids (H+)**	**1.44E-07**	**2.87E-08**
	(w) Aluminum (Al3+)	**1.30E-04**	**2.59E-05**
	(w) Ammonia (NH4+, NH3, as N)	**2.47E-02**	**4.92E-03**
	(w) AOX (Adsorbable Organic Halogens)	**3.43E-10**	**6.83E-11**
	(w) Aromatic Hydrocarbons (unspecified)	**8.03E-08**	**1.60E-08**
	(w) Barium (Ba++)	**2.57E-07**	**5.12E-08**
	(w) BOD5 (Biochemical Oxygen Demand)	**1.72E-01**	**3.43E-02**
	(w) Cadmium (Cd++)	**2.68E-10**	**5.33E-11**
	(w) Chlorides (Cl-)	**1.52E+01**	**3.02E+00**
	(w) Chromium (Cr III, Cr VI)	**4.89E-08**	**9.73E-09**
	(w) COD (Chemical Oxygen Demand)	**1.46E+00**	**2.90E-01**
	(w) Copper (Cu+, Cu++)	**5.36E-09**	**1.07E-09**
	(w) Cyanide (CN-)	**3.75E-10**	**7.47E-11**
	(w) Dissolved Matter (unspecified)	**8.49E-04**	**1.69E-04**
	(w) Fluorides (F-)	**7.46E-05**	**1.49E-05**
	(w) Halogenated Matter (organic)	**1.07E-10**	**2.13E-11**
	(w) Hydrocarbons (unspecified)	**9.75E-04**	**1.94E-04**
	(w) Iron (Fe++, Fe3+)	**4.07E-07**	**8.10E-08**
	(w) Lead (Pb++, Pb4+)	**1.07E-09**	**2.13E-10**
	(w) Mercury (Hg+, Hg++)	**1.23E-12**	**2.45E-13**
	(w) Metals (unspecified)	**2.27E-02**	**4.52E-03**
	(w) Nickel (Ni++, Ni3+)	**5.36E-10**	**1.07E-10**
	(w) Nitrate (NO3-)	**6.59E-05**	**1.31E-05**
	(w) Nitrogenous Matter (unspecified, as N)	**1.45E-08**	**2.88E-09**
	(w) Oils (unspecified)	**1.44E-01**	**2.87E-02**
	(w) Organic Matter (unspecified)	**3.73E-07**	**7.42E-08**
	(w) Phenol (C6H5OH)	**3.31E-03**	**6.59E-04**
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	**5.34E-07**	**1.06E-07**
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	**1.29E-09**	**2.56E-10**
	(w) Salts (unspecified)	**1.48E-03**	**2.95E-04**
	(w) Sodium (Na+)	**1.95E+01**	**3.88E+00**
	(w) Sulfate (SO4--)	**9.10E-05**	**1.81E-05**
	(w) Sulfide (S--)	**8.22E-08**	**1.64E-08**
	(w) Suspended Matter (unspecified)	**7.82E-01**	**1.56E-01**
	(w) TOC (Total Organic Carbon)	**8.03E-07**	**1.60E-07**
	(w) Toluene (C6H5CH3)	**1.18E-08**	**2.35E-09**
	(w) Zinc (Zn++)	**1.45E-08**	**2.88E-09**
	Total (g)		**7.42E+00**
Note: Water emissions exclude chemically polluted water, which equals		**4.40E-01**	**liters**
		Factor for 1 kg	**grams (g)**
Air Emissions	**(a) Acenaphthene (C12H10)**	**9.46E-09**	**1.88E-09**
	(a) Acenaphthylene (C12H8)	**4.38E-09**	**8.71E-10**
	(a) Acetaldehyde (CH3CHO)	**8.35E-06**	**1.66E-06**
	(a) Acetophenone (C8H8O)	**2.20E-07**	**4.38E-08**
	(a) Acrolein (CH2CHCHO)	**4.25E-06**	**8.46E-07**
	(a) Aldehyde (unspecified)	**2.31E-03**	**4.60E-04**
	(a) Aluminum (Al)	**5.49E-05**	**1.09E-05**
	(a) Ammonia (NH3)	**3.18E-03**	**6.33E-04**
	(a) Anthracene (C14H10)	**4.08E-09**	**8.13E-10**
	(a) Antimony (Sb)	**9.46E-07**	**1.88E-07**
	(a) Aromatic Hydrocarbons (unspecified)	**4.82E-08**	**9.60E-09**
	(a) Arsenic (As)	**3.15E-05**	**6.27E-06**
	(a) Barium (Ba)	**4.77E-07**	**9.50E-08**
	(a) Benzene (C6H6)	**2.22E-02**	**4.43E-03**
	(a) Benzo(a)anthracene	**2.12E-09**	**4.21E-10**
	(a) Benzo(a)pyrene (C20H12)	**1.38E-09**	**2.76E-10**
	(a) Benzo(b)fluoranthene	**7.44E-10**	**1.48E-10**
	(a) Benzo(bjk)fluoranthene	**1.61E-09**	**3.21E-10**
	(a) Benzo(ghi)perylene	**9.31E-10**	**1.85E-10**
	(a) Benzo(k)fluoranthene	**7.44E-10**	**1.48E-10**
	(a) Benzyl Chloride (C7H7Cl)	**1.03E-05**	**2.04E-06**
	(a) Beryllium (Be)	**3.04E-06**	**6.05E-07**
	(a) Bromoform (CHBr3)	**5.71E-07**	**1.14E-07**
	(a) Butane (C4H10)	**8.15E-04**	**1.62E-04**
	(a) Cadmium (Cd)	**1.73E-06**	**3.44E-07**
	(a) Calcium (Ca)	**4.76E-05**	**9.47E-06**
	(a) Carbon Dioxide (CO2, biomass)	**1.46E-04**	**2.90E-05**
	(a) Carbon Dioxide (CO2, fossil)	**2.31E+02**	**4.60E+01**
	(a) Carbon Disulfide (CS2)	**1.90E-06**	**3.79E-07**
	(a) Carbon Monoxide (CO)	**5.69E-01**	**1.13E-01**
	(a) Chlorides (Cl-)	**4.51E-05**	**8.97E-06**
	(a) Chlorine (Cl2)	**8.03E-09**	**1.60E-09**

		Factor for 1 kg	**grams (g)**
Air Emissions (cont.)	**(a) Chloroacetophenone (2-C8H7ClO)**	**1.03E-07**	**2.04E-08**
	(a) Chlorobenzene (C6H5Cl)	**3.22E-07**	**6.42E-08**
	(a) Chloroform (CHCl3, HC-20)	**8.64E-07**	**1.72E-07**
	(a) Chromium (Cr III, Cr VI)	**4.65E-05**	**9.27E-06**
	(a) Chrysene (C18H12)	**2.24E-09**	**4.45E-10**
	(a) Cobalt (Co)	**5.76E-06**	**1.15E-06**
	(a) Copper (Cu)	**3.83E-06**	**7.63E-07**
	(a) Cumene (C9H12)	**7.77E-08**	**1.55E-08**
	(a) Cyanide (CN-)	**3.66E-05**	**7.29E-06**
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	**1.07E-06**	**2.13E-07**
	(a) Dibenzo(a,h)anthracene	**5.17E-10**	**1.03E-10**
	(a) Dichlorobenzene (1,4-C6H4Cl2)	**4.66E-07**	**9.27E-08**
	(a) Dimethyl Benzanthracene (7,12-C20H16)	**5.82E-09**	**1.16E-09**
	(a) Dimethyl Sulfate (C2H6O4S)	**7.03E-07**	**1.40E-07**
	(a) Dinitrotoluene (2,4-C7H6N2O4)	**4.10E-09**	**8.17E-10**
	(a) Dioxins (unspecified)	**2.37E-10**	**4.72E-11**
	(a) Diphenyl ((C6H5)2)	**2.49E-08**	**4.96E-09**
	(a) Ethane (C2H6)	**1.20E-03**	**2.40E-04**
	(a) Ethyl Benzene (C6H5C2H5)	**1.39E-06**	**2.76E-07**
	(a) Ethyl Chloride (C2H5Cl)	**6.15E-07**	**1.23E-07**
	(a) Ethylene Dibromide (C2H4Br2)	**1.76E-08**	**3.50E-09**
	(a) Ethylene Dichloride (C2H4Cl2)	**5.86E-07**	**1.17E-07**
	(a) Fluoranthene	**1.17E-08**	**2.33E-09**
	(a) Fluorene (C13H10)	**1.46E-08**	**2.90E-09**
	(a) Fluorides (F-)	**5.24E-06**	**1.04E-06**
	(a) Formaldehyde (CH2O)	**3.24E-03**	**6.46E-04**
	(a) Furan (C4H4O)	**1.10E-09**	**2.20E-10**
	(a) Halogenated Hydrocarbons (unspecified)	**2.68E-13**	**5.33E-14**
	(a) Halon 1301 (CF3Br)	**4.66E-10**	**9.28E-11**
	(a) Hexane (C6H14)	**7.00E-04**	**1.39E-04**
	(a) Hydrocarbons (except methane)	**2.42E-01**	**4.82E-02**
	(a) Hydrocarbons (unspecified)	**3.66E-01**	**7.28E-02**
	(a) Hydrogen Chloride (HCl)	**1.76E-02**	**3.50E-03**
	(a) Hydrogen Fluoride (HF)	**2.20E-03**	**4.38E-04**
	(a) Hydrogen Sulfide (H2S)	**8.62E-03**	**1.72E-03**
	(a) Indeno (1,2,3,c,d) Pyrene	**1.66E-09**	**3.30E-10**
	(a) Iron (Fe)	**1.06E-04**	**2.11E-05**
	(a) Isophorone	**8.50E-06**	**1.69E-06**
	(a) Lead (Pb)	**2.71E-05**	**5.40E-06**
	(a) Magnesium (Mg)	**1.61E-04**	**3.21E-05**
	(a) Manganese (Mn)	**4.86E-05**	**9.67E-06**
	(a) Mercury (Hg)	**1.88E-06**	**3.75E-07**
	(a) Metals (unspecified)	**2.91E-07**	**5.79E-08**
	(a) Methane (CH4)	**1.60E+00**	**3.18E-01**
	(a) Methyl Bromide (CH3Br)	**2.34E-06**	**4.67E-07**
	(a) Methyl Chloride (CH3Cl)	**7.77E-06**	**1.55E-06**
	(a) Methyl Cholanthrene (3-C21H16)	**6.99E-10**	**1.39E-10**
	(a) Methyl Chrysene (5-C19H15)	**3.22E-10**	**6.42E-11**
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	**5.71E-06**	**1.14E-06**
	(a) Methyl Hydrazine (CH6N2)	**2.49E-06**	**4.96E-07**
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	**2.93E-07**	**5.83E-08**
	(a) Methyl Naphthalene (2-C11H10)	**9.32E-09**	**1.85E-09**
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	**5.13E-07**	**1.02E-07**
	(a) Methylene Chloride (CH2Cl2, HC-130)	**4.25E-06**	**8.46E-07**
	(a) Molybdenum (Mo)	**4.97E-06**	**9.90E-07**
	(a) Naphthalene (C10H8)	**5.74E-07**	**1.14E-07**
	(a) Nickel (Ni)	**3.20E-04**	**6.38E-05**
	(a) Nitrogen Oxides (NOx as NO2)	**1.11E+00**	**2.21E-01**
	(a) Nitrous Oxide (N2O)	**3.94E-02**	**7.84E-03**
	(a) Organic Matter (unspecified)	**1.10E-01**	**2.19E-02**
	(a) Particulates (PM 10)	**6.33E-04**	**1.26E-04**
	(a) Particulates (unspecified)	**2.51E-01**	**4.99E-02**
	(a) Pentane (C5H12)	**1.01E-03**	**2.01E-04**
	(a) Phenanthrene (C14H10)	**4.65E-08**	**9.25E-09**
	(a) Phenol (C6H5OH)	**2.34E-07**	**4.67E-08**
	(a) Phosphorus (P)	**3.34E-05**	**6.65E-06**
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	**5.36E-11**	**1.07E-11**
	(a) Propane (C3H8)	**3.63E-06**	**7.23E-07**
	(a) Propionaldehyde (CH3CH2CHO)	**5.57E-06**	**1.11E-06**
	(a) Pyrene (C16H10)	**6.91E-09**	**1.37E-09**
	(a) Selenium (Se)	**2.08E-05**	**4.13E-06**
	(a) Silicon (Si)	**4.76E-05**	**9.47E-06**
	(a) Sodium (Na)	**2.82E-04**	**5.61E-05**
	(a) Styrene (C6H5CHCH2)	**3.66E-07**	**7.29E-08**
	(a) Sulfur Oxides (SOx as SO2)	**1.48E+00**	**2.96E-01**
	(a) Tetrachloroethylene (C2Cl4)	**6.30E-07**	**1.25E-07**
	(a) Toluene (C6H5CH3)	**6.80E-06**	**1.35E-06**
	(a) Trichloroethane (1,1,1-CH3CCl3)	**2.93E-07**	**5.83E-08**
	(a) Vanadium (V)	**7.37E-04**	**1.47E-04**
	(a) Vinyl Acetate (C4H6O2)	**1.11E-07**	**2.22E-08**
	(a) Xylene (C6H4(CH3)2)	**1.75E-06**	**3.48E-07**
	(a) Zinc (Zn)	**1.50E-05**	**2.99E-06**
	Total (g)		**2.79E+02**
		Factor for 1 kg	**kilograms (kg)**
Solid Waste	**Waste (total)**	**0.155954**	**3.11E-02**
Note: Heavy fuel oil production includes:			
Domestic and foreign crude oil production (onshore conventional, advanced recov., offshore conventional recovery).			
Transportation to the refineries in the US.			
Crude oil refining into heavy fuel oil.			
Transportation from refinery to end-user.			

Appendix G (continued): Facility Infrastructure – Combustion of Residual Oil in Industrial Boilers

Assumptions and Variables:	Heavy Fuel Oil Requirement:	8.62	MJ/FU
		Factor for 1 MJ	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	6.05E-08	5.22E-07
	(a) Acenaphthylene (C12H8)	7.26E-10	6.26E-09
	(a) Anthracene (C14H10)	3.50E-09	3.02E-08
	(a) Antimony (Sb)	1.51E-05	1.30E-04
	(a) Arsenic (As)	3.79E-06	3.27E-05
	(a) Barium (Ba)	7.38E-06	6.36E-05
	(a) Benzene (C6H6)	6.14E-07	5.30E-06
	(a) Benzo(a)anthracene	1.15E-08	9.92E-08
	(a) Benzo(b)fluoranthene	2.12E-09	1.83E-08
	(a) Benzo(ghi)perylene	3.24E-09	2.80E-08
	(a) Benzo(k)fluoranthene	2.12E-09	1.83E-08
	(a) Beryllium (Be)	7.98E-08	6.88E-07
	(a) Cadmium (Cd)	1.14E-06	9.85E-06
	(a) Carbon Dioxide (CO2, fossil)	7.09E+01	6.11E+02
	(a) Carbon Monoxide (CO)	1.43E-02	1.24E-01
	(a) Chlorides (Cl-)	9.96E-04	8.59E-03
	(a) Chromium (Cr III, Cr VI)	3.14E-06	2.70E-05
	(a) Chrysene (C18H12)	3.41E-09	2.94E-08
	(a) Cobalt (Co)	1.73E-05	1.49E-04
	(a) Copper (Cu)	5.05E-06	4.35E-05
	(a) Dibenzo(a,h)anthracene	2.40E-09	2.07E-08
	(a) Ethyl Benzene (C6H5C2H5)	1.83E-07	1.57E-06
	(a) Fluoranthene	6.94E-09	5.99E-08
	(a) Fluorene (C13H10)	6.41E-09	5.53E-08
	(a) Fluorides (F-)	1.07E-04	9.23E-04
	(a) Formaldehyde (CH2O)	1.22E-04	1.05E-03
	(a) Hydrocarbons (except methane)	7.26E-04	6.26E-03
	(a) Indeno (1,2,3,c,d) Pyrene	3.07E-09	2.65E-08
	(a) Lead (Pb)	4.33E-06	3.74E-05
	(a) Manganese (Mn)	8.61E-06	7.42E-05
	(a) Mercury (Hg)	3.24E-07	2.80E-06
	(a) Methane (CH4)	1.96E-03	1.69E-02
	(a) Molybdenum (Mo)	2.26E-06	1.95E-05
	(a) Naphthalene (C10H8)	3.24E-06	2.80E-05
	(a) Nickel (Ni)	2.42E-04	2.09E-03
	(a) Nitrogen Oxides (NOx as NO2)	1.24E-01	1.07E+00
	(a) Nitrous Oxide (N2O)	3.16E-04	2.72E-03
	(a) Particulates (unspecified)	2.31E-01	1.99E+00
	(a) Phenanthrene (C14H10)	1.51E-08	1.30E-07
	(a) Phosphorus (P)	2.71E-05	2.34E-04
	(a) Pyrene (C16H10)	6.10E-09	5.26E-08
	(a) Selenium (Se)	1.96E-06	1.69E-05
	(a) Sulfur Oxides (SOx as SO2)	4.26E-01	3.67E+00
	(a) Toluene (C6H5CH3)	1.78E-05	1.53E-04
	(a) Vanadium (V)	9.13E-05	7.87E-04
	(a) Xylene (C6H4(CH3)2)	3.13E-07	2.70E-06
	(a) Zinc (Zn)	8.35E-05	7.20E-04
	Total (g)		6.18E+02

Note: Solid waste and water effluents were not considered in the DEAM database for combustion of heavy fuel oil in an an industrial boiler.

Appendix G (continued): Facility Infrastructure – Natural Gas Production

	Natural Gas Requirement	0.32	kg
		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	3.24E-07	1.02E-07
	(r) Coal (in ground)	8.39E-03	2.65E-03
	(r) Limestone (CaCO3, in ground)	6.62E-04	2.09E-04
	(r) Natural Gas (in ground)	1.22E+00	3.86E-01
	(r) Oil (in ground)	3.02E-03	9.53E-04
	(r) Sand (in ground)	1.98E-07	6.26E-08
	(r) Sodium Chloride (NaCl, in ground or in sea)	9.10E-08	2.87E-08
	(r) Uranium (U, ore)	1.44E-07	4.53E-08
	Total		3.90E-01
Note: Raw material requirements exclude water usage, which equals		2.41E-02	liters
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	5.28E+01	1.67E+01
	E Fuel Energy	1.13E+01	3.57E+00
	E Non Renewable Energy	6.41E+01	2.02E+01
	E Renewable Energy	1.13E-02	3.58E-03
	E Total Primary Energy	6.41E+01	2.02E+01
		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	2.99E-06	9.42E-07
	(w) Aluminum (Al3+)	1.03E-06	3.25E-07
	(w) Ammonia (NH4+, NH3, as N)	1.21E-04	3.82E-05
	(w) AOX (Adsorbable Organic Halogens)	2.72E-12	8.57E-13
	(w) Aromatic Hydrocarbons (unspecified)	6.37E-10	2.01E-10
	(w) Barium (Ba++)	2.04E-09	6.43E-10
	(w) BOD5 (Biochemical Oxygen Demand)	1.44E-03	4.55E-04
	(w) Cadmium (Cd++)	2.12E-12	6.70E-13
	(w) Chlorides (Cl-)	4.26E-02	1.34E-02
	(w) Chromium (Cr III, Cr VI)	7.91E-07	2.50E-07
	(w) COD (Chemical Oxygen Demand)	1.17E-02	3.69E-03
	(w) Copper (Cu+, Cu++)	4.25E-11	1.34E-11
	(w) Cyanide (CN-)	2.97E-12	9.38E-13
	(w) Dissolved Matter (unspecified)	2.65E-04	8.35E-05
	(w) Fluorides (F-)	2.15E-05	6.77E-06
	(w) Halogenated Matter (organic)	8.49E-13	2.68E-13
	(w) Hydrocarbons (unspecified)	3.12E-06	9.84E-07
	(w) Iron (Fe++, Fe3+)	4.52E-08	1.43E-08
	(w) Lead (Pb++, Pb4+)	8.49E-12	2.68E-12
	(w) Mercury (Hg+, Hg++)	9.77E-15	3.08E-15
	(w) Metals (unspecified)	7.49E-05	2.36E-05
	(w) Nickel (Ni++, Ni3+)	4.25E-12	1.34E-12
	(w) Nitrate (NO3-)	5.42E-06	1.71E-06
	(w) Nitrogenous Matter (unspecified, as N)	1.15E-10	3.62E-11
	(w) Oils (unspecified)	7.48E-04	2.36E-04
	(w) Organic Matter (unspecified)	7.91E-06	2.50E-06
	(w) Phenol (C6H5OH)	2.64E-05	8.34E-06
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	2.42E-08	7.62E-09
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	1.02E-11	3.22E-12
	(w) Salts (unspecified)	1.17E-05	3.70E-06
	(w) Sodium (Na+)	5.48E-02	1.73E-02
	(w) Sulfate (SO4--)	5.09E-06	1.61E-06
	(w) Sulfide (S--)	1.64E-06	5.18E-07
	(w) Suspended Matter (unspecified)	6.21E-03	1.96E-03
	(w) TOC (Total Organic Carbon)	6.37E-09	2.01E-09
	(w) Toluene (C6H5CH3)	9.34E-11	2.95E-11
	(w) Zinc (Zn++)	1.89E-07	5.95E-08
	Total (g)		3.73E-02
Note: Water emissions exclude chemically polluted water, which equals		2.17E-03	liters
		Factor for 1 kg	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	4.77E-09	1.50E-09
	(a) Acenaphthylene (C12H8)	2.52E-09	7.95E-10
	(a) Acetaldehyde (CH3CHO)	2.38E-06	7.51E-07
	(a) Acetophenone (C8H8O)	6.27E-08	1.98E-08
	(a) Acrolein (CH2CHCHO)	1.21E-06	3.82E-07
	(a) Aldehyde (unspecified)	3.88E-03	1.22E-03
	(a) Aluminum (Al)	1.54E-07	4.87E-08
	(a) Ammonia (NH3)	5.64E-02	1.78E-02
	(a) Anthracene (C14H10)	2.89E-09	9.13E-10
	(a) Antimony (Sb)	4.71E-07	1.48E-07
	(a) Aromatic Hydrocarbons (unspecified)	3.82E-10	1.21E-10
	(a) Arsenic (As)	7.62E-06	2.40E-06
	(a) Barium (Ba)	3.75E-07	1.18E-07
	(a) Benzene (C6H6)	4.56E-01	1.44E-01
	(a) Benzo(a)anthracene	2.02E-09	6.37E-10
	(a) Benzo(a)pyrene (C20H12)	1.13E-09	3.58E-10
	(a) Benzo(b)fluoranthene	1.50E-09	4.74E-10
	(a) Benzo(bjk)fluoranthene	4.60E-10	1.45E-10
	(a) Benzo(ghi)perylene	1.15E-09	3.63E-10
	(a) Benzo(k)fluoranthene	1.50E-09	4.74E-10
	(a) Benzyl Chloride (C7H7Cl)	2.92E-06	9.23E-07
	(a) Beryllium (Be)	1.01E-06	3.18E-07
	(a) Bromoform (CHBr3)	1.63E-07	5.14E-08
	(a) Butane (C4H10)	1.70E-03	5.38E-04
	(a) Cadmium (Cd)	5.05E-07	1.59E-07
	(a) Calcium (Ca)	1.34E-07	4.22E-08
	(a) Carbon Dioxide (CO2, biomass)	4.03E-05	1.27E-05
	(a) Carbon Dioxide (CO2, fossil)	4.76E+02	1.50E+02
	(a) Carbon Disulfide (CS2)	5.43E-07	1.71E-07
	(a) Carbon Monoxide (CO)	1.83E+00	5.78E-01
	(a) Chlorides (Cl-)	2.61E-05	8.24E-06
	(a) Chlorine (Cl2)	1.70E-07	5.37E-08

		Factor for 1 kg	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	2.92E-08	9.23E-09
	(a) Chlorobenzene (C6H5Cl)	9.19E-08	2.90E-08
	(a) Chloroform (CHCl3, HC-20)	2.46E-07	7.78E-08
	(a) Chromium (Cr III, Cr VI)	1.35E-05	4.26E-06
	(a) Chrysene (C18H12)	1.94E-09	6.14E-10
	(a) Cobalt (Co)	9.51E-07	3.00E-07
	(a) Copper (Cu)	8.46E-07	2.67E-07
	(a) Cumene (C9H12)	2.21E-08	6.99E-09
	(a) Cyanide (CN-)	1.04E-05	3.30E-06
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	3.05E-07	9.62E-08
	(a) Dibenzo(a,h)anthracene	1.02E-09	3.22E-10
	(a) Dichlorobenzene (1,4-C6H4Cl2)	9.74E-07	3.07E-07
	(a) Dimethyl Benzanthracene (7,12-C20H16)	1.22E-08	3.84E-09
	(a) Dimethyl Sulfate (C2H6O4S)	2.01E-07	6.33E-08
	(a) Dinitrotoluene (2,4-C7H6N2O4)	1.17E-09	3.69E-10
	(a) Dioxins (unspecified)	6.76E-11	2.13E-11
	(a) Diphenyl ((C6H5)2)	7.10E-09	2.24E-09
	(a) Ethane (C2H6)	2.51E-03	7.94E-04
	(a) Ethyl Benzene (C6H5C2H5)	3.98E-07	1.25E-07
	(a) Ethyl Chloride (C2H5Cl)	1.75E-07	5.54E-08
	(a) Ethylene Dibromide (C2H4Br2)	5.01E-09	1.58E-09
	(a) Ethylene Dichloride (C2H4Cl2)	1.67E-07	5.27E-08
	(a) Fluoranthene	5.53E-09	1.75E-09
	(a) Fluorene (C13H10)	6.20E-09	1.96E-09
	(a) Fluorides (F-)	3.09E-06	9.75E-07
	(a) Formaldehyde (CH2O)	8.71E-05	2.75E-05
	(a) Furan (C4H4O)	3.14E-10	9.92E-11
	(a) Halogenated Hydrocarbons (unspecified)	2.12E-15	6.70E-16
	(a) Halon 1301 (CF3Br)	3.69E-12	1.17E-12
	(a) Hexane (C6H14)	1.46E-03	4.61E-04
	(a) Hydrocarbons (except methane)	8.15E-01	2.57E-01
	(a) Hydrocarbons (unspecified)	2.24E-02	7.07E-03
	(a) Hydrogen Chloride (HCl)	5.02E-03	1.58E-03
	(a) Hydrogen Fluoride (HF)	6.27E-04	1.98E-04
	(a) Hydrogen Sulfide (H2S)	2.42E-05	7.64E-06
	(a) Indeno (1,2,3,c,d) Pyrene	1.77E-09	5.60E-10
	(a) Iron (Fe)	2.98E-07	9.41E-08
	(a) Isophorone	2.42E-06	7.65E-07
	(a) Lead (Pb)	7.80E-06	2.46E-06
	(a) Magnesium (Mg)	4.60E-05	1.45E-05
	(a) Manganese (Mn)	1.42E-05	4.49E-06
	(a) Mercury (Hg)	6.78E-07	2.14E-07
	(a) Metals (unspecified)	1.73E-07	5.45E-08
	(a) Methane (CH4)	1.81E+01	5.70E+00
	(a) Methyl Bromide (CH3Br)	6.68E-07	2.11E-07
	(a) Methyl Chloride (CH3Cl)	2.21E-06	6.99E-07
	(a) Methyl Cholanthrene (3-C21H16)	1.46E-09	4.61E-10
	(a) Methyl Chrysene (5-C19H15)	9.19E-11	2.90E-11
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	1.63E-06	5.14E-07
	(a) Methyl Hydrazine (CH6N2)	7.10E-07	2.24E-07
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	8.36E-08	2.64E-08
	(a) Methyl Naphthalene (2-C11H10)	1.95E-08	6.14E-09
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	1.46E-07	4.61E-08
	(a) Methylene Chloride (CH2Cl2, HC-130)	1.21E-06	3.82E-07
	(a) Molybdenum (Mo)	9.79E-07	3.09E-07
	(a) Naphthalene (C10H8)	6.34E-07	2.00E-07
	(a) Nickel (Ni)	1.86E-05	5.86E-06
	(a) Nitrogen Oxides (NOx as NO2)	3.36E+00	1.06E+00
	(a) Nitrous Oxide (N2O)	4.16E-03	1.31E-03
	(a) Organic Matter (unspecified)	2.28E+00	7.19E-01
	(a) Particulates (PM 10)	1.78E-06	5.61E-07
	(a) Particulates (unspecified)	1.49E-01	4.70E-02
	(a) Pentane (C5H12)	2.11E-03	6.66E-04
	(a) Phenanthrene (C14H10)	2.54E-08	8.00E-09
	(a) Phenol (C6H5OH)	6.68E-08	2.11E-08
	(a) Phosphorus (P)	8.03E-07	2.53E-07
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	4.25E-13	1.34E-13
	(a) Propane (C3H8)	1.15E-06	3.62E-07
	(a) Propionaldehyde (CH3CH2CHO)	1.59E-06	5.01E-07
	(a) Pyrene (C16H10)	5.55E-09	1.75E-09
	(a) Selenium (Se)	5.51E-06	1.74E-06
	(a) Silicon (Si)	1.34E-07	4.22E-08
	(a) Sodium (Na)	7.92E-07	2.50E-07
	(a) Styrene (C6H5CHCH2)	1.04E-07	3.30E-08
	(a) Sulfur Oxides (SOx as SO2)	9.92E-02	3.13E-02
	(a) Tetrachloroethylene (C2Cl4)	1.80E-07	5.67E-08
	(a) Toluene (C6H5CH3)	1.86E-05	5.87E-06
	(a) Trichloroethane (1,1,1-CH3CCl3)	8.36E-08	2.64E-08
	(a) Vanadium (V)	6.32E-06	1.99E-06
	(a) Vinyl Acetate (C4H6O2)	3.18E-08	1.00E-08
	(a) Xylene (C6H4(CH3)2)	2.49E-05	7.86E-06
	(a) Zinc (Zn)	2.57E-05	8.11E-06
	Total (g)		6.37E+02
		Factor for 1 kg	kilograms (kg)
Solid Waste	Waste (total)	4.22E-04	1.33E-04

Note: Production process includes:

Recovery of raw natural gas.

Glycol dehydration.

Gas sweetening using the amine process .

Pipeline transport to utilities (use of natural gas as pipeline fuel and electricity, including compressor station energy.

Appendix G (continued): Facility Infrastructure – Combustion of Natural Gas in a Utility Boiler

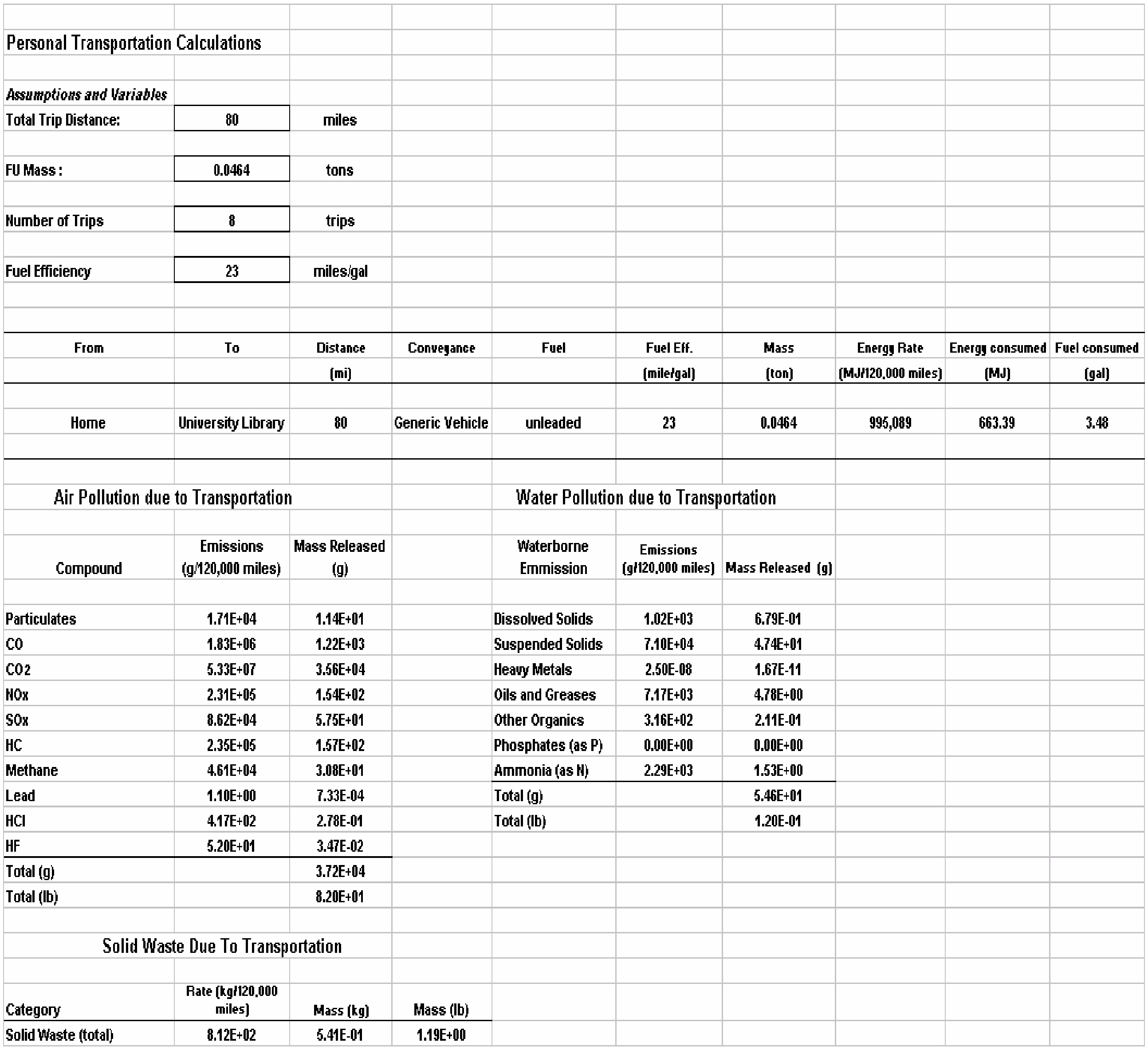
Assumptions and Variables:	**Natural Gas Requirement:**	**18.47**	**MJ**
		Factor for 1 MJ	**grams (g)**
Air Emissions	**(a) Acenaphthene (C12H10)**	**1.64E-09**	**3.03E-08**
	(a) Acenaphthylene (C12H8)	**1.64E-09**	**3.03E-08**
	(a) Ammonia (NH3)	**8.81E-04**	**1.63E-02**
	(a) Anthracene (C14H10)	**2.19E-09**	**4.05E-08**
	(a) Arsenic (As)	**1.42E-07**	**2.62E-06**
	(a) Barium (Ba)	**2.81E-06**	**5.18E-05**
	(a) Benzene (C6H6)	**1.48E-06**	**2.74E-05**
	(a) Benzo(a)anthracene	**1.64E-09**	**3.03E-08**
	(a) Benzo(a)pyrene (C20H12)	**1.10E-09**	**2.02E-08**
	(a) Benzo(b)fluoranthene	**1.64E-09**	**3.03E-08**
	(a) Benzo(ghi)perylene	**1.10E-09**	**2.02E-08**
	(a) Benzo(k)fluoranthene	**1.64E-09**	**3.03E-08**
	(a) Beryllium (Be)	**1.10E-08**	**2.02E-07**
	(a) Butane (C4H10)	**1.92E-03**	**3.54E-02**
	(a) Cadmium (Cd)	**5.11E-07**	**9.43E-06**
	(a) Carbon Dioxide (CO2, fossil)	**1.24E+02**	**2.30E+03**
	(a) Carbon Monoxide (CO)	**5.77E-02**	**1.07E+00**
	(a) Chromium (Cr III, Cr VI)	**9.65E-07**	**1.78E-05**
	(a) Chrysene (C18H12)	**1.64E-09**	**3.03E-08**
	(a) Cobalt (Co)	**9.58E-08**	**1.77E-06**
	(a) Copper (Cu)	**8.51E-07**	**1.57E-05**
	(a) Dibenzo(a,h)anthracene	**1.10E-09**	**2.02E-08**
	(a) Dichlorobenzene (1,4-C6H4Cl2)	**1.10E-06**	**2.02E-05**
	(a) Dimethyl Benzanthracene (7,12-C20H16)	**1.46E-08**	**2.70E-07**
	(a) Ethane (C2H6)	**2.83E-03**	**5.23E-02**
	(a) Fluoranthene	**2.74E-09**	**5.06E-08**
	(a) Fluorene (C13H10)	**2.56E-09**	**4.72E-08**
	(a) Formaldehyde (CH2O)	**2.21E-04**	**4.07E-03**
	(a) Hexane (C6H14)	**1.64E-03**	**3.03E-02**
	(a) Hydrocarbons (except methane)	**4.34E-04**	**8.01E-03**
	(a) Indeno (1,2,3,c,d) Pyrene	**1.64E-09**	**3.03E-08**
	(a) Lead (Pb)	**3.58E-07**	**6.61E-06**
	(a) Manganese (Mn)	**5.36E-07**	**9.90E-06**
	(a) Mercury (Hg)	**2.88E-07**	**5.32E-06**
	(a) Methane (CH4)	**3.29E-03**	**6.08E-02**
	(a) Methyl Cholanthrene (3-C21H16)	**1.64E-09**	**3.03E-08**
	(a) Methyl Naphthalene (2-C11H10)	**2.19E-08**	**4.05E-07**
	(a) Molybdenum (Mo)	**1.05E-06**	**1.95E-05**
	(a) Naphthalene (C10H8)	**5.57E-07**	**1.03E-05**
	(a) Nickel (Ni)	**1.48E-06**	**2.73E-05**
	(a) Nitrogen Oxides (NOx as NO2)	**1.02E-01**	**1.88E+00**
	(a) Nitrous Oxide (N2O)	**1.70E-03**	**3.14E-02**
	(a) Particulates (unspecified)	**1.26E-02**	**2.33E-01**
	(a) Pentane (C5H12)	**2.37E-03**	**4.38E-02**
	(a) Phenanthrene (C14H10)	**1.55E-08**	**2.87E-07**
	(a) Propane (C3H8)	**1.46E-03**	**2.70E-02**
	(a) Pyrene (C16H10)	**4.56E-09**	**8.43E-08**
	(a) Selenium (Se)	**2.19E-08**	**4.05E-07**
	(a) Sulfur Oxides (SOx as SO2)	**6.75E-04**	**1.25E-02**
	(a) Toluene (C6H5CH3)	**5.86E-06**	**1.08E-04**
	(a) Vanadium (V)	**1.37E-06**	**2.52E-05**
	(a) Zinc (Zn)	**2.65E-05**	**4.89E-04**
	Total (g)		**2.30E+03**

Note: Solid waste and water effluents were not considered in the DEAM database for the combustion of natural gas in a utility boiler.

APPENDIX H
PERSONAL TRANSPORTATION

1) Energy Consumed and Emissions Generated
2) Gasoline Production

Appendix H: Personal Transportation – Energy Consumed and Emissions Generated



Personal Transportation Calculations

Assumptions and Variables

Total Trip Distance:	80	miles
FU Mass :	0.0464	tons
Number of Trips	8	trips
Fuel Efficiency	23	miles/gal

From	To	Distance (mi)	Conveyance	Fuel	Fuel Eff. (mile/gal)	Mass (ton)	Energy Rate (MJ/120,000 miles)	Energy consumed (MJ)	Fuel consumed (gal)
Home	University Library	80	Generic Vehicle	unleaded	23	0.0464	995,089	663.39	3.48

Air Pollution due to Transportation

Compound	Emissions (g/120,000 miles)	Mass Released (g)
Particulates	1.71E+04	1.14E+01
CO	1.83E+06	1.22E+03
CO2	5.33E+07	3.56E+04
NOx	2.31E+05	1.54E+02
SOx	8.62E+04	5.75E+01
HC	2.35E+05	1.57E+02
Methane	4.61E+04	3.08E+01
Lead	1.10E+00	7.33E-04
HCl	4.17E+02	2.78E-01
HF	5.20E+01	3.47E-02
Total (g)		3.72E+04
Total (lb)		8.20E+01

Water Pollution due to Transportation

Waterborne Emmission	Emissions (g/120,000 miles)	Mass Released (g)
Dissolved Solids	1.02E+03	6.79E-01
Suspended Solids	7.10E+04	4.74E+01
Heavy Metals	2.50E-08	1.67E-11
Oils and Greases	7.17E+03	4.78E+00
Other Organics	3.16E+02	2.11E-01
Phosphates (as P)	0.00E+00	0.00E+00
Ammonia (as N)	2.29E+03	1.53E+00
Total (g)		5.46E+01
Total (lb)		1.20E-01

Solid Waste Due To Transportation

Category	Rate (kg/120,000 miles)	Mass (kg)	Mass (lb)
Solid Waste (total)	8.12E+02	5.41E-01	1.19E+00

Appendix H (continued): Personal Transportation – Gasoline Production

Assumptions and Variables:	**Gasoline Requirement:**	**3.48**	**gal**	
	Gasoline Equivilancy:	**9.22**	**kg**	**Note: This assumes that the density of gasoline is 0.7 kg/L**

		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.30E-04	2.12E-03
	(r) Coal (in ground)	4.88E-02	4.50E-01
	(r) Limestone (CaCO3, in ground)	3.88E-03	3.57E-02
	(r) Natural Gas (in ground)	1.89E-01	1.74E+00
	(r) Oil (in ground)	1.08E+00	9.96E+00
	(r) Sand (in ground)	1.41E-04	1.30E-03
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.48E-05	5.97E-04
	(r) Uranium (U, ore)	8.21E-07	7.56E-06
	Total		1.22E+01

Note: Raw material requirements exclude water usage, which equals	4.97E+02	liters

		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.59E+01	4.23E+02
	E Fuel Energy	1.19E+01	1.10E+02
	E Non Renewable Energy	5.78E+01	5.32E+02
	E Renewable Energy	6.59E-02	6.07E-01
	E Total Primary Energy	5.78E+01	5.33E+02

		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	4.13E-07	3.81E-06
	(w) Aluminum (Al3+)	7.33E-04	6.76E-03
	(w) Ammonia (NH4+, NH3, as N)	1.42E-01	1.31E+00
	(w) AOX (Adsorbable Organic Halogens)	1.93E-09	1.78E-08
	(w) Aromatic Hydrocarbons (unspecified)	4.53E-07	4.18E-06
	(w) Barium (Ba++)	1.45E-06	1.34E-05
	(w) BOD5 (Biochemical Oxygen Demand)	9.71E-01	8.95E+00
	(w) Cadmium (Cd++)	1.51E-09	1.39E-08
	(w) Chlorides (Cl-)	1.56E+01	1.43E+02
	(w) Chromium (Cr III, Cr VI)	1.70E-07	1.57E-06
	(w) COD (Chemical Oxygen Demand)	8.22E+00	7.57E+01
	(w) Copper (Cu+, Cu++)	3.02E-08	2.79E-07
	(w) Cyanide (CN-)	2.12E-09	1.95E-08
	(w) Dissolved Matter (unspecified)	1.41E-03	1.30E-02
	(w) Fluorides (F-)	1.24E-04	1.14E-03
	(w) Halogenated Matter (organic)	6.04E-10	5.57E-09
	(w) Hydrocarbons (unspecified)	1.00E-03	9.23E-03
	(w) Iron (Fe++, Fe3+)	1.72E-06	1.59E-05
	(w) Lead (Pb++, Pb4+)	6.04E-09	5.57E-08
	(w) Mercury (Hg+, Hg++)	6.95E-12	6.41E-11
	(w) Metals (unspecified)	3.31E-02	3.05E-01
	(w) Nickel (Ni++, Ni3+)	3.02E-09	2.79E-08
	(w) Nitrate (NO3-)	3.01E-04	2.78E-03
	(w) Nitrogenous Matter (unspecified, as N)	8.16E-08	7.52E-07
	(w) Oils (unspecified)	4.53E-01	4.18E+00
	(w) Organic Matter (unspecified)	1.09E-06	1.01E-05
	(w) Phenol (C6H5OH)	1.87E-02	1.72E-01
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.01E-06	2.77E-05
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	7.25E-09	6.68E-08
	(w) Salts (unspecified)	8.36E-03	7.70E-02
	(w) Sodium (Na+)	2.00E+01	1.84E+02
	(w) Sulfate (SO4--)	4.51E-04	4.15E-03
	(w) Sulfide (S--)	2.44E-07	2.25E-06
	(w) Suspended Matter (unspecified)	4.41E+00	4.06E+01
	(w) TOC (Total Organic Carbon)	4.53E-06	4.18E-05
	(w) Toluene (C6H5CH3)	6.65E-08	6.13E-07
	(w) Zinc (Zn++)	5.63E-08	5.19E-07
	Total (g)		4.59E+02

Note: Water emissions exclude chemically polluted water, which equals	1.00E+01	liters

		Factor for 1 kg	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	2.15E-08	1.98E-07
	(a) Acenaphthylene (C12H8)	8.16E-09	7.52E-08
	(a) Acetaldehyde (CH3CHO)	1.39E-05	1.28E-04
	(a) Acetophenone (C8H8O)	3.65E-07	3.36E-06
	(a) Acrolein (CH2CHCHO)	7.06E-06	6.51E-05
	(a) Aldehyde (unspecified)	6.60E-03	6.08E-02
	(a) Aluminum (Al)	5.63E-05	5.19E-04
	(a) Ammonia (NH3)	9.84E-03	9.07E-02
	(a) Anthracene (C14H10)	8.17E-09	7.53E-08
	(a) Antimony (Sb)	2.81E-06	2.59E-05
	(a) Aromatic Hydrocarbons (unspecified)	2.72E-07	2.51E-06
	(a) Arsenic (As)	4.92E-05	4.53E-04
	(a) Barium (Ba)	1.49E-06	1.37E-05
	(a) Benzene (C6H6)	6.33E-02	5.84E-01
	(a) Benzo(a)anthracene	5.29E-09	4.87E-08
	(a) Benzo(a)pyrene (C20H12)	2.62E-09	2.42E-08
	(a) Benzo(b)fluoranthene	2.24E-09	2.06E-08
	(a) Benzo(bjk)fluoranthene	2.68E-09	2.47E-08
	(a) Benzo(ghi)perylene	2.36E-09	2.18E-08
	(a) Benzo(k)fluoranthene	2.24E-09	2.06E-08
	(a) Benzyl Chloride (C7H7Cl)	1.70E-05	1.57E-04
	(a) Beryllium (Be)	5.15E-06	4.75E-05
	(a) Bromoform (CHBr3)	9.49E-07	8.75E-06
	(a) Butane (C4H10)	2.32E-03	2.14E-02
	(a) Cadmium (Cd)	3.00E-06	2.77E-05
	(a) Calcium (Ca)	4.88E-05	4.50E-04
	(a) Carbon Dioxide (CO2, biomass)	2.46E-04	2.27E-03
	(a) Carbon Dioxide (CO2, fossil)	6.70E+02	6.18E+03
	(a) Carbon Disulfide (CS2)	3.16E-06	2.92E-05
	(a) Carbon Monoxide (CO)	2.00E+00	1.85E+01
	(a) Chlorides (Cl-)	1.57E-04	1.44E-03
	(a) Chlorine (Cl2)	2.35E-08	2.17E-07

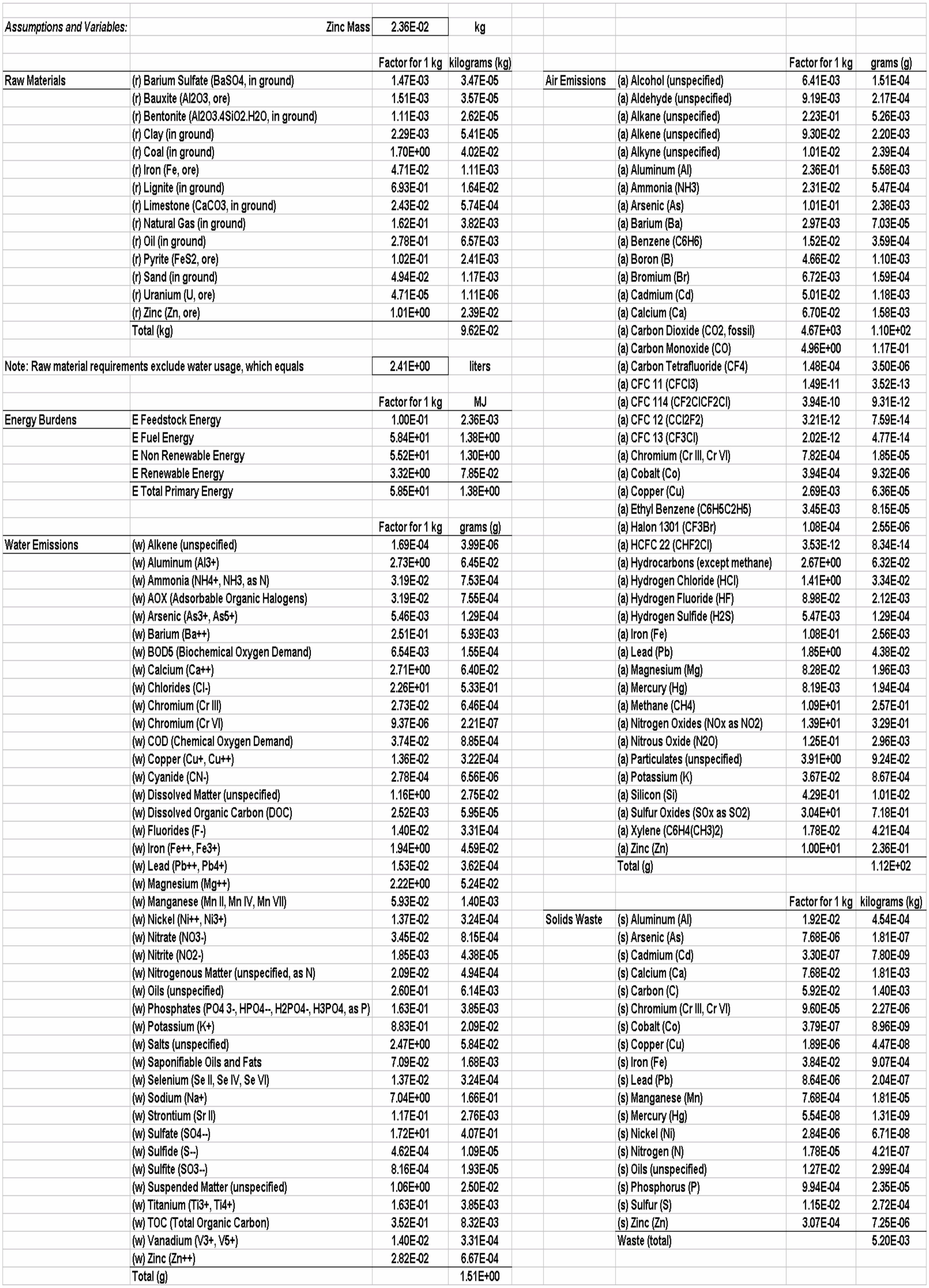
		Factor for 1 kg	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	1.70E-07	1.57E-06
	(a) Chlorobenzene (C6H5Cl)	5.36E-07	4.94E-06
	(a) Chloroform (CHCl3, HC-20)	1.44E-06	1.32E-05
	(a) Chromium (Cr III, Cr VI)	7.66E-05	7.06E-04
	(a) Chrysene (C18H12)	4.82E-09	4.45E-08
	(a) Cobalt (Co)	8.82E-06	8.13E-05
	(a) Copper (Cu)	5.13E-06	4.72E-05
	(a) Cumene (C9H12)	1.29E-07	1.19E-06
	(a) Cyanide (CN-)	6.09E-05	5.61E-04
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	1.78E-06	1.64E-05
	(a) Dibenzo(a,h)anthracene	1.61E-09	1.48E-08
	(a) Dichlorobenzene (1,4-C6H4Cl2)	1.32E-06	1.22E-05
	(a) Dimethyl Benzanthracene (7,12-C20H16)	1.66E-08	1.53E-07
	(a) Dimethyl Sulfate (C2H6O4S)	1.17E-06	1.08E-05
	(a) Dinitrotoluene (2,4-C7H6N2O4)	6.82E-09	6.28E-08
	(a) Dioxins (unspecified)	3.94E-10	3.63E-09
	(a) Diphenyl ((C6H5)2)	4.14E-08	3.81E-07
	(a) Ethane (C2H6)	3.42E-03	3.15E-02
	(a) Ethyl Benzene (C6H5C2H5)	2.32E-06	2.14E-05
	(a) Ethyl Chloride (C2H5Cl)	1.02E-06	9.42E-06
	(a) Ethylene Dibromide (C2H4Br2)	2.92E-08	2.69E-07
	(a) Ethylene Dichloride (C2H4Cl2)	9.74E-07	8.97E-06
	(a) Fluoranthene	2.14E-08	1.97E-07
	(a) Fluorene (C13H10)	2.60E-08	2.40E-07
	(a) Fluorides (F-)	1.75E-05	1.61E-04
	(a) Formaldehyde (CH2O)	3.43E-03	3.16E-02
	(a) Furan (C4H4O)	1.83E-09	1.69E-08
	(a) Halogenated Hydrocarbons (unspecified)	1.51E-12	1.39E-11
	(a) Halon 1301 (CF3Br)	2.63E-09	2.42E-08
	(a) Hexane (C6H14)	1.99E-03	1.83E-02
	(a) Hydrocarbons (except methane)	3.77E-01	3.48E+00
	(a) Hydrocarbons (unspecified)	5.40E-01	4.98E+00
	(a) Hydrogen Chloride (HCl)	2.92E-02	2.69E-01
	(a) Hydrogen Fluoride (HF)	3.65E-03	3.37E-02
	(a) Hydrogen Sulfide (H2S)	8.84E-03	8.15E-02
	(a) Indeno (1,2,3,c,d) Pyrene	3.83E-09	3.53E-08
	(a) Iron (Fe)	1.09E-04	1.00E-03
	(a) Isophorone	1.41E-05	1.30E-04
	(a) Lead (Pb)	4.49E-05	4.14E-04
	(a) Magnesium (Mg)	2.68E-04	2.47E-03
	(a) Manganese (Mn)	8.16E-05	7.52E-04
	(a) Mercury (Hg)	3.18E-06	2.93E-05
	(a) Metals (unspecified)	1.62E-06	1.49E-05
	(a) Methane (CH4)	3.34E+00	3.08E+01
	(a) Methyl Bromide (CH3Br)	3.89E-06	3.59E-05
	(a) Methyl Chloride (CH3Cl)	1.29E-05	1.19E-04
	(a) Methyl Cholanthrene (3-C21H16)	1.99E-09	1.83E-08
	(a) Methyl Chrysene (5-C19H15)	5.36E-10	4.94E-09
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	9.49E-06	8.75E-05
	(a) Methyl Hydrazine (CH6N2)	4.14E-06	3.81E-05
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	4.87E-07	4.49E-06
	(a) Methyl Naphthalene (2-C11H10)	2.65E-08	2.44E-07
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	8.52E-07	7.85E-06
	(a) Methylene Chloride (CH2Cl2, HC-130)	7.06E-06	6.51E-05
	(a) Molybdenum (Mo)	6.16E-06	5.68E-05
	(a) Naphthalene (C10H8)	1.50E-06	1.38E-05
	(a) Nickel (Ni)	3.79E-04	3.49E-03
	(a) Nitrogen Oxides (NOx as NO2)	2.26E+00	2.08E+01
	(a) Nitrous Oxide (N2O)	5.43E-02	5.00E-01
	(a) Organic Matter (unspecified)	3.15E-01	2.91E+00
	(a) Particulates (PM 10)	6.49E-04	5.98E-03
	(a) Particulates (unspecified)	5.07E-01	4.67E+00
	(a) Pentane (C5H12)	2.87E-03	2.65E-02
	(a) Phenanthrene (C14H10)	8.63E-08	7.95E-07
	(a) Phenol (C6H5OH)	3.89E-07	3.59E-06
	(a) Phosphorus (P)	3.73E-05	3.44E-04
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unsp.)	3.02E-10	2.79E-09
	(a) Propane (C3H8)	6.10E-06	5.62E-05
	(a) Propionaldehyde (CH3CH2CHO)	9.25E-06	8.52E-05
	(a) Pyrene (C16H10)	1.43E-08	1.32E-07
	(a) Selenium (Se)	3.36E-05	3.10E-04
	(a) Silicon (Si)	4.88E-05	4.50E-04
	(a) Sodium (Na)	2.89E-04	2.66E-03
	(a) Styrene (C6H5CHCH2)	6.09E-07	5.61E-06
	(a) Sulfur Oxides (SOx as SO2)	3.24E+00	2.98E+01
	(a) Tetrachloroethylene (C2Cl4)	1.05E-06	9.65E-06
	(a) Toluene (C6H5CH3)	1.51E-05	1.40E-04
	(a) Trichloroethane (1,1,1-CH3CCl3)	4.87E-07	4.49E-06
	(a) Vanadium (V)	7.68E-04	7.07E-03
	(a) Vinyl Acetate (C4H6O2)	1.85E-07	1.70E-06
	(a) Xylene (C6H4(CH3)2)	4.37E-06	4.03E-05
	(a) Zinc (Zn)	4.52E-05	4.16E-04
	Total (g)		6.97E+03

		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	2.65E-01	2.44E+00

APPENDIX I
LCI PRODUCTION DATA

1) Zinc
2) Aluminum
3) Steel
4) Cast Iron
5) Copper
6) Manganese
7) Acrylonitrile-Butadiene Styrene (ABS)
8) Styrene-Butadiene
9) Poly Vinyl Chloride (PVC)

Appendix I: LCI Production Data – Zinc



Assumptions and Variables:	Zinc Mass	2.36E-02	kg
		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Barium Sulfate (BaSO4, in ground)	1.47E-03	3.47E-05
	(r) Bauxite (Al2O3, ore)	1.51E-03	3.57E-05
	(r) Bentonite (Al2O3.4SiO2.H2O, in ground)	1.11E-03	2.62E-05
	(r) Clay (in ground)	2.29E-03	5.41E-05
	(r) Coal (in ground)	1.70E+00	4.02E-02
	(r) Iron (Fe, ore)	4.71E-02	1.11E-03
	(r) Lignite (in ground)	6.93E-01	1.64E-02
	(r) Limestone (CaCO3, in ground)	2.43E-02	5.74E-04
	(r) Natural Gas (in ground)	1.62E-01	3.82E-03
	(r) Oil (in ground)	2.78E-01	6.57E-03
	(r) Pyrite (FeS2, ore)	1.02E-01	2.41E-03
	(r) Sand (in ground)	4.94E-02	1.17E-03
	(r) Uranium (U, ore)	4.71E-05	1.11E-06
	(r) Zinc (Zn, ore)	1.01E+00	2.39E-02
	Total (kg)		9.62E-02
Note: Raw material requirements exclude water usage, which equals		2.41E+00	liters
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	1.00E-01	2.36E-03
	E Fuel Energy	5.84E+01	1.38E+00
	E Non Renewable Energy	5.52E+01	1.30E+00
	E Renewable Energy	3.32E+00	7.85E-02
	E Total Primary Energy	5.85E+01	1.38E+00
		Factor for 1 kg	grams (g)
Water Emissions	(w) Alkene (unspecified)	1.69E-04	3.99E-06
	(w) Aluminum (Al3+)	2.73E+00	6.45E-02
	(w) Ammonia (NH4+, NH3, as N)	3.19E-02	7.53E-04
	(w) AOX (Adsorbable Organic Halogens)	3.19E-02	7.55E-04
	(w) Arsenic (As3+, As5+)	5.46E-03	1.29E-04
	(w) Barium (Ba++)	2.51E-01	5.93E-03
	(w) BOD5 (Biochemical Oxygen Demand)	6.54E-03	1.55E-04
	(w) Calcium (Ca++)	2.71E+00	6.40E-02
	(w) Chlorides (Cl-)	2.26E+01	5.33E-01
	(w) Chromium (Cr III)	2.73E-02	6.46E-04
	(w) Chromium (Cr VI)	9.37E-06	2.21E-07
	(w) COD (Chemical Oxygen Demand)	3.74E-02	8.85E-04
	(w) Copper (Cu+, Cu++)	1.36E-02	3.22E-04
	(w) Cyanide (CN-)	2.78E-04	6.56E-06
	(w) Dissolved Matter (unspecified)	1.16E+00	2.75E-02
	(w) Dissolved Organic Carbon (DOC)	2.52E-03	5.95E-05
	(w) Fluorides (F-)	1.40E-02	3.31E-04
	(w) Iron (Fe++, Fe3+)	1.94E+00	4.59E-02
	(w) Lead (Pb++, Pb4+)	1.53E-02	3.62E-04
	(w) Magnesium (Mg++)	2.22E+00	5.24E-02
	(w) Manganese (Mn II, Mn IV, Mn VII)	5.93E-02	1.40E-03
	(w) Nickel (Ni++, Ni3+)	1.37E-02	3.24E-04
	(w) Nitrate (NO3-)	3.45E-02	8.15E-04
	(w) Nitrite (NO2-)	1.85E-03	4.38E-05
	(w) Nitrogenous Matter (unspecified, as N)	2.09E-02	4.94E-04
	(w) Oils (unspecified)	2.60E-01	6.14E-03
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	1.63E-01	3.85E-03
	(w) Potassium (K+)	8.83E-01	2.09E-02
	(w) Salts (unspecified)	2.47E+00	5.84E-02
	(w) Saponifiable Oils and Fats	7.09E-02	1.68E-03
	(w) Selenium (Se II, Se IV, Se VI)	1.37E-02	3.24E-04
	(w) Sodium (Na+)	7.04E+00	1.66E-01
	(w) Strontium (Sr II)	1.17E-01	2.76E-03
	(w) Sulfate (SO4--)	1.72E+01	4.07E-01
	(w) Sulfide (S--)	4.62E-04	1.09E-05
	(w) Sulfite (SO3--)	8.16E-04	1.93E-05
	(w) Suspended Matter (unspecified)	1.06E+00	2.50E-02
	(w) Titanium (Ti3+, Ti4+)	1.63E-01	3.85E-03
	(w) TOC (Total Organic Carbon)	3.52E-01	8.32E-03
	(w) Vanadium (V3+, V5+)	1.40E-02	3.31E-04
	(w) Zinc (Zn++)	2.82E-02	6.67E-04
	Total (g)		1.51E+00

		Factor for 1 kg	grams (g)
Air Emissions	(a) Alcohol (unspecified)	6.41E-03	1.51E-04
	(a) Aldehyde (unspecified)	9.19E-03	2.17E-04
	(a) Alkane (unspecified)	2.23E-01	5.26E-03
	(a) Alkene (unspecified)	9.30E-02	2.20E-03
	(a) Alkyne (unspecified)	1.01E-02	2.39E-04
	(a) Aluminum (Al)	2.36E-01	5.58E-03
	(a) Ammonia (NH3)	2.31E-02	5.47E-04
	(a) Arsenic (As)	1.01E-01	2.38E-03
	(a) Barium (Ba)	2.97E-03	7.03E-05
	(a) Benzene (C6H6)	1.52E-02	3.59E-04
	(a) Boron (B)	4.66E-02	1.10E-03
	(a) Bromium (Br)	6.72E-03	1.59E-04
	(a) Cadmium (Cd)	5.01E-02	1.18E-03
	(a) Calcium (Ca)	6.70E-02	1.58E-03
	(a) Carbon Dioxide (CO2, fossil)	4.67E+03	1.10E+02
	(a) Carbon Monoxide (CO)	4.96E+00	1.17E-01
	(a) Carbon Tetrafluoride (CF4)	1.48E-04	3.50E-06
	(a) CFC 11 (CFCl3)	1.49E-11	3.52E-13
	(a) CFC 114 (CF2ClCF2Cl)	3.94E-10	9.31E-12
	(a) CFC 12 (CCl2F2)	3.21E-12	7.59E-14
	(a) CFC 13 (CF3Cl)	2.02E-12	4.77E-14
	(a) Chromium (Cr III, Cr VI)	7.82E-04	1.85E-05
	(a) Cobalt (Co)	3.94E-04	9.32E-06
	(a) Copper (Cu)	2.69E-03	6.36E-05
	(a) Ethyl Benzene (C6H5C2H5)	3.45E-03	8.15E-05
	(a) Halon 1301 (CF3Br)	1.08E-04	2.55E-06
	(a) HCFC 22 (CHF2Cl)	3.53E-12	8.34E-14
	(a) Hydrocarbons (except methane)	2.67E+00	6.32E-02
	(a) Hydrogen Chloride (HCl)	1.41E+00	3.34E-02
	(a) Hydrogen Fluoride (HF)	8.98E-02	2.12E-03
	(a) Hydrogen Sulfide (H2S)	5.47E-03	1.29E-04
	(a) Iron (Fe)	1.08E-01	2.56E-03
	(a) Lead (Pb)	1.85E+00	4.38E-02
	(a) Magnesium (Mg)	8.28E-02	1.96E-03
	(a) Mercury (Hg)	8.19E-03	1.94E-04
	(a) Methane (CH4)	1.09E+01	2.57E-01
	(a) Nitrogen Oxides (NOx as NO2)	1.39E+01	3.29E-01
	(a) Nitrous Oxide (N2O)	1.25E-01	2.96E-03
	(a) Particulates (unspecified)	3.91E+00	9.24E-02
	(a) Potassium (K)	3.67E-02	8.67E-04
	(a) Silicon (Si)	4.29E-01	1.01E-02
	(a) Sulfur Oxides (SOx as SO2)	3.04E+01	7.18E-01
	(a) Xylene (C6H4(CH3)2)	1.78E-02	4.21E-04
	(a) Zinc (Zn)	1.00E+01	2.36E-01
	Total (g)		1.12E+02
		Factor for 1 kg	kilograms (kg)
Solids Waste	(s) Aluminum (Al)	1.92E-02	4.54E-04
	(s) Arsenic (As)	7.68E-06	1.81E-07
	(s) Cadmium (Cd)	3.30E-07	7.80E-09
	(s) Calcium (Ca)	7.68E-02	1.81E-03
	(s) Carbon (C)	5.92E-02	1.40E-03
	(s) Chromium (Cr III, Cr VI)	9.60E-05	2.27E-06
	(s) Cobalt (Co)	3.79E-07	8.96E-09
	(s) Copper (Cu)	1.89E-06	4.47E-08
	(s) Iron (Fe)	3.84E-02	9.07E-04
	(s) Lead (Pb)	8.64E-06	2.04E-07
	(s) Manganese (Mn)	7.68E-04	1.81E-05
	(s) Mercury (Hg)	5.54E-08	1.31E-09
	(s) Nickel (Ni)	2.84E-06	6.71E-08
	(s) Nitrogen (N)	1.78E-05	4.21E-07
	(s) Oils (unspecified)	1.27E-02	2.99E-04
	(s) Phosphorus (P)	9.94E-04	2.35E-05
	(s) Sulfur (S)	1.15E-02	2.72E-04
	(s) Zinc (Zn)	3.07E-04	7.25E-06
	Waste (total)		5.20E-03

Appendix I (continued): LCI Production Data - Aluminum

Assumptions and Variables:	Aluminum Mass	2.90E-02	kg
		Factor for 1000 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	3.71E+03	1.08E-01
	(r) Coal (in ground)	1.62E+03	4.70E-02
	(r) Iron (Fe, ore)	4.25E-02	1.23E-06
	(r) Lignite (in ground)	2.17E+02	6.30E-03
	(r) Limestone (CaCO3, in ground)	1.74E+02	5.05E-03
	(r) Natural Gas (in ground)	3.61E+02	1.05E-02
	(r) Oil (in ground)	1.30E+03	3.77E-02
	(r) Sand (in ground)	1.85E-02	5.37E-07
	(r) Sodium Chloride (NaCl, in ground or in sea)	5.45E+01	1.58E-03
	(r) Sulfur (S, in ground)	9.80E+00	2.84E-04
	(r) Uranium (U, ore)	7.80E-02	2.26E-06
	Fluorspar (CaF2)	2.54E+01	7.37E-04
	Raw Materials (unspecified)	1.06E+01	3.08E-04
	Total (kg)		2.17E-01
Note: Raw material requirements exclude water usage, which equals		5.16E-02	liters
		Factor for 1000 kg	MJ
Energy Burdens	E Feedstock Energy	1.00E+04	2.90E-01
	E Fuel Energy	1.60E+05	4.65E+00
	E Non Renewable Energy	1.22E+05	3.54E+00
	E Renewable Energy	4.83E+04	1.40E+00
	E Total Primary Energy	1.70E+02	4.94E+00
		Factor for 1000 kg	grams (g)
Water Emissions	(w) Acids (H+)	1.68E+01	4.87E-04
	(w) Aluminum (Al3+)	2.56E+03	7.43E-02
	(w) Ammonia (NH4+, NH3, as N)	6.21E+01	1.80E-03
	(w) AOX (Adsorbable Organic Halogens)	2.25E-01	6.53E-06
	(w) Aromatic Hydrocarbons (unspecified)	5.58E+01	1.62E-03
	(w) Arsenic (As3+, As5+)	5.18E+00	1.50E-04
	(w) Barium (Ba++)	3.65E+02	1.06E-02
	(w) BOD5 (Biochemical Oxygen Demand)	3.51E+00	1.02E-04
	(w) Cadmium (Cd++)	2.06E-01	5.98E-06
	(w) Chlorides (Cl-)	5.32E+04	1.54E+00
	(w) Chlorinated Matter (unspecified, as Cl)	6.23E-02	1.81E-06
	(w) Chromium (Cr III, Cr VI)	2.60E+01	7.54E-04
	(w) COD (Chemical Oxygen Demand)	8.59E+01	2.49E-03
	(w) Copper (Cu+, Cu++)	1.28E+01	3.71E-04
	(w) Cyanide (CN-)	3.02E-01	8.76E-06
	(w) Dissolved Organic Carbon (DOC)	5.35E+00	1.55E-04
	(w) Fluorides (F-)	2.71E+00	7.86E-05
	(w) Hydrocarbons (unspecified)	1.70E+00	4.93E-05
	(w) Inorganic Dissolved Matter (unspecified)	3.46E+04	1.00E+00
	(w) Iron (Fe++, Fe3+)	1.11E+03	3.22E-02
	(w) Lead (Pb++, Pb4+)	1.41E+01	4.09E-04
	(w) Mercury (Hg+, Hg++)	4.98E-03	1.44E-07
	(w) Metals (unspecified)	6.68E+02	1.94E-02
	(w) Nickel (Ni++, Ni3+)	1.30E+01	3.77E-04
	(w) Nitrate (NO3-)	9.60E+01	2.78E-03
	(w) Nitrogenous Matter (unspecified, as N)	6.49E+01	1.88E-03
	(w) Oils (unspecified)	1.73E+03	5.02E-02
	(w) Phenol (C6H5OH)	9.37E+00	2.72E-04
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	4.99E+01	1.45E-03
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	1.79E+01	5.19E-04
	(w) Sulfate (SO4--)	1.85E+04	5.37E-01
	(w) Sulfide (S--)	2.03E+00	5.89E-05
	(w) Suspended Matter (unspecified)	5.01E+03	1.45E-01
	(w) TOC (Total Organic Carbon)	8.69E+02	2.52E-02
	(w) Toluene (C6H5CH3)	7.73E+00	2.24E-04
	(w) Zinc (Zn++)	2.62E+01	7.60E-04
	Total (g)		3.46E+00

		Factor for 1000 kg	grams (g)
Air Emissions	(a) Aldehyde (unspecified)	1.00E-01	2.90E-06
	(a) Ammonia (NH3)	1.45E+01	4.21E-04
	(a) Aromatic Hydrocarbons (unspecified)	5.83E+01	1.69E-03
	(a) Benzene (C6H6)	1.63E+01	4.73E-04
	(a) Cadmium (Cd)	2.71E-01	7.86E-06
	(a) Carbon Dioxide (CO2, fossil)	8.22E+06	2.38E+02
	(a) Carbon Monoxide (CO)	6.16E+04	1.79E+00
	(a) Carbon Tetrafluoride (CF4)	4.00E+02	1.16E-02
	(a) Fluorides (F-)	8.24E+02	2.39E-02
	(a) Halogenated Matter (unspecified)	2.01E-03	5.83E-08
	(a) Halon 1301 (CF3Br)	3.09E-01	8.96E-06
	(a) Hydrocarbons (except methane)	1.12E+04	3.24E-01
	(a) Hydrogen Chloride (HCl)	7.48E+02	2.17E-02
	(a) Hydrogen Fluoride (HF)	7.79E+01	2.26E-03
	(a) Lead (Pb)	1.10E+00	3.19E-05
	(a) Manganese (Mn)	3.42E-01	9.92E-06
	(a) Mercury (Hg)	1.21E-01	3.51E-06
	(a) Metals (unspecified)	2.36E+02	6.85E-03
	(a) Methane (CH4)	1.80E+04	5.22E-01
	(a) Nickel (Ni)	8.88E+00	2.58E-04
	(a) Nitrogen Oxides (NOx as NO2)	1.70E+04	4.93E-01
	(a) Nitrous Oxide (N2O)	4.57E+01	1.33E-03
	(a) Particulates (unspecified)	2.16E+04	6.27E-01
	(a) Polycyclic Aromatic Hydrocarbons (PAH, except naphthalene)	4.00E+01	1.16E-03
	(a) Sulfur Oxides (SOx as SO2)	5.65E+04	1.64E+00
	(a) Zinc (Zn)	2.29E+00	6.64E-05
	Total (g)		2.44E+02
		Factor for 1000 kg	kilograms (kg)
Solids Waste	Waste (total)	2.12E+02	6.15E-03

Appendix I (continued): LCI Production Data - Steel

Assumptions and Variables:	Steel Mass	1.38E-02	kg
		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.57E-06	3.55E-08
	(r) Coal (in ground)	7.24E-01	1.00E-02
	(r) Iron (Fe, ore)	1.21E+00	1.67E-02
	(r) Limestone (CaCO3, in ground)	1.62E-01	2.24E-03
	(r) Natural Gas (in ground)	5.32E-02	7.36E-04
	(r) Oil (in ground)	4.35E-02	6.02E-04
	(r) Sand (in ground)	1.57E-06	2.18E-08
	(r) Sodium Chloride (NaCl, in ground or in sea)	7.22E-07	9.99E-09
	(r) Uranium (U, ore)	2.17E-06	3.00E-08
	Iron Scrap	1.72E-01	2.38E-03
	Total (kg)		3.27E-02
Note: Raw material requirements exclude water usage, which equals		1.16E+00	liters
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	1.42E+01	1.96E-01
	E Fuel Energy	1.28E+01	1.77E-01
	E Non Renewable Energy	2.68E+01	3.70E-01
	E Renewable Energy	1.74E-01	2.41E-03
	E Total Primary Energy	2.69E+01	3.73E-01
		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	1.27E-07	1.76E-09
	(w) Aluminum (Al3+)	8.18E-06	1.13E-07
	(w) Ammonia (NH4+, NH3, as N)	1.30E-01	1.79E-03
	(w) AOX (Adsorbable Organic Halogens)	2.16E-11	2.99E-13
	(w) Aromatic Hydrocarbons (unspecified)	5.06E-09	7.00E-11
	(w) Barium (Ba++)	1.62E-08	2.24E-10
	(w) BOD5 (Biochemical Oxygen Demand)	2.29E-02	3.17E-04
	(w) Cadmium (Cd++)	1.69E-11	2.34E-13
	(w) Chlorides (Cl-)	8.89E-01	1.23E-02
	(w) Chromium (Cr III, Cr VI)	3.41E-08	4.72E-10
	(w) COD (Chemical Oxygen Demand)	1.40E-01	1.93E-03
	(w) Copper (Cu+, Cu++)	3.37E-10	4.66E-12
	(w) Cyanide (CN-)	9.15E-05	1.27E-06
	(w) Dissolved Matter (unspecified)	2.02E-02	2.79E-04
	(w) Fluorides (F-)	1.29E-02	1.78E-04
	(w) Halogenated Matter (organic)	6.74E-12	9.33E-14
	(w) Hydrocarbons (unspecified)	3.87E-05	5.36E-07
	(w) Iron (Fe++, Fe3+)	6.48E-07	8.97E-09
	(w) Lead (Pb++, Pb4+)	6.74E-11	9.33E-13
	(w) Mercury (Hg+, Hg++)	1.57E-05	2.17E-07
	(w) Metals (unspecified)	9.50E-04	1.31E-05
	(w) Nickel (Ni++, Ni3+)	3.37E-11	4.66E-13
	(w) Nitrate (NO3-)	3.01E-04	4.16E-06
	(w) Nitrogenous Matter (unspecified, as N)	9.10E-10	1.26E-11
	(w) Oils (unspecified)	2.51E-01	3.48E-03
	(w) Organic Matter (unspecified)	3.33E-07	4.61E-09
	(w) Phenol (C6H5OH)	5.54E-04	7.66E-06
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.44E-08	4.76E-10
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	8.09E-11	1.12E-12
	(w) Salts (unspecified)	9.32E-05	1.29E-06
	(w) Sodium (Na+)	7.77E-01	1.08E-02
	(w) Sulfate (SO4--)	7.38E-05	1.02E-06
	(w) Sulfide (S--)	1.83E-04	2.53E-06
	(w) Suspended Matter (unspecified)	2.22E-01	3.07E-03
	(w) TOC (Total Organic Carbon)	5.06E-08	7.00E-10
	(w) Toluene (C6H5CH3)	7.41E-10	1.03E-11
	(w) Zinc (Zn++)	8.32E-09	1.15E-10
	Total (g)		3.41E-02
		Factor for 1 kg	kilograms (kg)
Solids Waste	Waste (total)	9.06E-01	1.25E-02

		Factor for 1 kg	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	1.09E-07	1.51E-09
	(a) Acenaphthylene (C12H8)	3.12E-08	4.32E-10
	(a) Acetaldehyde (CH3CHO)	6.66E-05	9.22E-07
	(a) Acetophenone (C8H8O)	1.75E-06	2.42E-08
	(a) Acrolein (CH2CHCHO)	3.39E-05	4.69E-07
	(a) Aldehyde (unspecified)	1.46E-02	2.02E-04
	(a) Aluminum (Al)	4.25E-05	5.88E-07
	(a) Ammonia (NH3)	7.72E-02	1.07E-03
	(a) Anthracene (C14H10)	2.92E-08	4.04E-10
	(a) Antimony (Sb)	1.57E-05	2.17E-07
	(a) Aromatic Hydrocarbons (unspecified)	3.03E-09	4.19E-11
	(a) Arsenic (As)	2.12E-04	2.94E-06
	(a) Barium (Ba)	7.09E-06	9.81E-08
	(a) Benzene (C6H6)	1.95E-02	2.69E-04
	(a) Benzo(a)anthracene	1.99E-08	2.75E-10
	(a) Benzo(a)pyrene (C20H12)	8.84E-09	1.22E-10
	(a) Benzo(b)fluoranthene	3.09E-09	4.28E-11
	(a) Benzo(bjk)fluoranthene	1.29E-08	1.79E-10
	(a) Benzo(ghi)perylene	6.68E-09	9.25E-11
	(a) Benzo(k)fluoranthene	3.09E-09	4.28E-11
	(a) Benzyl Chloride (C7H7Cl)	8.18E-05	1.13E-06
	(a) Beryllium (Be)	2.41E-05	3.34E-07
	(a) Bromoform (CHBr3)	4.56E-06	6.31E-08
	(a) Butane (C4H10)	1.64E-03	2.26E-05
	(a) Cadmium (Cd)	1.52E-05	2.10E-07
	(a) Calcium (Ca)	3.69E-05	5.11E-07
	(a) Carbon Dioxide (CO2, biomass)	6.29E-04	8.70E-06
	(a) Carbon Dioxide (CO2, fossil)	2.34E+03	3.24E+01
	(a) Carbon Disulfide (CS2)	1.52E-05	2.10E-07
	(a) Carbon Monoxide (CO)	8.10E-01	1.12E-02
	(a) Chlorides (Cl-)	8.98E-04	1.24E-05
	(a) Chlorine (Cl2)	7.17E-09	9.92E-11
	(a) Chloroacetophenone (2-C8H7ClO)	8.18E-07	1.13E-08
	(a) Chlorobenzene (C6H5Cl)	2.57E-06	3.56E-08
	(a) Chloroform (CHCl3, HC-20)	6.90E-06	9.55E-08
	(a) Chromium (Cr III, Cr VI)	3.74E-04	5.17E-06
	(a) Chrysene (C18H12)	1.58E-08	2.19E-10
	(a) Cobalt (Co)	3.01E-05	4.17E-07
	(a) Copper (Cu)	7.94E-06	1.10E-07
	(a) Cumene (C9H12)	6.20E-07	8.58E-09
	(a) Cyanide (CN-)	2.92E-04	4.05E-06
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	8.53E-06	1.18E-07
	(a) Dibenzo(a,h)anthracene	2.84E-09	3.93E-11
	(a) Dichlorobenzene (1,4-C6H4Cl2)	9.35E-07	1.29E-08
	(a) Dimethyl Benzanthracene (7,12-C20H16)	1.17E-08	1.62E-10
	(a) Dimethyl Sulfate (C2H6O4S)	5.61E-06	7.76E-08
	(a) Dinitrotoluene (2,4-C7H6N2O4)	3.27E-08	4.53E-10
	(a) Dioxins (unspecified)	2.19E-09	3.03E-11
	(a) Diphenyl ((C6H5)2)	1.99E-07	2.75E-09
	(a) Ethane (C2H6)	2.42E-03	3.34E-05
	(a) Ethyl Benzene (C6H5C2H5)	1.12E-05	1.55E-07
	(a) Ethyl Chloride (C2H5Cl)	4.91E-06	6.80E-08
	(a) Ethylene Dibromide (C2H4Br2)	1.40E-07	1.94E-09
	(a) Ethylene Dichloride (C2H4Cl2)	4.68E-06	6.48E-08
	(a) Fluoranthene	9.09E-08	1.26E-09
	(a) Fluorene (C13H10)	1.14E-07	1.58E-09
	(a) Fluorides (F-)	9.82E-05	1.36E-06
	(a) Formaldehyde (CH2O)	4.80E-04	6.65E-06
	(a) Furan (C4H4O)	1.02E-08	1.41E-10
	(a) Halogenated Hydrocarbons (unspecified)	1.69E-14	2.34E-16
	(a) Halon 1301 (CF3Br)	2.93E-11	4.06E-13
	(a) Hexane (C6H14)	1.41E-03	1.95E-05
	(a) Hydrocarbons (except methane)	9.05E-02	1.25E-03
	(a) Hydrocarbons (unspecified)	1.25E+00	1.73E-02
	(a) Hydrogen Chloride (HCl)	1.40E-01	1.94E-03
	(a) Hydrogen Fluoride (HF)	1.75E-02	2.43E-04
	(a) Hydrogen Sulfide (H2S)	3.42E-04	4.73E-06
	(a) Indeno (1,2,3,c,d) Pyrene	1.10E-08	1.52E-10
	(a) Iron (Fe)	8.22E-05	1.14E-06
	(a) Isophorone	6.78E-05	9.38E-07
	(a) Lead (Pb)	2.33E-04	3.22E-06
	(a) Magnesium (Mg)	1.29E-03	1.78E-05
	(a) Manganese (Mn)	4.27E-04	5.91E-06
	(a) Mercury (Hg)	1.31E-05	1.81E-07
	(a) Metals (unspecified)	2.50E-08	3.46E-10
	(a) Methane (CH4)	3.95E+00	5.47E-02
	(a) Methyl Bromide (CH3Br)	1.87E-05	2.59E-07
	(a) Methyl Chloride (CH3Cl)	6.20E-05	8.58E-07
	(a) Methyl Cholanthrene (3-C21H16)	1.40E-09	1.94E-11
	(a) Methyl Chrysene (5-C19H15)	2.57E-09	3.56E-11
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	4.56E-05	6.31E-07
	(a) Methyl Hydrazine (CH6N2)	1.99E-05	2.75E-07
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	2.34E-06	3.24E-08
	(a) Methyl Naphthalene (2-C11H10)	1.87E-08	2.59E-10
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	4.09E-06	5.66E-08
	(a) Methylene Chloride (CH2Cl2, HC-130)	3.39E-05	4.69E-07
	(a) Molybdenum (Mo)	6.53E-06	9.04E-08
	(a) Naphthalene (C10H8)	4.92E-06	6.81E-08
	(a) Nickel (Ni)	7.34E-04	1.02E-05
	(a) Nitrogen Oxides (NOx as NO2)	3.65E+00	5.06E-02
	(a) Nitrous Oxide (N2O)	5.66E-02	7.84E-04
	(a) Organic Matter (unspecified)	9.70E-02	1.34E-03
	(a) Particulates (PM 10)	2.51E-05	3.47E-07
	(a) Particulates (unspecified)	2.12E+01	2.94E-01
	(a) Pentane (C5H12)	2.03E-03	2.80E-05
	(a) Phenanthrene (C14H10)	3.41E-07	4.72E-09
	(a) Phenol (C6H5OH)	1.87E-06	2.59E-08
	(a) Phosphorus (P)	4.94E-05	6.84E-07
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	3.37E-12	4.66E-14
	(a) Propane (C3H8)	1.58E-05	2.19E-07
	(a) Propionaldehyde (CH3CH2CHO)	4.44E-05	6.14E-07
	(a) Pyrene (C16H10)	4.73E-08	6.55E-10
	(a) Selenium (Se)	1.55E-04	2.15E-06
	(a) Silicon (Si)	3.69E-05	5.11E-07
	(a) Sodium (Na)	2.18E-04	3.02E-06
	(a) Styrene (C6H5CHCH2)	2.92E-06	4.04E-08
	(a) Sulfur Oxides (SOx as SO2)	6.45E+00	8.92E-02
	(a) Tetrachloroethylene (C2Cl4)	5.03E-06	6.96E-08
	(a) Toluene (C6H5CH3)	4.94E-05	6.84E-07
	(a) Trichloroethane (1,1,1-CH3CCl3)	2.34E-06	3.24E-08
	(a) Vanadium (V)	6.51E-04	9.01E-06
	(a) Vinyl Acetate (C4H6O2)	8.89E-07	1.23E-08
	(a) Xylene (C6H4(CH3)2)	5.65E-06	7.82E-08
	(a) Zinc (Zn)	9.79E-05	1.35E-06
	Total (g)		3.29E+01

Appendix I (continued): LCI Production Data – Cast Iron

Assumptions and Variables:	Cast Iron Mass	2.31E-01	kg
		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.10E-03	4.86E-04
	(r) Bentonite (Al2O3.4SiO2.H2O, in ground)	3.29E-07	7.61E-08
	(r) Clay (in ground)	2.79E-07	6.45E-08
	(r) Coal (in ground)	7.77E-01	1.80E-01
	(r) Gypsum (CaSO4: in ground)	1.55E-08	3.59E-09
	(r) Ilmenite (FeO.TiO2, ore)	4.99E-05	1.15E-05
	(r) Iron (Fe, ore)	5.07E-01	1.17E-01
	(r) Limestone (CaCO3, in ground)	2.02E-01	4.66E-02
	(r) Natural Gas (in ground)	1.36E-01	3.14E-02
	(r) Oil (in ground)	4.37E-02	1.01E-02
	(r) Perlite (SiO2, ore)	1.70E-02	3.92E-03
	(r) Sand (in ground)	5.46E-01	1.26E-01
	(r) Sodium Carbonate (Na2CO3, in ground)	1.16E-05	2.68E-06
	(r) Sodium Chloride (NaCl, in ground or in sea)	1.23E-04	2.85E-05
	(r) Uranium (U, ore)	2.59E-06	5.99E-07
	Iron Scrap	9.79E-01	2.26E-01
	Raw Materials (Iron Casting Alloys)	8.49E-02	1.96E-02
	Raw Materials (unspecified)	2.08E-02	4.80E-03
	Total (kg)		7.67E-01
Note: Raw material requirements exclude water usage, which equals		8.00E+00	liters
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.39E-01	1.01E-01
	E Fuel Energy	3.24E+01	7.50E+00
	E Non Renewable Energy	3.28E+01	7.58E+00
	E Renewable Energy	7.81E-02	1.81E-02
	E Total Primary Energy	3.28E+01	7.60E+00
		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	1.48E-04	3.43E-05
	(w) Ammonia (NH4+, NH3, as N)	4.52E-03	1.05E-03
	(w) Arsenic (As3+, As5+)	1.76E-08	4.07E-09
	(w) Benzene (C6H6)	4.15E-07	9.60E-08
	(w) BOD5 (Biochemical Oxygen Demand)	4.69E-02	1.09E-02
	(w) Boron (B)	8.73E-06	2.02E-06
	(w) Calcium (Ca++)	3.17E-04	7.33E-05
	(w) Chlorides (Cl-)	4.69E-01	1.09E-01
	(w) Chromium (Cr III)	4.19E-06	9.69E-07
	(w) Chromium (Cr III, Cr VI)	5.06E-06	1.17E-06
	(w) COD (Chemical Oxygen Demand)	1.73E-01	4.01E-02
	(w) Copper (Cu+, Cu++)	1.50E-04	3.47E-05
	(w) Cyanides (CN-)	3.84E-05	8.88E-06
	(w) Dissolved Matter (unspecified)	2.13E+00	4.93E-01
	(w) Fluorides (F-)	3.81E-03	8.82E-04
	(w) Formaldehyde	5.90E-03	1.36E-03
	(w) Heavy Metals (total)	6.16E-03	1.42E-03
	(w) Hydrocarbons (unspecified)	2.18E-04	5.05E-05
	(w) Inorganic Dissolved Matter (unspecified)	1.24E-03	2.86E-04
	(w) Iron (Fe++, Fe3+)	3.32E-03	7.69E-04
	(w) Manganese (Mn II, Mn IV, Mn VII)	4.38E-03	1.01E-03
	(w) Metals (unspecified)	3.80E-03	8.79E-04
	(w) Mobile Ions	1.22E-04	2.81E-05
	(w) Nickel (Ni++, Ni3+)	4.21E-04	9.75E-05
	(w) Nitrates (NO3-)	8.80E-05	2.04E-05
	(w) Nitrogenous Matter (unspecified, as N)	2.50E-05	5.78E-06
	(w) Oils (unspecified)	1.19E-02	2.74E-03
	(w) Organic Dissolved Matter (unspecified)	4.19E-05	9.69E-06
	(w) Phenol (C6H6O)	1.61E-03	3.73E-04
	(w) Sodium (Na+)	5.98E-01	1.38E-01
	(w) Sulfates (SO4--)	7.74E-04	1.79E-04
	(w) Sulfides (S--)	7.67E-05	1.77E-05
	(w) Sulfurated Matter (unspecified, as S)	4.42E-06	1.02E-06
	(w) Suspended Matter (unspecified)	2.61E+00	6.04E-01
	(w) Water (unspecified)	6.15E-02	1.42E-02
	(w) Water: Chemically Polluted	5.10E-02	1.18E-02
	(w) Zinc (Zn++)	1.20E-03	2.77E-04
	Total (g)		1.43E+00

		Factor for 1 kg	grams (g)
Air Emissions	(a) Aldehydes	1.06E-02	2.45E-03
	(a) Ammonia (NH3)	3.11E-02	7.20E-03
	(a) Arsenic (As)	3.35E-13	7.75E-14
	(a) Cadmium (Cd)	2.38E-05	5.51E-06
	(a) Carbon Dioxide (CO2, fossil)	2.62E+03	6.06E+02
	(a) Carbon Monoxide (CO)	1.82E+00	4.22E-01
	(a) Chlorinated Matter (unspecified, as Cl)	1.69E-09	3.91E-10
	(a) Chromium (Cr)	6.24E-04	1.44E-04
	(a) Copper (Cu)	1.35E-03	3.12E-04
	(a) Fluorides (F-)	1.90E-06	4.40E-07
	(a) Formaldehyde	4.03E-06	9.32E-07
	(a) Formaldehyde (CH2O)	2.52E-03	5.83E-04
	(a) Heavy Metals (total)	4.47E-02	1.03E-02
	(a) Hydrocarbons (except methane)	6.29E+00	1.45E+00
	(a) Hydrogen Chloride (HCl)	1.37E-02	3.17E-03
	(a) Hydrogen Fluoride (HF)	1.93E-03	4.46E-04
	(a) Hydrogen Sulfide (H2S)	5.39E-04	1.25E-04
	(a) Lead (Pb)	3.60E-04	8.33E-05
	(a) Manganese (Mn)	3.20E-02	7.41E-03
	(a) Mercury (Hg)	9.31E-06	2.15E-06
	(a) Metals (unspecified)	3.11E-03	7.20E-04
	(a) Methane (CH4)	4.57E+00	1.06E+00
	(a) Nickel (Ni)	8.77E-04	2.03E-04
	(a) Nitrogen Oxides (NOx as NO2)	4.88E+00	1.13E+00
	(a) Nitrous Oxide (N2O)	1.80E-01	4.16E-02
	(a) Organic Matter (unspecified)	7.73E-03	1.79E-03
	(a) Particulates (unspecified)	2.04E+01	4.73E+00
	(a) Sulfur Oxides (SOx as SO2)	8.57E+00	1.98E+00
	(a) Zinc (Zn)	9.78E-03	2.26E-03
	Total (g)		6.17E+02
		Factor for 1 kg	kilograms (kg)
Solids Waste	Waste (FGD Sludge)	5.13E-03	1.19E-03
	Waste (hazardous)	3.46E-03	8.01E-04
	Waste (municipal and industrial)	2.09E-03	4.83E-04
	Waste (non-hazardous)	4.23E-02	9.78E-03
	Waste (total)	4.73E-01	1.10E-01

Appendix I (continued): LCI Production Data – Copper

Assumptions and Variables:	Copper Mass	0.082	kg

		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Barium Sulfate (BaSO4, in ground)	3.76E-03	3.09E-04
	(r) Bauxite (Al2O3, ore)	1.60E-03	1.32E-04
	(r) Bentonite (Al2O3.4SiO2.H2O, in ground)	1.03E-03	8.47E-05
	(r) Clay (in ground)	4.05E-03	3.33E-04
	(r) Coal (in ground)	7.73E-01	6.36E-02
	(r) Copper (Cu, ore)	1.00E+00	8.23E-02
	(r) Iron (Fe, ore)	1.91E-02	1.57E-03
	(r) Lignite (in ground)	7.18E-01	5.91E-02
	(r) Limestone (CaCO3, in ground)	2.80E-02	2.30E-03
	(r) Natural Gas (in ground)	5.05E-01	4.15E-02
	(r) Oil (in ground)	6.56E-01	5.40E-02
	(r) Pyrite (FeS2, ore)	5.30E-01	4.36E-02
	(r) Sand (in ground)	1.66E-02	1.37E-03
	(r) Sodium Chloride (NaCl, in ground or in sea)	1.74E-03	1.43E-04
	(r) Uranium (U, ore)	5.00E-05	4.11E-06
	Wood	1.01E-02	8.31E-04
	Total (kg)		3.51E-01

Note: Raw material requirements exclude water usage, which equals	8.64E+00	liters

		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.19E-01	3.44E-02
	E Fuel Energy	7.36E+01	6.05E+00
	E Non Renewable Energy	7.03E+01	5.78E+00
	E Renewable Energy	3.68E+00	3.02E-01
	E Total Primary Energy	7.40E+01	6.09E+00

		Factor for 1 kg	grams (g)
Water Emissions	(w) Aluminum (Al3+)	1.27E+00	1.04E-01
	(w) Ammonia (NH4+, NH3, as N)	4.95E-02	4.07E-03
	(w) AOX (Adsorbable Organic Halogens)	1.01E-04	8.27E-06
	(w) Arsenic (As3+, As5+)	2.53E-03	2.08E-04
	(w) Barium (Ba++)	1.78E-01	1.47E-02
	(w) Barytes	7.12E-01	5.86E-02
	(w) Benzene (C6H6)	4.19E-03	3.45E-04
	(w) BOD5 (Biochemical Oxygen Demand)	5.85E-03	4.81E-04
	(w) Calcium (Ca++)	2.40E+00	1.98E-01
	(w) Chlorides (Cl-)	2.55E+01	2.10E+00
	(w) Chromium (Cr VI)	1.88E-06	1.55E-07
	(w) COD (Chemical Oxygen Demand)	1.02E-01	8.38E-03
	(w) Copper (Cu+, Cu++)	6.31E-03	5.19E-04
	(w) Cyanide (CN-)	4.49E-04	3.69E-05
	(w) Dissolved Matter (unspecified)	5.16E-01	4.24E-02
	(w) Dissolved Organic Carbon (DOC)	8.54E-03	7.02E-04
	(w) Fluorides (F-)	1.02E-02	8.38E-04
	(w) Iron (Fe++, Fe3+)	1.55E+00	1.28E-01
	(w) Lead (Pb++, Pb4+)	7.48E-03	6.15E-04
	(w) Magnesium (Mg++)	1.06E+00	8.75E-02
	(w) Mercury (Hg+, Hg++)	4.25E-06	3.50E-07
	(w) Nitrate (NO3-)	4.08E-02	3.36E-03
	(w) Nitrite (NO2-)	1.98E-03	1.63E-04
	(w) Oils (unspecified)	6.16E-01	5.07E-02
	(w) Phenol (C6H5OH)	4.00E-03	3.29E-04
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	7.51E-02	6.17E-03
	(w) Potassium (K+)	5.24E-01	4.31E-02
	(w) Salts (unspecified)	2.60E+00	2.14E-01
	(w) Saponifiable Oils and Fats	1.59E-01	1.31E-02
	(w) Sodium (Na+)	1.18E+01	9.68E-01
	(w) Strontium (Sr II)	2.03E-01	1.67E-02
	(w) Sulfate (SO4--)	1.15E+01	9.43E-01
	(w) Sulfide (S--)	8.36E-04	6.88E-05
	(w) Sulfite (SO3--)	1.09E-03	8.97E-05
	(w) Suspended Matter (unspecified)	2.33E+00	1.92E-01
	(w) TOC (Total Organic Carbon)	8.39E-01	6.90E-02
	(w) Zinc (Zn++)	1.39E-02	1.14E-03
	Total (g)		5.27E+00

		Factor for 1 kg	grams (g)
Air Emissions	(a) Aldehyde (unspecified)	3.99E-05	3.28E-06
	(a) Alkane (unspecified)	3.28E-01	2.70E-02
	(a) Ammonia (NH3)	8.97E-03	7.37E-04
	(a) Arsenic (As)	1.79E-04	1.47E-05
	(a) Benzene (C6H6)	1.64E-02	1.35E-03
	(a) Carbon Dioxide (CO2, fossil)	5.21E+03	4.29E+02
	(a) Carbon Monoxide (CO)	2.00E+00	1.64E-01
	(a) Copper (Cu)	1.43E-02	1.18E-03
	(a) Halon 1301 (CF3Br)	2.56E-04	2.11E-05
	(a) Hydrocarbons (except methane)	5.40E+00	4.44E-01
	(a) Hydrogen Chloride (HCl)	4.22E-01	3.47E-02
	(a) Hydrogen Fluoride (HF)	5.56E-02	4.57E-03
	(a) Hydrogen Sulfide (H2S)	1.48E-02	1.21E-03
	(a) Iron (Fe)	2.63E-02	2.16E-03
	(a) Lead (Pb)	1.60E-02	1.32E-03
	(a) Methane (CH4)	1.02E+01	8.42E-01
	(a) Nitrogen Oxides (NOx as NO2)	8.00E+00	6.58E-01
	(a) Nitrous Oxide (N2O)	1.30E-01	1.07E-02
	(a) Particulates (unspecified)	2.65E+00	2.18E-01
	(a) Phosphorus (P)	2.68E-03	2.20E-04
	(a) Silicon (Si)	1.35E-01	1.11E-02
	(a) Sulfur Oxides (SOx as SO2)	1.36E+02	1.12E+01
	(a) Zinc (Zn)	1.36E-01	1.12E-02
	Total (g)		4.42E+02

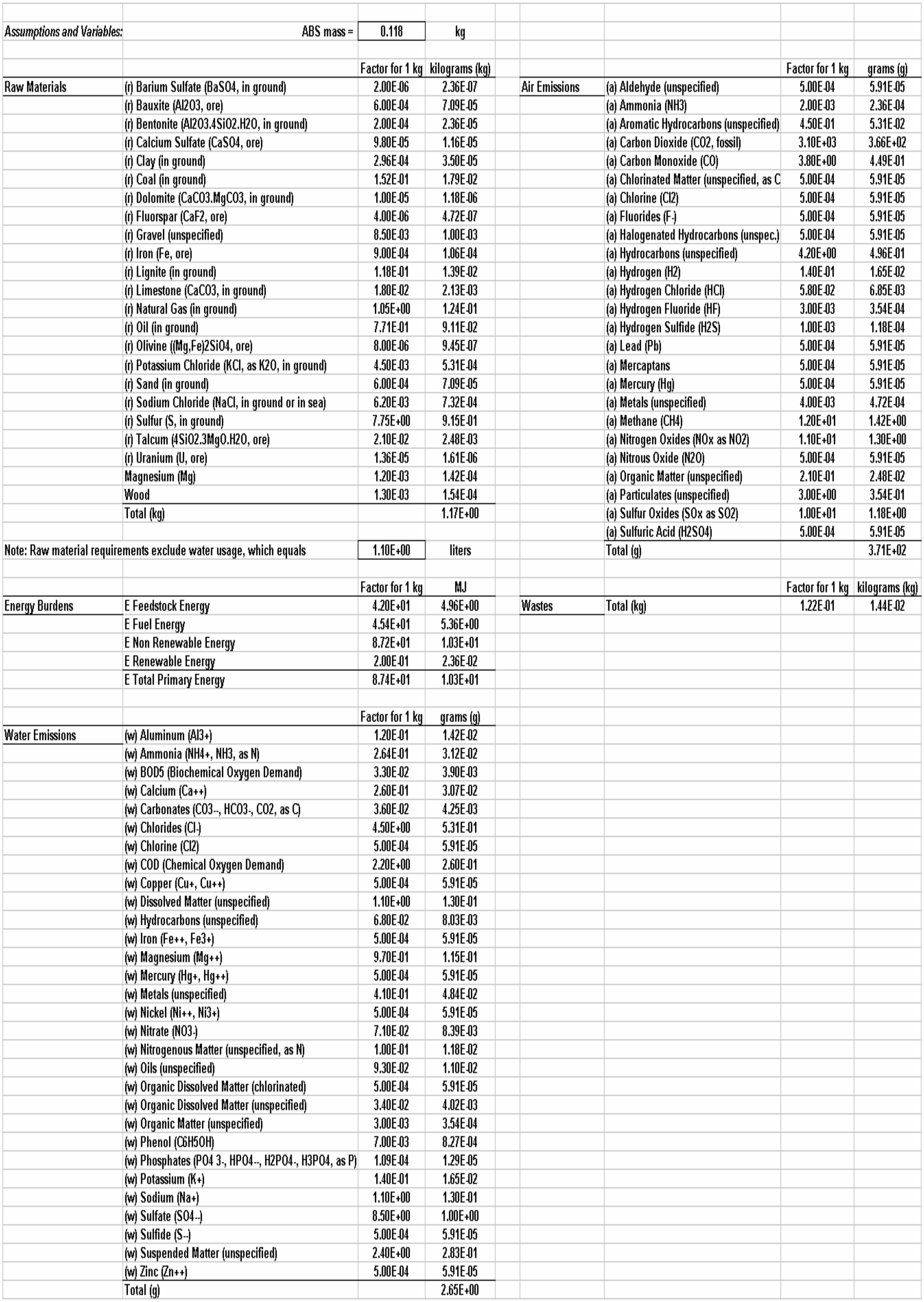
		Factor for 1 kg	kilograms (g)
Solids Waste	(s) Aluminum (Al)	5.11E-02	4.20E-03
	(s) Arsenic (As)	2.04E-05	1.68E-06
	(s) Cadmium (Cd)	7.43E-07	6.11E-08
	(s) Calcium (Ca)	2.04E-01	1.68E-02
	(s) Carbon (C)	1.57E-01	1.29E-02
	(s) Chromium (Cr III, Cr VI)	2.55E-04	2.10E-05
	(s) Cobalt (Co)	8.51E-07	7.00E-08
	(s) Copper (Cu)	4.25E-06	3.50E-07
	(s) Iron (Fe)	1.02E-01	8.39E-03
	(s) Lead (Pb)	1.94E-05	1.60E-06
	(s) Manganese (Mn)	2.04E-03	1.68E-04
	(s) Mercury (Hg)	1.32E-07	1.09E-08
	(s) Nickel (Ni)	6.38E-06	5.25E-07
	(s) Oils (unspecified)	2.78E-02	2.28E-03
	(s) Sulfur (S)	3.07E-02	2.53E-03
	(s) Zinc (Zn)	8.09E-04	6.65E-05
	Total (kg)		4.74E-05

Appendix I (continued): LCI Production Data – Manganese

Assumptions and Variables:	Manganese Mass	0.011	kg
		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Barium Sulfate (BaSO4, in ground)	1.71E-03	1.91E-05
	(r) Bauxite (Al2O3, ore)	2.63E-03	2.94E-05
	(r) Bentonite (Al2O3.4SiO2.H2O, in ground)	1.59E-03	1.78E-05
	(r) Clay (in ground)	2.49E-03	2.78E-05
	(r) Coal (in ground)	1.27E+00	1.42E-02
	(r) Copper (Cu, ore)	1.16E-03	1.30E-05
	(r) Iron (Fe, ore)	1.69E-02	1.89E-04
	(r) Lignite (in ground)	1.61E+00	1.80E-02
	(r) Limestone (CaCO3, in ground)	3.13E-02	3.50E-04
	(r) Manganese (Mn, ore)	1.00E+00	1.12E-02
	(r) Natural Gas (in ground)	2.84E-01	3.17E-03
	(r) Oil (in ground)	3.18E-01	3.55E-03
	(r) Pyrite (FeS2, ore)	7.44E-02	8.31E-04
	(r) Sand (in ground)	7.34E-03	8.20E-05
	(r) Sodium Chloride (NaCl, in ground or in sea)	1.04E-03	1.16E-05
	(r) Uranium (U, ore)	1.09E-04	1.22E-06
	Total (kg)		5.16E-02
Note: Raw material requirements exclude water usage, which equals		2.56E+00	liters
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	1.00E-01	1.12E-03
	E Fuel Energy	6.99E+01	7.81E-01
	E Non Renewable Energy	6.26E+01	6.99E-01
	E Renewable Energy	7.40E+00	8.27E-02
	E Total Primary Energy	7.00E+01	7.82E-01
		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	4.83E-04	5.40E-06
	(w) Alkane (unspecified)	2.10E-03	2.35E-05
	(w) Alkene (unspecified)	1.94E-04	2.17E-06
	(w) Aluminum (Al3+)	2.10E+00	2.35E-02
	(w) Ammonia (NH4+, NH3, as N)	4.06E-02	4.53E-04
	(w) AOX (Adsorbable Organic Halogens)	9.18E-05	1.03E-06
	(w) Arsenic (As3+, As5+)	4.13E-03	4.62E-05
	(w) Barium (Ba++)	2.03E-01	2.26E-03
	(w) Barytes	3.40E-01	3.80E-03
	(w) Benzene (C6H6)	2.11E-03	2.36E-05
	(w) BOD5 (Biochemical Oxygen Demand)	3.62E-03	4.04E-05
	(w) Boron (B III)	3.68E-03	4.11E-05
	(w) Cadmium (Cd++)	1.42E-04	1.59E-06
	(w) Calcium (Ca++)	2.75E+00	3.07E-02
	(w) Chlorides (Cl-)	2.19E+01	2.44E-01
	(w) Chromium (Cr III)	2.06E-02	2.31E-04
	(w) Chromium (Cr VI)	4.18E-06	4.67E-08
	(w) Cobalt (Co I, Co II, Co III)	4.05E-03	4.52E-05
	(w) COD (Chemical Oxygen Demand)	4.00E-02	4.47E-04
	(w) Copper (Cu+, Cu++)	1.03E-02	1.15E-04
	(w) Cyanide (CN-)	1.94E-04	2.16E-06
	(w) Dissolved Matter (unspecified)	8.63E-01	9.64E-03
	(w) Dissolved Organic Carbon (DOC)	3.24E-03	3.62E-05
	(w) Ethyl Benzene (C6H5C2H5)	3.83E-04	4.27E-06
	(w) Fluorides (F-)	9.18E-03	1.03E-04
	(w) Formaldehyde (CH2O)	2.18E-07	2.44E-09
	(w) Iron (Fe++, Fe3+)	3.22E+00	3.60E-02
	(w) Lead (Pb++, Pb4+)	1.24E-02	1.39E-04
	(w) Magnesium (Mg++)	1.73E+00	1.93E-02
	(w) Manganese (Mn II, Mn IV, Mn VII)	4.97E-02	5.55E-04
	(w) Mercury (Hg+, Hg++)	4.22E-06	4.72E-08
	(w) Methylene Chloride (CH2Cl2, HC-130)	1.55E-04	1.73E-06
	(w) Molybdenum (Mo II, Mo III, Mo IV, Mo V, Mo VI)	7.59E-03	8.48E-05
	(w) Nickel (Ni++, Ni3+)	1.03E-02	1.15E-04
	(w) Nitrate (NO3-)	5.30E-02	5.92E-04
	(w) Nitrite (NO2-)	4.30E-03	4.80E-05
	(w) Nitrogenous Matter (unspecified, as N)	2.31E-02	2.58E-04
	(w) Oils (unspecified)	2.98E-01	3.33E-03
	(w) Phenol (C6H5OH)	2.25E-03	2.51E-05
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	1.23E-01	1.37E-03
	(w) Potassium (K+)	6.90E-01	7.71E-03
	(w) Salts (unspecified)	5.66E+00	6.32E-02
	(w) Saponifiable Oils and Fats	8.13E-02	9.08E-04
	(w) Selenium (Se II, Se IV, Se VI)	1.05E-02	1.17E-04
	(w) Silver (Ag+)	1.12E-05	1.25E-07
	(w) Sodium (Na+)	7.34E+00	8.20E-02
	(w) Strontium (Sr II)	1.21E-01	1.35E-03
	(w) Sulfate (SO4--)	2.14E+01	2.39E-01
	(w) Sulfide (S--)	5.32E-04	5.94E-06
	(w) Sulfite (SO3--)	1.84E-03	2.06E-05
	(w) Suspended Matter (unspecified)	1.33E+00	1.49E-02
	(w) Titanium (Ti3+, Ti4+)	1.22E-01	1.36E-03
	(w) TOC (Total Organic Carbon)	3.16E-01	3.53E-03
	(w) Triethylene Glycol (C6H14O4)	3.24E-03	3.62E-05
	(w) Vanadium (V3+, V5+)	1.10E-02	1.23E-04
	(w) Xylene (C6H4(CH3)2)	1.52E-03	1.70E-05
	(w) Zinc (Zn++)	2.14E-02	2.40E-04
	Total (g)		7.92E-01

		Factor for 1 kg	grams (g)
Air Emissions	(a) Acetaldehyde (CH3CHO)	2.38E-03	2.66E-05
	(a) Acetic Acid (CH3COOH)	1.07E-02	1.20E-04
	(a) Acetone (CH3COCH3)	2.37E-03	2.65E-05
	(a) Acrolein (CH2CHCHO)	4.44E-08	4.96E-10
	(a) Alcohol (unspecified)	9.55E-03	1.07E-04
	(a) Aldehyde (unspecified)	1.91E-02	2.13E-04
	(a) Alkane (unspecified)	2.07E-01	2.31E-03
	(a) Alkene (unspecified)	1.55E-02	1.74E-04
	(a) Alkyne (unspecified)	8.23E-05	9.19E-07
	(a) Aluminum (Al)	8.06E-02	9.00E-04
	(a) Ammonia (NH3)	2.64E-02	2.95E-04
	(a) Antimony (Sb)	7.65E-05	8.55E-07
	(a) Arsenic (As)	3.15E-04	3.52E-06
	(a) Barium (Ba)	1.32E-03	1.47E-05
	(a) Benzaldehyde (C6H5CHO)	2.32E-08	2.59E-10
	(a) Benzene (C6H6)	6.50E-03	7.26E-05
	(a) Benzo(a)pyrene (C20H12)	3.20E-06	3.58E-08
	(a) Boron (B)	6.14E-02	6.86E-04
	(a) Bromium (Br)	6.28E-03	7.02E-05
	(a) Calcium (Ca)	9.47E-02	1.06E-03
	(a) Carbon Dioxide (CO2, fossil)	5.11E+03	5.70E+01
	(a) Carbon Monoxide (CO)	1.80E+00	2.01E-02
	(a) Copper (Cu)	1.41E-03	1.57E-05
	(a) Ethanol (C2H5OH)	4.77E-03	5.33E-05
	(a) Ethyl Benzene (C6H5C2H5)	7.41E-03	8.28E-05
	(a) Ethylene (C2H4)	8.23E-05	9.19E-07
	(a) Halon 1301 (CF3Br)	1.23E-04	1.37E-06
	(a) Hydrocarbons (except methane)	2.75E+00	3.07E-02
	(a) Hydrogen Chloride (HCl)	9.36E-01	1.05E-02
	(a) Hydrogen Fluoride (HF)	1.24E-01	1.38E-03
	(a) Hydrogen Sulfide (H2S)	5.11E-03	5.71E-05
	(a) Iron (Fe)	5.54E-02	6.19E-04
	(a) Lead (Pb)	1.40E-03	1.57E-05
	(a) Magnesium (Mg)	2.87E-02	3.21E-04
	(a) Manganese (Mn)	1.22E-03	1.36E-05
	(a) Methane (CH4)	9.41E+00	1.05E-01
	(a) Methanol (CH3OH)	4.78E-03	5.34E-05
	(a) Nickel (Ni)	4.83E-03	5.39E-05
	(a) Nitrogen Oxides (NOx as NO2)	9.73E+00	1.09E-01
	(a) Nitrous Oxide (N2O)	2.31E-01	2.58E-03
	(a) Particulates (unspecified)	3.79E+00	4.24E-02
	(a) Potassium (K)	1.34E-02	1.49E-04
	(a) Scandium (Sc)	1.27E-05	1.42E-07
	(a) Selenium (Se)	8.05E-04	8.99E-06
	(a) Silicon (Si)	2.97E-01	3.31E-03
	(a) Sodium (Na)	1.46E-02	1.63E-04
	(a) Strontium (Sr)	1.30E-03	1.45E-05
	(a) Sulfur Oxides (SOx as SO2)	3.05E+01	3.41E-01
	(a) Tin (Sn)	2.79E-05	3.11E-07
	(a) Titanium (Ti)	3.64E-03	4.06E-05
	(a) Toluene (C6H5CH3)	8.62E-03	9.63E-05
	(a) Vanadium (V)	1.64E-02	1.83E-04
	(a) Xylene (C6H4(CH3)2)	3.17E-02	3.54E-04
	(a) Zinc (Zn)	2.33E-03	2.60E-05
	(a) Dioxins (unspecified)	2.19E-09	2.45E-11
	(a) Diphenyl ((C6H5)2)	1.99E-07	2.22E-09
	(a) Ethane (C2H6)	2.42E-03	2.70E-05
	(a) Ethyl Benzene (C6H5C2H5)	1.12E-05	1.25E-07
	(a) Ethyl Chloride (C2H5Cl)	4.91E-06	5.48E-08
	(a) Ethylene Dibromide (C2H4Br2)	1.40E-07	1.56E-09
	(a) Ethylene Dichloride (C2H4Cl2)	4.68E-06	5.23E-08
	(a) Fluoranthene	9.09E-08	1.02E-09
	(a) Fluorene (C13H10)	1.14E-07	1.27E-09
	(a) Fluorides (F-)	9.82E-05	1.10E-06
	(a) Formaldehyde (CH2O)	4.80E-04	5.37E-06
	(a) Furan (C4H4O)	1.02E-08	1.14E-10
	Total (g)		5.77E+01
		Factor for 1 kg	kilograms (kg)
Solids Waste	(s) Aluminum (Al)	2.23E-02	2.49E-04
	(s) Arsenic (As)	8.92E-06	9.96E-08
	(s) Cadmium (Cd)	3.38E-07	3.78E-09
	(s) Calcium (Ca)	8.92E-02	9.96E-04
	(s) Carbon (C)	6.87E-02	7.67E-04
	(s) Chromium (Cr III, Cr VI)	1.11E-04	1.24E-06
	(s) Cobalt (Co)	4.34E-07	4.85E-09
	(s) Copper (Cu)	2.17E-06	2.42E-08
	(s) Iron (Fe)	4.46E-02	4.98E-04
	(s) Lead (Pb)	9.91E-06	1.11E-07
	(s) Manganese (Mn)	8.92E-04	9.96E-06
	(s) Mercury (Hg)	6.45E-08	7.20E-10
	(s) Nickel (Ni)	3.26E-06	3.64E-08
	(s) Nitrogen (N)	2.07E-05	2.31E-07
	(s) Oils (unspecified)	1.44E-02	1.61E-04
	(s) Phosphorus (P)	1.16E-03	1.30E-05
	(s) Sulfur (S)	1.34E-02	1.50E-04
	(s) Zinc (Zn)	3.56E-04	3.98E-06
	Total (kg)		2.85E-03

Appendix I (continued): LCI Production Data – ABS



Assumptions and Variables:	ABS mass =	0.118	kg

		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Barium Sulfate (BaSO4, in ground)	2.00E-06	2.36E-07
	(r) Bauxite (Al2O3, ore)	6.00E-04	7.09E-05
	(r) Bentonite (Al2O3.4SiO2.H2O, in ground)	2.00E-04	2.36E-05
	(r) Calcium Sulfate (CaSO4, ore)	9.80E-05	1.16E-05
	(r) Clay (in ground)	2.96E-04	3.50E-05
	(r) Coal (in ground)	1.52E-01	1.79E-02
	(r) Dolomite (CaCO3.MgCO3, in ground)	1.00E-05	1.18E-06
	(r) Fluorspar (CaF2, ore)	4.00E-06	4.72E-07
	(r) Gravel (unspecified)	8.50E-03	1.00E-03
	(r) Iron (Fe, ore)	9.00E-04	1.06E-04
	(r) Lignite (in ground)	1.18E-01	1.39E-02
	(r) Limestone (CaCO3, in ground)	1.80E-02	2.13E-03
	(r) Natural Gas (in ground)	1.05E+00	1.24E-01
	(r) Oil (in ground)	7.71E-01	9.11E-02
	(r) Olivine ((Mg,Fe)2SiO4, ore)	8.00E-06	9.45E-07
	(r) Potassium Chloride (KCl, as K2O, in ground)	4.50E-03	5.31E-04
	(r) Sand (in ground)	6.00E-04	7.09E-05
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.20E-03	7.32E-04
	(r) Sulfur (S, in ground)	7.75E+00	9.15E-01
	(r) Talcum (4SiO2.3MgO.H2O, ore)	2.10E-02	2.48E-03
	(r) Uranium (U, ore)	1.36E-05	1.61E-06
	Magnesium (Mg)	1.20E-03	1.42E-04
	Wood	1.30E-03	1.54E-04
	Total (kg)		1.17E+00

Note: Raw material requirements exclude water usage, which equals	1.10E+00	liters

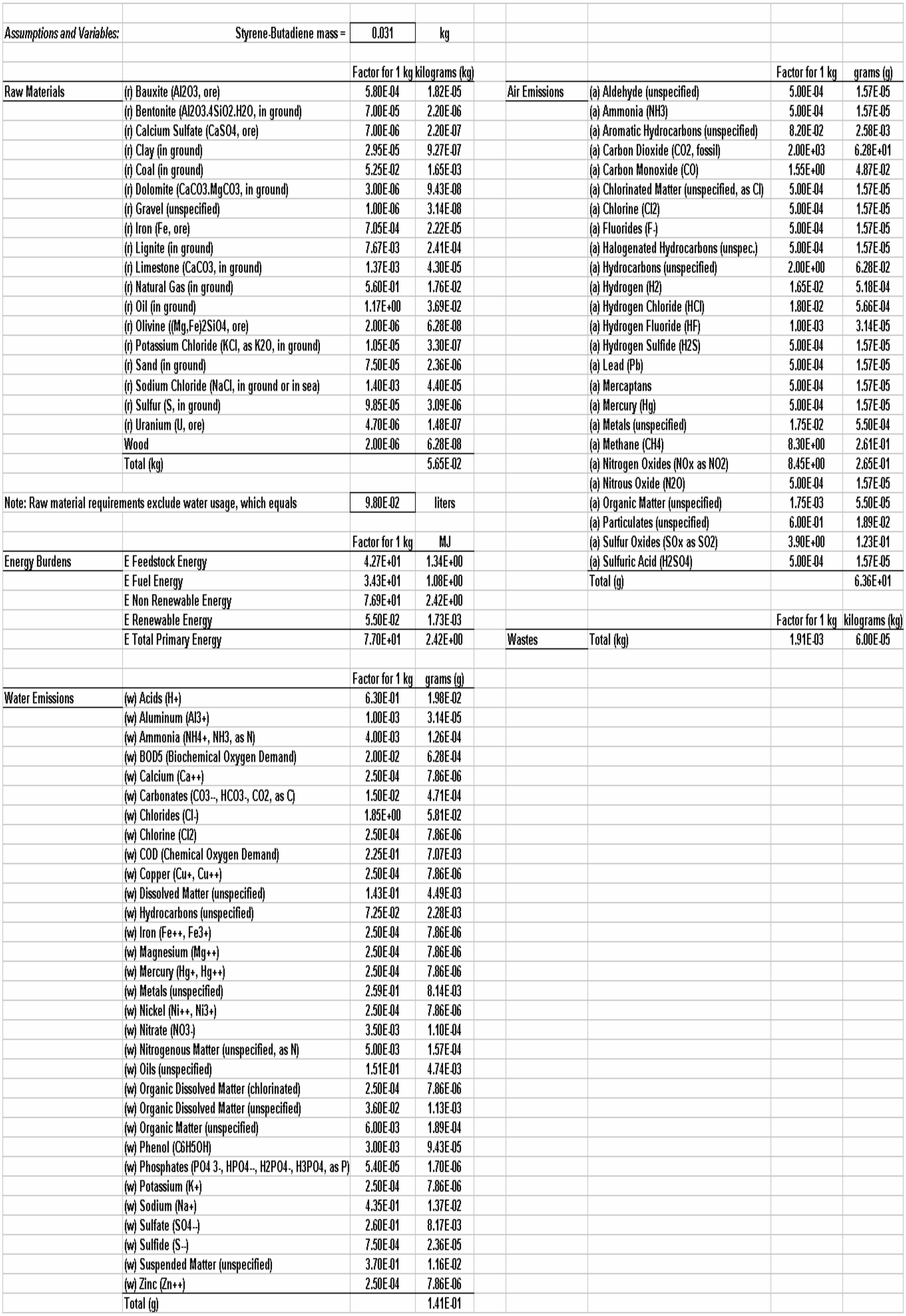
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.20E+01	4.96E+00
	E Fuel Energy	4.54E+01	5.36E+00
	E Non Renewable Energy	8.72E+01	1.03E+01
	E Renewable Energy	2.00E-01	2.36E-02
	E Total Primary Energy	8.74E+01	1.03E+01

		Factor for 1 kg	grams (g)
Water Emissions	(w) Aluminum (Al3+)	1.20E-01	1.42E-02
	(w) Ammonia (NH4+, NH3, as N)	2.64E-01	3.12E-02
	(w) BOD5 (Biochemical Oxygen Demand)	3.30E-02	3.90E-03
	(w) Calcium (Ca++)	2.60E-01	3.07E-02
	(w) Carbonates (CO3--, HCO3-, CO2, as C)	3.60E-02	4.25E-03
	(w) Chlorides (Cl-)	4.50E+00	5.31E-01
	(w) Chlorine (Cl2)	5.00E-04	5.91E-05
	(w) COD (Chemical Oxygen Demand)	2.20E+00	2.60E-01
	(w) Copper (Cu+, Cu++)	5.00E-04	5.91E-05
	(w) Dissolved Matter (unspecified)	1.10E+00	1.30E-01
	(w) Hydrocarbons (unspecified)	6.80E-02	8.03E-03
	(w) Iron (Fe++, Fe3+)	5.00E-04	5.91E-05
	(w) Magnesium (Mg++)	9.70E-01	1.15E-01
	(w) Mercury (Hg+, Hg++)	5.00E-04	5.91E-05
	(w) Metals (unspecified)	4.10E-01	4.84E-02
	(w) Nickel (Ni++, Ni3+)	5.00E-04	5.91E-05
	(w) Nitrate (NO3-)	7.10E-02	8.39E-03
	(w) Nitrogenous Matter (unspecified, as N)	1.00E-01	1.18E-02
	(w) Oils (unspecified)	9.30E-02	1.10E-02
	(w) Organic Dissolved Matter (chlorinated)	5.00E-04	5.91E-05
	(w) Organic Dissolved Matter (unspecified)	3.40E-02	4.02E-03
	(w) Organic Matter (unspecified)	3.00E-03	3.54E-04
	(w) Phenol (C6H5OH)	7.00E-03	8.27E-04
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	1.09E-04	1.29E-05
	(w) Potassium (K+)	1.40E-01	1.65E-02
	(w) Sodium (Na+)	1.10E+00	1.30E-01
	(w) Sulfate (SO4--)	8.50E+00	1.00E+00
	(w) Sulfide (S--)	5.00E-04	5.91E-05
	(w) Suspended Matter (unspecified)	2.40E+00	2.83E-01
	(w) Zinc (Zn++)	5.00E-04	5.91E-05
	Total (g)		2.65E+00

		Factor for 1 kg	grams (g)
Air Emissions	(a) Aldehyde (unspecified)	5.00E-04	5.91E-05
	(a) Ammonia (NH3)	2.00E-03	2.36E-04
	(a) Aromatic Hydrocarbons (unspecified)	4.50E-01	5.31E-02
	(a) Carbon Dioxide (CO2, fossil)	3.10E+03	3.66E+02
	(a) Carbon Monoxide (CO)	3.80E+00	4.49E-01
	(a) Chlorinated Matter (unspecified, as C	5.00E-04	5.91E-05
	(a) Chlorine (Cl2)	5.00E-04	5.91E-05
	(a) Fluorides (F-)	5.00E-04	5.91E-05
	(a) Halogenated Hydrocarbons (unspec.)	5.00E-04	5.91E-05
	(a) Hydrocarbons (unspecified)	4.20E+00	4.96E-01
	(a) Hydrogen (H2)	1.40E-01	1.65E-02
	(a) Hydrogen Chloride (HCl)	5.80E-02	6.85E-03
	(a) Hydrogen Fluoride (HF)	3.00E-03	3.54E-04
	(a) Hydrogen Sulfide (H2S)	1.00E-03	1.18E-04
	(a) Lead (Pb)	5.00E-04	5.91E-05
	(a) Mercaptans	5.00E-04	5.91E-05
	(a) Mercury (Hg)	5.00E-04	5.91E-05
	(a) Metals (unspecified)	4.00E-03	4.72E-04
	(a) Methane (CH4)	1.20E+01	1.42E+00
	(a) Nitrogen Oxides (NOx as NO2)	1.10E+01	1.30E+00
	(a) Nitrous Oxide (N2O)	5.00E-04	5.91E-05
	(a) Organic Matter (unspecified)	2.10E-01	2.48E-02
	(a) Particulates (unspecified)	3.00E+00	3.54E-01
	(a) Sulfur Oxides (SOx as SO2)	1.00E+01	1.18E+00
	(a) Sulfuric Acid (H2SO4)	5.00E-04	5.91E-05
	Total (g)		3.71E+02

		Factor for 1 kg	kilograms (kg)
Wastes	Total (kg)	1.22E-01	1.44E-02

Appendix I (continued): LCI Production Data – Styrene-Butadiene



Assumptions and Variables:	Styrene-Butadiene mass =	0.031	kg

		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	5.80E-04	1.82E-05
	(r) Bentonite (Al2O3.4SiO2.H2O, in ground)	7.00E-05	2.20E-06
	(r) Calcium Sulfate (CaSO4, ore)	7.00E-06	2.20E-07
	(r) Clay (in ground)	2.95E-05	9.27E-07
	(r) Coal (in ground)	5.25E-02	1.65E-03
	(r) Dolomite (CaCO3.MgCO3, in ground)	3.00E-06	9.43E-08
	(r) Gravel (unspecified)	1.00E-06	3.14E-08
	(r) Iron (Fe, ore)	7.05E-04	2.22E-05
	(r) Lignite (in ground)	7.67E-03	2.41E-04
	(r) Limestone (CaCO3, in ground)	1.37E-03	4.30E-05
	(r) Natural Gas (in ground)	5.60E-01	1.76E-02
	(r) Oil (in ground)	1.17E+00	3.69E-02
	(r) Olivine ((Mg,Fe)2SiO4, ore)	2.00E-06	6.28E-08
	(r) Potassium Chloride (KCl, as K2O, in ground)	1.05E-05	3.30E-07
	(r) Sand (in ground)	7.50E-05	2.36E-06
	(r) Sodium Chloride (NaCl, in ground or in sea)	1.40E-03	4.40E-05
	(r) Sulfur (S, in ground)	9.85E-05	3.09E-06
	(r) Uranium (U, ore)	4.70E-06	1.48E-07
	Wood	2.00E-06	6.28E-08
	Total (kg)		5.65E-02

Note: Raw material requirements exclude water usage, which equals	9.80E-02	liters

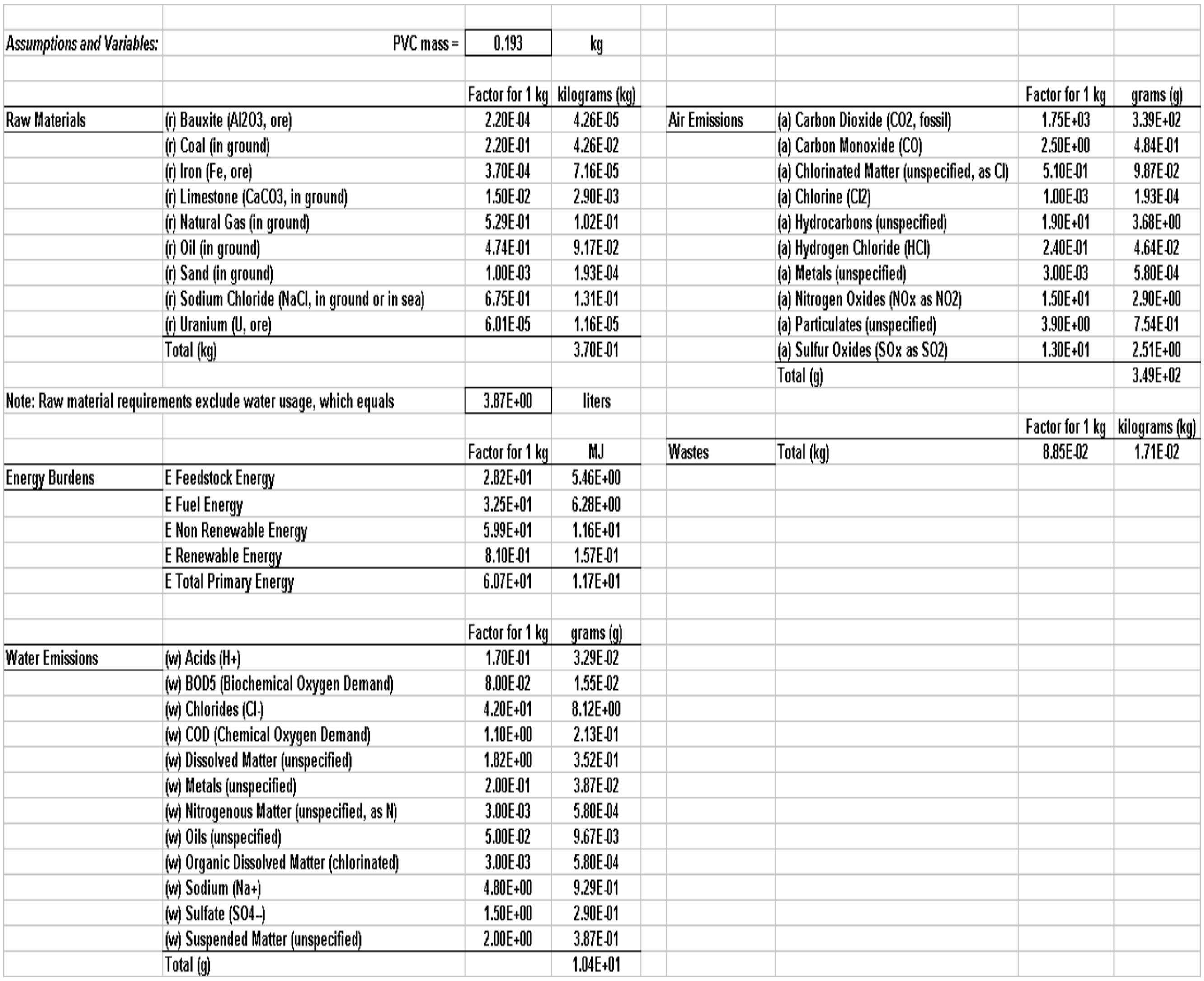
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.27E+01	1.34E+00
	E Fuel Energy	3.43E+01	1.08E+00
	E Non Renewable Energy	7.69E+01	2.42E+00
	E Renewable Energy	5.50E-02	1.73E-03
	E Total Primary Energy	7.70E+01	2.42E+00

		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	6.30E-01	1.98E-02
	(w) Aluminum (Al3+)	1.00E-03	3.14E-05
	(w) Ammonia (NH4+, NH3, as N)	4.00E-03	1.26E-04
	(w) BOD5 (Biochemical Oxygen Demand)	2.00E-02	6.28E-04
	(w) Calcium (Ca++)	2.50E-04	7.86E-06
	(w) Carbonates (CO3--, HCO3-, CO2, as C)	1.50E-02	4.71E-04
	(w) Chlorides (Cl-)	1.85E+00	5.81E-02
	(w) Chlorine (Cl2)	2.50E-04	7.86E-06
	(w) COD (Chemical Oxygen Demand)	2.25E-01	7.07E-03
	(w) Copper (Cu+, Cu++)	2.50E-04	7.86E-06
	(w) Dissolved Matter (unspecified)	1.43E-01	4.49E-03
	(w) Hydrocarbons (unspecified)	7.25E-02	2.28E-03
	(w) Iron (Fe++, Fe3+)	2.50E-04	7.86E-06
	(w) Magnesium (Mg++)	2.50E-04	7.86E-06
	(w) Mercury (Hg+, Hg++)	2.50E-04	7.86E-06
	(w) Metals (unspecified)	2.59E-01	8.14E-03
	(w) Nickel (Ni++, Ni3+)	2.50E-04	7.86E-06
	(w) Nitrate (NO3-)	3.50E-03	1.10E-04
	(w) Nitrogenous Matter (unspecified, as N)	5.00E-03	1.57E-04
	(w) Oils (unspecified)	1.51E-01	4.74E-03
	(w) Organic Dissolved Matter (chlorinated)	2.50E-04	7.86E-06
	(w) Organic Dissolved Matter (unspecified)	3.60E-02	1.13E-03
	(w) Organic Matter (unspecified)	6.00E-03	1.89E-04
	(w) Phenol (C6H5OH)	3.00E-03	9.43E-05
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	5.40E-05	1.70E-06
	(w) Potassium (K+)	2.50E-04	7.86E-06
	(w) Sodium (Na+)	4.35E-01	1.37E-02
	(w) Sulfate (SO4--)	2.60E-01	8.17E-03
	(w) Sulfide (S--)	7.50E-04	2.36E-05
	(w) Suspended Matter (unspecified)	3.70E-01	1.16E-02
	(w) Zinc (Zn++)	2.50E-04	7.86E-06
	Total (g)		1.41E-01

		Factor for 1 kg	grams (g)
Air Emissions	(a) Aldehyde (unspecified)	5.00E-04	1.57E-05
	(a) Ammonia (NH3)	5.00E-04	1.57E-05
	(a) Aromatic Hydrocarbons (unspecified)	8.20E-02	2.58E-03
	(a) Carbon Dioxide (CO2, fossil)	2.00E+03	6.28E+01
	(a) Carbon Monoxide (CO)	1.55E+00	4.87E-02
	(a) Chlorinated Matter (unspecified, as Cl)	5.00E-04	1.57E-05
	(a) Chlorine (Cl2)	5.00E-04	1.57E-05
	(a) Fluorides (F-)	5.00E-04	1.57E-05
	(a) Halogenated Hydrocarbons (unspec.)	5.00E-04	1.57E-05
	(a) Hydrocarbons (unspecified)	2.00E+00	6.28E-02
	(a) Hydrogen (H2)	1.65E-02	5.18E-04
	(a) Hydrogen Chloride (HCl)	1.80E-02	5.66E-04
	(a) Hydrogen Fluoride (HF)	1.00E-03	3.14E-05
	(a) Hydrogen Sulfide (H2S)	5.00E-04	1.57E-05
	(a) Lead (Pb)	5.00E-04	1.57E-05
	(a) Mercaptans	5.00E-04	1.57E-05
	(a) Mercury (Hg)	5.00E-04	1.57E-05
	(a) Metals (unspecified)	1.75E-02	5.50E-04
	(a) Methane (CH4)	8.30E+00	2.61E-01
	(a) Nitrogen Oxides (NOx as NO2)	8.45E+00	2.65E-01
	(a) Nitrous Oxide (N2O)	5.00E-04	1.57E-05
	(a) Organic Matter (unspecified)	1.75E-03	5.50E-05
	(a) Particulates (unspecified)	6.00E-01	1.89E-02
	(a) Sulfur Oxides (SOx as SO2)	3.90E+00	1.23E-01
	(a) Sulfuric Acid (H2SO4)	5.00E-04	1.57E-05
	Total (g)		6.36E+01

		Factor for 1 kg	kilograms (kg)
Wastes	Total (kg)	1.91E-03	6.00E-05

Appendix I (continued): LCI Production Data – PVC



Assumptions and Variables: PVC mass = 0.193 kg

		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.20E-04	4.26E-05
	(r) Coal (in ground)	2.20E-01	4.26E-02
	(r) Iron (Fe, ore)	3.70E-04	7.16E-05
	(r) Limestone (CaCO3, in ground)	1.50E-02	2.90E-03
	(r) Natural Gas (in ground)	5.29E-01	1.02E-01
	(r) Oil (in ground)	4.74E-01	9.17E-02
	(r) Sand (in ground)	1.00E-03	1.93E-04
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.75E-01	1.31E-01
	(r) Uranium (U, ore)	6.01E-05	1.16E-05
	Total (kg)		3.70E-01

Note: Raw material requirements exclude water usage, which equals 3.87E+00 liters

		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	2.82E+01	5.46E+00
	E Fuel Energy	3.25E+01	6.28E+00
	E Non Renewable Energy	5.99E+01	1.16E+01
	E Renewable Energy	8.10E-01	1.57E-01
	E Total Primary Energy	6.07E+01	1.17E+01

		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	1.70E-01	3.29E-02
	(w) BOD5 (Biochemical Oxygen Demand)	8.00E-02	1.55E-02
	(w) Chlorides (Cl-)	4.20E+01	8.12E+00
	(w) COD (Chemical Oxygen Demand)	1.10E+00	2.13E-01
	(w) Dissolved Matter (unspecified)	1.82E+00	3.52E-01
	(w) Metals (unspecified)	2.00E-01	3.87E-02
	(w) Nitrogenous Matter (unspecified, as N)	3.00E-03	5.80E-04
	(w) Oils (unspecified)	5.00E-02	9.67E-03
	(w) Organic Dissolved Matter (chlorinated)	3.00E-03	5.80E-04
	(w) Sodium (Na+)	4.80E+00	9.29E-01
	(w) Sulfate (SO4--)	1.50E+00	2.90E-01
	(w) Suspended Matter (unspecified)	2.00E+00	3.87E-01
	Total (g)		1.04E+01

		Factor for 1 kg	grams (g)
Air Emissions	(a) Carbon Dioxide (CO2, fossil)	1.75E+03	3.39E+02
	(a) Carbon Monoxide (CO)	2.50E+00	4.84E-01
	(a) Chlorinated Matter (unspecified, as Cl)	5.10E-01	9.87E-02
	(a) Chlorine (Cl2)	1.00E-03	1.93E-04
	(a) Hydrocarbons (unspecified)	1.90E+01	3.68E+00
	(a) Hydrogen Chloride (HCl)	2.40E-01	4.64E-02
	(a) Metals (unspecified)	3.00E-03	5.80E-04
	(a) Nitrogen Oxides (NOx as NO2)	1.50E+01	2.90E+00
	(a) Particulates (unspecified)	3.90E+00	7.54E-01
	(a) Sulfur Oxides (SOx as SO2)	1.30E+01	2.51E+00
	Total (g)		3.49E+02

		Factor for 1 kg	kilograms (kg)
Wastes	Total (kg)	8.85E-02	1.71E-02

APPENDIX J
E-READER MATERIALS TRANSPORTATION

1) Energy Consumed and Emissions Generated
2) Diesel Fuel Production

Appendix J: E-reader Materials Transportation – Energy Consumed and Emissions Generated

Assumptions and Variables

Total Trip Distance:	500	miles
Material Mass:	0.59	kg
FU Mass equivilency:	0.00064	tons
Fuel Efficiency	9.4	gal/1000 ton-miles
Energy Consumption:	1,465	Btu/ton-mile

Note: energy consumed and emissions generated during transportation are calculated for those materials where transportation is omitted
This includes ABS, PVC, SB, iron and manganese only.

From	To	Distance (mi)	Conveyance	Fuel	Fuel Eff. (gal/1000 ton.mi)	Mass (ton)	Energy Rate (Btu/ton.mi)	Energy consumed (MJ)	Fuel consumed (gal)
Material Production Facility	Material Manufacturing Facility	500	Tractor-trailer	diesel	9.4	0.00064	1,465	0.50	0.00303

Air Pollution due to Transportation

Compound	Emissions (lbs/1000 gal)	Mass Released (lbs)
Particulates	3.15E+01	9.55E-05
Nox	2.18E+02	6.61E-04
HC	8.79E+01	2.66E-04
Sox	6.20E+01	1.88E-04
CO	2.15E+02	6.52E-04
CO2 (total)	2.54E+04	7.71E-02
Formaldehyde	2.10E-05	6.36E-11
Other Aldehydes	5.97E+00	1.81E-05
Other Organics	1.16E+02	3.52E-04
Ammonia	4.00E-02	1.21E-07
Lead	1.40E-04	4.24E-10
Methane	4.05E+00	1.23E-05
Kerosene	1.00E-04	3.03E-10
Chlorine	1.50E-03	4.55E-09
HCl	2.50E-02	7.58E-08
HF	3.30E-03	1.00E-08
Metals	2.50E-03	7.58E-09
Antimony	3.80E-05	1.15E-10
Arsenic	7.90E-05	2.39E-10
Beryllium	5.50E-06	1.67E-11
Cadmium	1.20E-04	3.64E-10
Chromium	9.00E-05	2.73E-10
Cobalt	1.10E-04	3.33E-10
Manganese	1.10E-04	3.33E-10
Mercury	2.60E-05	7.88E-11
Nickel	1.70E-03	5.15E-09
Selenium	7.20E-05	2.18E-10
Acreolin	4.70E-06	1.42E-11
Nitrous Oxide	2.80E-03	8.49E-09
Benzene	1.50E-05	4.55E-11
Perchloroethylene	4.60E-06	1.39E-11
TCE	4.40E-06	1.33E-11
Methylene Chloride	2.10E-05	6.36E-11
Carbon Tetrachloride	1.90E-05	5.76E-11
Phenols	1.20E-04	3.64E-10
Naphthalene	7.00E-06	2.12E-11
Dioxins	2.50E-10	7.58E-16
n-nitrodimethylamine	9.90E-07	3.00E-12
Radionuclides (Ci)	8.70E-05	2.64E-10
		7.93E-02
Total (g)		3.60E+01

Water Pollution due to Transportation

Waterborne Emmission	Emissions (lbs/1000 gal)	Mass Released (lb)
Acid	8.40E-06	2.55E-11
Metal Ion	1.80E-01	5.46E-07
Dissolved Solids	3.48E+01	1.05E-04
Suspended Solids	7.90E-01	2.39E-06
BOD	1.30E-01	3.94E-07
COD	8.70E-01	2.64E-06
Phenol	5.80E-04	1.76E-09
Oil	8.10E-01	2.45E-06
Sufuric Acid	6.90E-03	2.09E-08
iron	1.90E-02	5.76E-08
Ammonia	1.40E-02	4.24E-08
Chromium	1.30E-03	3.94E-09
Lead	1.50E-05	4.55E-11
Zinc	6.50E-04	1.97E-09
Chlorides	1.28E+00	3.88E-06
Sodium	1.60E-04	4.85E-10
Calcium	9.00E-05	2.73E-10
Sulfates	1.03E+00	3.12E-06
Manganese	9.20E-03	2.79E-08
Fluorides	4.10E-04	1.24E-09
Nitrates	3.90E-05	1.18E-10
Phosphates	3.50E-03	1.06E-08
Boron	2.80E-02	8.49E-08
Other organics	8.50E-02	2.58E-07
Chromates	9.80E-05	2.97E-10
Cyanide	1.90E-06	5.76E-12
Mercury	9.80E-08	2.97E-13
Cadmium	1.30E-03	3.94E-09
Total (lb)		1.21E-04
Total (g)		5.51E-02

Solid Waste Due To Transportation

Category	Emission (lb/1000 gal)	Mass (lb)	Mass (kg)
Solid Waste	133	4.03E-04	1.83E-04

Appendix J (continued): E-reader Materials Transportation – Diesel Fuel Production

Assumptions and Variables:	Diesel Requirement:	0.0030	gal	
	Diesel Equivilancy:	0.01	kg	Note: This assumes that the density of diesel = 0.827 g/ml

		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.30E-04	2.18E-06
	(r) Coal (in ground)	4.88E-02	4.63E-04
	(r) Limestone (CaCO3, in ground)	3.88E-03	3.68E-05
	(r) Natural Gas (in ground)	1.89E-01	1.79E-03
	(r) Oil (in ground)	1.08E+00	1.03E-02
	(r) Sand (in ground)	1.41E-04	1.34E-06
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.48E-05	6.14E-07
	(r) Uranium (U, ore)	8.21E-07	7.79E-09
	Total		1.26E-02

Note: Raw material requirements exclude water usage, which equals 5.11E-01 liters

		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.59E+01	4.35E-01
	E Fuel Energy	1.19E+01	1.13E-01
	E Non Renewable Energy	5.78E+01	5.48E-01
	E Renewable Energy	6.59E-02	6.25E-04
	E Total Primary Energy	5.78E+01	5.49E-01

		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	4.13E-07	3.92E-09
	(w) Aluminum (Al3+)	7.33E-04	6.96E-06
	(w) Ammonia (NH4+, NH3, as N)	1.42E-01	1.35E-03
	(w) AOX (Adsorbable Organic Halogens)	1.93E-09	1.83E-11
	(w) Aromatic Hydrocarbons (unspecified)	4.53E-07	4.30E-09
	(w) Barium (Ba++)	1.45E-06	1.38E-08
	(w) BOD5 (Biochemical Oxygen Demand)	9.71E-01	9.21E-03
	(w) Cadmium (Cd++)	1.51E-09	1.43E-11
	(w) Chlorides (Cl-)	1.56E+01	1.48E-01
	(w) Chromium (Cr III, Cr VI)	1.70E-07	1.61E-09
	(w) COD (Chemical Oxygen Demand)	8.22E+00	7.80E-02
	(w) Copper (Cu+, Cu++)	3.02E-08	2.87E-10
	(w) Cyanide (CN-)	2.12E-09	2.01E-11
	(w) Dissolved Matter (unspecified)	1.41E-03	1.34E-05
	(w) Fluorides (F-)	1.24E-04	1.17E-06
	(w) Halogenated Matter (organic)	6.04E-10	5.73E-12
	(w) Hydrocarbons (unspecified)	1.00E-03	9.50E-06
	(w) Iron (Fe++, Fe3+)	1.72E-06	1.63E-08
	(w) Lead (Pb++, Pb4+)	6.04E-09	5.73E-11
	(w) Mercury (Hg+, Hg++)	6.95E-12	6.59E-14
	(w) Metals (unspecified)	3.31E-02	3.14E-04
	(w) Nickel (Ni++, Ni3+)	3.02E-09	2.87E-11
	(w) Nitrate (NO3-)	3.01E-04	2.86E-06
	(w) Nitrogenous Matter (unspecified, as N)	8.16E-08	7.74E-10
	(w) Oils (unspecified)	4.53E-01	4.30E-03
	(w) Organic Matter (unspecified)	1.09E-06	1.04E-08
	(w) Phenol (C6H5OH)	1.87E-02	1.77E-04
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.01E-06	2.86E-08
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	7.25E-09	6.88E-11
	(w) Salts (unspecified)	8.36E-03	7.93E-05
	(w) Sodium (Na+)	2.00E+01	1.90E-01
	(w) Sulfate (SO4--)	4.51E-04	4.28E-06
	(w) Sulfide (S--)	2.44E-07	2.32E-09
	(w) Suspended Matter (unspecified)	4.41E+00	4.18E-02
	(w) TOC (Total Organic Carbon)	4.53E-06	4.30E-08
	(w) Toluene (C6H5CH3)	6.65E-08	6.31E-10
	(w) Zinc (Zn++)	5.63E-08	5.34E-10
	Total (g)		4.73E-01

Note: Water emissions exclude chemically polluted water, which equals 2.73E-02 liters

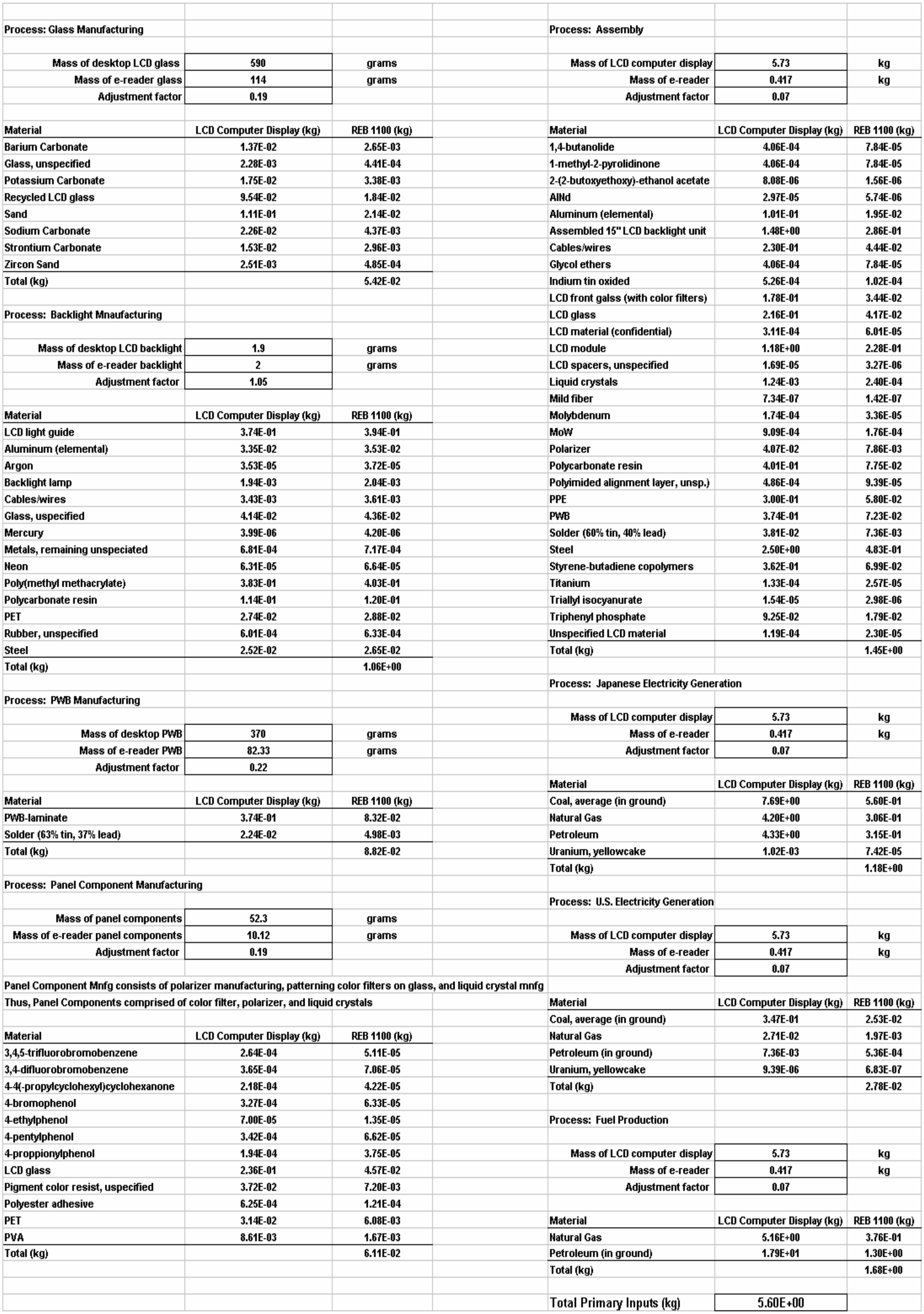
		Factor for 1 kg	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	2.15E-08	2.04E-10
	(a) Acenaphthylene (C12H8)	8.16E-09	7.74E-11
	(a) Acetaldehyde (CH3CHO)	1.39E-05	1.32E-07
	(a) Acetophenone (C8H8O)	3.65E-07	3.46E-09
	(a) Acrolein (CH2CHCHO)	7.06E-06	6.70E-08
	(a) Aldehyde (unspecified)	6.60E-03	6.26E-05
	(a) Aluminum (Al)	5.63E-05	5.34E-07
	(a) Ammonia (NH3)	9.84E-03	9.34E-05
	(a) Anthracene (C14H10)	8.17E-09	7.75E-11
	(a) Antimony (Sb)	2.81E-06	2.67E-08
	(a) Aromatic Hydrocarbons (unspecified)	2.72E-07	2.58E-09
	(a) Arsenic (As)	4.92E-05	4.67E-07
	(a) Barium (Ba)	1.49E-06	1.41E-08
	(a) Benzene (C6H6)	6.33E-02	6.01E-04
	(a) Benzo(a)anthracene	5.29E-09	5.02E-11
	(a) Benzo(a)pyrene (C20H12)	2.62E-09	2.49E-11
	(a) Benzo(b)fluoranthene	2.24E-09	2.12E-11
	(a) Benzo(bjk)fluoranthene	2.68E-09	2.54E-11
	(a) Benzo(ghi)perylene	2.36E-09	2.24E-11
	(a) Benzo(k)fluoranthene	2.24E-09	2.12E-11
	(a) Benzyl Chloride (C7H7Cl)	1.70E-05	1.62E-07
	(a) Beryllium (Be)	5.15E-06	4.89E-08
	(a) Bromoform (CHBr3)	9.49E-07	9.01E-09
	(a) Butane (C4H10)	2.32E-03	2.20E-05
	(a) Cadmium (Cd)	3.00E-06	2.85E-08
	(a) Calcium (Ca)	4.88E-05	4.63E-07
	(a) Carbon Dioxide (CO2, biomass)	2.46E-04	2.34E-06
	(a) Carbon Dioxide (CO2, fossil)	6.70E+02	6.36E+00
	(a) Carbon Disulfide (CS2)	3.16E-06	3.00E-08
	(a) Carbon Monoxide (CO)	2.00E+00	1.90E-02
	(a) Chlorides (Cl-)	1.57E-04	1.49E-06
	(a) Chlorine (Cl2)	2.35E-08	2.23E-10
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	1.70E-07	1.62E-09
	(a) Chlorobenzene (C6H5Cl)	5.36E-07	5.08E-09
	(a) Chloroform (CHCl3, HC-20)	1.44E-06	1.36E-08
	(a) Chromium (Cr III, Cr VI)	7.66E-05	7.27E-07
	(a) Chrysene (C18H12)	4.82E-09	4.58E-11
	(a) Cobalt (Co)	8.82E-06	8.37E-08
	(a) Copper (Cu)	5.13E-06	4.86E-08
	(a) Cumene (C9H12)	1.29E-07	1.22E-09
	(a) Cyanide (CN-)	6.09E-05	5.77E-07
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	1.78E-06	1.69E-08
	(a) Dibenzo(a,h)anthracene	1.61E-09	1.52E-11
	(a) Dichlorobenzene (1,4-C6H4Cl2)	1.32E-06	1.26E-08
	(a) Dimethyl Benzanthracene (7,12-C20H16)	1.66E-08	1.57E-10
	(a) Dimethyl Sulfate (C2H6O4S)	1.17E-06	1.11E-08
	(a) Dinitrotoluene (2,4-C7H6N2O4)	6.82E-09	6.47E-11
	(a) Dioxins (unspecified)	3.94E-10	3.74E-12
	(a) Diphenyl ((C6H5)2)	4.14E-08	3.93E-10
	(a) Ethane (C2H6)	3.42E-03	3.25E-05
	(a) Ethyl Benzene (C6H5C2H5)	2.32E-06	2.20E-08
	(a) Ethyl Chloride (C2H5Cl)	1.02E-06	9.70E-09
	(a) Ethylene Dibromide (C2H4Br2)	2.92E-08	2.77E-10
	(a) Ethylene Dichloride (C2H4Cl2)	9.74E-07	9.24E-09
	(a) Fluoranthene	2.14E-08	2.03E-10
	(a) Fluorene (C13H10)	2.60E-08	2.47E-10
	(a) Fluorides (F-)	1.75E-05	1.66E-07
	(a) Formaldehyde (CH2O)	3.43E-03	3.25E-05
	(a) Furan (C4H4O)	1.83E-09	1.74E-11
	(a) Halogenated Hydrocarbons (unspecified)	1.51E-12	1.43E-14
	(a) Halon 1301 (CF3Br)	2.63E-09	2.49E-11
	(a) Hexane (C6H14)	1.99E-03	1.89E-05
	(a) Hydrocarbons (except methane)	3.77E-01	3.58E-03
	(a) Hydrocarbons (unspecified)	5.40E-01	5.12E-03
	(a) Hydrogen Chloride (HCl)	2.92E-02	2.77E-04
	(a) Hydrogen Fluoride (HF)	3.65E-03	3.46E-05
	(a) Hydrogen Sulfide (H2S)	8.84E-03	8.39E-05
	(a) Indeno (1,2,3,c,d) Pyrene	3.83E-09	3.64E-11
	(a) Iron (Fe)	1.09E-04	1.03E-06
	(a) Isophorone	1.41E-05	1.34E-07
	(a) Lead (Pb)	4.49E-05	4.26E-07
	(a) Magnesium (Mg)	2.68E-04	2.54E-06
	(a) Manganese (Mn)	8.16E-05	7.74E-07
	(a) Mercury (Hg)	3.18E-06	3.02E-08
	(a) Metals (unspecified)	1.62E-06	1.53E-08
	(a) Methane (CH4)	3.34E+00	3.17E-02
	(a) Methyl Bromide (CH3Br)	3.89E-06	3.69E-08
	(a) Methyl Chloride (CH3Cl)	1.29E-05	1.22E-07
	(a) Methyl Cholanthrene (3-C21H16)	1.99E-09	1.89E-11
	(a) Methyl Chrysene (5-C19H15)	5.36E-10	5.08E-12
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	9.49E-06	9.01E-08
	(a) Methyl Hydrazine (CH6N2)	4.14E-06	3.93E-08
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	4.87E-07	4.62E-09
	(a) Methyl Naphthalene (2-C11H10)	2.65E-08	2.51E-10
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	8.52E-07	8.08E-09
	(a) Methylene Chloride (CH2Cl2, HC-130)	7.06E-06	6.70E-08
	(a) Molybdenum (Mo)	6.16E-06	5.85E-08
	(a) Naphthalene (C10H8)	1.50E-06	1.42E-08
	(a) Nickel (Ni)	3.79E-04	3.60E-06
	(a) Nitrogen Oxides (NOx as NO2)	2.26E+00	2.14E-02
	(a) Nitrous Oxide (N2O)	5.43E-02	5.15E-04
	(a) Organic Matter (unspecified)	3.15E-01	2.99E-03
	(a) Particulates (PM 10)	6.49E-04	6.16E-06
	(a) Particulates (unspecified)	5.07E-01	4.81E-03
	(a) Pentane (C5H12)	2.87E-03	2.72E-05
	(a) Phenanthrene (C14H10)	8.63E-08	8.18E-10
	(a) Phenol (C6H5OH)	3.89E-07	3.69E-09
	(a) Phosphorus (P)	3.73E-05	3.54E-07
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unsp.)	3.02E-10	2.87E-12
	(a) Propane (C3H8)	6.10E-06	5.79E-08
	(a) Propionaldehyde (CH3CH2CHO)	9.25E-06	8.78E-08
	(a) Pyrene (C16H10)	1.43E-08	1.35E-10
	(a) Selenium (Se)	3.36E-05	3.19E-07
	(a) Silicon (Si)	4.88E-05	4.63E-07
	(a) Sodium (Na)	2.89E-04	2.74E-06
	(a) Styrene (C6H5CHCH2)	6.09E-07	5.77E-09
	(a) Sulfur Oxides (SOx as SO2)	3.24E+00	3.07E-02
	(a) Tetrachloroethylene (C2Cl4)	1.05E-06	9.93E-09
	(a) Toluene (C6H5CH3)	1.51E-05	1.44E-07
	(a) Trichloroethane (1,1,1-CH3CCl3)	4.87E-07	4.62E-09
	(a) Vanadium (V)	7.68E-04	7.28E-06
	(a) Vinyl Acetate (C4H6O2)	1.85E-07	1.76E-09
	(a) Xylene (C6H4(CH3)2)	4.37E-06	4.15E-08
	(a) Zinc (Zn)	4.52E-05	4.29E-07
	Total (g)		6.79E+02

		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	2.65E-01	2.51E-03

APPENDIX K
LCI E-READER MANUFACTURING DATA

1) Primary Material Inputs
2) Ancillary Inputs
3) Energy Requirements
4) Air Emissions
5) Water Emissions
6) Solid Waste Generated

Appendix K: LCI E-reader Manufacturing Data – Primary Material Inputs



Process: Glass Manufacturing

Mass of desktop LCD glass	590	grams
Mass of e-reader glass	114	grams
Adjustment factor	0.19	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Barium Carbonate	1.37E-02	2.65E-03
Glass, unspecified	2.28E-03	4.41E-04
Potassium Carbonate	1.75E-02	3.38E-03
Recycled LCD glass	9.54E-02	1.84E-02
Sand	1.11E-01	2.14E-02
Sodium Carbonate	2.26E-02	4.37E-03
Strontium Carbonate	1.53E-02	2.96E-03
Zircon Sand	2.51E-03	4.85E-04
Total (kg)		5.42E-02

Process: Backlight Mnaufacturing

Mass of desktop LCD backlight	1.9	grams
Mass of e-reader backlight	2	grams
Adjustment factor	1.05	

Material	LCD Computer Display (kg)	REB 1100 (kg)
LCD light guide	3.74E-01	3.94E-01
Aluminum (elemental)	3.35E-02	3.53E-02
Argon	3.53E-05	3.72E-05
Backlight lamp	1.94E-03	2.04E-03
Cables/wires	3.43E-03	3.61E-03
Glass, uspecified	4.14E-02	4.36E-02
Mercury	3.99E-06	4.20E-06
Metals, remaining unspeciated	6.81E-04	7.17E-04
Neon	6.31E-05	6.64E-05
Poly(methyl methacrylate)	3.83E-01	4.03E-01
Polycarbonate resin	1.14E-01	1.20E-01
PET	2.74E-02	2.88E-02
Rubber, unspecified	6.01E-04	6.33E-04
Steel	2.52E-02	2.65E-02
Total (kg)		1.06E+00

Process: PWB Manufacturing

Mass of desktop PWB	370	grams
Mass of e-reader PWB	82.33	grams
Adjustment factor	0.22	

Material	LCD Computer Display (kg)	REB 1100 (kg)
PWB-laminate	3.74E-01	8.32E-02
Solder (63% tin, 37% lead)	2.24E-02	4.98E-03
Total (kg)		8.82E-02

Process: Panel Component Manufacturing

Mass of panel components	52.3	grams
Mass of e-reader panel components	10.12	grams
Adjustment factor	0.19	

Panel Component Mnfg consists of polarizer manufacturing, patterning color filters on glass, and liquid crystal mnfg

Thus, Panel Components comprised of color filter, polarizer, and liquid crystals

Material	LCD Computer Display (kg)	REB 1100 (kg)
3,4,5-trifluorobromobenzene	2.64E-04	5.11E-05
3,4-difluorobromobenzene	3.65E-04	7.06E-05
4-4(-propylcyclohexyl)cyclohexanone	2.18E-04	4.22E-05
4-bromophenol	3.27E-04	6.33E-05
4-ethylphenol	7.00E-05	1.35E-05
4-pentylphenol	3.42E-04	6.62E-05
4-proppionylphenol	1.94E-04	3.75E-05
LCD glass	2.36E-01	4.57E-02
Pigment color resist, uspecified	3.72E-02	7.20E-03
Polyester adhesive	6.25E-04	1.21E-04
PET	3.14E-02	6.08E-03
PVA	8.61E-03	1.67E-03
Total (kg)		6.11E-02

Process: Assembly

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
1,4-butanolide	4.06E-04	7.84E-05
1-methyl-2-pyrolidinone	4.06E-04	7.84E-05
2-(2-butoxyethoxy)-ethanol acetate	8.08E-06	1.56E-06
AlNd	2.97E-05	5.74E-06
Aluminum (elemental)	1.01E-01	1.95E-02
Assembled 15" LCD backlight unit	1.48E+00	2.86E-01
Cables/wires	2.30E-01	4.44E-02
Glycol ethers	4.06E-04	7.84E-05
Indium tin oxided	5.26E-04	1.02E-04
LCD front galss (with color filters)	1.78E-01	3.44E-02
LCD glass	2.16E-01	4.17E-02
LCD material (confidential)	3.11E-04	6.01E-05
LCD module	1.18E+00	2.28E-01
LCD spacers, unspecified	1.69E-05	3.27E-06
Liquid crystals	1.24E-03	2.40E-04
Mild fiber	7.34E-07	1.42E-07
Molybdenum	1.74E-04	3.36E-05
MoW	9.09E-04	1.76E-04
Polarizer	4.07E-02	7.86E-03
Polycarbonate resin	4.01E-01	7.75E-02
Polyimided alignment layer, unsp.)	4.86E-04	9.39E-05
PPE	3.00E-01	5.80E-02
PWB	3.74E-01	7.23E-02
Solder (60% tin, 40% lead)	3.81E-02	7.36E-03
Steel	2.50E+00	4.83E-01
Styrene-butadiene copolymers	3.62E-01	6.99E-02
Titanium	1.33E-04	2.57E-05
Triallyl isocyanurate	1.54E-05	2.98E-06
Triphenyl phosphate	9.25E-02	1.79E-02
Unspecified LCD material	1.19E-04	2.30E-05
Total (kg)		1.45E+00

Process: Japanese Electricity Generation

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Coal, average (in ground)	7.69E+00	5.60E-01
Natural Gas	4.20E+00	3.06E-01
Petroleum	4.33E+00	3.15E-01
Uranium, yellowcake	1.02E-03	7.42E-05
Total (kg)		1.18E+00

Process: U.S. Electricity Generation

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Coal, average (in ground)	3.47E-01	2.53E-02
Natural Gas	2.71E-02	1.97E-03
Petroleum (in ground)	7.36E-03	5.36E-04
Uranium, yellowcake	9.39E-06	6.83E-07
Total (kg)		2.78E-02

Process: Fuel Production

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Natural Gas	5.16E+00	3.76E-01
Petroleum (in ground)	1.79E+01	1.30E+00
Total (kg)		1.68E+00

Total Primary Inputs (kg)	5.60E+00

Appendix K: LCI E-reader Manufacturing Data – Ancillary Material Inputs

Process: Glass Manufacturing

Mass of desktop LCD glass	590	grams
Mass of e-reader glass	114	grams
Adjustment factor	0.19	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Aluminum oxide	1.56E-03	3.01E-04
Cerium xide	1.52E-04	2.94E-05
Chromium oxide	2.60E-06	5.02E-07
Hydrofluoric acid	3.66E-03	7.07E-04
Pumice	3.64E-03	7.03E-04
Total (kg)		1.74E-03

Process: Backlight Mnaufacturing

Mass of desktop LCD backlight	1.9	grams
Mass of e-reader backlight	2	grams
Adjustment factor	1.05	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Diethyl ether	9.28E-05	9.77E-05
Ethanol	4.63E-05	4.87E-05
Process materil for backlight assembly	7.03E-05	7.40E-05
Unspecified ancillary material	4.19E-04	4.41E-04
Total (kg)		6.61E-04

Process: PWB Manufacturing

Mass of desktop PWB	370	grams
Mass of e-reader PWB	82.33	grams
Adjustment factor	0.22	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Ammonium chloride	3.42E-02	7.61E-03
Ammonium hydroxide	3.42E-02	7.61E-03
Formaldehyde	2.91E-03	6.48E-04
Glycol ethers	1.04E-02	2.31E-03
Hydrochloric acid	8.46E-02	1.88E-02
Hydrogen peroxide	1.37E-02	3.05E-03
Nitric acid	5.99E-02	1.33E-02
Poylethylene glycol	2.23E-02	4.96E-03
Potassium hydroxide	1.88E-02	4.18E-03
potassium permangante	5.14E-04	1.14E-04
Potassium peroxymonosulfate	3.12E-02	6.94E-03
PWB-solder mask solids	1.93E-02	4.29E-03
Sodium Carbonate	1.42E-02	3.16E-03
Sodium hydroxide	8.56E-02	1.90E-02
Sulfuric acid	8.05E-02	1.79E-02
Total (kg)		1.14E-01

Process: Panel Component Manufacturing

Mass of panel components	52.3	grams
Mass of e-reader panel components	10.12	grams
Adjustment factor	0.19	

Panel Component Mnfg consists of polarizer manufacturing, patterning color filters on glass, and liquid crystal mnfg

Thus, Panel Components comprised of color filter, polarizer, and liquid crystals

Material	LCD Computer Display (kg)	REB 1100 (kg)
Acetone	1.03E-02	1.99E-03
Borax	9.13E-05	1.77E-05
Carbon dioxide	4.82E-03	9.33E-04
Cyclohexane	3.89E-03	7.53E-04
Developming solution, unspecified	4.00E-02	7.74E-03
Diluent, uspecified	8.27E-03	1.60E-03
Ethanol	1.17E-02	2.26E-03
Ethylacetate	9.68E-04	1.87E-04
Exfoliation liquid, unspecified	1.43E-02	2.77E-03
HCFC-225ca	1.37E-04	2.65E-05
HCFC-225cb	1.37E-04	2.65E-05
Heptane	1.03E-02	1.99E-03
Hydrochloric acid	1.74E-03	3.37E-04
Hydrogen	3.14E-06	6.08E-07
Methyl ethyl ketone	4.84E-04	9.37E-05
Nitric acid second cerium ammonium	1.13E-02	2.19E-03
Nitrogen	1.17E-01	2.26E-02
Orthoboric acid	7.30E-04	1.41E-04
Perchloric acid	3.82E-03	7.39E-04
Photoresis, unspecified	2.94E-03	5.69E-04
PET	3.20E-02	6.19E-03
Sulfuric acid	1.58E-02	3.06E-03
Tetrahydrofuran	3.82E-03	7.39E-04
Toluene	2.75E-02	5.32E-03
Total (kg)		6.23E-02

Process: Assembly

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
1,4-butanolide	4.04E-05	2.94E-06
1-Methoxy-2-propanol	1.10E-02	8.01E-04
2-(2-butoxyethoxy)-ethanol	3.04E-02	2.21E-03
2,2,4-trimethylpentane	1.52E-05	1.11E-06
2-ethoxyl ethylacetate	1.78E-03	1.30E-04
Acetic acid	6.40E-03	4.66E-04
Acetone	1.03E-02	7.50E-04
Al-etchant, uspecified	5.88E-03	4.28E-04
Aluminum sulfate	1.05E-01	7.64E-03
Ammonia	1.55E-02	1.13E-03
Ammonium bifluoride	2.36E-03	1.72E-04
Ammonium fluoride	1.14E-02	8.30E-04
Ammonium hydroxide	5.15E-06	3.75E-07
Argon	7.87E-03	5.73E-04
Calcium hydroxide	1.39E-01	1.01E-02
Carbon dioxide	3.74E-05	2.72E-06
Chlorine	1.55E-02	1.13E-03
Cleaner, unspecified	1.47E-04	1.07E-05
Cresol-formaldehyde resin	8.29E-04	6.03E-05
Cr-etchant, uspecified	1.77E-02	1.29E-03
Cyclohexane	2.03E-05	1.48E-06
Dimethylsufoxide	6.63E-02	4.82E-03
Ethanol	1.35E-02	9.82E-04
Ethanol amine	7.85E-02	5.71E-03
Ferric chloride	8.92E-03	6.49E-04
Fluorocarbon resin	3.38E-06	2.46E-07
Flux, unspecified	7.35E-05	5.35E-06
Glycol ethers	2.12E-02	1.54E-03
helium	6.18E-04	4.50E-05
Hexamethyldisizane	2.58E-04	1.88E-05
Hydrochloric acid	4.31E-02	3.14E-03
Hydrofluoric acid	4.21E-02	3.06E-03
Hydrogen	4.44E-01	3.23E-02
Hydrogen peroxide	1.47E-04	1.07E-05
Isopropyl alcohol	3.49E-01	2.54E-02
ITO etchant, unspecified	2.94E-03	2.14E-04
Krypton	2.58E-05	1.88E-06
LNG	1.94E+02	1.41E+01
Methyl ethyl ketone	7.35E-06	5.35E-07
Monosilane	1.12E-03	8.15E-05
N-Butylacetate	3.83E-02	2.79E-03
Nitric acid	1.24E-02	9.02E-04
Nitrogen	5.90E+00	4.29E-01
Nitrogen fluoride	1.08E-01	7.86E-03
Nitrous oxide	1.36E-03	9.90E-05
Oxygen	7.75E-03	5.64E-04
Perfluoromethane	1.29E-03	9.39E-05
Phosphine	2.69E-02	1.96E-03
Phosphoric acid	3.95E-02	2.87E-03
Photresist, unspecified	1.38E-02	1.00E-03
Polyaluminum chloride	6.40E-03	4.66E-04
Polyethylene mono(nonylphenyl) ether glycol	3.40E-04	2.47E-05
Polyimide, unspecified	2.94E-05	2.14E-06
Propylene glycol	4.46E-03	3.25E-04
Propylene glycol monomethyl ether acetate	1.56E-02	1.14E-03
Rinse, unspecified	5.27E-02	3.84E-03
Sodium dihydrogen phosphate dihydrate	4.06E-06	2.95E-07
Sodium hydroxide	3.59E-01	2.61E-02
Solder, uspecified	7.35E-05	5.35E-06
Sulfurhexafluoride	1.62E-02	1.18E-03
Sulfuric acid	2.29E-01	1.67E-02
Surfactant, unspecified	1.09E-04	7.93E-06
Synthetic resin, unspecified	6.57E-04	4.78E-05
Tetramethyl ammonium hydroxide	1.29E-01	9.39E-03
Unspecified LCD process material	2.58E-02	1.88E-03
Water	6.88E-02	5.01E-03
Xylene (mixed isomers)	1.57E-03	1.14E-04
Total (kg)		1.47E+01

Process: Japanese Electricity Generation

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Lime	4.53E-02	3.30E-03
Limestone	1.03E-01	7.50E-03
Total (kg)		1.08E-02

Process: U.S. Electricity Generation

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Lime	2.05E-03	1.49E-04
Limestone	4.66E-03	3.39E-04
Total (kg)		4.88E-04

Process: Fuel Production

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Bauxite (Al_2O_3, ore)	2.16E-03	1.57E-04
Limestone ($CaCO_3$, in ground)	5.49E-02	4.00E-03
Sand (in ground)	1.32E-03	9.61E-05
Sodium chloride (NaCl, in ground or sea)	6.08E-04	4.42E-05
Total (kg)		4.29E-03

Total ancillary inputs (kg)	1.49E+01

Appendix K: LCI E-reader Manufacturing Data – Energy Requirements

Process: Glass Manufacturing

Mass of desktop LCD glass	590	grams
Mass of e-reader glass	114	grams
Adjustment factor	0.19	

Fuels and Electricity	LCD Computer Display (MJ)	REB 1100 (MJ)
Total energy	7.05E+02	1.36E+02

Process: Backlight Mnaufacturing

Mass of desktop LCD backlight	1.9	grams
Mass of e-reader backlight	2	grams
Adjustment factor	1.05	

Fuels and Electricity	LCD Computer Display (MJ)	REB 1100 (MJ)
Total energy	4.46E+00	4.69E+00

Process: PWB Manufacturing

Mass of desktop PWB	370	grams
Mass of e-reader PWB	82.33	grams
Adjustment factor	0.22	

Fuels and Electricity	LCD Computer Display (MJ)	REB 1100 (MJ)
Total energy	1.21E+01	2.69E+00

Process: Panel Component Manufacturing

Mass of panel components	52.3	grams
Mass of e-reader panel components	10.12	grams
Adjustment factor	0.19	

Panel Component Mnfg consists of polarizer manufacturing, patterning color filters on glass, and liquid crystal mnfg

Thus, Panel Components comprised of color filter, polarizer, and liquid crystals

Fuels and Electricity	LCD Computer Display (MJ)	REB 1100 (MJ)
Total energy	6.29E+01	1.22E+01

Process: Assembly

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Fuels and Electricity	LCD Computer Display (MJ)	REB 1100 (MJ)
Total energy	5.08E+02	3.70E+01

Process: Fuel Production

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Fuels and Electricity	LCD Computer Display (MJ)	REB 1100 (MJ)
Total energy	1.45E+02	1.06E+01

Total Energy (All Processes)	2.03E+02	MJ

Appendix K: LCI E-reader Manufacturing Data – Air Emissions

Note: Only air emmissions greater than .01% of the process group total

Process: Glass Manufacturing

Mass of desktop LCD glass	590	grams
Mass of e-reader glass	114	grams
Adjustment factor	0.19	

Air Emissions	LCD Computer Display (kg)	REB 1100 (kg)
Carbon dioxide	1.30E-01	2.51E-02
Nitrogen oxides	9.54E-02	1.84E-02
Total (kg)		4.36E-02
Total (g)		4.36E+01

Process: Backlight Mnaufacturing

Mass of desktop LCD backlight	1.9	grams
Mass of e-reader backlight	2	grams
Adjustment factor	1.05	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Diethyl ether	9.26E-05	9.75E-05
Ethanol	4.63E-05	4.87E-05
Nitrogen oxides	2.95E-02	3.11E-02
process material for backlight assembly	7.03E-05	7.40E-05
Total (kg)		3.13E-02
Total (g)		3.13E+01

Process: PWB Manufacturing

Mass of desktop PWB	370	grams
Mass of e-reader PWB	82.33	grams
Adjustment factor	0.22	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Formaldehyde	1.71E-05	3.80E-06
Total (kg)		3.80E-06
Total (g)		3.80E-03

Process: Panel Component Manufacturing

Mass of panel components	52.3	grams
Mass of e-reader panel components	10.12	grams
Adjustment factor	0.19	

Panel Component Mnfg consists of polarizer manufacturing, patterning color filters on glass, and liquid crystal mnfg

Thus, Panel Components comprised of color filter, polarizer, and liquid crystals

Material	LCD Computer Display (kg)	REB 1100 (kg)
Carbon dioxide	4.82E-03	9.33E-04
HCFC-225ca	1.40E-04	2.71E-05
HCFC-225cb	1.40E-04	2.71E-05
Heptane	7.77E-05	1.50E-05
Hydrochloric acid	7.32E-06	1.42E-06
Methyl ethyl ketone	1.35E-04	2.61E-05
Nitrogen oxides	4.11E-04	7.95E-05
Nonmethan hydrocarbons, remaining unspeciated	7.77E-05	1.50E-05
PM	2.74E-05	5.30E-06
Toluene	5.44E-05	1.05E-05
Total (kg)		1.14E-03
		1.14E+00

Process: Assembly

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Acetic acid	1.36E-03	9.90E-05
Acetone	1.86E-04	1.35E-05
Al-etchant, unspecified	1.37E-02	9.97E-04
Ammonia	6.23E-02	4.53E-03
Argon	5.80E-03	4.22E-04
Carbon dioxide	2.16E-03	1.57E-04
Cr-etchant, unspecified	4.12E-02	3.00E-03
Diethylen glycol	9.69E-05	7.05E-06
Hydrochloric acid	6.06E-02	4.41E-03
Hydrofluoric acid	5.21E-02	3.79E-03
Hydrogen	1.33E-04	9.68E-06
Isopropyl alcohol	1.78E-02	1.30E-03
ITO etchant, unspecified	6.86E-03	4.99E-04
Monosilane	1.54E-03	1.12E-04
N-bromoacetamide	9.18E-03	6.68E-04
Nitric acid	2.69E-04	1.96E-05
Nitrogen fluoride	2.45E-01	1.78E-02
Nittogen oxides	5.48E-01	3.99E-02
Phospine	6.26E-02	4.56E-03
Polyimide, unspecified	1.40E-04	1.02E-05
Sulfur hexafluoride	7.30E-03	5.31E-04
Sulfur oxides	1.12E-03	8.15E-05
Tetramethyl ammonium hydroxide	6.43E-01	4.68E-02
Unspecified LCD process material	4.49E-02	3.27E-03
Total (kg)		1.33E-01
Total (g)		1.33E+02

Process: Japanese Electricity Generation

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Carbon dioxide	5.18E+01	3.77E+00
Carbon monoxide	9.43E-03	6.86E-04
Hydrochloric acid	4.61E-03	3.35E-04
Nitrogen oxides	1.37E-01	9.97E-03
PM-10	6.72E-03	4.89E-04
Sulfur dioxide	2.90E-01	2.11E-02
Total (kg)		3.80E+00
Total (g)		3.80E+03

Process: U.S. Electricity Generation

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Carbon dioxide	8.61E-01	6.27E-02
Carbon monoxide	1.57E-04	1.14E-05
Hydrochloric acid	2.08E-04	1.51E-05
Methane	1.25E-03	9.10E-05
Nitrogen oxides	2.28E-03	1.66E-04
PM-10	1.12E-04	8.15E-06
Sulfur dioxide	4.83E-03	3.52E-04
Total (kg)		6.33E-02
Total (g)		6.33E+01

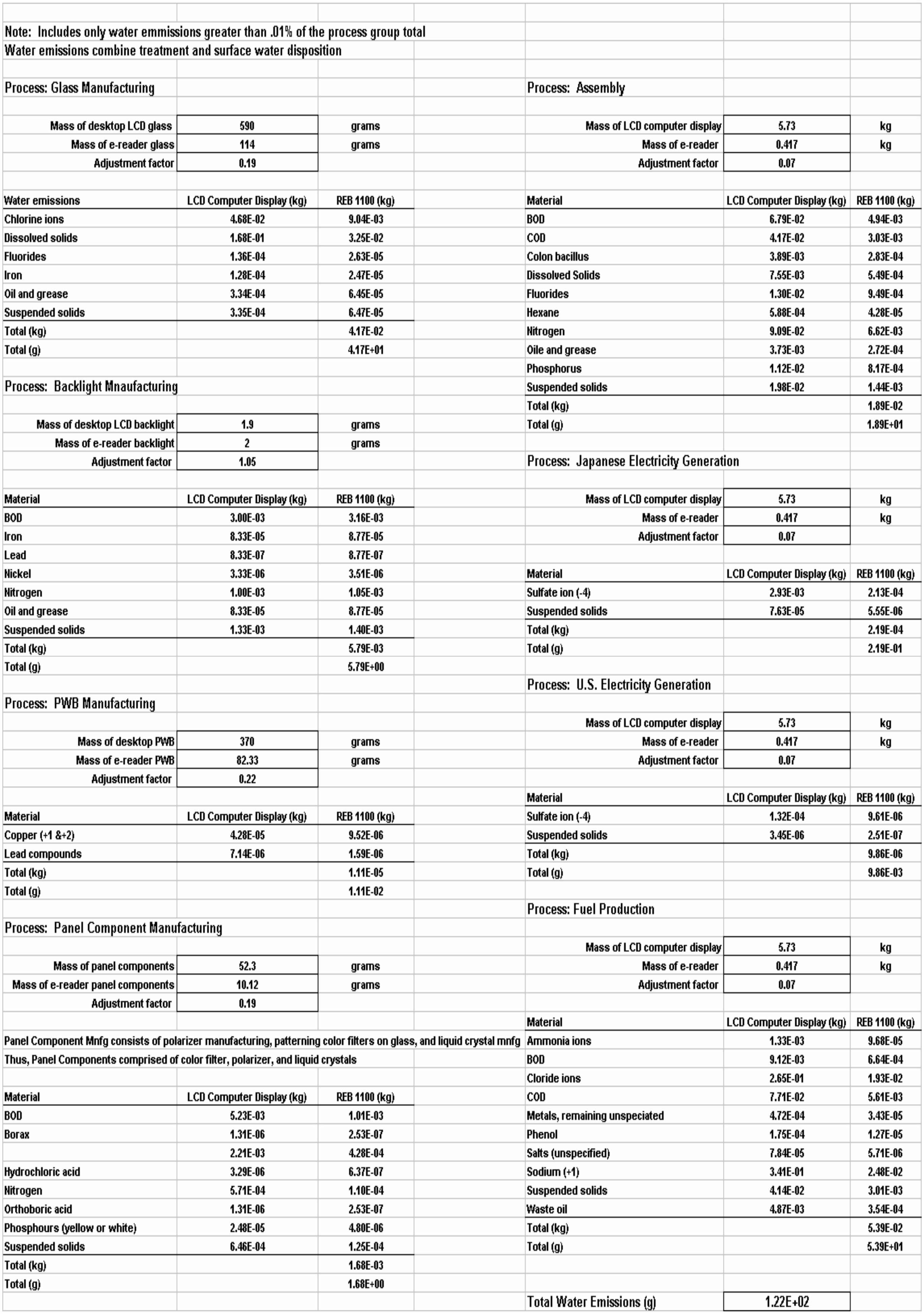
Process: Fuel Production

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Benzene	2.70E-03	1.96E-04
Carbon dioxide	9.44E+00	6.87E-01
Carbon monoxide	2.89E-02	2.10E-03
Hydrocarbons, unspecified	7.75E-03	5.64E-04
Methane	1.20E-01	8.73E-03
Nitrogen oxides	4.27E-02	3.11E-03
Nitrous oxide	8.13E-04	5.92E-05
Nonmethan hydrocarbons, remaining unspeciated	8.79E-03	6.40E-04
Other organics	1.35E-02	9.82E-04
PM	6.95E-03	5.06E-04
Sulfur oxides	3.96E-02	2.88E-03
Total (kg)		7.07E-01
Total (g)		7.07E+02

Total Air Emissions (g)	4.78E+03

Appendix K: LCI E-reader Manufacturing Data – Water Emissions



Note: Includes only water emmissions greater than .01% of the process group total

Water emissions combine treatment and surface water disposition

Process: Glass Manufacturing

Mass of desktop LCD glass	590	grams
Mass of e-reader glass	114	grams
Adjustment factor	0.19	

Water emissions	LCD Computer Display (kg)	REB 1100 (kg)
Chlorine ions	4.68E-02	9.04E-03
Dissolved solids	1.68E-01	3.25E-02
Fluorides	1.36E-04	2.63E-05
Iron	1.28E-04	2.47E-05
Oil and grease	3.34E-04	6.45E-05
Suspended solids	3.35E-04	6.47E-05
Total (kg)		4.17E-02
Total (g)		4.17E+01

Process: Backlight Mnaufacturing

Mass of desktop LCD backlight	1.9	grams
Mass of e-reader backlight	2	grams
Adjustment factor	1.05	

Material	LCD Computer Display (kg)	REB 1100 (kg)
BOD	3.00E-03	3.16E-03
Iron	8.33E-05	8.77E-05
Lead	8.33E-07	8.77E-07
Nickel	3.33E-06	3.51E-06
Nitrogen	1.00E-03	1.05E-03
Oil and grease	8.33E-05	8.77E-05
Suspended solids	1.33E-03	1.40E-03
Total (kg)		5.79E-03
Total (g)		5.79E+00

Process: PWB Manufacturing

Mass of desktop PWB	370	grams
Mass of e-reader PWB	82.33	grams
Adjustment factor	0.22	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Copper (+1 &+2)	4.28E-05	9.52E-06
Lead compounds	7.14E-06	1.59E-06
Total (kg)		1.11E-05
Total (g)		1.11E-02

Process: Panel Component Manufacturing

Mass of panel components	52.3	grams
Mass of e-reader panel components	10.12	grams
Adjustment factor	0.19	

Panel Component Mnfg consists of polarizer manufacturing, patterning color filters on glass, and liquid crystal mnfg

Thus, Panel Components comprised of color filter, polarizer, and liquid crystals

Material	LCD Computer Display (kg)	REB 1100 (kg)
BOD	5.23E-03	1.01E-03
Borax	1.31E-06	2.53E-07
	2.21E-03	4.28E-04
Hydrochloric acid	3.29E-06	6.37E-07
Nitrogen	5.71E-04	1.10E-04
Orthoboric acid	1.31E-06	2.53E-07
Phosphours (yellow or white)	2.48E-05	4.80E-06
Suspended solids	6.46E-04	1.25E-04
Total (kg)		1.68E-03
Total (g)		1.68E+00

Process: Assembly

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
BOD	6.79E-02	4.94E-03
COD	4.17E-02	3.03E-03
Colon bacillus	3.89E-03	2.83E-04
Dissolved Solids	7.55E-03	5.49E-04
Fluorides	1.30E-02	9.49E-04
Hexane	5.88E-04	4.28E-05
Nitrogen	9.09E-02	6.62E-03
Oile and grease	3.73E-03	2.72E-04
Phosphorus	1.12E-02	8.17E-04
Suspended solids	1.98E-02	1.44E-03
Total (kg)		1.89E-02
Total (g)		1.89E+01

Process: Japanese Electricity Generation

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Sulfate ion (-4)	2.93E-03	2.13E-04
Suspended solids	7.63E-05	5.55E-06
Total (kg)		2.19E-04
Total (g)		2.19E-01

Process: U.S. Electricity Generation

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Sulfate ion (-4)	1.32E-04	9.61E-06
Suspended solids	3.45E-06	2.51E-07
Total (kg)		9.86E-06
Total (g)		9.86E-03

Process: Fuel Production

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Ammonia ions	1.33E-03	9.68E-05
BOD	9.12E-03	6.64E-04
Cloride ions	2.65E-01	1.93E-02
COD	7.71E-02	5.61E-03
Metals, remaining unspeciated	4.72E-04	3.43E-05
Phenol	1.75E-04	1.27E-05
Salts (unspecified)	7.84E-05	5.71E-06
Sodium (+1)	3.41E-01	2.48E-02
Suspended solids	4.14E-02	3.01E-03
Waste oil	4.87E-03	3.54E-04
Total (kg)		5.39E-02
Total (g)		5.39E+01

Total Water Emissions (g)	1.22E+02

Appendix K: LCI E-reader Manufacturing Data – Solid Waste Generated

Note: Includes only solid wastes greater than .01% of the process group total
Solid Waste totals combine treatment and landfill water disposition

Process: Glass Manufacturing

Mass of desktop LCD glass	590	grams
Mass of e-reader glass	114	grams
Adjustment factor	0.19	

Material	LCD Computer Display (kg)	REB 1100 (kg)
abrasive sludge	1.95E-03	3.77E-04
acid absorbent	3.77E-06	7.28E-07
blasting media	1.70E-05	3.28E-06
Cinders from LCD glass mfg	3.83E-04	7.40E-05
Cobalt nitrate	2.83E-06	5.47E-07
Diesel fuel	1.88E-06	3.63E-07
dust	1.59E-04	3.07E-05
LCD glass EP dust	2.80E-04	5.40E-05
LCD glass, uspecified	1.13E-03	2.18E-04
Nickel nitrate	2.83E-06	5.47E-07
Oily rags & filter media	1.70E-05	3.28E-06
parts cleaner solvent	3.77E-06	7.28E-07
Plating process sludge	1.52E-05	2.94E-06
Potassium Carbonate	1.53E-04	2.96E-05
sludge (Calcium fluoride, CaF2)	8.13E-04	1.57E-04
Suldge from LCD glass mfg	4.06E-05	7.84E-06
Sodium Carbonate	1.53E-04	2.96E-05
Unspecified sludge	3.56E-04	6.88E-05
Wast alkali, unspecified	1.95E-06	3.77E-07
Waste LCD glass	8.70E-05	1.68E-05
Waste oil	3.03E-04	5.85E-05
Waste refractory	1.13E-04	2.18E-05
Total (kg)		1.16E-03

Process: Backlight Mnaufacturing

Mass of desktop LCD backlight	1.9	grams
Mass of e-reader backlight	2	grams
Adjustment factor	1.05	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Cardboard	1.82E-05	1.92E-05
PE, foamed	9.99E-04	1.05E-03
PE/PP waste	2.72E-03	2.86E-03
unspecified nonhazardous waste	1.26E-04	1.33E-04
Waste backlight casing (PC)	1.46E-05	1.54E-05
Waste backlight guide (PMMA)	1.52E-03	1.60E-03
Total (kg)		5.68E-03

Process: PWB Manufacturing

Mass of desktop PWB	370	grams
Mass of e-reader PWB	82.33	grams
Adjustment factor	0.22	

Material	LCD Computer Display (kg)	REB 1100 (kg)
PWB drill dust	6.59E-03	1.47E-03
unspecified solid waste	1.81E+00	4.03E-01
Total (kg)		4.04E-01

Mass of panel components	52.3	grams
Mass of e-reader panel components	10.12	grams
Adjustment factor	0.19	

Panel Component Mnfg consists of polarizer manufacturing, patterning color filters on glass, and liquid crystal mnfg
Thus, Panel Components comprised of color filter, polarizer, and liquid crystals

Material	LCD Computer Display (kg)	REB 1100 (kg)
Isopropyl alcohol	2.53E-02	4.90E-03
Polyester resin	3.20E-02	6.19E-03
unspecified soled waste	1.10E-02	2.13E-03
Used silica gel	6.22E-04	1.20E-04
Wast alkali	8.91E-02	1.72E-02
Waste LCD glass	5.74E-02	1.11E-02
Total (kg)		4.17E-02

Process: Assembly

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Isopropy alcohol	1.03E-02	7.50E-04
LCD panel waste	2.43E-02	1.77E-03
PWB	7.50E-03	5.46E-04
Remover, unspecified	3.09E-02	2.25E-03
unspecified sludge	9.03E-01	6.57E-02
unspecified solid waste	2.02E-02	1.47E-03
waste acid (containing F and detergents)	2.70E-01	1.96E-02
waste acids, unspecified	1.05E-01	7.64E-03
waste alkali, unspecified	3.23E-01	2.35E-02
Waste LCD glass	9.26E-01	6.74E-02
Waste metals, unspecified	2.93E-03	2.13E-04
Waste oil	1.61E-02	1.17E-03
Waset plastic from LCD modules	4.77E-01	3.47E-02
Waste plastic from LCD monitor	4.05E-02	2.95E-03
Total (kg)		2.30E-01

Process: Japanese Electricity Generation

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Coal waste	2.18E+00	1.59E-01
Dust/sludge	8.42E-01	6.13E-02
Fly/bottom ash	5.45E-01	3.97E-02
Total (kg)		2.60E-01

Process: U.S. Electricity Generation

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Coal waste	9.85E-02	7.17E-03
Dust/sludge	3.81E-02	2.77E-03
Fly/bottom ash	2.46E-02	1.79E-03
Total (kg)		1.17E-02

Process: Fuel Production

Mass of LCD computer display	5.73	kg
Mass of e-reader	0.417	kg
Adjustment factor	0.07	

Material	LCD Computer Display (kg)	REB 1100 (kg)
Bauxite residues	5.87E-04	4.27E-05
FGD sludge	1.09E-02	7.93E-04
mixed industrial (waste)	4.83E-02	3.52E-03
slag and ash	3.43E+00	2.50E-01
unspecified solid waste (incinerated)	6.44E-04	4.69E-05
unspecified waste	1.72E-01	1.25E-02
Total (kg)		2.67E-01

Total Solid Waste (kg)	1.22E+00

APPENDIX L
LCI DATA
CABLE MANUFACTURING

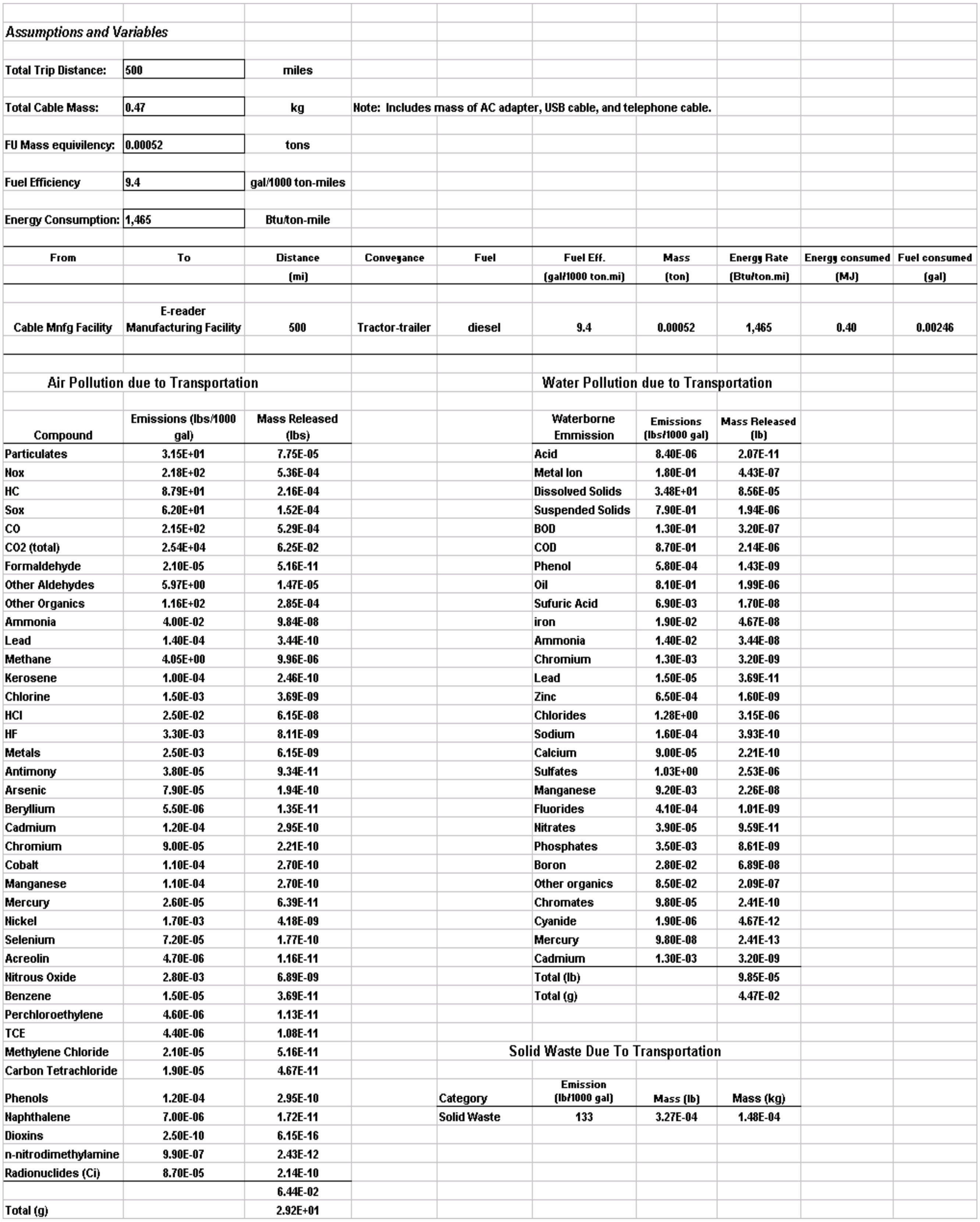
1) Electricity Production
2) Energy Consumed and Emissions Generated for Delivery of Cable
3) Diesel Fuel Production for Delivery of Cable

Appendix L: Cable Manufacturing – Electricity Generation

Assumptions and Variables:	Electricity Requirement:	1.42	MJ
		Factor for 1 MJ	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.46E-07	3.49E-07
	(r) Coal (in ground)	1.48E-01	2.10E-01
	(r) Limestone (CaCO3, in ground)	1.17E-02	1.66E-02
	(r) Natural Gas (in ground)	9.17E-04	1.30E-03
	(r) Oil (in ground)	2.99E-03	4.23E-03
	(r) Sand (in ground)	1.51E-07	2.14E-07
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.92E-08	9.81E-08
	(r) Uranium (U, ore)	7.17E-07	1.02E-06
	Total		2.33E-01
Note: Raw material requirements exclude water usage, which equals		8.51E-02	liters
		Factor for 1 MJ	MJ
Energy Burdens	E Feedstock Energy	3.94E-01	5.59E-01
	E Fuel Energy	4.47E+00	6.34E+00
	E Non Renewable Energy	4.85E+00	6.88E+00
	E Renewable Energy	7.96E-03	1.13E-02
	Electricity	1.50E-02	2.13E-02
	E Total Primary Energy	4.86E+00	6.89E+00
		Factor for 1 MJ	grams (g)
Water Emissions	(w) Acids (H+)	1.06E-09	1.51E-09
	(w) Aluminum (Al3+)	7.83E-07	1.11E-06
	(w) Ammonia (NH4+, NH3, as N)	1.89E-04	2.67E-04
	(w) AOX (Adsorbable Organic Halogens)	2.07E-12	2.93E-12
	(w) Aromatic Hydrocarbons (unspecified)	4.84E-10	6.87E-10
	(w) Barium (Ba++)	1.55E-09	2.20E-09
	(w) BOD5 (Biochemical Oxygen Demand)	1.04E-03	1.47E-03
	(w) Cadmium (Cd++)	1.61E-12	2.29E-12
	(w) Chlorides (Cl-)	3.75E-02	5.32E-02
	(w) Chromium (Cr III, Cr VI)	3.46E-10	4.90E-10
	(w) COD (Chemical Oxygen Demand)	8.78E-03	1.25E-02
	(w) Copper (Cu+, Cu++)	3.23E-11	4.58E-11
	(w) Cyanide (CN-)	2.26E-12	3.20E-12
	(w) Dissolved Matter (unspecified)	4.28E-03	6.07E-03
	(w) Fluorides (F-)	1.08E-04	1.53E-04
	(w) Halogenated Matter (organic)	6.46E-13	9.15E-13
	(w) Hydrocarbons (unspecified)	2.41E-06	3.42E-06
	(w) Iron (Fe++, Fe3+)	2.11E-07	2.99E-07
	(w) Lead (Pb++, Pb4+)	6.46E-12	9.15E-12
	(w) Mercury (Hg+, Hg++)	7.42E-15	1.05E-14
	(w) Metals (unspecified)	6.37E-05	9.03E-05
	(w) Nickel (Ni++, Ni3+)	3.23E-12	4.58E-12
	(w) Nitrate (NO3-)	2.59E-05	3.67E-05
	(w) Nitrogenous Matter (unspecified, as N)	8.71E-11	1.24E-10
	(w) Oils (unspecified)	6.61E-04	9.37E-04
	(w) Organic Matter (unspecified)	2.79E-09	3.95E-09
	(w) Phenol (C6H5OH)	1.99E-05	2.83E-05
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.22E-09	4.57E-09
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	7.75E-12	1.10E-11
	(w) Salts (unspecified)	8.92E-06	1.27E-05
	(w) Sodium (Na+)	4.83E-02	6.85E-02
	(w) Sulfate (SO4--)	2.33E-05	3.31E-05
	(w) Sulfide (S--)	6.02E-10	8.54E-10
	(w) Suspended Matter (unspecified)	4.74E-03	6.73E-03
	(w) TOC (Total Organic Carbon)	4.84E-09	6.87E-09
	(w) Toluene (C6H5CH3)	7.10E-11	1.01E-10
	(w) Zinc (Zn++)	9.93E-11	1.41E-10
	Total (g)		1.50E-01
Note: Water emissions exclude chemically polluted water, which equals		8.41E-03	liters
		Factor for 1 MJ	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	3.78E-08	5.36E-08
	(a) Acenaphthylene (C12H8)	1.85E-08	2.63E-08
	(a) Acetaldehyde (CH3CHO)	4.22E-05	5.98E-05
	(a) Acetophenone (C8H8O)	1.11E-06	1.57E-06
	(a) Acrolein (CH2CHCHO)	2.15E-05	3.04E-05
	(a) Aldehyde (unspecified)	7.58E-03	1.08E-02
	(a) Aluminum (Al)	1.36E-07	1.92E-07
	(a) Ammonia (NH3)	5.11E-05	7.25E-05
	(a) Anthracene (C14H10)	1.56E-08	2.21E-08
	(a) Antimony (Sb)	1.51E-06	2.14E-06
	(a) Aromatic Hydrocarbons (unspecified)	2.90E-10	4.12E-10
	(a) Arsenic (As)	1.30E-04	1.84E-04
	(a) Barium (Ba)	9.72E-08	1.38E-07
	(a) Benzene (C6H6)	2.59E-04	3.67E-04
	(a) Benzo(a)anthracene	5.93E-09	8.41E-09
	(a) Benzo(a)pyrene (C20H12)	2.82E-09	3.99E-09
	(a) Benzo(b)fluoranthene	3.86E-12	5.47E-12
	(a) Benzo(bjk)fluoranthene	8.14E-09	1.15E-08
	(a) Benzo(ghi)perylene	2.00E-09	2.84E-09
	(a) Benzo(k)fluoranthene	3.86E-12	5.47E-12
	(a) Benzyl Chloride (C7H7Cl)	5.18E-05	7.35E-05
	(a) Beryllium (Be)	1.49E-05	2.12E-05
	(a) Bromoform (CHBr3)	2.89E-06	4.09E-06
	(a) Butane (C4H10)	4.18E-06	5.93E-06
	(a) Cadmium (Cd)	8.42E-06	1.19E-05
	(a) Calcium (Ca)	1.18E-07	1.67E-07
	(a) Carbon Dioxide (CO2, biomass)	2.97E-05	4.22E-05
	(a) Carbon Dioxide (CO2, fossil)	3.77E+02	5.34E+02
	(a) Carbon Disulfide (CS2)	9.62E-06	1.36E-05
	(a) Carbon Monoxide (CO)	1.62E-01	2.30E-01
	(a) Chlorides (Cl-)	1.16E-05	1.65E-05
	(a) Chlorine (Cl2)	6.00E-11	8.51E-11

		Factor for 1 MJ	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	5.18E-07	7.35E-07
	(a) Chlorobenzene (C6H5Cl)	1.63E-06	2.31E-06
	(a) Chloroform (CHCl3, HC-20)	4.37E-06	6.19E-06
	(a) Chromium (Cr III, Cr VI)	2.17E-04	3.08E-04
	(a) Chrysene (C18H12)	7.41E-09	1.05E-08
	(a) Cobalt (Co)	7.61E-06	1.08E-05
	(a) Copper (Cu)	7.73E-08	1.10E-07
	(a) Cumene (C9H12)	3.92E-07	5.56E-07
	(a) Cyanide (CN-)	1.85E-04	2.62E-04
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	5.40E-06	7.66E-06
	(a) Dibenzo(a,h)anthracene	2.70E-12	3.83E-12
	(a) Dichlorobenzene (1,4-C6H4Cl2)	2.39E-09	3.39E-09
	(a) Dimethyl Benzanthracene (7,12-C20H16)	3.02E-11	4.29E-11
	(a) Dimethyl Sulfate (C2H6O4S)	3.55E-06	5.04E-06
	(a) Dinitrotoluene (2,4-C7H6N2O4)	2.07E-08	2.94E-08
	(a) Dioxins (unspecified)	1.20E-09	1.70E-09
	(a) Diphenyl ((C6H5)2)	1.26E-07	1.78E-07
	(a) Ethane (C2H6)	6.17E-06	8.76E-06
	(a) Ethyl Benzene (C6H5C2H5)	6.96E-06	9.87E-06
	(a) Ethyl Chloride (C2H5Cl)	3.11E-06	4.41E-06
	(a) Ethylene Dibromide (C2H4Br2)	8.88E-08	1.26E-07
	(a) Ethylene Dichloride (C2H4Cl2)	2.96E-06	4.20E-06
	(a) Fluoranthene	5.26E-08	7.46E-08
	(a) Fluorene (C13H10)	6.74E-08	9.55E-08
	(a) Fluorides (F-)	1.82E-06	2.58E-06
	(a) Formaldehyde (CH2O)	3.16E-05	4.48E-05
	(a) Furan (C4H4O)	5.57E-09	7.90E-09
	(a) Halogenated Hydrocarbons (unspecified)	1.61E-15	2.29E-15
	(a) Halon 1301 (CF3Br)	2.81E-12	3.98E-12
	(a) Hexane (C6H14)	8.54E-06	1.21E-05
	(a) Hydrocarbons (except methane)	1.39E-02	1.97E-02
	(a) Hydrocarbons (unspecified)	2.68E-02	3.80E-02
	(a) Hydrogen Chloride (HCl)	8.88E-02	1.26E-01
	(a) Hydrogen Fluoride (HF)	1.11E-02	1.57E-02
	(a) Hydrogen Sulfide (H2S)	2.13E-05	3.02E-05
	(a) Indeno (1,2,3,c,d) Pyrene	4.52E-09	6.41E-09
	(a) Iron (Fe)	2.62E-07	3.72E-07
	(a) Isophorone	4.29E-05	6.09E-05
	(a) Lead (Pb)	1.29E-04	1.83E-04
	(a) Magnesium (Mg)	8.14E-04	1.15E-03
	(a) Manganese (Mn)	2.42E-04	3.44E-04
	(a) Mercury (Hg)	8.08E-06	1.15E-05
	(a) Metals (unspecified)	1.76E-09	2.50E-09
	(a) Methane (CH4)	6.60E-01	9.36E-01
	(a) Methyl Bromide (CH3Br)	1.18E-05	1.68E-05
	(a) Methyl Chloride (CH3Cl)	3.92E-05	5.56E-05
	(a) Methyl Cholanthrene (3-C21H16)	3.58E-12	5.08E-12
	(a) Methyl Chrysene (5-C19H15)	1.63E-09	2.31E-09
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	2.89E-05	4.09E-05
	(a) Methyl Hydrazine (CH6N2)	1.26E-05	1.78E-05
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	1.48E-06	2.10E-06
	(a) Methyl Naphthalene (2-C11H10)	4.78E-11	6.78E-11
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	2.59E-06	3.67E-06
	(a) Methylene Chloride (CH2Cl2, HC-130)	2.15E-05	3.04E-05
	(a) Molybdenum (Mo)	4.80E-08	6.80E-08
	(a) Naphthalene (C10H8)	1.00E-06	1.42E-06
	(a) Nickel (Ni)	1.76E-04	2.49E-04
	(a) Nitrogen Oxides (NOx as NO2)	1.40E+00	1.99E+00
	(a) Nitrous Oxide (N2O)	5.14E-02	7.29E-02
	(a) Organic Matter (unspecified)	8.45E-04	1.20E-03
	(a) Particulates (PM 10)	1.56E-06	2.22E-06
	(a) Particulates (unspecified)	9.04E-01	1.28E+00
	(a) Pentane (C5H12)	5.18E-06	7.34E-06
	(a) Phenanthrene (C14H10)	2.00E-07	2.84E-07
	(a) Phenol (C6H5OH)	1.18E-06	1.68E-06
	(a) Phosphorus (P)	3.97E-07	5.63E-07
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	3.23E-13	4.58E-13
	(a) Propane (C3H8)	5.75E-07	8.15E-07
	(a) Propionaldehyde (CH3CH2CHO)	2.81E-05	3.99E-05
	(a) Pyrene (C16H10)	2.44E-08	3.47E-08
	(a) Selenium (Se)	9.63E-05	1.37E-04
	(a) Silicon (Si)	1.18E-07	1.67E-07
	(a) Sodium (Na)	6.97E-07	9.88E-07
	(a) Styrene (C6H5CHCH2)	1.85E-06	2.62E-06
	(a) Sulfur Oxides (SOx as SO2)	1.35E+00	1.92E+00
	(a) Tetrachloroethylene (C2Cl4)	3.18E-06	4.51E-06
	(a) Toluene (C6H5CH3)	1.81E-05	2.56E-05
	(a) Trichloroethane (1,1,1-CH3CCl3)	1.48E-06	2.10E-06
	(a) Vanadium (V)	2.88E-06	4.08E-06
	(a) Vinyl Acetate (C4H6O2)	5.63E-07	7.98E-07
	(a) Xylene (C6H4(CH3)2)	2.75E-06	3.90E-06
	(a) Zinc (Zn)	1.03E-06	1.47E-06
	Total (g)		9.18E+02
		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	7.81E-01	1.11E+00

Appendix L (cont.): Cable Mnfg. – Energy Consumed and Emissions Generated for Delivery



Assumptions and Variables

Total Trip Distance:	500	miles	
Total Cable Mass:	0.47	kg	Note: Includes mass of AC adapter, USB cable, and telephone cable.
FU Mass equivilency:	0.00052	tons	
Fuel Efficiency	9.4	gal/1000 ton-miles	
Energy Consumption:	1,465	Btu/ton-mile	

From	To	Distance (mi)	Conveyance	Fuel	Fuel Eff. (gal/1000 ton.mi)	Mass (ton)	Energy Rate (Btu/ton.mi)	Energy consumed (MJ)	Fuel consumed (gal)
Cable Mnfg Facility	E-reader Manufacturing Facility	500	Tractor-trailer	diesel	9.4	0.00052	1,465	0.40	0.00246

Air Pollution due to Transportation

Compound	Emissions (lbs/1000 gal)	Mass Released (lbs)
Particulates	3.15E+01	7.75E-05
Nox	2.18E+02	5.36E-04
HC	8.79E+01	2.16E-04
Sox	6.20E+01	1.52E-04
CO	2.15E+02	5.29E-04
CO2 (total)	2.54E+04	6.25E-02
Formaldehyde	2.10E-05	5.16E-11
Other Aldehydes	5.97E+00	1.47E-05
Other Organics	1.16E+02	2.85E-04
Ammonia	4.00E-02	9.84E-08
Lead	1.40E-04	3.44E-10
Methane	4.05E+00	9.96E-06
Kerosene	1.00E-04	2.46E-10
Chlorine	1.50E-03	3.69E-09
HCl	2.50E-02	6.15E-08
HF	3.30E-03	8.11E-09
Metals	2.50E-03	6.15E-09
Antimony	3.80E-05	9.34E-11
Arsenic	7.90E-05	1.94E-10
Beryllium	5.50E-06	1.35E-11
Cadmium	1.20E-04	2.95E-10
Chromium	9.00E-05	2.21E-10
Cobalt	1.10E-04	2.70E-10
Manganese	1.10E-04	2.70E-10
Mercury	2.60E-05	6.39E-11
Nickel	1.70E-03	4.18E-09
Selenium	7.20E-05	1.77E-10
Acreolin	4.70E-06	1.16E-11
Nitrous Oxide	2.80E-03	6.89E-09
Benzene	1.50E-05	3.69E-11
Perchloroethylene	4.60E-06	1.13E-11
TCE	4.40E-06	1.08E-11
Methylene Chloride	2.10E-05	5.16E-11
Carbon Tetrachloride	1.90E-05	4.67E-11
Phenols	1.20E-04	2.95E-10
Naphthalene	7.00E-06	1.72E-11
Dioxins	2.50E-10	6.15E-16
n-nitrodimethylamine	9.90E-07	2.43E-12
Radionuclides (Ci)	8.70E-05	2.14E-10
		6.44E-02
Total (g)		2.92E+01

Water Pollution due to Transportation

Waterborne Emmission	Emissions (lbs/1000 gal)	Mass Released (lb)
Acid	8.40E-06	2.07E-11
Metal Ion	1.80E-01	4.43E-07
Dissolved Solids	3.48E+01	8.56E-05
Suspended Solids	7.90E-01	1.94E-06
BOD	1.30E-01	3.20E-07
COD	8.70E-01	2.14E-06
Phenol	5.80E-04	1.43E-09
Oil	8.10E-01	1.99E-06
Sufuric Acid	6.90E-03	1.70E-08
iron	1.90E-02	4.67E-08
Ammonia	1.40E-02	3.44E-08
Chromium	1.30E-03	3.20E-09
Lead	1.50E-05	3.69E-11
Zinc	6.50E-04	1.60E-09
Chlorides	1.28E+00	3.15E-06
Sodium	1.60E-04	3.93E-10
Calcium	9.00E-05	2.21E-10
Sulfates	1.03E+00	2.53E-06
Manganese	9.20E-03	2.26E-08
Fluorides	4.10E-04	1.01E-09
Nitrates	3.90E-05	9.59E-11
Phosphates	3.50E-03	8.61E-09
Boron	2.80E-02	6.89E-08
Other organics	8.50E-02	2.09E-07
Chromates	9.80E-05	2.41E-10
Cyanide	1.90E-06	4.67E-12
Mercury	9.80E-08	2.41E-13
Cadmium	1.30E-03	3.20E-09
Total (lb)		9.85E-05
Total (g)		4.47E-02

Solid Waste Due To Transportation

Category	Emission (lb/1000 gal)	Mass (lb)	Mass (kg)
Solid Waste	133	3.27E-04	1.48E-04

Appendix L (continued): Cable Manufacturing – Diesel Fuel Production for Delivery

Assumptions and Variables:	Diesel Requirement:	0.0025	gal
	Diesel Equivilancy:	0.01	kg

Note: This assumes that the density of diesel = 0.827 g/ml

		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.30E-04	1.77E-06
	(r) Coal (in ground)	4.88E-02	3.76E-04
	(r) Limestone (CaCO3, in ground)	3.88E-03	2.99E-05
	(r) Natural Gas (in ground)	1.89E-01	1.45E-03
	(r) Oil (in ground)	1.08E+00	8.32E-03
	(r) Sand (in ground)	1.41E-04	1.09E-06
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.48E-05	4.98E-07
	(r) Uranium (U, ore)	8.21E-07	6.32E-09
	Total		1.02E-02

Note: Raw material requirements exclude water usage, which equals	4.15E-01	liters

		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.59E+01	3.53E-01
	E Fuel Energy	1.19E+01	9.18E-02
	E Non Renewable Energy	5.78E+01	4.45E-01
	E Renewable Energy	6.59E-02	5.07E-04
	E Total Primary Energy	5.78E+01	4.45E-01

		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	4.13E-07	3.18E-09
	(w) Aluminum (Al3+)	7.33E-04	5.65E-06
	(w) Ammonia (NH4+, NH3, as N)	1.42E-01	1.09E-03
	(w) AOX (Adsorbable Organic Halogens)	1.93E-09	1.49E-11
	(w) Aromatic Hydrocarbons (unspecified)	4.53E-07	3.49E-09
	(w) Barium (Ba++)	1.45E-06	1.12E-08
	(w) BOD5 (Biochemical Oxygen Demand)	9.71E-01	7.48E-03
	(w) Cadmium (Cd++)	1.51E-09	1.16E-11
	(w) Chlorides (Cl-)	1.56E+01	1.20E-01
	(w) Chromium (Cr III, Cr VI)	1.70E-07	1.31E-09
	(w) COD (Chemical Oxygen Demand)	8.22E+00	6.33E-02
	(w) Copper (Cu+, Cu++)	3.02E-08	2.33E-10
	(w) Cyanide (CN-)	2.12E-09	1.63E-11
	(w) Dissolved Matter (unspecified)	1.41E-03	1.09E-05
	(w) Fluorides (F-)	1.24E-04	9.53E-07
	(w) Halogenated Matter (organic)	6.04E-10	4.65E-12
	(w) Hydrocarbons (unspecified)	1.00E-03	7.71E-06
	(w) Iron (Fe++, Fe3+)	1.72E-06	1.32E-08
	(w) Lead (Pb++, Pb4+)	6.04E-09	4.65E-11
	(w) Mercury (Hg+, Hg++)	6.95E-12	5.35E-14
	(w) Metals (unspecified)	3.31E-02	2.55E-04
	(w) Nickel (Ni++, Ni3+)	3.02E-09	2.33E-11
	(w) Nitrate (NO3-)	3.01E-04	2.32E-06
	(w) Nitrogenous Matter (unspecified, as N)	8.16E-08	6.28E-10
	(w) Oils (unspecified)	4.53E-01	3.49E-03
	(w) Organic Matter (unspecified)	1.09E-06	8.41E-09
	(w) Phenol (C6H5OH)	1.87E-02	1.44E-04
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.01E-06	2.32E-08
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	7.25E-09	5.58E-11
	(w) Salts (unspecified)	8.36E-03	6.43E-05
	(w) Sodium (Na+)	2.00E+01	1.54E-01
	(w) Sulfate (SO4--)	4.51E-04	3.47E-06
	(w) Sulfide (S--)	2.44E-07	1.88E-09
	(w) Suspended Matter (unspecified)	4.41E+00	3.39E-02
	(w) TOC (Total Organic Carbon)	4.53E-06	3.49E-08
	(w) Toluene (C6H5CH3)	6.65E-08	5.12E-10
	(w) Zinc (Zn++)	5.63E-08	4.33E-10
	Total (g)		3.84E-01

Note: Water emissions exclude chemically polluted water, which equals	2.21E-02	liters

		Factor for 1 kg	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	2.15E-08	1.66E-10
	(a) Acenaphthylene (C12H8)	8.16E-09	6.28E-11
	(a) Acetaldehyde (CH3CHO)	1.39E-05	1.07E-07
	(a) Acetophenone (C8H8O)	3.65E-07	2.81E-09
	(a) Acrolein (CH2CHCHO)	7.06E-06	5.43E-08
	(a) Aldehyde (unspecified)	6.60E-03	5.08E-05
	(a) Aluminum (Al)	5.63E-05	4.33E-07
	(a) Ammonia (NH3)	9.84E-03	7.57E-05
	(a) Anthracene (C14H10)	8.17E-09	6.29E-11
	(a) Antimony (Sb)	2.81E-06	2.16E-08
	(a) Aromatic Hydrocarbons (unspecified)	2.72E-07	2.09E-09
	(a) Arsenic (As)	4.92E-05	3.79E-07
	(a) Barium (Ba)	1.49E-06	1.15E-08
	(a) Benzene (C6H6)	6.33E-02	4.87E-04
	(a) Benzo(a)anthracene	5.29E-09	4.07E-11
	(a) Benzo(a)pyrene (C20H12)	2.62E-09	2.02E-11
	(a) Benzo(b)fluoranthene	2.24E-09	1.72E-11
	(a) Benzo(bjk)fluoranthene	2.68E-09	2.06E-11
	(a) Benzo(ghi)perylene	2.36E-09	1.82E-11
	(a) Benzo(k)fluoranthene	2.24E-09	1.72E-11
	(a) Benzyl Chloride (C7H7Cl)	1.70E-05	1.31E-07
	(a) Beryllium (Be)	5.15E-06	3.97E-08
	(a) Bromoform (CHBr3)	9.49E-07	7.31E-09
	(a) Butane (C4H10)	2.32E-03	1.78E-05
	(a) Cadmium (Cd)	3.00E-06	2.31E-08
	(a) Calcium (Ca)	4.88E-05	3.76E-07
	(a) Carbon Dioxide (CO2, biomass)	2.46E-04	1.89E-06
	(a) Carbon Dioxide (CO2, fossil)	6.70E+02	5.16E+00
	(a) Carbon Disulfide (CS2)	3.16E-06	2.44E-08
	(a) Carbon Monoxide (CO)	2.00E+00	1.54E-02
	(a) Chlorides (Cl-)	1.57E-04	1.21E-06
	(a) Chlorine (Cl2)	2.35E-08	1.81E-10

		Factor for 1 kg	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	1.70E-07	1.31E-09
	(a) Chlorobenzene (C6H5Cl)	5.36E-07	4.12E-09
	(a) Chloroform (CHCl3, HC-20)	1.44E-06	1.11E-08
	(a) Chromium (Cr III, Cr VI)	7.66E-05	5.90E-07
	(a) Chrysene (C18H12)	4.82E-09	3.71E-11
	(a) Cobalt (Co)	8.82E-06	6.79E-08
	(a) Copper (Cu)	5.13E-06	3.95E-08
	(a) Cumene (C9H12)	1.29E-07	9.93E-10
	(a) Cyanide (CN-)	6.09E-05	4.68E-07
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	1.78E-06	1.37E-08
	(a) Dibenzo(a,h)anthracene	1.61E-09	1.24E-11
	(a) Dichlorobenzene (1,4-C6H4Cl2)	1.32E-06	1.02E-08
	(a) Dimethyl Benzanthracene (7,12-C20H16)	1.66E-08	1.27E-10
	(a) Dimethyl Sulfate (C2H6O4S)	1.17E-06	8.99E-09
	(a) Dinitrotoluene (2,4-C7H6N2O4)	6.82E-09	5.25E-11
	(a) Dioxins (unspecified)	3.94E-10	3.03E-12
	(a) Diphenyl ((C6H5)2)	4.14E-08	3.19E-10
	(a) Ethane (C2H6)	3.42E-03	2.63E-05
	(a) Ethyl Benzene (C6H5C2H5)	2.32E-06	1.78E-08
	(a) Ethyl Chloride (C2H5Cl)	1.02E-06	7.87E-09
	(a) Ethylene Dibromide (C2H4Br2)	2.92E-08	2.25E-10
	(a) Ethylene Dichloride (C2H4Cl2)	9.74E-07	7.49E-09
	(a) Fluoranthene	2.14E-08	1.65E-10
	(a) Fluorene (C13H10)	2.60E-08	2.00E-10
	(a) Fluorides (F-)	1.75E-05	1.35E-07
	(a) Formaldehyde (CH2O)	3.43E-03	2.64E-05
	(a) Furan (C4H4O)	1.83E-09	1.41E-11
	(a) Halogenated Hydrocarbons (unspecified)	1.51E-12	1.16E-14
	(a) Halon 1301 (CF3Br)	2.63E-09	2.02E-11
	(a) Hexane (C6H14)	1.99E-03	1.53E-05
	(a) Hydrocarbons (except methane)	3.77E-01	2.90E-03
	(a) Hydrocarbons (unspecified)	5.40E-01	4.16E-03
	(a) Hydrogen Chloride (HCl)	2.92E-02	2.25E-04
	(a) Hydrogen Fluoride (HF)	3.65E-03	2.81E-05
	(a) Hydrogen Sulfide (H2S)	8.84E-03	6.81E-05
	(a) Indeno (1,2,3,c,d) Pyrene	3.83E-09	2.95E-11
	(a) Iron (Fe)	1.09E-04	8.38E-07
	(a) Isophorone	1.41E-05	1.09E-07
	(a) Lead (Pb)	4.49E-05	3.46E-07
	(a) Magnesium (Mg)	2.68E-04	2.06E-06
	(a) Manganese (Mn)	8.16E-05	6.28E-07
	(a) Mercury (Hg)	3.18E-06	2.45E-08
	(a) Metals (unspecified)	1.62E-06	1.24E-08
	(a) Methane (CH4)	3.34E+00	2.57E-02
	(a) Methyl Bromide (CH3Br)	3.89E-06	3.00E-08
	(a) Methyl Chloride (CH3Cl)	1.29E-05	9.93E-08
	(a) Methyl Cholanthrene (3-C21H16)	1.99E-09	1.53E-11
	(a) Methyl Chrysene (5-C19H15)	5.36E-10	4.12E-12
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	9.49E-06	7.31E-08
	(a) Methyl Hydrazine (CH6N2)	4.14E-06	3.19E-08
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	4.87E-07	3.75E-09
	(a) Methyl Naphthalene (2-C11H10)	2.65E-08	2.04E-10
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	8.52E-07	6.56E-09
	(a) Methylene Chloride (CH2Cl2, HC-130)	7.06E-06	5.43E-08
	(a) Molybdenum (Mo)	6.16E-06	4.74E-08
	(a) Naphthalene (C10H8)	1.50E-06	1.15E-08
	(a) Nickel (Ni)	3.79E-04	2.92E-06
	(a) Nitrogen Oxides (NOx as NO2)	2.26E+00	1.74E-02
	(a) Nitrous Oxide (N2O)	5.43E-02	4.18E-04
	(a) Organic Matter (unspecified)	3.15E-01	2.43E-03
	(a) Particulates (PM 10)	6.49E-04	5.00E-06
	(a) Particulates (unspecified)	5.07E-01	3.90E-03
	(a) Pentane (C5H12)	2.87E-03	2.21E-05
	(a) Phenanthrene (C14H10)	8.63E-08	6.64E-10
	(a) Phenol (C6H5OH)	3.89E-07	3.00E-09
	(a) Phosphorus (P)	3.73E-05	2.87E-07
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	3.02E-10	2.33E-12
	(a) Propane (C3H8)	6.10E-06	4.70E-08
	(a) Propionaldehyde (CH3CH2CHO)	9.25E-06	7.12E-08
	(a) Pyrene (C16H10)	1.43E-08	1.10E-10
	(a) Selenium (Se)	3.36E-05	2.59E-07
	(a) Silicon (Si)	4.88E-05	3.76E-07
	(a) Sodium (Na)	2.89E-04	2.22E-06
	(a) Styrene (C6H5CHCH2)	6.09E-07	4.68E-09
	(a) Sulfur Oxides (SOx as SO2)	3.24E+00	2.49E-02
	(a) Tetrachloroethylene (C2Cl4)	1.05E-06	8.06E-09
	(a) Toluene (C6H5CH3)	1.51E-05	1.17E-07
	(a) Trichloroethane (1,1,1-CH3CCl3)	4.87E-07	3.75E-09
	(a) Vanadium (V)	7.68E-04	5.91E-06
	(a) Vinyl Acetate (C4H6O2)	1.85E-07	1.42E-09
	(a) Xylene (C6H4(CH3)2)	4.37E-06	3.37E-08
	(a) Zinc (Zn)	4.52E-05	3.48E-07
	Total (g)		6.78E+02

		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	2.65E-01	2.04E-03

APPENDIX M
LCI DATA
BATTERY MANUFACTURING

1) Electricity Production
2) Energy Consumed and Emissions Generated for Delivery of Battery
3) Diesel Fuel Production for Delivery of Battery

Appendix M: Battery Manufacturing – Electricity Production

Assumptions and Variables:	Electricity Requirement:	0.50	MJ
		Factor for 1 MJ	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.46E-07	1.23E-07
	(r) Coal (in ground)	1.48E-01	7.41E-02
	(r) Limestone (CaCO3, in ground)	1.17E-02	5.85E-03
	(r) Natural Gas (in ground)	9.17E-04	4.58E-04
	(r) Oil (in ground)	2.99E-03	1.49E-03
	(r) Sand (in ground)	1.51E-07	7.53E-08
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.92E-08	3.45E-08
	(r) Uranium (U, ore)	7.17E-07	3.58E-07
	Total		8.19E-02
Note: Raw material requirements exclude water usage, which equals		3.00E-02	liters
		Factor for 1 MJ	MJ
Energy Burdens	E Feedstock Energy	3.94E-01	1.97E-01
	E Fuel Energy	4.47E+00	2.23E+00
	E Non Renewable Energy	4.85E+00	2.42E+00
	E Renewable Energy	7.96E-03	3.98E-03
	Electricity	1.50E-02	7.49E-03
	E Total Primary Energy	4.86E+00	2.43E+00
		Factor for 1 MJ	grams (g)
Water Emissions	(w) Acids (H+)	1.06E-09	5.30E-10
	(w) Aluminum (Al3+)	7.83E-07	3.91E-07
	(w) Ammonia (NH4+, NH3, as N)	1.89E-04	9.42E-05
	(w) AOX (Adsorbable Organic Halogens)	2.07E-12	1.03E-12
	(w) Aromatic Hydrocarbons (unspecified)	4.84E-10	2.42E-10
	(w) Barium (Ba++)	1.55E-09	7.74E-10
	(w) BOD5 (Biochemical Oxygen Demand)	1.04E-03	5.19E-04
	(w) Cadmium (Cd++)	1.61E-12	8.06E-13
	(w) Chlorides (Cl-)	3.75E-02	1.87E-02
	(w) Chromium (Cr III, Cr VI)	3.46E-10	1.73E-10
	(w) COD (Chemical Oxygen Demand)	8.78E-03	4.39E-03
	(w) Copper (Cu+, Cu++)	3.23E-11	1.61E-11
	(w) Cyanide (CN-)	2.26E-12	1.13E-12
	(w) Dissolved Matter (unspecified)	4.28E-03	2.14E-03
	(w) Fluorides (F-)	1.08E-04	5.40E-05
	(w) Halogenated Matter (organic)	6.46E-13	3.22E-13
	(w) Hydrocarbons (unspecified)	2.41E-06	1.21E-06
	(w) Iron (Fe++, Fe3+)	2.11E-07	1.05E-07
	(w) Lead (Pb++, Pb4+)	6.46E-12	3.22E-12
	(w) Mercury (Hg+, Hg++)	7.42E-15	3.71E-15
	(w) Metals (unspecified)	6.37E-05	3.18E-05
	(w) Nickel (Ni++, Ni3+)	3.23E-12	1.61E-12
	(w) Nitrate (NO3-)	2.59E-05	1.29E-05
	(w) Nitrogenous Matter (unspecified, as N)	8.71E-11	4.35E-11
	(w) Oils (unspecified)	6.61E-04	3.30E-04
	(w) Organic Matter (unspecified)	2.79E-09	1.39E-09
	(w) Phenol (C6H5OH)	1.99E-05	9.96E-06
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.22E-09	1.61E-09
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	7.75E-12	3.87E-12
	(w) Salts (unspecified)	8.92E-06	4.46E-06
	(w) Sodium (Na+)	4.83E-02	2.41E-02
	(w) Sulfate (SO4--)	2.33E-05	1.16E-05
	(w) Sulfide (S--)	6.02E-10	3.01E-10
	(w) Suspended Matter (unspecified)	4.74E-03	2.37E-03
	(w) TOC (Total Organic Carbon)	4.84E-09	2.42E-09
	(w) Toluene (C6H5CH3)	7.10E-11	3.55E-11
	(w) Zinc (Zn++)	9.93E-11	4.96E-11
	Total (g)		5.28E-02
Note: Water emissions exclude chemically polluted water, which equals		2.96E-03	liters
		Factor for 1 MJ	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	3.78E-08	1.89E-08
	(a) Acenaphthylene (C12H8)	1.85E-08	9.25E-09
	(a) Acetaldehyde (CH3CHO)	4.22E-05	2.11E-05
	(a) Acetophenone (C8H8O)	1.11E-06	5.55E-07
	(a) Acrolein (CH2CHCHO)	2.15E-05	1.07E-05
	(a) Aldehyde (unspecified)	7.58E-03	3.79E-03
	(a) Aluminum (Al)	1.36E-07	6.78E-08
	(a) Ammonia (NH3)	5.11E-05	2.55E-05
	(a) Anthracene (C14H10)	1.56E-08	7.77E-09
	(a) Antimony (Sb)	1.51E-06	7.54E-07
	(a) Aromatic Hydrocarbons (unspecified)	2.90E-10	1.45E-10
	(a) Arsenic (As)	1.30E-04	6.49E-05
	(a) Barium (Ba)	9.72E-08	4.86E-08
	(a) Benzene (C6H6)	2.59E-04	1.29E-04
	(a) Benzo(a)anthracene	5.93E-09	2.96E-09
	(a) Benzo(a)pyrene (C20H12)	2.82E-09	1.41E-09
	(a) Benzo(b)fluoranthene	3.86E-12	1.93E-12
	(a) Benzo(bjk)fluoranthene	8.14E-09	4.07E-09
	(a) Benzo(ghi)perylene	2.00E-09	1.00E-09
	(a) Benzo(k)fluoranthene	3.86E-12	1.93E-12
	(a) Benzyl Chloride (C7H7Cl)	5.18E-05	2.59E-05
	(a) Beryllium (Be)	1.49E-05	7.46E-06
	(a) Bromoform (CHBr3)	2.89E-06	1.44E-06
	(a) Butane (C4H10)	4.18E-06	2.09E-06
	(a) Cadmium (Cd)	8.42E-06	4.21E-06
	(a) Calcium (Ca)	1.18E-07	5.88E-08
	(a) Carbon Dioxide (CO2, biomass)	2.97E-05	1.48E-05
	(a) Carbon Dioxide (CO2, fossil)	3.77E+02	1.88E+02
	(a) Carbon Disulfide (CS2)	9.62E-06	4.81E-06
	(a) Carbon Monoxide (CO)	1.62E-01	8.09E-02
	(a) Chlorides (Cl-)	1.16E-05	5.81E-06
	(a) Chlorine (Cl2)	6.00E-11	3.00E-11

		Factor for 1 MJ	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	5.18E-07	2.59E-07
	(a) Chlorobenzene (C6H5Cl)	1.63E-06	8.14E-07
	(a) Chloroform (CHCl3, HC-20)	4.37E-06	2.18E-06
	(a) Chromium (Cr III, Cr VI)	2.17E-04	1.09E-04
	(a) Chrysene (C18H12)	7.41E-09	3.70E-09
	(a) Cobalt (Co)	7.61E-06	3.80E-06
	(a) Copper (Cu)	7.73E-08	3.86E-08
	(a) Cumene (C9H12)	3.92E-07	1.96E-07
	(a) Cyanide (CN-)	1.85E-04	9.24E-05
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	5.40E-06	2.70E-06
	(a) Dibenzo(a,h)anthracene	2.70E-12	1.35E-12
	(a) Dichlorobenzene (1,4-C6H4Cl2)	2.39E-09	1.19E-09
	(a) Dimethyl Benzanthracene (7,12-C20H16)	3.02E-11	1.51E-11
	(a) Dimethyl Sulfate (C2H6O4S)	3.55E-06	1.78E-06
	(a) Dinitrotoluene (2,4-C7H6N2O4)	2.07E-08	1.04E-08
	(a) Dioxins (unspecified)	1.20E-09	5.99E-10
	(a) Diphenyl ((C6H5)2)	1.26E-07	6.29E-08
	(a) Ethane (C2H6)	6.17E-06	3.08E-06
	(a) Ethyl Benzene (C6H5C2H5)	6.96E-06	3.48E-06
	(a) Ethyl Chloride (C2H5Cl)	3.11E-06	1.55E-06
	(a) Ethylene Dibromide (C2H4Br2)	8.88E-08	4.44E-08
	(a) Ethylene Dichloride (C2H4Cl2)	2.96E-06	1.48E-06
	(a) Fluoranthene	5.26E-08	2.63E-08
	(a) Fluorene (C13H10)	6.74E-08	3.37E-08
	(a) Fluorides (F-)	1.82E-06	9.08E-07
	(a) Formaldehyde (CH2O)	3.16E-05	1.58E-05
	(a) Furan (C4H4O)	5.57E-09	2.78E-09
	(a) Halogenated Hydrocarbons (unspecified)	1.61E-15	8.06E-16
	(a) Halon 1301 (CF3Br)	2.81E-12	1.40E-12
	(a) Hexane (C6H14)	8.54E-06	4.27E-06
	(a) Hydrocarbons (except methane)	1.39E-02	6.94E-03
	(a) Hydrocarbons (unspecified)	2.68E-02	1.34E-02
	(a) Hydrogen Chloride (HCl)	8.88E-02	4.44E-02
	(a) Hydrogen Fluoride (HF)	1.11E-02	5.55E-03
	(a) Hydrogen Sulfide (H2S)	2.13E-05	1.06E-05
	(a) Indeno (1,2,3,c,d) Pyrene	4.52E-09	2.26E-09
	(a) Iron (Fe)	2.62E-07	1.31E-07
	(a) Isophorone	4.29E-05	2.14E-05
	(a) Lead (Pb)	1.29E-04	6.44E-05
	(a) Magnesium (Mg)	8.14E-04	4.07E-04
	(a) Manganese (Mn)	2.42E-04	1.21E-04
	(a) Mercury (Hg)	8.08E-06	4.03E-06
	(a) Metals (unspecified)	1.76E-09	8.81E-10
	(a) Methane (CH4)	6.60E-01	3.30E-01
	(a) Methyl Bromide (CH3Br)	1.18E-05	5.92E-06
	(a) Methyl Chloride (CH3Cl)	3.92E-05	1.96E-05
	(a) Methyl Cholanthrene (3-C21H16)	3.58E-12	1.79E-12
	(a) Methyl Chrysene (5-C19H15)	1.63E-09	8.14E-10
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	2.89E-05	1.44E-05
	(a) Methyl Hydrazine (CH6N2)	1.26E-05	6.29E-06
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	1.48E-06	7.40E-07
	(a) Methyl Naphthalene (2-C11H10)	4.78E-11	2.39E-11
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	2.59E-06	1.29E-06
	(a) Methylene Chloride (CH2Cl2, HC-130)	2.15E-05	1.07E-05
	(a) Molybdenum (Mo)	4.80E-08	2.40E-08
	(a) Naphthalene (C10H8)	1.00E-06	5.00E-07
	(a) Nickel (Ni)	1.76E-04	8.78E-05
	(a) Nitrogen Oxides (NOx as NO2)	1.40E+00	7.00E-01
	(a) Nitrous Oxide (N2O)	5.14E-02	2.57E-02
	(a) Organic Matter (unspecified)	8.45E-04	4.22E-04
	(a) Particulates (PM 10)	1.56E-06	7.82E-07
	(a) Particulates (unspecified)	9.04E-01	4.52E-01
	(a) Pentane (C5H12)	5.18E-06	2.59E-06
	(a) Phenanthrene (C14H10)	2.00E-07	9.99E-08
	(a) Phenol (C6H5OH)	1.18E-06	5.92E-07
	(a) Phosphorus (P)	3.97E-07	1.98E-07
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	3.23E-13	1.61E-13
	(a) Propane (C3H8)	5.75E-07	2.87E-07
	(a) Propionaldehyde (CH3CH2CHO)	2.81E-05	1.41E-05
	(a) Pyrene (C16H10)	2.44E-08	1.22E-08
	(a) Selenium (Se)	9.63E-05	4.81E-05
	(a) Silicon (Si)	1.18E-07	5.88E-08
	(a) Sodium (Na)	6.97E-07	3.48E-07
	(a) Styrene (C6H5CHCH2)	1.85E-06	9.24E-07
	(a) Sulfur Oxides (SOx as SO2)	1.35E+00	6.75E-01
	(a) Tetrachloroethylene (C2Cl4)	3.18E-06	1.59E-06
	(a) Toluene (C6H5CH3)	1.81E-05	9.02E-06
	(a) Trichloroethane (1,1,1-CH3CCl3)	1.48E-06	7.40E-07
	(a) Vanadium (V)	2.88E-06	1.44E-06
	(a) Vinyl Acetate (C4H6O2)	5.63E-07	2.81E-07
	(a) Xylene (C6H4(CH3)2)	2.75E-06	1.37E-06
	(a) Zinc (Zn)	1.03E-06	5.16E-07
	Total (g)		5.67E+02
		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	7.81E-01	3.90E-01

Appendix M (cont.): Battery Mnfg. – Energy Consumed and Emissions Generated for Delivery

Assumptions and Variables

Total Trip Distance:	500	miles
Total Battery Mass:	0.09	kg
FU Mass equivilency:	0.00010	tons
Fuel Efficiency	9.4	gal/1000 ton-miles
Energy Consumption:	1,465	Btu/ton-mile

From	To	Distance (mi)	Conveyance	Fuel	Fuel Eff. (gal/1000 ton.mi)	Mass (ton)	Energy Rate (Btu/ton.mi)	Energy consumed (MJ)	Fuel consumed (gal)
Battery Mnfg Facility	E-reader Manufacturing Facility	500	Tractor-trailer	diesel	9.4	0.000101	1,465	0.08	0.00048

Air Pollution due to Transportation

Compound	Emissions (lbs/1000 gal)	Mass Released (lbs)
Particulates	3.15E+01	1.50E-05
Nox	2.18E+02	1.04E-04
HC	8.79E+01	4.18E-05
Sox	6.20E+01	2.95E-05
CO	2.15E+02	1.02E-04
CO2 (total)	2.54E+04	1.21E-02
Formaldehyde	2.10E-05	1.00E-11
Other Aldehydes	5.97E+00	2.84E-06
Other Organics	1.16E+02	5.52E-05
Ammonia	4.00E-02	1.90E-08
Lead	1.40E-04	6.66E-11
Methane	4.05E+00	1.93E-06
Kerosene	1.00E-04	4.76E-11
Chlorine	1.50E-03	7.14E-10
HCl	2.50E-02	1.19E-08
HF	3.30E-03	1.57E-09
Metals	2.50E-03	1.19E-09
Antimony	3.80E-05	1.81E-11
Arsenic	7.90E-05	3.76E-11
Beryllium	5.50E-06	2.62E-12
Cadmium	1.20E-04	5.71E-11
Chromium	9.00E-05	4.28E-11
Cobalt	1.10E-04	5.24E-11
Manganese	1.10E-04	5.24E-11
Mercury	2.60E-05	1.24E-11
Nickel	1.70E-03	8.09E-10
Selenium	7.20E-05	3.43E-11
Acreolin	4.70E-06	2.24E-12
Nitrous Oxide	2.80E-03	1.33E-09
Benzene	1.50E-05	7.14E-12
Perchloroethylene	4.60E-06	2.19E-12
TCE	4.40E-06	2.09E-12
Methylene Chloride	2.10E-05	1.00E-11
Carbon Tetrachloride	1.90E-05	9.05E-12
Phenols	1.20E-04	5.71E-11
Naphthalene	7.00E-06	3.33E-12
Dioxins	2.50E-10	1.19E-16
n-nitrodimethylamine	9.90E-07	4.71E-13
Radionuclides (Ci)	8.70E-05	4.14E-11
		1.25E-02
Total (g)		5.65E+00

Water Pollution due to Transportation

Waterborne Emmission	Emissions (lbs/1000 gal)	Mass Released (lb)
Acid	8.40E-06	4.00E-12
Metal Ion	1.80E-01	8.57E-08
Dissolved Solids	3.48E+01	1.66E-05
Suspended Solids	7.90E-01	3.76E-07
BOD	1.30E-01	6.19E-08
COD	8.70E-01	4.14E-07
Phenol	5.80E-04	2.76E-10
Oil	8.10E-01	3.86E-07
Sufuric Acid	6.90E-03	3.28E-09
iron	1.90E-02	9.05E-09
Ammonia	1.40E-02	6.66E-09
Chromium	1.30E-03	6.19E-10
Lead	1.50E-05	7.14E-12
Zinc	6.50E-04	3.09E-10
Chlorides	1.28E+00	6.09E-07
Sodium	1.60E-04	7.62E-11
Calcium	9.00E-05	4.28E-11
Sulfates	1.03E+00	4.90E-07
Manganese	9.20E-03	4.38E-09
Fluorides	4.10E-04	1.95E-10
Nitrates	3.90E-05	1.86E-11
Phosphates	3.50E-03	1.67E-09
Boron	2.80E-02	1.33E-08
Other organics	8.50E-02	4.05E-08
Chromates	9.80E-05	4.67E-11
Cyanide	1.90E-06	9.05E-13
Mercury	9.80E-08	4.67E-14
Cadmium	1.30E-03	6.19E-10
Total (lb)		1.91E-05
Total (g)		8.65E-03

Solid Waste Due To Transportation

Category	Emission (lb/1000 gal)	Mass (lb)	Mass (kg)
Solid Waste	133	6.33E-05	2.87E-05

Appendix M (continued): Battery Manufacturing – Diesel Fuel Production for Delivery

Assumptions and Variables:	Diesel Requirement:	0.0005	gal
	Diesel Equivilancy:	0.0015	kg

Note: This assumes that the density of diesel = 0.827 g/ml

		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.30E-04	3.43E-07
	(r) Coal (in ground)	4.88E-02	7.27E-05
	(r) Limestone (CaCO3, in ground)	3.88E-03	5.78E-06
	(r) Natural Gas (in ground)	1.89E-01	2.82E-04
	(r) Oil (in ground)	1.08E+00	1.61E-03
	(r) Sand (in ground)	1.41E-04	2.10E-07
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.48E-05	9.65E-08
	(r) Uranium (U, ore)	8.21E-07	1.22E-09
	Total		1.97E-03
Note: Raw material requirements exclude water usage, which equals		8.03E-02	liters
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.59E+01	6.84E-02
	E Fuel Energy	1.19E+01	1.78E-02
	E Non Renewable Energy	5.78E+01	8.61E-02
	E Renewable Energy	6.59E-02	9.82E-05
	E Total Primary Energy	5.78E+01	8.62E-02
		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	4.13E-07	6.15E-10
	(w) Aluminum (Al3+)	7.33E-04	1.09E-06
	(w) Ammonia (NH4+, NH3, as N)	1.42E-01	2.11E-04
	(w) AOX (Adsorbable Organic Halogens)	1.93E-09	2.88E-12
	(w) Aromatic Hydrocarbons (unspecified)	4.53E-07	6.76E-10
	(w) Barium (Ba++)	1.45E-06	2.16E-09
	(w) BOD5 (Biochemical Oxygen Demand)	9.71E-01	1.45E-03
	(w) Cadmium (Cd++)	1.51E-09	2.25E-12
	(w) Chlorides (Cl-)	1.56E+01	2.32E-02
	(w) Chromium (Cr III, Cr VI)	1.70E-07	2.53E-10
	(w) COD (Chemical Oxygen Demand)	8.22E+00	1.22E-02
	(w) Copper (Cu+, Cu++)	3.02E-08	4.50E-11
	(w) Cyanide (CN-)	2.12E-09	3.15E-12
	(w) Dissolved Matter (unspecified)	1.41E-03	2.10E-06
	(w) Fluorides (F-)	1.24E-04	1.84E-07
	(w) Halogenated Matter (organic)	6.04E-10	9.01E-13
	(w) Hydrocarbons (unspecified)	1.00E-03	1.49E-06
	(w) Iron (Fe++, Fe3+)	1.72E-06	2.56E-09
	(w) Lead (Pb++, Pb4+)	6.04E-09	9.01E-12
	(w) Mercury (Hg+, Hg++)	6.95E-12	1.04E-14
	(w) Metals (unspecified)	3.31E-02	4.93E-05
	(w) Nickel (Ni++, Ni3+)	3.02E-09	4.50E-12
	(w) Nitrate (NO3-)	3.01E-04	4.49E-07
	(w) Nitrogenous Matter (unspecified, as N)	8.16E-08	1.22E-10
	(w) Oils (unspecified)	4.53E-01	6.76E-04
	(w) Organic Matter (unspecified)	1.09E-06	1.63E-09
	(w) Phenol (C6H5OH)	1.87E-02	2.78E-05
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.01E-06	4.49E-09
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	7.25E-09	1.08E-11
	(w) Salts (unspecified)	8.36E-03	1.25E-05
	(w) Sodium (Na+)	2.00E+01	2.98E-02
	(w) Sulfate (SO4--)	4.51E-04	6.72E-07
	(w) Sulfide (S--)	2.44E-07	3.64E-10
	(w) Suspended Matter (unspecified)	4.41E+00	6.57E-03
	(w) TOC (Total Organic Carbon)	4.53E-06	6.76E-09
	(w) Toluene (C6H5CH3)	6.65E-08	9.91E-11
	(w) Zinc (Zn++)	5.63E-08	8.39E-11
	Total (g)		7.43E-02
Note: Water emissions exclude chemically polluted water, which equals		4.29E-03	liters
		Factor for 1 kg	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	2.15E-08	3.21E-11
	(a) Acenaphthylene (C12H8)	8.16E-09	1.22E-11
	(a) Acetaldehyde (CH3CHO)	1.39E-05	2.07E-08
	(a) Acetophenone (C8H8O)	3.65E-07	5.44E-10
	(a) Acrolein (CH2CHCHO)	7.06E-06	1.05E-08
	(a) Aldehyde (unspecified)	6.60E-03	9.83E-06
	(a) Aluminum (Al)	5.63E-05	8.39E-08
	(a) Ammonia (NH3)	9.84E-03	1.47E-05
	(a) Anthracene (C14H10)	8.17E-09	1.22E-11
	(a) Antimony (Sb)	2.81E-06	4.19E-09
	(a) Aromatic Hydrocarbons (unspecified)	2.72E-07	4.05E-10
	(a) Arsenic (As)	4.92E-05	7.33E-08
	(a) Barium (Ba)	1.49E-06	2.22E-09
	(a) Benzene (C6H6)	6.33E-02	9.44E-05
	(a) Benzo(a)anthracene	5.29E-09	7.88E-12
	(a) Benzo(a)pyrene (C20H12)	2.62E-09	3.91E-12
	(a) Benzo(b)fluoranthene	2.24E-09	3.33E-12
	(a) Benzo(bjk)fluoranthene	2.68E-09	3.99E-12
	(a) Benzo(ghi)perylene	2.36E-09	3.52E-12
	(a) Benzo(k)fluoranthene	2.24E-09	3.33E-12
	(a) Benzyl Chloride (C7H7Cl)	1.70E-05	2.54E-08
	(a) Beryllium (Be)	5.15E-06	7.68E-09
	(a) Bromoform (CHBr3)	9.49E-07	1.41E-09
	(a) Butane (C4H10)	2.32E-03	3.45E-06
	(a) Cadmium (Cd)	3.00E-06	4.47E-09
	(a) Calcium (Ca)	4.88E-05	7.27E-08
	(a) Carbon Dioxide (CO2, biomass)	2.46E-04	3.67E-07
	(a) Carbon Dioxide (CO2, fossil)	6.70E+02	9.99E-01
	(a) Carbon Disulfide (CS2)	3.16E-06	4.72E-09
	(a) Carbon Monoxide (CO)	2.00E+00	2.98E-03
	(a) Chlorides (Cl-)	1.57E-04	2.34E-07
	(a) Chlorine (Cl2)	2.35E-08	3.51E-11

		Factor for 1 kg	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	1.70E-07	2.54E-10
	(a) Chlorobenzene (C6H5Cl)	5.36E-07	7.98E-10
	(a) Chloroform (CHCl3, HC-20)	1.44E-06	2.14E-09
	(a) Chromium (Cr III, Cr VI)	7.66E-05	1.14E-07
	(a) Chrysene (C18H12)	4.82E-09	7.19E-12
	(a) Cobalt (Co)	8.82E-06	1.31E-08
	(a) Copper (Cu)	5.13E-06	7.64E-09
	(a) Cumene (C9H12)	1.29E-07	1.92E-10
	(a) Cyanide (CN-)	6.09E-05	9.07E-08
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	1.78E-06	2.65E-09
	(a) Dibenzo(a,h)anthracene	1.61E-09	2.39E-12
	(a) Dichlorobenzene (1,4-C6H4Cl2)	1.32E-06	1.97E-09
	(a) Dimethyl Benzanthracene (7,12-C20H16)	1.66E-08	2.47E-11
	(a) Dimethyl Sulfate (C2H6O4S)	1.17E-06	1.74E-09
	(a) Dinitrotoluene (2,4-C7H6N2O4)	6.82E-09	1.02E-11
	(a) Dioxins (unspecified)	3.94E-10	5.88E-13
	(a) Diphenyl ((C6H5)2)	4.14E-08	6.17E-11
	(a) Ethane (C2H6)	3.42E-03	5.10E-06
	(a) Ethyl Benzene (C6H5C2H5)	2.32E-06	3.45E-09
	(a) Ethyl Chloride (C2H5Cl)	1.02E-06	1.52E-09
	(a) Ethylene Dibromide (C2H4Br2)	2.92E-08	4.35E-11
	(a) Ethylene Dichloride (C2H4Cl2)	9.74E-07	1.45E-09
	(a) Fluoranthene	2.14E-08	3.19E-11
	(a) Fluorene (C13H10)	2.60E-08	3.87E-11
	(a) Fluorides (F-)	1.75E-05	2.61E-08
	(a) Formaldehyde (CH2O)	3.43E-03	5.11E-06
	(a) Furan (C4H4O)	1.83E-09	2.73E-12
	(a) Halogenated Hydrocarbons (unspecified)	1.51E-12	2.25E-15
	(a) Halon 1301 (CF3Br)	2.63E-09	3.92E-12
	(a) Hexane (C6H14)	1.99E-03	2.96E-06
	(a) Hydrocarbons (except methane)	3.77E-01	5.62E-04
	(a) Hydrocarbons (unspecified)	5.40E-01	8.05E-04
	(a) Hydrogen Chloride (HCl)	2.92E-02	4.36E-05
	(a) Hydrogen Fluoride (HF)	3.65E-03	5.44E-06
	(a) Hydrogen Sulfide (H2S)	8.84E-03	1.32E-05
	(a) Indeno (1,2,3,c,d) Pyrene	3.83E-09	5.71E-12
	(a) Iron (Fe)	1.09E-04	1.62E-07
	(a) Isophorone	1.41E-05	2.10E-08
	(a) Lead (Pb)	4.49E-05	6.69E-08
	(a) Magnesium (Mg)	2.68E-04	3.99E-07
	(a) Manganese (Mn)	8.16E-05	1.22E-07
	(a) Mercury (Hg)	3.18E-06	4.74E-09
	(a) Metals (unspecified)	1.62E-06	2.41E-09
	(a) Methane (CH4)	3.34E+00	4.98E-03
	(a) Methyl Bromide (CH3Br)	3.89E-06	5.80E-09
	(a) Methyl Chloride (CH3Cl)	1.29E-05	1.92E-08
	(a) Methyl Cholanthrene (3-C21H16)	1.99E-09	2.96E-12
	(a) Methyl Chrysene (5-C19H15)	5.36E-10	7.98E-13
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	9.49E-06	1.41E-08
	(a) Methyl Hydrazine (CH6N2)	4.14E-06	6.17E-09
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	4.87E-07	7.25E-10
	(a) Methyl Naphthalene (2-C11H10)	2.65E-08	3.95E-11
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	8.52E-07	1.27E-09
	(a) Methylene Chloride (CH2Cl2, HC-130)	7.06E-06	1.05E-08
	(a) Molybdenum (Mo)	6.16E-06	9.18E-09
	(a) Naphthalene (C10H8)	1.50E-06	2.24E-09
	(a) Nickel (Ni)	3.79E-04	5.65E-07
	(a) Nitrogen Oxides (NOx as NO2)	2.26E+00	3.36E-03
	(a) Nitrous Oxide (N2O)	5.43E-02	8.09E-05
	(a) Organic Matter (unspecified)	3.15E-01	4.70E-04
	(a) Particulates (PM 10)	6.49E-04	9.67E-07
	(a) Particulates (unspecified)	5.07E-01	7.55E-04
	(a) Pentane (C5H12)	2.87E-03	4.28E-06
	(a) Phenanthrene (C14H10)	8.63E-08	1.29E-10
	(a) Phenol (C6H5OH)	3.89E-07	5.80E-10
	(a) Phosphorus (P)	3.73E-05	5.56E-08
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	3.02E-10	4.50E-13
	(a) Propane (C3H8)	6.10E-06	9.09E-09
	(a) Propionaldehyde (CH3CH2CHO)	9.25E-06	1.38E-08
	(a) Pyrene (C16H10)	1.43E-08	2.13E-11
	(a) Selenium (Se)	3.36E-05	5.01E-08
	(a) Silicon (Si)	4.88E-05	7.27E-08
	(a) Sodium (Na)	2.89E-04	4.31E-07
	(a) Styrene (C6H5CHCH2)	6.09E-07	9.07E-10
	(a) Sulfur Oxides (SOx as SO2)	3.24E+00	4.82E-03
	(a) Tetrachloroethylene (C2Cl4)	1.05E-06	1.56E-09
	(a) Toluene (C6H5CH3)	1.51E-05	2.26E-08
	(a) Trichloroethane (1,1,1-CH3CCl3)	4.87E-07	7.25E-10
	(a) Vanadium (V)	7.68E-04	1.14E-06
	(a) Vinyl Acetate (C4H6O2)	1.85E-07	2.76E-10
	(a) Xylene (C6H4(CH3)2)	4.37E-06	6.52E-09
	(a) Zinc (Zn)	4.52E-05	6.73E-08
	Total (g)		6.73E+02
		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	2.65E-01	3.95E-04

APPENDIX N
LCI DATA
PACKAGING PRODUCTION

1) Corrugated Container (Box)
2) Paper
3) Polyethylene (PE)
4) Calendered PVC

Appendix N: Packaging Production - Corrugated Container (Box)

Assumptions:	Mass per FU	0.55	kg
	Equivalent Mass	0.00061	tons

		Factor for 1000 kg	kg
Raw Materials	Bauxite (Al2O3, ore)	1.02E+00	5.61E-04
	Clay (in ground)	5.54E+00	3.05E-03
	Coal (in ground)	1.93E+01	1.06E-02
	Iron (Fe, ore)	1.10E-03	6.05E-07
	Lignite (in ground)	1.65E+01	9.08E-03
	Limestone (CaCO3, in ground)	4.47E+00	2.46E-03
	Natural Gas (in ground)	1.02E+02	5.59E-02
	Oil (in ground)	5.55E+01	3.05E-02
	Sand (in ground)	5.00E-04	2.75E-07
	Sodium Chloride (NaCl, in ground or in sea)	1.41E+00	7.76E-04
	Sulfur (S, in ground)	1.85E+00	1.01E-03
	Uranium (U, ore)	1.25E-02	6.88E-06
	Borax (B4Na2O7)	3.40E-01	1.87E-04
	Maize	6.49E+01	3.57E-02
	Potatoes	1.39E+01	7.65E-03
	Raw Materials (unspecified)	7.74E+01	4.26E-02
	Urea (H2NCONH2)	2.76E+00	1.52E-03
	Wastepaper	8.30E+02	4.57E-01
	Wood	3.82E+02	2.10E-01
	Total (kg)	1.58E+03	8.68E-01

Note: Raw material requirements exclude water usage, which equals	5.90E+00	liters

		Factor for 1 ton	Millions of BTUs
Combustion Process Energy	Electricity	3.74E+00	2.27E-03
	Natural Gas	1.81E+00	1.10E-03
	LPG	1.74E-04	1.05E-07
	Coal	4.18E+00	2.53E-03
	Distilate Oil	4.50E-03	2.73E-06
	Residual Oil	1.30E-01	7.88E-05
	Gasoline	3.14E-04	1.90E-07
	Diesel	1.58E+00	9.58E-04
	Wood	1.54E+01	9.34E-03
Precombustion Process Energy	Natural Gas	5.40E-02	3.27E-05
	Residual Oil	1.00E-02	6.06E-06
	Distilate Oil	2.60E-03	1.58E-06
	Gasoline	2.70E-03	1.64E-06
	LPG	1.78E-04	1.08E-07
	Coal	4.42E-06	2.68E-09
	Nuclear	1.90E-03	1.15E-06
	Hydropower	2.77E-04	1.68E-07
	Other	2.68E-04	1.62E-07
Total Energy (mmBtu)			1.63E-02
Total Energy (MJ)			1.72E+01

		Factor for 1 ton	lbs
Air Emissions	Particulates	4.98E+00	3.02E-03
	Nitrogen oxides	2.02E+01	1.22E-02
	Hydrocarbons	2.50E+00	1.52E-03
	Sulfur Oxides	3.10E+01	1.88E-02
	Carbon Monoxide	3.77E+01	2.29E-02
	Aldehydes	1.06E-01	6.43E-05
	Total Reduced Sulfur	7.90E-02	4.79E-05
	Ammonia	1.61E-01	9.77E-05
	Mercury	1.63E-04	9.88E-08
	Fossil Carbon Dioxide	1.98E+03	1.20E+00
	Methane	3.65E+00	2.21E-03
	Other Organics	1.35E+00	8.18E-04
	Kerosene	1.80E-04	1.09E-07
	Lead	2.10E-03	1.27E-06
	Chlorine	1.30E-02	7.88E-06
	Hydrochloric acid	3.60E-02	2.18E-05
	Hydrogen Fluoride	5.00E-03	3.03E-06
	Metals	1.46E+00	8.85E-04
	Antimony	6.40E-06	3.88E-09
	Arsenic	5.00E-04	3.03E-07
	Beryllium	4.10E-05	2.49E-08
	Cadmium	1.20E-04	7.28E-08
	Chromium	7.70E-04	4.67E-07
	Cobalt	1.90E-05	1.15E-08
	Manganese	1.70E-02	1.03E-05
	Nickel	1.60E-03	9.70E-07
	Selenium	5.50E-05	3.33E-08
	Acreolin	7.00E-06	4.24E-09
	Nitrous Oxide	1.90E-02	1.15E-05
	Benzene	6.30E-03	3.82E-06
	Perchloroethylene	6.90E-06	4.18E-09
	Trichloroethylene	6.80E-06	4.12E-09
	Methylene Chloride	3.20E-05	1.94E-08
	Carbon Tetrachloride	1.30E-05	7.88E-09
	Phenols	6.60E-02	4.00E-05
	Napthalene	4.00E-03	2.43E-06
	Dioxins	4.00E-11	2.43E-14
	n-Nitrosodimethylamine	1.50E-06	9.09E-10
	Total (lb)	2.08E+03	1.20E+00
	Total (g)		5.46E+02

		Factor for 1 ton	lbs
Water Emissions	Dissolved solids (lb)	7.78E+00	4.72E-03
	Suspended solids (lb)	6.00E+00	3.64E-03
	BOD (lb)	3.82E+00	2.32E-03
	COD (lb)	2.09E+01	1.27E-02
	Phenol (lb)	8.04E-06	4.87E-09
	Sulfides (lb)	1.60E-05	9.70E-09
	Oil (lb)	1.40E-01	8.49E-05
	Sulfuric Acid (lb)	1.30E-02	7.88E-06
	Iron (lb)	7.20E-02	4.37E-05
	Ammonia (lb)	5.86E-02	3.55E-05
	Cyanide (lb)	6.02E-07	3.65E-10
	Cadmium (lb)	3.50E-04	2.12E-07
	Aluminum (lb)	1.50E-01	9.09E-05
	Mercury (lb)	2.70E-08	1.64E-11
	Phosphates (lb)	1.37E-01	8.28E-05
	Phosphorus (lb)	8.80E-02	5.34E-05
	Selenium (lb)	0.00E+00	0.00E+00
	Nitrogen (lb)	3.10E-02	1.88E-05
	Nitrates (lb)	3.37E-03	2.04E-06
	Chromium (lb)	3.50E-04	2.12E-07
	Lead (lb)	2.00E-07	1.21E-10
	Chloride (lb)	3.50E-01	2.12E-04
	Sodium (lb)	2.80E-04	1.70E-07
	Calcium (lb)	1.50E-04	9.09E-08
	Sulfates (lb)	3.50E-01	2.12E-04
	Manganese (lb)	4.50E-02	2.73E-05
	Fluorides (lb)	7.00E-04	4.24E-07
	Boron (lb)	5.30E-02	3.21E-05
	Other Organics (lb)	3.20E-02	1.94E-05
	Chromates (lb)	1.50E-05	9.09E-09
	Metal Ion (lb)	2.40E-03	1.46E-06
	Acid (lb)	2.50E-03	1.52E-06
	Zinc (lb)	3.50E-01	2.12E-04
	Total (lb)		2.45E-02
	Total (g)		1.11E+01
Solid Waste	Sludge (lb)	5.06E+01	3.07E-02
	Unspecified (lb)	6.23E+01	3.78E-02
	Ash (lb)	4.24E+02	2.57E-01
	Total (lb)		3.26E-01
	Total (kg)		1.48E-01

Note: LCI combines data for process and tranportation related activities

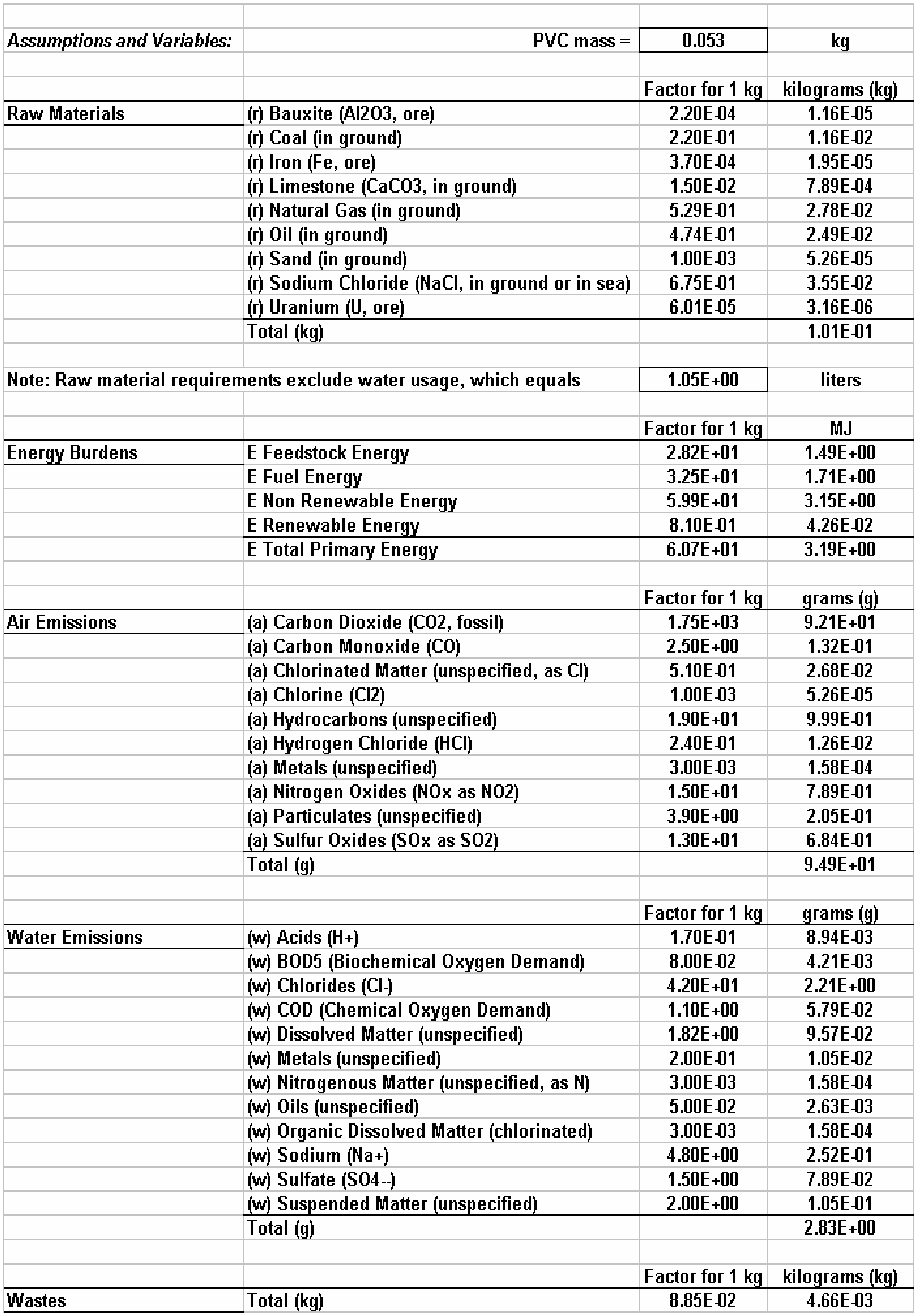
Appendix N (continued): Packaging Production – Paper

Assumptions and Variables:	Mass per FU	4.38E-02	kg
	Equivalent Mass	4.82E-05	tons
		Factor for 1,000 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	1.93E-02	8.44E-07
	(r) Clay (in ground)	6.46E+01	2.83E-03
	(r) Coal (in ground)	7.64E+01	3.34E-03
	(r) Iron (Fe, ore)	1.07E-02	4.68E-07
	(r) Lignite (in ground)	3.04E+01	1.33E-03
	(r) Limestone (CaCO3, in ground)	3.45E+01	1.51E-03
	(r) Natural Gas (in ground)	2.03E+02	8.89E-03
	(r) Oil (in ground)	7.81E+01	3.42E-03
	(r) Sand (in ground)	5.70E-03	2.49E-07
	(r) Sodium Chloride (NaCl, in ground or in sea)	3.67E+01	1.61E-03
	(r) Sulfur (S, in ground)	1.38E+01	6.02E-04
	(r) Uranium (U, ore)	1.83E-02	8.01E-07
	Raw Materials (unspecified)	2.25E+01	9.83E-04
	Total (kg)		2.45E-02
Note: Raw material requirements exclude water usage, which equals		3.90E+00	liters
		Factor for 1 ton	Millions of BTUs
Combustion Process Energy	Electricity	4.90E+00	2.36E-04
	Natural Gas	4.14E+00	2.00E-04
	LPG	0.00E+00	0.00E+00
	Coal	3.24E+00	1.56E-04
	Distilate Oil	0.00E+00	0.00E+00
	Residual Oil	1.52E+00	7.33E-05
	Gasoline	0.00E+00	0.00E+00
	Diesel	0.00E+00	0.00E+00
	Wood	6.05E+00	2.92E-04
	Black Liquor	1.64E+01	7.91E-04
Precombustion Process Energy	Natural Gas	6.21E-02	2.99E-06
	Residual Oil	1.02E-02	4.92E-07
	Distilate Oil	7.47E-03	3.60E-07
	Gasoline	3.44E-03	1.66E-07
	LPG	1.61E-04	7.76E-09
	Coal	1.29E-03	6.22E-08
	Nuclear	9.97E-04	4.81E-08
	Hydropower	3.12E-03	1.50E-07
	Other	2.76E-03	1.33E-07
Total Energy (mmBtu)			1.75E-03
Total Energy (MJ)			1.85E+00
			Pounds (lbs)
Air Emissions	Particulates (lb)	1.17E+01	5.64E-04
	Nitrogen Oxides (lb)	1.35E+01	6.51E-04
	Hydrocarbons-non CH4 (lb)	7.80E+00	3.76E-04
	Sulfur Oxides (lb)	2.37E+01	1.14E-03
	Carbon Monoxide (lb)	9.33E-01	4.50E-05
	CO2 (lb)	6.46E+03	3.12E-01
	Ammonia (lb)	7.98E-05	3.85E-09
	Lead (lb)	3.00E-06	1.45E-10
	Methane (lb)	1.36E-01	6.56E-06
	Hydrochloric acid (lb)	8.92E-04	4.30E-08
	Total (lb)		3.14E-01
	Total (g)		1.43E+02
Water Emissions	Dissolved solids (lb)	1.16E+00	5.59E-05
	Suspended solids (lb)	6.95E-02	3.35E-06
	BOD (lb)	6.91E-02	3.33E-06
	COD (lb)	3.60E+00	1.74E-04
	Oil (lb)	1.63E-02	7.86E-07
	Sulfuric Acid (lb)	2.12E-04	1.02E-08
	Iron (lb)	6.46E-04	3.12E-08
	Ammonia (lb)	3.01E-05	1.45E-09
	Copper (lb)	0.00E+00	0.00E+00
	Cadmium (lb)	4.16E-05	2.01E-09
	Arsenic (lb)	0.00E+00	0.00E+00
	Mercury (lb)	7.05E-09	3.40E-13
	Phosphate (lb)	1.07E-04	5.16E-09
	Selenium (lb)	0.00E+00	0.00E+00
	Chromium (lb)	4.16E-05	2.01E-09
	Lead (lb)	1.71E-08	1.71E-08
	Zinc (lb)	1.42E-05	6.85E-10
	Total (lb)		2.37E-04
	Total (g)		1.08E-01
Solid Waste	Solid Waste #1(lb)	0.00E+00	0.00E+00
	Ash (lb)	0.00E+00	0.00E+00
	Sludge (lb)	0.00E+00	0.00E+00
	Scrap (lb)	0.00E+00	0.00E+00
	Unspecified (lb)	4.92E+01	2.37E-03
	Total (lb)		2.37E-03
	Total (g)		1.08E-03

Appendix N (continued): Packaging Production – Polyethylene (PE)

Assumptions and Variables:	PE mass =	0.014	kg
		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	3.00E-04	4.20E-06
	(r) Clay (in ground)	2.00E-05	2.80E-07
	(r) Coal (in ground)	8.99E-02	1.26E-03
	(r) Iron (Fe, ore)	2.00E-04	2.80E-06
	(r) Limestone (CaCO3, in ground)	1.50E-04	2.10E-06
	(r) Natural Gas (in ground)	8.34E-01	1.17E-02
	(r) Oil (in ground)	7.96E-01	1.11E-02
	(r) Sodium Chloride (NaCl, in ground or in sea)	7.00E-03	9.80E-05
	Total		2.42E-02
Note: Raw material requirements exclude water usage, which equals		2.52E-01	liters
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	61.34	8.59E-01
	E Fuel Energy	18.11	2.54E-01
	E Non Renewable Energy	78.99	1.11E+00
	E Renewable Energy	0.46	6.44E-03
	Electricity	2.58	3.61E-02
	E Total Primary Energy	79.45	1.11E+00
		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	7.00E-02	9.80E-04
	(w) Ammonia (NH4+, NH3, as N)	5.00E-03	7.00E-05
	(w) BOD5 (Biochemical Oxygen Demand)	1.50E-01	2.10E-03
	(w) Chlorides (Cl-)	1.20E-01	1.68E-03
	(w) COD (Chemical Oxygen Demand)	1.00E+00	1.40E-02
	(w) Hydrocarbons (unspecified)	1.00E-01	1.40E-03
	(w) Inorganic Dissolved Matter (unspecified)	4.00E-01	5.60E-03
	(w) Metals (unspecified)	3.00E-01	4.20E-03
	(w) Nitrate (NO3-)	5.00E-03	7.00E-05
	(w) Nitrogenous Matter (unspecified, as N)	1.00E-02	1.40E-04
	(w) Oils (unspecified)	1.00E-01	1.40E-03
	(w) Organic Dissolved Matter (unspecified)	2.00E-02	2.80E-04
	(w) Phenol (C6H5OH)	1.00E-03	1.40E-05
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	5.00E-03	7.00E-05
	(w) Sulfate (SO4--)	1.00E-02	1.40E-04
	(w) Suspended Matter (unspecified)	4.00E-01	5.60E-03
	Total (g)		3.77E-02
		Factor for 1 kg	grams (g)
Air Emissions	(a) Aldehyde (unspecified)	5.00E-03	7.00E-05
	(a) Carbon Dioxide (CO2, fossil)	1.10E+03	1.54E+01
	(a) Carbon Monoxide (CO)	8.00E-01	1.12E-02
	(a) Hydrocarbons (unspecified)	2.10E+01	2.94E-01
	(a) Hydrogen (H2)	1.00E-03	1.40E-05
	(a) Hydrogen Chloride (HCl)	6.00E-02	8.40E-04
	(a) Hydrogen Fluoride (HF)	1.00E-03	1.40E-05
	(a) Metals (unspecified)	1.00E-03	1.40E-05
	(a) Nitrogen Oxides (NOx as NO2)	1.10E+01	1.54E-01
	(a) Organic Matter (unspecified)	5.00E-03	7.00E-05
	(a) Particulates (unspecified)	2.00E+00	2.80E-02
	(a) Sulfur Oxides (SOx as SO2)	7.00E+00	9.80E-02
	Total (g)		1.60E+01
		Factor for 1 kg	kilograms (kg)
Wastes	Waste (hazardous)	7.00E-05	9.80E-07
	Waste (municipal and industrial)	3.10E-03	4.34E-05
	Waste: Mineral (inert)	2.20E-02	3.08E-04
	Waste: Non Toxic Chemicals (unspecified)	2.00E-03	2.80E-05
	Waste: Slags and Ash (unspecified)	7.00E-03	9.80E-05
	Total (kg)		4.78E-04

Appendix N (continued): Packaging Production – Calendered PVC



Assumptions and Variables:	PVC mass =	0.053	kg
		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.20E-04	1.16E-05
	(r) Coal (in ground)	2.20E-01	1.16E-02
	(r) Iron (Fe, ore)	3.70E-04	1.95E-05
	(r) Limestone (CaCO3, in ground)	1.50E-02	7.89E-04
	(r) Natural Gas (in ground)	5.29E-01	2.78E-02
	(r) Oil (in ground)	4.74E-01	2.49E-02
	(r) Sand (in ground)	1.00E-03	5.26E-05
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.75E-01	3.55E-02
	(r) Uranium (U, ore)	6.01E-05	3.16E-06
	Total (kg)		1.01E-01
Note: Raw material requirements exclude water usage, which equals		1.05E+00	liters
		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	2.82E+01	1.49E+00
	E Fuel Energy	3.25E+01	1.71E+00
	E Non Renewable Energy	5.99E+01	3.15E+00
	E Renewable Energy	8.10E-01	4.26E-02
	E Total Primary Energy	6.07E+01	3.19E+00
		Factor for 1 kg	grams (g)
Air Emissions	(a) Carbon Dioxide (CO2, fossil)	1.75E+03	9.21E+01
	(a) Carbon Monoxide (CO)	2.50E+00	1.32E-01
	(a) Chlorinated Matter (unspecified, as Cl)	5.10E-01	2.68E-02
	(a) Chlorine (Cl2)	1.00E-03	5.26E-05
	(a) Hydrocarbons (unspecified)	1.90E+01	9.99E-01
	(a) Hydrogen Chloride (HCl)	2.40E-01	1.26E-02
	(a) Metals (unspecified)	3.00E-03	1.58E-04
	(a) Nitrogen Oxides (NOx as NO2)	1.50E+01	7.89E-01
	(a) Particulates (unspecified)	3.90E+00	2.05E-01
	(a) Sulfur Oxides (SOx as SO2)	1.30E+01	6.84E-01
	Total (g)		9.49E+01
		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	1.70E-01	8.94E-03
	(w) BOD5 (Biochemical Oxygen Demand)	8.00E-02	4.21E-03
	(w) Chlorides (Cl-)	4.20E+01	2.21E+00
	(w) COD (Chemical Oxygen Demand)	1.10E+00	5.79E-02
	(w) Dissolved Matter (unspecified)	1.82E+00	9.57E-02
	(w) Metals (unspecified)	2.00E-01	1.05E-02
	(w) Nitrogenous Matter (unspecified, as N)	3.00E-03	1.58E-04
	(w) Oils (unspecified)	5.00E-02	2.63E-03
	(w) Organic Dissolved Matter (chlorinated)	3.00E-03	1.58E-04
	(w) Sodium (Na+)	4.80E+00	2.52E-01
	(w) Sulfate (SO4--)	1.50E+00	7.89E-02
	(w) Suspended Matter (unspecified)	2.00E+00	1.05E-01
	Total (g)		2.83E+00
		Factor for 1 kg	kilograms (kg)
Wastes	Total (kg)	8.85E-02	4.66E-03

APPENDIX O
E-READER PACKAGING TRANSPORTATION

1) Energy Consumed and Emissions Generated
2) Diesel Fuel Production

Appendix O: E-reader Packaging Transportation – Energy Consumed and Emissions Generated

Assumptions and Variables

Total Trip Distance:	500	miles
Total Packaging Mass:	0.66	kg
FU Mass equivilency:	0.00073	tons
Fuel Efficiency	9.4	gal/1000 ton-miles
Energy Consumption:	1,465	Btu/ton-mile

From	To	Distance (mi)	Conveyance	Fuel	Fuel Eff. (gal/1000 ton.mi)	Mass (ton)	Energy Rate (Btu/ton.mi)	Energy consumed (MJ)	Fuel consumed (gal)
Packaging Facility	E-reader Manufacturing Facility	500	Tractor-trailer	diesel	9.4	0.00073	1,465	0.56	0.00343

Air Pollution due to Transportation

Compound	Emissions (lbs/1000 gal)	Mass Released (lbs)
Particulates	3.15E+01	1.08E-04
Nox	2.18E+02	7.48E-04
HC	8.79E+01	3.01E-04
Sox	6.20E+01	2.13E-04
CO	2.15E+02	7.37E-04
CO2 (total)	2.54E+04	8.72E-02
Formaldehyde	2.10E-05	7.20E-11
Other Aldehydes	5.97E+00	2.05E-05
Other Organics	1.16E+02	3.98E-04
Ammonia	4.00E-02	1.37E-07
Lead	1.40E-04	4.80E-10
Methane	4.05E+00	1.39E-05
Kerosene	1.00E-04	3.43E-10
Chlorine	1.50E-03	5.14E-09
HCl	2.50E-02	8.57E-08
HF	3.30E-03	1.13E-08
Metals	2.50E-03	8.57E-09
Antimony	3.80E-05	1.30E-10
Arsenic	7.90E-05	2.71E-10
Beryllium	5.50E-06	1.89E-11
Cadmium	1.20E-04	4.12E-10
Chromium	9.00E-05	3.09E-10
Cobalt	1.10E-04	3.77E-10
Manganese	1.10E-04	3.77E-10
Mercury	2.60E-05	8.92E-11
Nickel	1.70E-03	5.83E-09
Selenium	7.20E-05	2.47E-10
Acreolin	4.70E-06	1.61E-11
Nitrous Oxide	2.80E-03	9.60E-09
Benzene	1.50E-05	5.14E-11
Perchloroethylene	4.60E-06	1.58E-11
TCE	4.40E-06	1.51E-11
Methylene Chloride	2.10E-05	7.20E-11
Carbon Tetrachloride	1.90E-05	6.52E-11
Phenols	1.20E-04	4.12E-10
Naphthalene	7.00E-06	2.40E-11
Dioxins	2.50E-10	8.57E-16
n-nitrodimethylamine	9.90E-07	3.40E-12
Radionuclides (Ci)	8.70E-05	2.98E-10
		8.98E-02
Total (g)		4.07E+01

Water Pollution due to Transportation

Waterborne Emmission	Emissions (lbs/1000 gal)	Mass Released (lb)
Acid	8.40E-06	2.88E-11
Metal Ion	1.80E-01	6.17E-07
Dissolved Solids	3.48E+01	1.19E-04
Suspended Solids	7.90E-01	2.71E-06
BOD	1.30E-01	4.46E-07
COD	8.70E-01	2.98E-06
Phenol	5.80E-04	1.99E-09
Oil	8.10E-01	2.78E-06
Sufuric Acid	6.90E-03	2.37E-08
iron	1.90E-02	6.52E-08
Ammonia	1.40E-02	4.80E-08
Chromium	1.30E-03	4.46E-09
Lead	1.50E-05	5.14E-11
Zinc	6.50E-04	2.23E-09
Chlorides	1.28E+00	4.39E-06
Sodium	1.60E-04	5.49E-10
Calcium	9.00E-05	3.09E-10
Sulfates	1.03E+00	3.53E-06
Manganese	9.20E-03	3.16E-08
Fluorides	4.10E-04	1.41E-09
Nitrates	3.90E-05	1.34E-10
Phosphates	3.50E-03	1.20E-08
Boron	2.80E-02	9.60E-08
Other organics	8.50E-02	2.92E-07
Chromates	9.80E-05	3.36E-10
Cyanide	1.90E-06	6.52E-12
Mercury	9.80E-08	3.36E-13
Cadmium	1.30E-03	4.46E-09
Total (lb)		1.37E-04
Total (g)		6.23E-02

Solid Waste Due To Transportation

Category	Emission (lb/1000 gal)	Mass (lb)	Mass (kg)
Solid Waste	133	4.56E-04	2.07E-04

Appendix O (continued): E-reader Packaging Transportation – Diesel Fuel Production

Assumptions and Variables:	**Diesel Requirement:**	**0.0034**	**gal**
	Diesel Equivilancy:	**0.0107**	**kg**

Note: This assumes that the density of diesel = 0.827 g/ml

		Factor for 1 kg	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.30E-04	2.47E-06
	(r) Coal (in ground)	4.88E-02	5.24E-04
	(r) Limestone (CaCO3, in ground)	3.88E-03	4.16E-05
	(r) Natural Gas (in ground)	1.89E-01	2.03E-03
	(r) Oil (in ground)	1.08E+00	1.16E-02
	(r) Sand (in ground)	1.41E-04	1.52E-06
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.48E-05	6.95E-07
	(r) Uranium (U, ore)	8.21E-07	8.81E-09
	Total		1.42E-02

Note: Raw material requirements exclude water usage, which equals	5.79E-01	liters

		Factor for 1 kg	MJ
Energy Burdens	E Feedstock Energy	4.59E+01	4.93E-01
	E Fuel Energy	1.19E+01	1.28E-01
	E Non Renewable Energy	5.78E+01	6.20E-01
	E Renewable Energy	6.59E-02	7.07E-04
	E Total Primary Energy	5.78E+01	6.21E-01

		Factor for 1 kg	grams (g)
Water Emissions	(w) Acids (H+)	4.13E-07	4.43E-09
	(w) Aluminum (Al3+)	7.33E-04	7.87E-06
	(w) Ammonia (NH4+, NH3, as N)	1.42E-01	1.52E-03
	(w) AOX (Adsorbable Organic Halogens)	1.93E-09	2.08E-11
	(w) Aromatic Hydrocarbons (unspecified)	4.53E-07	4.87E-09
	(w) Barium (Ba++)	1.45E-06	1.56E-08
	(w) BOD5 (Biochemical Oxygen Demand)	9.71E-01	1.04E-02
	(w) Cadmium (Cd++)	1.51E-09	1.62E-11
	(w) Chlorides (Cl-)	1.56E+01	1.67E-01
	(w) Chromium (Cr III, Cr VI)	1.70E-07	1.82E-09
	(w) COD (Chemical Oxygen Demand)	8.22E+00	8.82E-02
	(w) Copper (Cu+, Cu++)	3.02E-08	3.24E-10
	(w) Cyanide (CN-)	2.12E-09	2.27E-11
	(w) Dissolved Matter (unspecified)	1.41E-03	1.51E-05
	(w) Fluorides (F-)	1.24E-04	1.33E-06
	(w) Halogenated Matter (organic)	6.04E-10	6.49E-12
	(w) Hydrocarbons (unspecified)	1.00E-03	1.07E-05
	(w) Iron (Fe++, Fe3+)	1.72E-06	1.85E-08
	(w) Lead (Pb++, Pb4+)	6.04E-09	6.49E-11
	(w) Mercury (Hg+, Hg++)	6.95E-12	7.46E-14
	(w) Metals (unspecified)	3.31E-02	3.55E-04
	(w) Nickel (Ni++, Ni3+)	3.02E-09	3.24E-11
	(w) Nitrate (NO3-)	3.01E-04	3.23E-06
	(w) Nitrogenous Matter (unspecified, as N)	8.16E-08	8.76E-10
	(w) Oils (unspecified)	4.53E-01	4.87E-03
	(w) Organic Matter (unspecified)	1.09E-06	1.17E-08
	(w) Phenol (C6H5OH)	1.87E-02	2.01E-04
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.01E-06	3.23E-08
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	7.25E-09	7.79E-11
	(w) Salts (unspecified)	8.36E-03	8.97E-05
	(w) Sodium (Na+)	2.00E+01	2.15E-01
	(w) Sulfate (SO4--)	4.51E-04	4.84E-06
	(w) Sulfide (S--)	2.44E-07	2.62E-09
	(w) Suspended Matter (unspecified)	4.41E+00	4.73E-02
	(w) TOC (Total Organic Carbon)	4.53E-06	4.87E-08
	(w) Toluene (C6H5CH3)	6.65E-08	7.14E-10
	(w) Zinc (Zn++)	5.63E-08	6.05E-10
	Total (g)		5.35E-01

Note: Water emissions exclude chemically polluted water, which equals	3.09E-02	liters

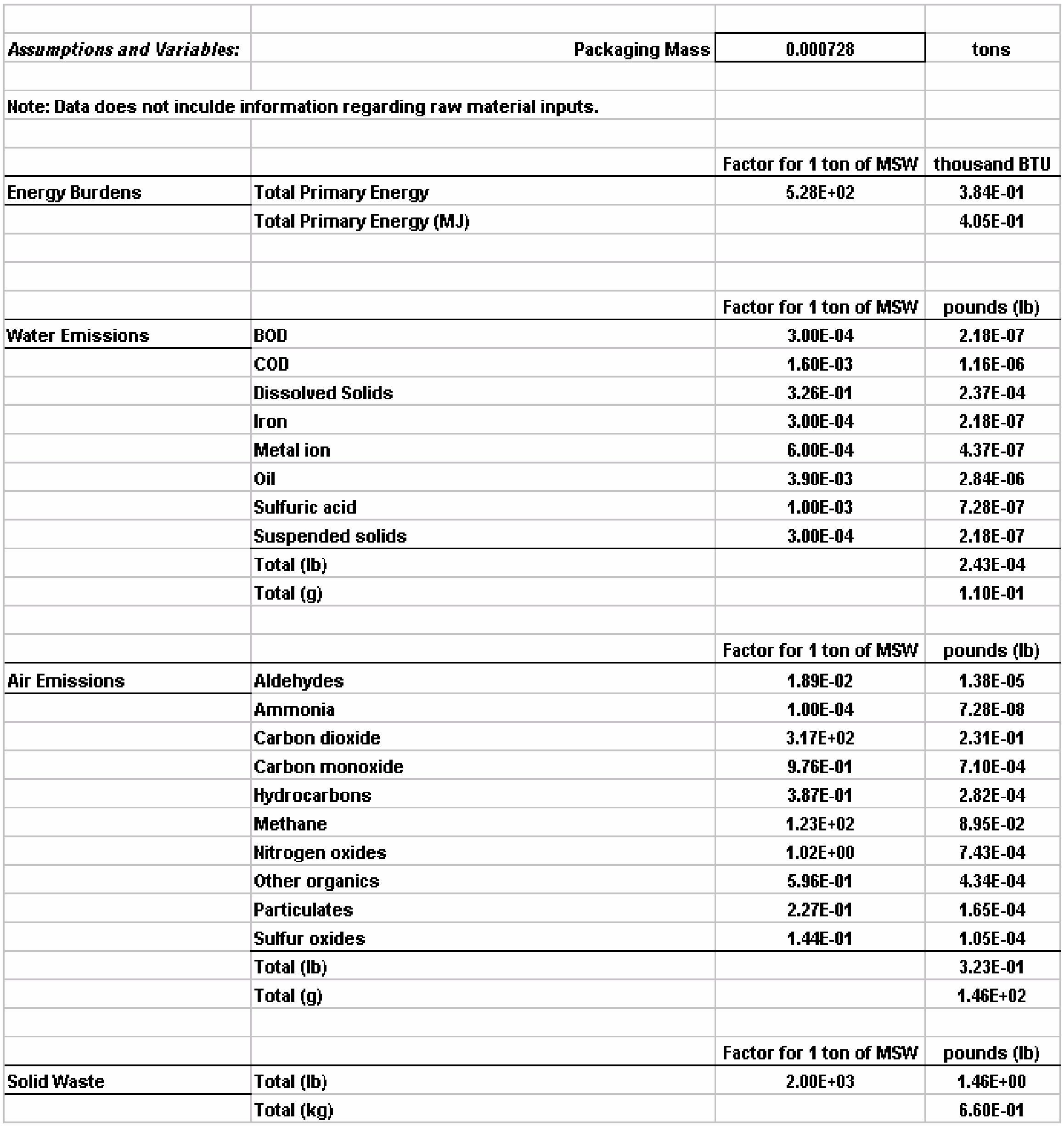
		Factor for 1 kg	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	2.15E-08	2.31E-10
	(a) Acenaphthylene (C12H8)	8.16E-09	8.76E-11
	(a) Acetaldehyde (CH3CHO)	1.39E-05	1.49E-07
	(a) Acetophenone (C8H8O)	3.65E-07	3.92E-09
	(a) Acrolein (CH2CHCHO)	7.06E-06	7.58E-08
	(a) Aldehyde (unspecified)	6.60E-03	7.08E-05
	(a) Aluminum (Al)	5.63E-05	6.04E-07
	(a) Ammonia (NH3)	9.84E-03	1.06E-04
	(a) Anthracene (C14H10)	8.17E-09	8.77E-11
	(a) Antimony (Sb)	2.81E-06	3.02E-08
	(a) Aromatic Hydrocarbons (unspecified)	2.72E-07	2.92E-09
	(a) Arsenic (As)	4.92E-05	5.28E-07
	(a) Barium (Ba)	1.49E-06	1.60E-08
	(a) Benzene (C6H6)	6.33E-02	6.80E-04
	(a) Benzo(a)anthracene	5.29E-09	5.68E-11
	(a) Benzo(a)pyrene (C20H12)	2.62E-09	2.81E-11
	(a) Benzo(b)fluoranthene	2.24E-09	2.40E-11
	(a) Benzo(bjk)fluoranthene	2.68E-09	2.87E-11
	(a) Benzo(ghi)perylene	2.36E-09	2.54E-11
	(a) Benzo(k)fluoranthene	2.24E-09	2.40E-11
	(a) Benzyl Chloride (C7H7Cl)	1.70E-05	1.83E-07
	(a) Beryllium (Be)	5.15E-06	5.53E-08
	(a) Bromoform (CHBr3)	9.49E-07	1.02E-08
	(a) Butane (C4H10)	2.32E-03	2.49E-05
	(a) Cadmium (Cd)	3.00E-06	3.22E-08
	(a) Calcium (Ca)	4.88E-05	5.24E-07
	(a) Carbon Dioxide (CO2, biomass)	2.46E-04	2.64E-06
	(a) Carbon Dioxide (CO2, fossil)	6.70E+02	7.20E+00
	(a) Carbon Disulfide (CS2)	3.16E-06	3.40E-08
	(a) Carbon Monoxide (CO)	2.00E+00	2.15E-02
	(a) Chlorides (Cl-)	1.57E-04	1.68E-06
	(a) Chlorine (Cl2)	2.35E-08	2.53E-10

		Factor for 1 kg	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	1.70E-07	1.83E-09
	(a) Chlorobenzene (C6H5Cl)	5.36E-07	5.75E-09
	(a) Chloroform (CHCl3, HC-20)	1.44E-06	1.54E-08
	(a) Chromium (Cr III, Cr VI)	7.66E-05	8.23E-07
	(a) Chrysene (C18H12)	4.82E-09	5.18E-11
	(a) Cobalt (Co)	8.82E-06	9.47E-08
	(a) Copper (Cu)	5.13E-06	5.50E-08
	(a) Cumene (C9H12)	1.29E-07	1.38E-09
	(a) Cyanide (CN-)	6.09E-05	6.53E-07
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	1.78E-06	1.91E-08
	(a) Dibenzo(a,h)anthracene	1.61E-09	1.72E-11
	(a) Dichlorobenzene (1,4-C6H4Cl2)	1.32E-06	1.42E-08
	(a) Dimethyl Benzanthracene (7,12-C20H16)	1.66E-08	1.78E-10
	(a) Dimethyl Sulfate (C2H6O4S)	1.17E-06	1.25E-08
	(a) Dinitrotoluene (2,4-C7H6N2O4)	6.82E-09	7.32E-11
	(a) Dioxins (unspecified)	3.94E-10	4.23E-12
	(a) Diphenyl ((C6H5)2)	4.14E-08	4.44E-10
	(a) Ethane (C2H6)	3.42E-03	3.67E-05
	(a) Ethyl Benzene (C6H5C2H5)	2.32E-06	2.49E-08
	(a) Ethyl Chloride (C2H5Cl)	1.02E-06	1.10E-08
	(a) Ethylene Dibromide (C2H4Br2)	2.92E-08	3.14E-10
	(a) Ethylene Dichloride (C2H4Cl2)	9.74E-07	1.05E-08
	(a) Fluoranthene	2.14E-08	2.30E-10
	(a) Fluorene (C13H10)	2.60E-08	2.79E-10
	(a) Fluorides (F-)	1.75E-05	1.88E-07
	(a) Formaldehyde (CH2O)	3.43E-03	3.68E-05
	(a) Furan (C4H4O)	1.83E-09	1.97E-11
	(a) Halogenated Hydrocarbons (unspecified)	1.51E-12	1.62E-14
	(a) Halon 1301 (CF3Br)	2.63E-09	2.82E-11
	(a) Hexane (C6H14)	1.99E-03	2.13E-05
	(a) Hydrocarbons (except methane)	3.77E-01	4.05E-03
	(a) Hydrocarbons (unspecified)	5.40E-01	5.80E-03
	(a) Hydrogen Chloride (HCl)	2.92E-02	3.14E-04
	(a) Hydrogen Fluoride (HF)	3.65E-03	3.92E-05
	(a) Hydrogen Sulfide (H2S)	8.84E-03	9.49E-05
	(a) Indeno (1,2,3,c,d) Pyrene	3.83E-09	4.12E-11
	(a) Iron (Fe)	1.09E-04	1.17E-06
	(a) Isophorone	1.41E-05	1.52E-07
	(a) Lead (Pb)	4.49E-05	4.82E-07
	(a) Magnesium (Mg)	2.68E-04	2.87E-06
	(a) Manganese (Mn)	8.16E-05	8.76E-07
	(a) Mercury (Hg)	3.18E-06	3.42E-08
	(a) Metals (unspecified)	1.62E-06	1.74E-08
	(a) Methane (CH4)	3.34E+00	3.59E-02
	(a) Methyl Bromide (CH3Br)	3.89E-06	4.18E-08
	(a) Methyl Chloride (CH3Cl)	1.29E-05	1.38E-07
	(a) Methyl Cholanthrene (3-C21H16)	1.99E-09	2.13E-11
	(a) Methyl Chrysene (5-C19H15)	5.36E-10	5.75E-12
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	9.49E-06	1.02E-07
	(a) Methyl Hydrazine (CH6N2)	4.14E-06	4.44E-08
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	4.87E-07	5.23E-09
	(a) Methyl Naphthalene (2-C11H10)	2.65E-08	2.84E-10
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	8.52E-07	9.15E-09
	(a) Methylene Chloride (CH2Cl2, HC-130)	7.06E-06	7.58E-08
	(a) Molybdenum (Mo)	6.16E-06	6.62E-08
	(a) Naphthalene (C10H8)	1.50E-06	1.61E-08
	(a) Nickel (Ni)	3.79E-04	4.07E-06
	(a) Nitrogen Oxides (NOx as NO2)	2.26E+00	2.42E-02
	(a) Nitrous Oxide (N2O)	5.43E-02	5.83E-04
	(a) Organic Matter (unspecified)	3.15E-01	3.38E-03
	(a) Particulates (PM 10)	6.49E-04	6.97E-06
	(a) Particulates (unspecified)	5.07E-01	5.44E-03
	(a) Pentane (C5H12)	2.87E-03	3.08E-05
	(a) Phenanthrene (C14H10)	8.63E-08	9.26E-10
	(a) Phenol (C6H5OH)	3.89E-07	4.18E-09
	(a) Phosphorus (P)	3.73E-05	4.00E-07
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	3.02E-10	3.24E-12
	(a) Propane (C3H8)	6.10E-06	6.55E-08
	(a) Propionaldehyde (CH3CH2CHO)	9.25E-06	9.93E-08
	(a) Pyrene (C16H10)	1.43E-08	1.53E-10
	(a) Selenium (Se)	3.36E-05	3.61E-07
	(a) Silicon (Si)	4.88E-05	5.24E-07
	(a) Sodium (Na)	2.89E-04	3.10E-06
	(a) Styrene (C6H5CHCH2)	6.09E-07	6.53E-09
	(a) Sulfur Oxides (SOx as SO2)	3.24E+00	3.48E-02
	(a) Tetrachloroethylene (C2Cl4)	1.05E-06	1.12E-08
	(a) Toluene (C6H5CH3)	1.51E-05	1.63E-07
	(a) Trichloroethane (1,1,1-CH3CCl3)	4.87E-07	5.23E-09
	(a) Vanadium (V)	7.68E-04	8.24E-06
	(a) Vinyl Acetate (C4H6O2)	1.85E-07	1.99E-09
	(a) Xylene (C6H4(CH3)2)	4.37E-06	4.69E-08
	(a) Zinc (Zn)	4.52E-05	4.85E-07
	Total (g)		6.80E+02

		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	2.65E-01	2.84E-03

APPENDIX P
LCI DATA
PACKAGING DISPOSITION

Appendix P: Packaging Disposition



Assumptions and Variables:	Packaging Mass	0.000728	tons
Note: Data does not inculde information regarding raw material inputs.			
		Factor for 1 ton of MSW	thousand BTU
Energy Burdens	Total Primary Energy	5.28E+02	3.84E-01
	Total Primary Energy (MJ)		4.05E-01
		Factor for 1 ton of MSW	pounds (lb)
Water Emissions	BOD	3.00E-04	2.18E-07
	COD	1.60E-03	1.16E-06
	Dissolved Solids	3.26E-01	2.37E-04
	Iron	3.00E-04	2.18E-07
	Metal ion	6.00E-04	4.37E-07
	Oil	3.90E-03	2.84E-06
	Sulfuric acid	1.00E-03	7.28E-07
	Suspended solids	3.00E-04	2.18E-07
	Total (lb)		2.43E-04
	Total (g)		1.10E-01
		Factor for 1 ton of MSW	pounds (lb)
Air Emissions	Aldehydes	1.89E-02	1.38E-05
	Ammonia	1.00E-04	7.28E-08
	Carbon dioxide	3.17E+02	2.31E-01
	Carbon monoxide	9.76E-01	7.10E-04
	Hydrocarbons	3.87E-01	2.82E-04
	Methane	1.23E+02	8.95E-02
	Nitrogen oxides	1.02E+00	7.43E-04
	Other organics	5.96E-01	4.34E-04
	Particulates	2.27E-01	1.65E-04
	Sulfur oxides	1.44E-01	1.05E-04
	Total (lb)		3.23E-01
	Total (g)		1.46E+02
		Factor for 1 ton of MSW	pounds (lb)
Solid Waste	Total (lb)	2.00E+03	1.46E+00
	Total (kg)		6.60E-01

APPENDIX Q
E-READER TRANSPORTATION

1) Energy Consumed and Emissions Generated
2) Diesel Fuel Production

Appendix Q: E-reader Transportation - Energy Consumed and Emissions Generated

Assumptions and Variables

Total Trip Distance:	500	miles	
TotalE-reader Mass:	1.67	kg	
FU Mass :	0.00184	tons	Note: This value combines the e-reader mass and the device's total packaging mass
Fuel Efficiency	9.4	gal/1000 ton-miles	
Energy Consumptio	1,465	Btu/ton-mile	

From	To	Distance (mi)	Conveyance	Fuel	Fuel Eff. (gal/1000 ton.mi)	Mass (ton)	Energy Rate (Btu/ton.mi)	Energy consumed (MJ)	Fuel consumed (gal)
E-reader Manufacturing Facility	Sudent	500	Tractor-trailer	diesel	9.4	0.0018	1,465	1.42	0.00865

Air Pollution due to Transportation

Compound	Emissions (lbs/1000 gal)	Mass Released (lbs)
Particulates	3.15E+01	2.73E-04
Nox	2.18E+02	1.89E-03
HC	8.79E+01	7.61E-04
Sox	6.20E+01	5.36E-04
CO	2.15E+02	1.86E-03
CO2 (total)	2.54E+04	2.20E-01
Formaldehyde	2.10E-05	1.82E-10
Other Aldehydes	5.97E+00	5.17E-05
Other Organics	1.16E+02	1.00E-03
Ammonia	4.00E-02	3.46E-07
Lead	1.40E-04	1.21E-09
Methane	4.05E+00	3.50E-05
Kerosene	1.00E-04	8.65E-10
Chlorine	1.50E-03	1.30E-08
HCl	2.50E-02	2.16E-07
HF	3.30E-03	2.86E-08
Metals	2.50E-03	2.16E-08
Antimony	3.80E-05	3.29E-10
Arsenic	7.90E-05	6.84E-10
Beryllium	5.50E-06	4.76E-11
Cadmium	1.20E-04	1.04E-09
Chromium	9.00E-05	7.79E-10
Cobalt	1.10E-04	9.52E-10
Manganese	1.10E-04	9.52E-10
Mercury	2.60E-05	2.25E-10
Nickel	1.70E-03	1.47E-08
Selenium	7.20E-05	6.23E-10
Acreolin	4.70E-06	4.07E-11
Nitrous Oxide	2.80E-03	2.42E-08
Benzene	1.50E-05	1.30E-10
Perchloroethylene	4.60E-06	3.98E-11
TCE	4.40E-06	3.81E-11
Methylene Chloride	2.10E-05	1.82E-10
Carbon Tetrachlorid	1.90E-05	1.64E-10
Phenols	1.20E-04	1.04E-09
Naphthalene	7.00E-06	6.06E-11
Dioxins	2.50E-10	2.16E-15
n-nitrodimethylamin	9.90E-07	8.57E-12
Radionuclides (Ci)	8.70E-05	7.53E-10
		2.26E-01
Total (g)		1.03E+02

Water Pollution due to Transportation

Waterborne Emmission	Emissions (lbs/1000 gal)	Mass Released (lb)
Acid	8.40E-06	7.27E-11
Metal Ion	1.80E-01	1.56E-06
Dissolved Solids	3.48E+01	3.01E-04
Suspended Solids	7.90E-01	6.84E-06
BOD	1.30E-01	1.12E-06
COD	8.70E-01	7.53E-06
Phenol	5.80E-04	5.02E-09
Oil	8.10E-01	7.01E-06
Sufuric Acid	6.90E-03	5.97E-08
iron	1.90E-02	1.64E-07
Ammonia	1.40E-02	1.21E-07
Chromium	1.30E-03	1.12E-08
Lead	1.50E-05	1.30E-10
Zinc	6.50E-04	5.62E-09
Chlorides	1.28E+00	1.11E-05
Sodium	1.60E-04	1.38E-09
Calcium	9.00E-05	7.79E-10
Sulfates	1.03E+00	8.91E-06
Manganese	9.20E-03	7.96E-08
Fluorides	4.10E-04	3.55E-09
Nitrates	3.90E-05	3.37E-10
Phosphates	3.50E-03	3.03E-08
Boron	2.80E-02	2.42E-07
Other organics	8.50E-02	7.35E-07
Chromates	9.80E-05	8.48E-10
Cyanide	1.90E-06	1.64E-11
Mercury	9.80E-08	8.48E-13
Cadmium	1.30E-03	1.12E-08
Total (lb)		3.47E-04
Total (g)		1.57E-01

Solid Waste Due To Transportation

Category	Emission (lb/1000 gal)	Mass (lb)	Mass (kg)
Solid Waste	133	1.15E-03	5.22E-04

Appendix Q (continued): E-reader Transportation – Diesel Fuel Production

Assumptions and Variables:	Diesel Requirement:	0.0087	gal	
	Diesel Equivilancy:	0.0271	kg	Note: This assumes that the density of diesel = 0.827 g/ml
		Factor for 1 kg	kilograms (kg)	
Raw Materials	(r) Bauxite (Al2O3, ore)	2.30E-04	6.24E-06	
	(r) Coal (in ground)	4.88E-02	1.32E-03	
	(r) Limestone (CaCO3, in ground)	3.88E-03	1.05E-04	
	(r) Natural Gas (in ground)	1.89E-01	5.12E-03	
	(r) Oil (in ground)	1.08E+00	2.93E-02	
	(r) Sand (in ground)	1.41E-04	3.82E-06	
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.48E-05	1.75E-06	
	(r) Uranium (U, ore)	8.21E-07	2.22E-08	
	Total		3.58E-02	
Note: Raw material requirements exclude water usage, which equals		1.46E+00	liters	
		Factor for 1 kg	MJ	
Energy Burdens	E Feedstock Energy	4.59E+01	1.24E+00	
	E Fuel Energy	1.19E+01	3.23E-01	
	E Non Renewable Energy	5.78E+01	1.56E+00	
	E Renewable Energy	6.59E-02	1.78E-03	
	E Total Primary Energy	5.78E+01	1.57E+00	
		Factor for 1 kg	grams (g)	
Water Emissions	(w) Acids (H+)	4.13E-07	1.12E-08	
	(w) Aluminum (Al3+)	7.33E-04	1.99E-05	
	(w) Ammonia (NH4+, NH3, as N)	1.42E-01	3.84E-03	
	(w) AOX (Adsorbable Organic Halogens)	1.93E-09	5.24E-11	
	(w) Aromatic Hydrocarbons (unspecified)	4.53E-07	1.23E-08	
	(w) Barium (Ba++)	1.45E-06	3.93E-08	
	(w) BOD5 (Biochemical Oxygen Demand)	9.71E-01	2.63E-02	
	(w) Cadmium (Cd++)	1.51E-09	4.09E-11	
	(w) Chlorides (Cl-)	1.56E+01	4.21E-01	
	(w) Chromium (Cr III, Cr VI)	1.70E-07	4.60E-09	
	(w) COD (Chemical Oxygen Demand)	8.22E+00	2.23E-01	
	(w) Copper (Cu+, Cu++)	3.02E-08	8.18E-10	
	(w) Cyanide (CN-)	2.12E-09	5.73E-11	
	(w) Dissolved Matter (unspecified)	1.41E-03	3.82E-05	
	(w) Fluorides (F-)	1.24E-04	3.35E-06	
	(w) Halogenated Matter (organic)	6.04E-10	1.64E-11	
	(w) Hydrocarbons (unspecified)	1.00E-03	2.71E-05	
	(w) Iron (Fe++, Fe3+)	1.72E-06	4.66E-08	
	(w) Lead (Pb++, Pb4+)	6.04E-09	1.64E-10	
	(w) Mercury (Hg+, Hg++)	6.95E-12	1.88E-13	
	(w) Metals (unspecified)	3.31E-02	8.96E-04	
	(w) Nickel (Ni++, Ni3+)	3.02E-09	8.18E-11	
	(w) Nitrate (NO3-)	3.01E-04	8.16E-06	
	(w) Nitrogenous Matter (unspecified, as N)	8.16E-08	2.21E-09	
	(w) Oils (unspecified)	4.53E-01	1.23E-02	
	(w) Organic Matter (unspecified)	1.09E-06	2.96E-08	
	(w) Phenol (C6H5OH)	1.87E-02	5.06E-04	
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.01E-06	8.15E-08	
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	7.25E-09	1.96E-10	
	(w) Salts (unspecified)	8.36E-03	2.26E-04	
	(w) Sodium (Na+)	2.00E+01	5.42E-01	
	(w) Sulfate (SO4--)	4.51E-04	1.22E-05	
	(w) Sulfide (S--)	2.44E-07	6.61E-09	
	(w) Suspended Matter (unspecified)	4.41E+00	1.19E-01	
	(w) TOC (Total Organic Carbon)	4.53E-06	1.23E-07	
	(w) Toluene (C6H5CH3)	6.65E-08	1.80E-09	
	(w) Zinc (Zn++)	5.63E-08	1.53E-09	
	Total (g)		1.35E+00	
Note: Water emissions exclude chemically polluted water, which equals		7.79E-02	liters	
		Factor for 1 kg	grams (g)	
Air Emissions	(a) Acenaphthene (C12H10)	2.15E-08	5.83E-10	
	(a) Acenaphthylene (C12H8)	8.16E-09	2.21E-10	
	(a) Acetaldehyde (CH3CHO)	1.39E-05	3.76E-07	
	(a) Acetophenone (C8H8O)	3.65E-07	9.89E-09	
	(a) Acrolein (CH2CHCHO)	7.06E-06	1.91E-07	
	(a) Aldehyde (unspecified)	6.60E-03	1.79E-04	
	(a) Aluminum (Al)	5.63E-05	1.52E-06	
	(a) Ammonia (NH3)	9.84E-03	2.66E-04	
	(a) Anthracene (C14H10)	8.17E-09	2.21E-10	
	(a) Antimony (Sb)	2.81E-06	7.61E-08	
	(a) Aromatic Hydrocarbons (unspecified)	2.72E-07	7.37E-09	
	(a) Arsenic (As)	4.92E-05	1.33E-06	
	(a) Barium (Ba)	1.49E-06	4.04E-08	
	(a) Benzene (C6H6)	6.33E-02	1.72E-03	
	(a) Benzo(a)anthracene	5.29E-09	1.43E-10	
	(a) Benzo(a)pyrene (C20H12)	2.62E-09	7.10E-11	
	(a) Benzo(b)fluoranthene	2.24E-09	6.06E-11	
	(a) Benzo(bjk)fluoranthene	2.68E-09	7.25E-11	
	(a) Benzo(ghi)perylene	2.36E-09	6.40E-11	
	(a) Benzo(k)fluoranthene	2.24E-09	6.06E-11	
	(a) Benzyl Chloride (C7H7Cl)	1.70E-05	4.61E-07	
	(a) Beryllium (Be)	5.15E-06	1.40E-07	
	(a) Bromoform (CHBr3)	9.49E-07	2.57E-08	
	(a) Butane (C4H10)	2.32E-03	6.28E-05	
	(a) Cadmium (Cd)	3.00E-06	8.13E-08	
	(a) Calcium (Ca)	4.88E-05	1.32E-06	
	(a) Carbon Dioxide (CO2, biomass)	2.46E-04	6.67E-06	
	(a) Carbon Dioxide (CO2, fossil)	6.70E+02	1.82E+01	
	(a) Carbon Disulfide (CS2)	3.16E-06	8.57E-08	
	(a) Carbon Monoxide (CO)	2.00E+00	5.42E-02	
	(a) Chlorides (Cl-)	1.57E-04	4.25E-06	
	(a) Chlorine (Cl2)	2.35E-08	6.37E-10	

		Factor for 1 kg	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	1.70E-07	4.61E-09
	(a) Chlorobenzene (C6H5Cl)	5.36E-07	1.45E-08
	(a) Chloroform (CHCl3, HC-20)	1.44E-06	3.89E-08
	(a) Chromium (Cr III, Cr VI)	7.66E-05	2.08E-06
	(a) Chrysene (C18H12)	4.82E-09	1.31E-10
	(a) Cobalt (Co)	8.82E-06	2.39E-07
	(a) Copper (Cu)	5.13E-06	1.39E-07
	(a) Cumene (C9H12)	1.29E-07	3.49E-09
	(a) Cyanide (CN-)	6.09E-05	1.65E-06
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	1.78E-06	4.81E-08
	(a) Dibenzo(a,h)anthracene	1.61E-09	4.35E-11
	(a) Dichlorobenzene (1,4-C6H4Cl2)	1.32E-06	3.59E-08
	(a) Dimethyl Benzanthracene (7,12-C20H16)	1.66E-08	4.49E-10
	(a) Dimethyl Sulfate (C2H6O4S)	1.17E-06	3.16E-08
	(a) Dinitrotoluene (2,4-C7H6N2O4)	6.82E-09	1.85E-10
	(a) Dioxins (unspecified)	3.94E-10	1.07E-11
	(a) Diphenyl ((C6H5)2)	4.14E-08	1.12E-09
	(a) Ethane (C2H6)	3.42E-03	9.27E-05
	(a) Ethyl Benzene (C6H5C2H5)	2.32E-06	6.27E-08
	(a) Ethyl Chloride (C2H5Cl)	1.02E-06	2.77E-08
	(a) Ethylene Dibromide (C2H4Br2)	2.92E-08	7.91E-10
	(a) Ethylene Dichloride (C2H4Cl2)	9.74E-07	2.64E-08
	(a) Fluoranthene	2.14E-08	5.80E-10
	(a) Fluorene (C13H10)	2.60E-08	7.04E-10
	(a) Fluorides (F-)	1.75E-05	4.75E-07
	(a) Formaldehyde (CH2O)	3.43E-03	9.29E-05
	(a) Furan (C4H4O)	1.83E-09	4.96E-11
	(a) Halogenated Hydrocarbons (unspecified)	1.51E-12	4.09E-14
	(a) Halon 1301 (CF3Br)	2.63E-09	7.12E-11
	(a) Hexane (C6H14)	1.99E-03	5.39E-05
	(a) Hydrocarbons (except methane)	3.77E-01	1.02E-02
	(a) Hydrocarbons (unspecified)	5.40E-01	1.46E-02
	(a) Hydrogen Chloride (HCl)	2.92E-02	7.92E-04
	(a) Hydrogen Fluoride (HF)	3.65E-03	9.89E-05
	(a) Hydrogen Sulfide (H2S)	8.84E-03	2.40E-04
	(a) Indeno (1,2,3,c,d) Pyrene	3.83E-09	1.04E-10
	(a) Iron (Fe)	1.09E-04	2.95E-06
	(a) Isophorone	1.41E-05	3.82E-07
	(a) Lead (Pb)	4.49E-05	1.22E-06
	(a) Magnesium (Mg)	2.68E-04	7.25E-06
	(a) Manganese (Mn)	8.16E-05	2.21E-06
	(a) Mercury (Hg)	3.18E-06	8.62E-08
	(a) Metals (unspecified)	1.62E-06	4.38E-08
	(a) Methane (CH4)	3.34E+00	9.05E-02
	(a) Methyl Bromide (CH3Br)	3.89E-06	1.05E-07
	(a) Methyl Chloride (CH3Cl)	1.29E-05	3.49E-07
	(a) Methyl Cholanthrene (3-C21H16)	1.99E-09	5.38E-11
	(a) Methyl Chrysene (5-C19H15)	5.36E-10	1.45E-11
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	9.49E-06	2.57E-07
	(a) Methyl Hydrazine (CH6N2)	4.14E-06	1.12E-07
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	4.87E-07	1.32E-08
	(a) Methyl Naphthalene (2-C11H10)	2.65E-08	7.18E-10
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	8.52E-07	2.31E-08
	(a) Methylene Chloride (CH2Cl2, HC-130)	7.06E-06	1.91E-07
	(a) Molybdenum (Mo)	6.16E-06	1.67E-07
	(a) Naphthalene (C10H8)	1.50E-06	4.06E-08
	(a) Nickel (Ni)	3.79E-04	1.03E-05
	(a) Nitrogen Oxides (NOx as NO2)	2.26E+00	6.11E-02
	(a) Nitrous Oxide (N2O)	5.43E-02	1.47E-03
	(a) Organic Matter (unspecified)	3.15E-01	8.54E-03
	(a) Particulates (PM 10)	6.49E-04	1.76E-05
	(a) Particulates (unspecified)	5.07E-01	1.37E-02
	(a) Pentane (C5H12)	2.87E-03	7.77E-05
	(a) Phenanthrene (C14H10)	8.63E-08	2.34E-09
	(a) Phenol (C6H5OH)	3.89E-07	1.05E-08
	(a) Phosphorus (P)	3.73E-05	1.01E-06
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	3.02E-10	8.18E-12
	(a) Propane (C3H8)	6.10E-06	1.65E-07
	(a) Propionaldehyde (CH3CH2CHO)	9.25E-06	2.51E-07
	(a) Pyrene (C16H10)	1.43E-08	3.86E-10
	(a) Selenium (Se)	3.36E-05	9.11E-07
	(a) Silicon (Si)	4.88E-05	1.32E-06
	(a) Sodium (Na)	2.89E-04	7.83E-06
	(a) Styrene (C6H5CHCH2)	6.09E-07	1.65E-08
	(a) Sulfur Oxides (SOx as SO2)	3.24E+00	8.77E-02
	(a) Tetrachloroethylene (C2Cl4)	1.05E-06	2.83E-08
	(a) Toluene (C6H5CH3)	1.51E-05	4.10E-07
	(a) Trichloroethane (1,1,1-CH3CCl3)	4.87E-07	1.32E-08
	(a) Vanadium (V)	7.68E-04	2.08E-05
	(a) Vinyl Acetate (C4H6O2)	1.85E-07	5.01E-09
	(a) Xylene (C6H4(CH3)2)	4.37E-06	1.18E-07
	(a) Zinc (Zn)	4.52E-05	1.22E-06
	Total (g)		6.91E+02
		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	2.65E-01	7.17E-03

APPENDIX R
LCI DATA
DATA STORAGE
ELECTRICITY REQUIREMENTS

Appendix R: Data Storage - Electricity Requirements

Assumptions and Variables:	Electricity Requirement:	42.00	MJ
		Factor for 1 MJ	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.46E-07	1.03E-05
	(r) Coal (in ground)	1.48E-01	6.23E+00
	(r) Limestone (CaCO3, in ground)	1.17E-02	4.92E-01
	(r) Natural Gas (in ground)	9.17E-04	3.85E-02
	(r) Oil (in ground)	2.99E-03	1.25E-01
	(r) Sand (in ground)	1.51E-07	6.33E-06
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.92E-08	2.90E-06
	(r) Uranium (U, ore)	7.17E-07	3.01E-05
	Total		6.89E+00
Note: Raw material requirements exclude water usage, which equals		2.52E+00	liters
		Factor for 1 MJ	MJ
Energy Burdens	E Feedstock Energy	3.94E-01	1.65E+01
	E Fuel Energy	4.47E+00	1.88E+02
	E Non Renewable Energy	4.85E+00	2.04E+02
	E Renewable Energy	7.96E-03	3.34E-01
	Electricity	1.50E-02	6.29E-01
	E Total Primary Energy	4.86E+00	2.04E+02
		Factor for 1 MJ	grams (g)
Water Emissions	(w) Acids (H+)	1.06E-09	4.46E-08
	(w) Aluminum (Al3+)	7.83E-07	3.29E-05
	(w) Ammonia (NH4+, NH3, as N)	1.89E-04	7.92E-03
	(w) AOX (Adsorbable Organic Halogens)	2.07E-12	8.68E-11
	(w) Aromatic Hydrocarbons (unspecified)	4.84E-10	2.03E-08
	(w) Barium (Ba++)	1.55E-09	6.51E-08
	(w) BOD5 (Biochemical Oxygen Demand)	1.04E-03	4.36E-02
	(w) Cadmium (Cd++)	1.61E-12	6.78E-11
	(w) Chlorides (Cl-)	3.75E-02	1.57E+00
	(w) Chromium (Cr III, Cr VI)	3.46E-10	1.45E-08
	(w) COD (Chemical Oxygen Demand)	8.78E-03	3.69E-01
	(w) Copper (Cu+, Cu++)	3.23E-11	1.36E-09
	(w) Cyanide (CN-)	2.26E-12	9.49E-11
	(w) Dissolved Matter (unspecified)	4.28E-03	1.80E-01
	(w) Fluorides (F-)	1.08E-04	4.54E-03
	(w) Halogenated Matter (organic)	6.46E-13	2.71E-11
	(w) Hydrocarbons (unspecified)	2.41E-06	1.01E-04
	(w) Iron (Fe++, Fe3+)	2.11E-07	8.85E-06
	(w) Lead (Pb++, Pb4+)	6.46E-12	2.71E-10
	(w) Mercury (Hg+, Hg++)	7.42E-15	3.12E-13
	(w) Metals (unspecified)	6.37E-05	2.68E-03
	(w) Nickel (Ni++, Ni3+)	3.23E-12	1.36E-10
	(w) Nitrate (NO3-)	2.59E-05	1.09E-03
	(w) Nitrogenous Matter (unspecified, as N)	8.71E-11	3.66E-09
	(w) Oils (unspecified)	6.61E-04	2.77E-02
	(w) Organic Matter (unspecified)	2.79E-09	1.17E-07
	(w) Phenol (C6H5OH)	1.99E-05	8.38E-04
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.22E-09	1.35E-07
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	7.75E-12	3.25E-10
	(w) Salts (unspecified)	8.92E-06	3.75E-04
	(w) Sodium (Na+)	4.83E-02	2.03E+00
	(w) Sulfate (SO4--)	2.33E-05	9.79E-04
	(w) Sulfide (S--)	6.02E-10	2.53E-08
	(w) Suspended Matter (unspecified)	4.74E-03	1.99E-01
	(w) TOC (Total Organic Carbon)	4.84E-09	2.03E-07
	(w) Toluene (C6H5CH3)	7.10E-11	2.98E-09
	(w) Zinc (Zn++)	9.93E-11	4.17E-09
	Total (g)		4.44E+00
Note: Water emissions exclude chemically polluted water, which equals		2.49E-01	liters
		Factor for 1 MJ	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	3.78E-08	1.59E-06
	(a) Acenaphthylene (C12H8)	1.85E-08	7.77E-07
	(a) Acetaldehyde (CH3CHO)	4.22E-05	1.77E-03
	(a) Acetophenone (C8H8O)	1.11E-06	4.66E-05
	(a) Acrolein (CH2CHCHO)	2.15E-05	9.02E-04
	(a) Aldehyde (unspecified)	7.58E-03	3.18E-01
	(a) Aluminum (Al)	1.36E-07	5.70E-06
	(a) Ammonia (NH3)	5.11E-05	2.15E-03
	(a) Anthracene (C14H10)	1.56E-08	6.53E-07
	(a) Antimony (Sb)	1.51E-06	6.34E-05
	(a) Aromatic Hydrocarbons (unspecified)	2.90E-10	1.22E-08
	(a) Arsenic (As)	1.30E-04	5.46E-03
	(a) Barium (Ba)	9.72E-08	4.08E-06
	(a) Benzene (C6H6)	2.59E-04	1.09E-02
	(a) Benzo(a)anthracene	5.93E-09	2.49E-07
	(a) Benzo(a)pyrene (C20H12)	2.82E-09	1.18E-07
	(a) Benzo(b)fluoranthene	3.86E-12	1.62E-10
	(a) Benzo(bjk)fluoranthene	8.14E-09	3.42E-07
	(a) Benzo(ghi)perylene	2.00E-09	8.41E-08
	(a) Benzo(k)fluoranthene	3.86E-12	1.62E-10
	(a) Benzyl Chloride (C7H7Cl)	5.18E-05	2.18E-03
	(a) Beryllium (Be)	1.49E-05	6.27E-04
	(a) Bromoform (CHBr3)	2.89E-06	1.21E-04
	(a) Butane (C4H10)	4.18E-06	1.76E-04
	(a) Cadmium (Cd)	8.42E-06	3.54E-04
	(a) Calcium (Ca)	1.18E-07	4.94E-06
	(a) Carbon Dioxide (CO2, biomass)	2.97E-05	1.25E-03
	(a) Carbon Dioxide (CO2, fossil)	3.77E+02	1.58E+04
	(a) Carbon Disulfide (CS2)	9.62E-06	4.04E-04
	(a) Carbon Monoxide (CO)	1.62E-01	6.80E+00
	(a) Chlorides (Cl-)	1.16E-05	4.89E-04
	(a) Chlorine (Cl2)	6.00E-11	2.52E-09

		Factor for 1 MJ	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	5.18E-07	2.18E-05
	(a) Chlorobenzene (C6H5Cl)	1.63E-06	6.84E-05
	(a) Chloroform (CHCl3, HC-20)	4.37E-06	1.83E-04
	(a) Chromium (Cr III, Cr VI)	2.17E-04	9.13E-03
	(a) Chrysene (C18H12)	7.41E-09	3.11E-07
	(a) Cobalt (Co)	7.61E-06	3.20E-04
	(a) Copper (Cu)	7.73E-08	3.25E-06
	(a) Cumene (C9H12)	3.92E-07	1.65E-05
	(a) Cyanide (CN-)	1.85E-04	7.77E-03
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	5.40E-06	2.27E-04
	(a) Dibenzo(a,h)anthracene	2.70E-12	1.13E-10
	(a) Dichlorobenzene (1,4-C6H4Cl2)	2.39E-09	1.00E-07
	(a) Dimethyl Benzanthracene (7,12-C20H16)	3.02E-11	1.27E-09
	(a) Dimethyl Sulfate (C2H6O4S)	3.55E-06	1.49E-04
	(a) Dinitrotoluene (2,4-C7H6N2O4)	2.07E-08	8.71E-07
	(a) Dioxins (unspecified)	1.20E-09	5.03E-08
	(a) Diphenyl ((C6H5)2)	1.26E-07	5.29E-06
	(a) Ethane (C2H6)	6.17E-06	2.59E-04
	(a) Ethyl Benzene (C6H5C2H5)	6.96E-06	2.92E-04
	(a) Ethyl Chloride (C2H5Cl)	3.11E-06	1.31E-04
	(a) Ethylene Dibromide (C2H4Br2)	8.88E-08	3.73E-06
	(a) Ethylene Dichloride (C2H4Cl2)	2.96E-06	1.24E-04
	(a) Fluoranthene	5.26E-08	2.21E-06
	(a) Fluorene (C13H10)	6.74E-08	2.83E-06
	(a) Fluorides (F-)	1.82E-06	7.64E-05
	(a) Formaldehyde (CH2O)	3.16E-05	1.33E-03
	(a) Furan (C4H4O)	5.57E-09	2.34E-07
	(a) Halogenated Hydrocarbons (unspecified)	1.61E-15	6.78E-14
	(a) Halon 1301 (CF3Br)	2.81E-12	1.18E-10
	(a) Hexane (C6H14)	8.54E-06	3.59E-04
	(a) Hydrocarbons (except methane)	1.39E-02	5.83E-01
	(a) Hydrocarbons (unspecified)	2.68E-02	1.13E+00
	(a) Hydrogen Chloride (HCl)	8.88E-02	3.73E+00
	(a) Hydrogen Fluoride (HF)	1.11E-02	4.66E-01
	(a) Hydrogen Sulfide (H2S)	2.13E-05	8.95E-04
	(a) Indeno (1,2,3,c,d) Pyrene	4.52E-09	1.90E-07
	(a) Iron (Fe)	2.62E-07	1.10E-05
	(a) Isophorone	4.29E-05	1.80E-03
	(a) Lead (Pb)	1.29E-04	5.41E-03
	(a) Magnesium (Mg)	8.14E-04	3.42E-02
	(a) Manganese (Mn)	2.42E-04	1.02E-02
	(a) Mercury (Hg)	8.08E-06	3.39E-04
	(a) Metals (unspecified)	1.76E-09	7.40E-08
	(a) Methane (CH4)	6.60E-01	2.77E+01
	(a) Methyl Bromide (CH3Br)	1.18E-05	4.97E-04
	(a) Methyl Chloride (CH3Cl)	3.92E-05	1.65E-03
	(a) Methyl Cholanthrene (3-C21H16)	3.58E-12	1.51E-10
	(a) Methyl Chrysene (5-C19H15)	1.63E-09	6.84E-08
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	2.89E-05	1.21E-03
	(a) Methyl Hydrazine (CH6N2)	1.26E-05	5.29E-04
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	1.48E-06	6.22E-05
	(a) Methyl Naphthalene (2-C11H10)	4.78E-11	2.01E-09
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	2.59E-06	1.09E-04
	(a) Methylene Chloride (CH2Cl2, HC-130)	2.15E-05	9.02E-04
	(a) Molybdenum (Mo)	4.80E-08	2.01E-06
	(a) Naphthalene (C10H8)	1.00E-06	4.21E-05
	(a) Nickel (Ni)	1.76E-04	7.39E-03
	(a) Nitrogen Oxides (NOx as NO2)	1.40E+00	5.89E+01
	(a) Nitrous Oxide (N2O)	5.14E-02	2.16E+00
	(a) Organic Matter (unspecified)	8.45E-04	3.55E-02
	(a) Particulates (PM 10)	1.56E-06	6.57E-05
	(a) Particulates (unspecified)	9.04E-01	3.80E+01
	(a) Pentane (C5H12)	5.18E-06	2.17E-04
	(a) Phenanthrene (C14H10)	2.00E-07	8.40E-06
	(a) Phenol (C6H5OH)	1.18E-06	4.97E-05
	(a) Phosphorus (P)	3.97E-07	1.67E-05
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	3.23E-13	1.36E-11
	(a) Propane (C3H8)	5.75E-07	2.41E-05
	(a) Propionaldehyde (CH3CH2CHO)	2.81E-05	1.18E-03
	(a) Pyrene (C16H10)	2.44E-08	1.03E-06
	(a) Selenium (Se)	9.63E-05	4.04E-03
	(a) Silicon (Si)	1.18E-07	4.94E-06
	(a) Sodium (Na)	6.97E-07	2.93E-05
	(a) Styrene (C6H5CHCH2)	1.85E-06	7.77E-05
	(a) Sulfur Oxides (SOx as SO2)	1.35E+00	5.68E+01
	(a) Tetrachloroethylene (C2Cl4)	3.18E-06	1.34E-04
	(a) Toluene (C6H5CH3)	1.81E-05	7.59E-04
	(a) Trichloroethane (1,1,1-CH3CCl3)	1.48E-06	6.22E-05
	(a) Vanadium (V)	2.88E-06	1.21E-04
	(a) Vinyl Acetate (C4H6O2)	5.63E-07	2.36E-05
	(a) Xylene (C6H4(CH3)2)	2.75E-06	1.16E-04
	(a) Zinc (Zn)	1.03E-06	4.34E-05
	Total (g)		1.64E+04
		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	7.81E-01	3.28E+01

APPENDIX S
LCI DATA
SERVER PRODUCTION DATA

1) Material Production
2) Server Manufacturing
3) Server Transportation

Appendix S: Server Production Data – Material Production

Personal Computer Power Rating	160.00	Watts
Server Power Rating	3,040.00	Watts
Power Rating Ratio	19.000	
Allocation Ratio (calculated in Section 5.3.4.5)	0.0016	
User Ratio (calculated in Section 5.3.4.5)	0.0333	

	Personal Computer	Server
Aluminum	5.74E+02	5.80E-01
Clacium carbonate	1.73E+03	1.75E+00
Chromium	4.25E+01	4.29E-02
Copper	1.16E+03	1.17E+00
Crude Oil	7.62E+03	7.70E+00
Hard coal, cleaned	3.90E+03	3.94E+00
Hard coal, uncleaned	4.25E+03	4.29E+00
Iron	6.90E+03	6.97E+00
lead	5.11E+02	5.16E-01
Lignite	1.42E+03	1.43E+00
Manganese	4.75E+01	4.80E-02
Natural Gas	5.54E+03	5.60E+00
Nickel	3.48E+01	3.52E-02
Quartz	3.86E+03	3.90E+00
Sodium Chloride	6.93E+02	7.00E-01
Straw, dry matter	0.00E+00	0.00E+00
Tin	0.00E+00	0.00E+00
Uranium	1.35E-01	1.36E-04
Wood	6.66E+03	6.73E+00
Zinc	2.59E+01	2.62E-02
Total (g)	4.50E+04	4.54E+01
Total (kg)	4.50E+01	1.36E+00

water requirements

	Personal Computer	Server
Primary Energy, Materials	2.77E+02	2.80E-01
Primary Energy, processes	7.63E+02	7.71E-01
Total Energy (MJ)	1.04E+03	1.05E+00

	Personal Computer	Server
1-Methoxy-2-hydroxypropane	5.23E-01	5.28E-04
2-propanol (isopropanol)	0.00E+00	0.00E+00
Acetone	3.66E+00	3.70E-03
Benz(a)Pyrene	3.20E-08	3.23E-11
Benzene	2.05E-03	2.07E-06
Boron	6.82E-03	6.89E-06
Carbon dioxide	5.00E+04	5.05E+01
Carbon Monoxide	1.83E+02	1.85E-01
Copper	1.42E-03	1.43E-06
Dioxin	1.38E-06	1.39E-09
hydrocarbons	1.23E+02	1.24E-01
Hydrogen bromide	0.00E+00	0.00E+00
Hydrogen chloride	6.33E-01	6.39E-04
Hydrogen fluoride	9.36E-03	9.46E-06
Hydrogen sulphide	9.36E-01	9.46E-04
Lead	1.24E-02	1.25E-05
Magnesium	2.02E-03	2.04E-06
Manganese	1.08E+00	1.09E-03
Methane	3.12E+01	3.15E-02
Nickel	2.08E-02	2.10E-05
Nox	2.44E+02	2.46E-01
Nitrous Oxide	8.22E-01	8.30E-04
NMVOC	7.47E+00	7.55E-03
PAH	2.85E-02	2.88E-05
Sulpher dioxide	2.88E+02	2.91E-01
Thallium	1.92E-07	1.94E-10
Toluene	5.09E-04	5.14E-07
Unspecified Particles	3.85E+01	3.89E-02
Uranium	1.06E-06	1.07E-09
Vanadium	6.46E-02	6.53E-05
VOCs	3.15E+00	3.18E-03
Zinc	5.81E-03	5.87E-06
Total (g)	5.09E+04	5.14E+01

		Personal Computer	Server
Water Emissions (g/FU)	Ammonium	1.70E-01	1.72E-04
	BOD	4.61E-01	4.66E-04
	Cadmium	1.06E-02	1.07E-05
	COD	3.47E+01	3.51E-02
	Chlorate	1.99E-03	2.01E-06
	Copper	7.67E-02	7.75E-05
	Ethylne diamine tetraacetic acid	0.00E+00	0.00E+00
	Fluoride	8.84E-03	8.93E-06
	Formaldehyde	0.00E+00	0.00E+00
	Hydrocarbons	1.46E+00	1.47E-03
	Hydrogen chloride	0.00E+00	0.00E+00
	H+	7.67E-01	7.75E-04
	Hydrogenbromide	0.00E+00	0.00E+00
	Iron	6.14E+00	6.20E-03
	Lead	3.62E-03	3.66E-06
	Manganese	2.44E-03	2.46E-06
	Nickel	1.22E-01	1.23E-04
	Nitrate-N	2.42E-02	2.44E-05
	Phosphate	2.36E-02	2.38E-05
	PAH	1.14E-02	1.15E-05
	Strontium	1.20E-02	1.21E-05
	SS	4.60E+00	4.65E-03
	Total N	3.65E-03	3.69E-06
	Total P	0.00E+00	0.00E+00
	Unspecified anionic detergen	0.00E+00	0.00E+00
	Unspecified cooling agent/lubricant	4.90E-04	4.95E-07
	Unspecified N	5.88E-02	5.94E-05
	Unspecified oil	7.12E-01	7.19E-04
	Unspecified Salt	5.23E+00	5.28E-03
	Zinc	7.25E-02	7.32E-05
	Total (g)	5.47E+01	5.52E-02

		Personal Computer	Server
Solid Waste (kg/FU)	Cardboard	0.00E+00	0.00E+00
	Chromium-rich slags	8.88E-02	8.97E-05
	HCl in slag and ashes	0.00E+00	0.00E+00
	Iron-rich oven slag	1.07E+00	1.08E-03
	Lead	0.00E+00	0.00E+00
	Sodium hydroxide	4.44E-03	4.49E-06
	Tin	0.00E+00	0.00E+00
	Unspecified bauxit waste	6.09E-01	6.15E-04
	Unspecified bulk waste	1.56E+00	1.58E-03
	Unspecified dust with heavy metal content	9.34E-03	9.44E-06
	Unspecified hazrdous waste	1.06E-02	1.07E-05
	Unspecified industrial waste	1.41E-01	1.42E-04
	Unspecified plastic waste	0.00E+00	0.00E+00
	Unspecified radioactive waste	3.13E-04	3.16E-07
	Unspecified slag and ashes	4.42E-01	4.47E-04
	Unspecified sludge with heavy metal content	0.00E+00	0.00E+00
	Zinc-rich dust	0.00E+00	0.00E+00
	Total (kg)	3.94E+00	3.98E-03

Appendix S (continued): Server Production Data – Manufacturing

Assumptions:	Personal Computer Power Rating	160.00	Watts
	Server Power Rating	3,040.00	Watts
	Power Rating Ratio	19.000	
	Allocation Ratio (calculated in Section 5.3.4.5)	0.0016	
	User Ratio (calculated in Section 5.3.4.5)	0.0333	

LCI Manufacturing Data

		Personal Computer	Server
Raw Materials (g/FU)	Aluminum	2.88E+00	2.91E-03
	Clacium carbonate	2.83E+00	2.86E-03
	Chromium	0.00E+00	0.00E+00
	Copper	4.52E+01	4.57E-02
	Crude Oil	8.41E+03	8.50E+00
	Hard coal, cleaned	6.64E+01	6.71E-02
	Hard coal, uncleaned	2.69E+04	2.72E+01
	Iron	1.35E+01	1.36E-02
	lead	2.46E+01	2.49E-02
	Lignite	1.82E+03	1.84E+00
	Manganese	8.70E-03	8.79E-06
	Natural Gas	1.67E+04	1.69E+01
	Nickel	0.00E+00	0.00E+00
	Quartz	2.26E-02	2.28E-05
	Sodium Chloride	1.19E+02	1.20E-01
	Straw, dry matter	0.00E+00	0.00E+00
	Tin	4.36E+01	4.40E-02
	Uranium	1.68E+00	1.70E-03
	Wood	6.04E+00	6.10E-03
	Zinc	1.75E+02	1.77E-01
	Total (g)	5.43E+04	5.49E+01
	Total (kg)	5.43E+01	5.49E-02

Note: Raw materials exclude water requirements

		Personal Computer	Server
Energy Inputs (MJ/FU))	Primary Energy, Materials	1.19E-01	1.20E-04
	Primary Energy, processes	2.59E+03	2.62E+00
	Total Energy (MJ)	2.59E+03	2.62E+00

		Personal Computer	Server
Air Emissions (g/FU)	1-Methoxy-2-hydroxypropane	2.26E+00	2.28E-03
	2-propanol (isopropanol)	6.00E+00	6.06E-03
	Acetone	0.00E+00	0.00E+00
	Benz(a)Pyrene	3.31E-06	3.34E-09
	Benzene	2.12E-01	2.14E-04
	Boron	7.07E-01	7.14E-04
	Carbon dioxide	1.25E+05	1.26E+02
	Carbon Monoxide	9.02E+01	9.11E-02
	Copper	1.14E-02	1.15E-05
	Dioxin	1.79E-08	1.81E-11
	hydrocarbons	4.54E+01	4.59E-02
	Hydrogen bromide	0.00E+00	0.00E+00
	Hydrogen chloride	3.65E+00	3.69E-03
	Hydrogen fluoride	6.29E-02	6.35E-05
	Hydrogen sulphide	2.62E-03	2.65E-06
	Lead	2.58E-02	2.61E-05
	Magnesium	2.09E-01	2.11E-04
	Manganese	5.52E-03	5.58E-06
	Methane	2.24E+02	2.26E-01
	Nickel	6.05E-02	6.11E-05
	Nox	3.80E+02	3.84E-01
	Nitrous Oxide	7.95E+00	8.03E-03
	NMVOC	3.97E+01	4.01E-02
	PAH	2.95E-03	2.98E-06
	Sulpher dioxide	6.01E+02	6.07E-01
	Thallium	1.99E-05	2.01E-08
	Toluene	5.27E-02	5.32E-05
	Unspecified Particles	4.94E+01	4.99E-02
	Uranium	1.11E-04	1.12E-07
	Vanadium	1.93E-01	1.95E-04
	VOCs	1.08E+01	1.09E-02
	Zinc	2.31E-02	2.33E-05
	Total (g)	1.26E+05	1.28E+02

		Personal Computer	Server
Water Emissions (g/FU)	Ammonium	2.08E-01	2.10E-04
	BOD	1.99E-02	2.01E-05
	Cadmium	1.40E-03	1.41E-06
	COD	4.52E+00	4.57E-03
	Chlorate	2.06E-01	2.08E-04
	Copper	1.29E-01	1.30E-04
	Ethylne diamine tetraacetic acid	9.74E+00	9.84E-03
	Fluoride	1.53E+00	1.55E-03
	Formaldehyde	7.89E-01	7.97E-04
	Hydrocarbons	2.14E-01	2.16E-04
	Hydrogen chloride	0.00E+00	0.00E+00
	H+	1.18E+00	1.19E-03
	Hydrogenbromide	0.00E+00	0.00E+00
	Iron	2.89E+01	2.92E-02
	Lead	4.43E-03	4.48E-06
	Manganese	1.72E-02	1.74E-05
	Nickel	3.15E-03	3.18E-06
	Nitrate-N	1.08E-03	1.09E-06
	Phosphate	1.56E+00	1.58E-03
	PAH	0.00E+00	0.00E+00
	Strontium	8.16E-02	8.24E-05
	SS	1.69E+00	1.71E-03
	Total N	3.78E-01	3.82E-04
	Total P	3.71E-02	3.75E-05
	Unspecified anionic detergen	7.24E-01	7.31E-04
	Unspecified cooling agent/lubricant	1.40E-02	1.41E-05
	Unspecified N	3.98E-03	4.02E-06
	Unspecified oil	4.36E+00	4.40E-03
	Unspecified Salt	6.49E+01	6.56E-02
	Zinc	8.37E-02	8.46E-05
	Total (g)	1.21E+02	1.23E-01

		Personal Computer	Server
Solid Waste (kg/FU)	Cardboard	0.00E+00	0.00E+00
	Chromium-rich slags	0.00E+00	0.00E+00
	HCl in slag and ashes	0.00E+00	0.00E+00
	Iron-rich oven slag	1.98E-03	2.00E-06
	Lead	3.69E-03	3.73E-06
	Sodium hydroxide	3.12E+00	3.15E-03
	Tin	6.20E-03	6.26E-06
	Unspecified bauxit waste	0.00E+00	0.00E+00
	Unspecified bulk waste	8.66E+00	8.75E-03
	Unspecified dust with heavy metal content	0.00E+00	0.00E+00
	Unspecified hazrdous waste	2.10E+00	2.12E-03
	Unspecified industrial waste	1.50E+01	1.52E-02
	Unspecified plastic waste	0.00E+00	0.00E+00
	Unspecified radioactive waste	4.94E-03	4.99E-06
	Unspecified slag and ashes	1.89E+00	1.91E-03
	Unspecified sludge with heavy metal content	2.54E-02	2.57E-05
	Zinc-rich dust	0.00E+00	0.00E+00
	Total (kg)	3.08E+01	3.11E-02

Appendix S (continued): Server Production Data – Transportation

Assumptions:	Personal Computer Power Rating	160.00	Watts
	Server Power Rating	3,040.00	Watts
	Power Rating Ratio	19.000	
	Allocation Ratio (calculated in Section 5.3.4.5)	0.0016	
	User Ratio (calculated in Section 5.3.4.5)	0.0333	

LCI Transportation Data

		Personal Computer	Server
Raw Materials (g/FU)	Aluminum	2.22E-02	2.24E-05
	Clacium carbonate	5.90E-02	5.96E-05
	Chromium	0.00E+00	0.00E+00
	Copper	0.00E+00	0.00E+00
	Crude Oil	2.86E+02	2.89E-01
	Hard coal, cleaned	1.36E+00	1.37E-03
	Hard coal, uncleaned	2.51E-02	2.54E-05
	Iron	2.33E-02	2.35E-05
	lead	0.00E+00	0.00E+00
	Lignite	3.59E-04	3.63E-07
	Manganese	1.39E-04	1.40E-07
	Natural Gas	1.71E+01	1.73E-02
	Nickel	0.00E+00	0.00E+00
	Quartz	0.00E+00	0.00E+00
	Sodium Chloride	3.88E-02	3.92E-05
	Straw, dry matter	0.00E+00	0.00E+00
	Tin	0.00E+00	0.00E+00
	Uranium	7.21E-06	7.28E-09
	Wood	0.00E+00	0.00E+00
	Zinc	0.00E+00	0.00E+00
	Total (g)	3.05E+02	3.08E-01
	Total (kg)	3.05E-01	9.23E-03

Note: Raw materials exclude water requirements

		Personal Computer	Server
Energy Inputs (MJ/FU))	Primary Energy, Materials	4.16E-02	4.20E-05
	Primary Energy, processes	1.30E+01	1.31E-02
	Total Energy (MJ)	1.30E+01	1.32E-02

		Personal Computer	Server
Air Emissions (g/FU)	1-Methoxy-2-hydroxypropane	0.00E+00	0.00E+00
	2-propanol (isopropanol)	0.00E+00	0.00E+00
	Acetone	0.00E+00	0.00E+00
	Benz(a)Pyrene	0.00E+00	0.00E+00
	Benzene	0.00E+00	0.00E+00
	Boron	0.00E+00	0.00E+00
	Carbon dioxide	9.36E+02	9.46E-01
	Carbon Monoxide	3.80E+00	3.84E-03
	Copper	3.93E-09	3.97E-12
	Dioxin	9.79E-12	9.89E-15
	hydrocarbons	8.04E-02	8.12E-05
	Hydrogen bromide	0.00E+00	0.00E+00
	Hydrogen chloride	1.39E-03	1.40E-06
	Hydrogen fluoride	0.00E+00	0.00E+00
	Hydrogen sulphide	0.00E+00	0.00E+00
	Lead	1.86E-09	1.88E-12
	Magnesium	0.00E+00	0.00E+00
	Manganese	0.00E+00	0.00E+00
	Methane	5.88E-02	5.94E-05
	Nickel	9.08E-10	9.17E-13
	Nox	1.20E+01	1.21E-02
	Nitrous Oxide	3.72E-02	3.76E-05
	NMVOC	1.97E+00	1.99E-03
	PAH	2.48E-11	2.51E-14
	Sulpher dioxide	1.60E+00	1.62E-03
	Thallium	0.00E+00	0.00E+00
	Toluene	0.00E+00	0.00E+00
	Unspecified Particles	1.24E+00	1.25E-03
	Uranium	0.00E+00	0.00E+00
	Vanadium	3.18E-08	3.21E-11
	VOCs	1.58E-06	1.60E-09
	Zinc	1.93E-08	1.95E-11
	Total (g)	9.57E+02	9.67E-01

		Personal Computer	Server
Water Emissions (g/FU)	Ammonium	2.22E-04	2.24E-07
	BOD	1.39E-03	1.40E-06
	Cadmium	0.00E+00	0.00E+00
	COD	2.77E-03	2.80E-06
	Chlorate	0.00E+00	0.00E+00
	Copper	0.00E+00	0.00E+00
	Ethylne diamine tetraacetic acid	0.00E+00	0.00E+00
	Fluoride	4.39E-08	4.43E-11
	Formaldehyde	0.00E+00	0.00E+00
	Hydrocarbons	5.55E-03	5.61E-06
	Hydrogen chloride	0.00E+00	0.00E+00
	H+	8.32E-03	8.40E-06
	Hydrogenbromide	0.00E+00	0.00E+00
	Iron	8.67E-08	8.76E-11
	Lead	0.00E+00	0.00E+00
	Manganese	1.46E-08	1.47E-11
	Nickel	1.46E-09	1.47E-12
	Nitrate-N	6.93E-05	7.00E-08
	Phosphate	0.00E+00	0.00E+00
	PAH	0.00E+00	0.00E+00
	Strontium	7.32E-08	7.39E-11
	SS	1.66E-02	1.68E-05
	Total N	0.00E+00	0.00E+00
	Total P	0.00E+00	0.00E+00
	Unspecified anionic detergen	0.00E+00	0.00E+00
	Unspecified cooling agent/lubricant	0.00E+00	0.00E+00
	Unspecified N	2.77E-04	2.80E-07
	Unspecified oil	5.80E-08	5.86E-11
	Unspecified Salt	1.59E-06	1.61E-09
	Zinc	1.46E-09	1.47E-12
	Total (g)	3.52E-02	3.56E-05

		Personal Computer	Server
Solid Waste (kg/FU)	Cardboard	0.00E+00	0.00E+00
	Chromium-rich slags	0.00E+00	0.00E+00
	HCl in slag and ashes	0.00E+00	0.00E+00
	Iron-rich oven slag	0.00E+00	0.00E+00
	Lead	0.00E+00	0.00E+00
	Sodium hydroxide	0.00E+00	0.00E+00
	Tin	0.00E+00	0.00E+00
	Unspecified bauxit waste	0.00E+00	0.00E+00
	Unspecified bulk waste	8.32E-06	8.40E-09
	Unspecified dust with heavy metal content	0.00E+00	0.00E+00
	Unspecified hazrdous waste	1.70E-12	1.72E-15
	Unspecified industrial waste	8.60E-05	8.69E-08
	Unspecified plastic waste	0.00E+00	0.00E+00
	Unspecified radioactive waste	1.47E-01	1.48E-04
	Unspecified slag and ashes	7.39E-04	7.47E-07
	Unspecified sludge with heavy metal content	0.00E+00	0.00E+00
	Zinc-rich dust	0.00E+00	0.00E+00
	Total (kg)	1.48E-01	1.49E-04

APPENDIX T
LCI DATA
SERVER DISPOSITION

Appendix T: Server Disposition

Assumptions:	Personal Computer Power Rating	160.00	Watts
	Server Power Rating	3,040.00	Watts
	Power Rating Ratio	19.000	
	Allocation Ratio (calculated in Section 5.3.4.5)	0.0016	
	User Ratio (calculated in Section 5.3.4.5)	0.0333	

LCI Disposal Data

		Personal Computer	Server
Raw Materials (g/FU)	Aluminum	2.21E-02	2.23E-05
	Clacium carbonate	2.06E+02	2.08E-01
	Chromium	0.00E+00	0.00E+00
	Copper	0.00E+00	0.00E+00
	Crude Oil	1.05E+02	1.06E-01
	Hard coal, cleaned	1.11E+01	1.12E-02
	Hard coal, uncleaned	2.95E+02	2.98E-01
	Iron	1.84E-01	1.86E-04
	lead	0.00E+00	0.00E+00
	Lignite	9.20E+01	9.29E-02
	Manganese	3.44E-05	3.48E-08
	Natural Gas	1.03E+02	1.04E-01
	Nickel	0.00E+00	0.00E+00
	Quartz	3.17E-06	3.20E-09
	Sodium Chloride	5.76E+00	5.82E-03
	Straw, dry matter	1.05E+02	1.06E-01
	Tin	0.00E+00	0.00E+00
	Uranium	8.67E-03	8.76E-06
	Wood	0.00E+00	0.00E+00
	Zinc	0.00E+00	0.00E+00
	Total (g)	9.23E+02	9.32E-01
	Total (kg)	9.23E-01	2.80E-02

Note: Raw materials exclude water requirements

		Personal Computer	Server
Energy Inputs (MJ/FU))	Primary Energy, Materials	-4.13E+00	-4.17E-03
	Primary Energy, processes	-1.07E+01	-1.08E-02
	Total Energy (MJ)	-1.48E+01	-1.50E-02

		Personal Computer	Server
Air Emissions (g/FU)	1-Methoxy-2-hydroxypropane	0.00E+00	0.00E+00
	2-propanol (isopropanol)	0.00E+00	0.00E+00
	Acetone	0.00E+00	0.00E+00
	Benz(a)Pyrene	1.68E-08	1.70E-11
	Benzene	1.08E-03	1.09E-06
	Boron	3.58E-03	3.62E-06
	Carbon dioxide	4.85E+03	4.90E+00
	Carbon Monoxide	1.54E+01	1.56E-02
	Copper	2.49E-01	2.52E-04
	Dioxin	5.50E-07	5.56E-10
	hydrocarbons	6.80E-01	6.87E-04
	Hydrogen bromide	1.83E+00	1.85E-03
	Hydrogen chloride	1.56E+01	1.58E-02
	Hydrogen fluoride	3.83E-04	3.87E-07
	Hydrogen sulphide	2.90E-05	2.93E-08
	Lead	1.58E-02	1.60E-05
	Magnesium	1.06E-03	1.07E-06
	Manganese	1.84E-05	1.86E-08
	Methane	2.40E+00	2.42E-03
	Nickel	8.37E-04	8.46E-07
	Nox	1.27E+01	1.28E-02
	Nitrous Oxide	5.78E-02	5.84E-05
	NMVOC	5.49E+00	5.55E-03
	PAH	1.55E-05	1.57E-08
	Sulpher dioxide	7.10E+00	7.17E-03
	Thallium	1.01E-07	1.02E-10
	Toluene	2.67E-04	2.70E-07
	Unspecified Particles	6.28E-01	6.34E-04
	Uranium	5.62E-07	5.68E-10
	Vanadium	2.78E-03	2.81E-06
	VOCs	8.23E-02	8.31E-05
	Zinc	2.55E-04	2.58E-07
	Total (g)	4.91E+03	4.96E+00

		Personal Computer	Server
Water Emissions (g/FU)	Ammonium	1.19E-03	1.20E-06
	BOD	3.97E-04	4.01E-07
	Cadmium	1.59E-03	1.61E-06
	COD	2.02E-01	2.04E-04
	Chlorate	1.04E-03	1.05E-06
	Copper	5.92E-02	5.98E-05
	Ethylne diamine tetraacetic acid	1.53E+00	1.55E-03
	Fluoride	8.30E-04	8.38E-07
	Formaldehyde	0.00E+00	0.00E+00
	Hydrocarbons	2.41E-03	2.43E-06
	Hydrogen chloride	2.23E+01	2.25E-02
	H+	8.68E-03	8.77E-06
	Hydrogenbromide	1.10E+00	1.11E-03
	Iron	6.13E-01	6.19E-04
	Lead	1.57E-03	1.59E-06
	Manganese	1.76E-04	1.78E-07
	Nickel	5.32E-02	5.37E-05
	Nitrate-N	4.57E-05	4.62E-08
	Phosphate	5.16E-05	5.21E-08
	PAH	0.00E+00	0.00E+00
	Strontium	8.57E-04	8.66E-07
	SS	1.28E-02	1.29E-05
	Total N	1.92E-03	1.94E-06
	Total P	0.00E+00	0.00E+00
	Unspecified anionic detergen	0.00E+00	0.00E+00
	Unspecified cooling agent/lubricant	7.90E-05	7.98E-08
	Unspecified N	7.95E-05	8.03E-08
	Unspecified oil	2.30E-02	2.32E-05
	Unspecified Salt	3.37E-01	3.40E-04
	Zinc	9.05E-03	9.14E-06
	Total (g)	2.63E+01	2.65E-02

		Personal Computer	Server
Solid Waste (kg/FU)	Cardboard	2.53E+00	2.56E-03
	Chromium-rich slags	0.00E+00	0.00E+00
	HCl in slag and ashes	5.72E-02	5.78E-05
	Iron-rich oven slag	1.27E-01	1.28E-04
	Lead	0.00E+00	0.00E+00
	Sodium hydroxide	0.00E+00	0.00E+00
	Tin	0.00E+00	0.00E+00
	Unspecified bauxit waste	0.00E+00	0.00E+00
	Unspecified bulk waste	1.52E+01	1.54E-02
	Unspecified dust with heavy metal content	3.71E-03	3.75E-06
	Unspecified hazrdous waste	5.04E-03	5.09E-06
	Unspecified industrial waste	3.93E-02	3.97E-05
	Unspecified plastic waste	2.58E-01	2.61E-04
	Unspecified radioactive waste	2.56E-05	2.59E-08
	Unspecified slag and ashes	2.20E+01	2.22E-02
	Unspecified sludge with heavy metal content	2.42E-03	2.44E-06
	Zinc-rich dust	1.48E-02	1.50E-05
	Total (kg)	4.02E+01	4.06E-02

APPENDIX U
LCI DATA
ELECTRIC DATA FILE TRANSFER
ELECTRICITY REQUIREMENTS

Appendix U: Electric Data File Transfer - Electricity Requirements

Assumptions and Variables:	Energy Requirement (calculated in Section 5.3.5.6):	0.01	MJ

		Factor for 1 MJ	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.46E-07	1.82E-09
	(r) Coal (in ground)	1.48E-01	1.10E-03
	(r) Limestone (CaCO3, in ground)	1.17E-02	8.67E-05
	(r) Natural Gas (in ground)	9.17E-04	6.79E-06
	(r) Oil (in ground)	2.99E-03	2.21E-05
	(r) Sand (in ground)	1.51E-07	1.12E-09
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.92E-08	5.12E-10
	(r) Uranium (U, ore)	7.17E-07	5.31E-09
	Total		1.21E-03

Note: Raw material requirements exclude water usage, which equals	1.33E-01	liters

		Factor for 1 MJ	MJ
Energy Burdens	E Feedstock Energy	3.94E-01	2.91E-03
	E Fuel Energy	4.47E+00	3.31E-02
	E Non Renewable Energy	4.85E+00	3.59E-02
	E Renewable Energy	7.96E-03	5.89E-05
	Electricity	1.50E-02	1.11E-04
	E Total Primary Energy	4.86E+00	3.60E-02

		Factor for 1 MJ	grams (g)
Water Emissions	(w) Acids (H+)	1.06E-09	7.86E-12
	(w) Aluminum (Al3+)	7.83E-07	5.80E-09
	(w) Ammonia (NH4+, NH3, as N)	1.89E-04	1.40E-06
	(w) AOX (Adsorbable Organic Halogens)	2.07E-12	1.53E-14
	(w) Aromatic Hydrocarbons (unspecified)	4.84E-10	3.58E-12
	(w) Barium (Ba++)	1.55E-09	1.15E-11
	(w) BOD5 (Biochemical Oxygen Demand)	1.04E-03	7.69E-06
	(w) Cadmium (Cd++)	1.61E-12	1.19E-14
	(w) Chlorides (Cl-)	3.75E-02	2.77E-04
	(w) Chromium (Cr III, Cr VI)	3.46E-10	2.56E-12
	(w) COD (Chemical Oxygen Demand)	8.78E-03	6.50E-05
	(w) Copper (Cu+, Cu++)	3.23E-11	2.39E-13
	(w) Cyanide (CN-)	2.26E-12	1.67E-14
	(w) Dissolved Matter (unspecified)	4.28E-03	3.17E-05
	(w) Fluorides (F-)	1.08E-04	8.00E-07
	(w) Halogenated Matter (organic)	6.46E-13	4.78E-15
	(w) Hydrocarbons (unspecified)	2.41E-06	1.79E-08
	(w) Iron (Fe++, Fe3+)	2.11E-07	1.56E-09
	(w) Lead (Pb++, Pb4+)	6.46E-12	4.78E-14
	(w) Mercury (Hg+, Hg++)	7.42E-15	5.49E-17
	(w) Metals (unspecified)	6.37E-05	4.71E-07
	(w) Nickel (Ni++, Ni3+)	3.23E-12	2.39E-14
	(w) Nitrate (NO3-)	2.59E-05	1.91E-07
	(w) Nitrogenous Matter (unspecified, as N)	8.71E-11	6.45E-13
	(w) Oils (unspecified)	6.61E-04	4.89E-06
	(w) Organic Matter (unspecified)	2.79E-09	2.06E-11
	(w) Phenol (C6H5OH)	1.99E-05	1.48E-07
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.22E-09	2.38E-11
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	7.75E-12	5.73E-14
	(w) Salts (unspecified)	8.92E-06	6.60E-08
	(w) Sodium (Na+)	4.83E-02	3.57E-04
	(w) Sulfate (SO4--)	2.33E-05	1.72E-07
	(w) Sulfide (S--)	6.02E-10	4.45E-12
	(w) Suspended Matter (unspecified)	4.74E-03	3.51E-05
	(w) TOC (Total Organic Carbon)	4.84E-09	3.58E-11
	(w) Toluene (C6H5CH3)	7.10E-11	5.25E-13
	(w) Water: Chemically Polluted	5.69E+00	4.21E-02
	(w) Zinc (Zn++)	9.93E-11	7.35E-13
	Total (g)		4.29E-02

		Factor for 1 MJ	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	3.78E-08	2.79E-10
	(a) Acenaphthylene (C12H8)	1.85E-08	1.37E-10
	(a) Acetaldehyde (CH3CHO)	4.22E-05	3.12E-07
	(a) Acetophenone (C8H8O)	1.11E-06	8.22E-09
	(a) Acrolein (CH2CHCHO)	2.15E-05	1.59E-07
	(a) Aldehyde (unspecified)	7.58E-03	5.61E-05
	(a) Aluminum (Al)	1.36E-07	1.00E-09
	(a) Ammonia (NH3)	5.11E-05	3.78E-07
	(a) Anthracene (C14H10)	1.56E-08	1.15E-10
	(a) Antimony (Sb)	1.51E-06	1.12E-08
	(a) Aromatic Hydrocarbons (unspecified)	2.90E-10	2.15E-12
	(a) Arsenic (As)	1.30E-04	9.62E-07
	(a) Barium (Ba)	9.72E-08	7.19E-10
	(a) Benzene (C6H6)	2.59E-04	1.92E-06
	(a) Benzo(a)anthracene	5.93E-09	4.39E-11
	(a) Benzo(a)pyrene (C20H12)	2.82E-09	2.08E-11
	(a) Benzo(b)fluoranthene	3.86E-12	2.86E-14
	(a) Benzo(bjk)fluoranthene	8.14E-09	6.03E-11
	(a) Benzo(ghi)perylene	2.00E-09	1.48E-11
	(a) Benzo(k)fluoranthene	3.86E-12	2.86E-14
	(a) Benzyl Chloride (C7H7Cl)	5.18E-05	3.83E-07
	(a) Beryllium (Be)	1.49E-05	1.11E-07
	(a) Bromoform (CHBr3)	2.89E-06	2.14E-08
	(a) Butane (C4H10)	4.18E-06	3.09E-08
	(a) Cadmium (Cd)	8.42E-06	6.23E-08
	(a) Calcium (Ca)	1.18E-07	8.70E-10
	(a) Carbon Dioxide (CO2, biomass)	2.97E-05	2.20E-07
	(a) Carbon Dioxide (CO2, fossil)	3.77E+02	2.79E+00
	(a) Carbon Disulfide (CS2)	9.62E-06	7.12E-08
	(a) Carbon Monoxide (CO)	1.62E-01	1.20E-03
	(a) Chlorides (Cl-)	1.16E-05	8.61E-08
	(a) Chlorine (Cl2)	6.00E-11	4.44E-13

		Factor for 1 MJ	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	5.18E-07	3.83E-09
	(a) Chlorobenzene (C6H5Cl)	1.63E-06	1.21E-08
	(a) Chloroform (CHCl3, HC-20)	4.37E-06	3.23E-08
	(a) Chromium (Cr III, Cr VI)	2.17E-04	1.61E-06
	(a) Chrysene (C18H12)	7.41E-09	5.48E-11
	(a) Cobalt (Co)	7.61E-06	5.63E-08
	(a) Copper (Cu)	7.73E-08	5.72E-10
	(a) Cumene (C9H12)	3.92E-07	2.90E-09
	(a) Cyanide (CN-)	1.85E-04	1.37E-06
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	5.40E-06	4.00E-08
	(a) Dibenzo(a,h)anthracene	2.70E-12	2.00E-14
	(a) Dichlorobenzene (1,4-C6H4Cl2)	2.39E-09	1.77E-11
	(a) Dimethyl Benzanthracene (7,12-C20H16)	3.02E-11	2.24E-13
	(a) Dimethyl Sulfate (C2H6O4S)	3.55E-06	2.63E-08
	(a) Dinitrotoluene (2,4-C7H6N2O4)	2.07E-08	1.53E-10
	(a) Dioxins (unspecified)	1.20E-09	8.87E-12
	(a) Diphenyl ((C6H5)2)	1.26E-07	9.31E-10
	(a) Ethane (C2H6)	6.17E-06	4.57E-08
	(a) Ethyl Benzene (C6H5C2H5)	6.96E-06	5.15E-08
	(a) Ethyl Chloride (C2H5Cl)	3.11E-06	2.30E-08
	(a) Ethylene Dibromide (C2H4Br2)	8.88E-08	6.57E-10
	(a) Ethylene Dichloride (C2H4Cl2)	2.96E-06	2.19E-08
	(a) Fluoranthene	5.26E-08	3.89E-10
	(a) Fluorene (C13H10)	6.74E-08	4.99E-10
	(a) Fluorides (F-)	1.82E-06	1.35E-08
	(a) Formaldehyde (CH2O)	3.16E-05	2.34E-07
	(a) Furan (C4H4O)	5.57E-09	4.12E-11
	(a) Halogenated Hydrocarbons (unspecified)	1.61E-15	1.19E-17
	(a) Halon 1301 (CF3Br)	2.81E-12	2.08E-14
	(a) Hexane (C6H14)	8.54E-06	6.32E-08
	(a) Hydrocarbons (except methane)	1.39E-02	1.03E-04
	(a) Hydrocarbons (unspecified)	2.68E-02	1.98E-04
	(a) Hydrogen Chloride (HCl)	8.88E-02	6.57E-04
	(a) Hydrogen Fluoride (HF)	1.11E-02	8.22E-05
	(a) Hydrogen Sulfide (H2S)	2.13E-05	1.58E-07
	(a) Indeno (1,2,3,c,d) Pyrene	4.52E-09	3.34E-11
	(a) Iron (Fe)	2.62E-07	1.94E-09
	(a) Isophorone	4.29E-05	3.18E-07
	(a) Lead (Pb)	1.29E-04	9.53E-07
	(a) Magnesium (Mg)	8.14E-04	6.03E-06
	(a) Manganese (Mn)	2.42E-04	1.79E-06
	(a) Mercury (Hg)	8.08E-06	5.98E-08
	(a) Metals (unspecified)	1.76E-09	1.30E-11
	(a) Methane (CH4)	6.60E-01	4.88E-03
	(a) Methyl Bromide (CH3Br)	1.18E-05	8.77E-08
	(a) Methyl Chloride (CH3Cl)	3.92E-05	2.90E-07
	(a) Methyl Cholanthrene (3-C21H16)	3.58E-12	2.65E-14
	(a) Methyl Chrysene (5-C19H15)	1.63E-09	1.21E-11
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	2.89E-05	2.14E-07
	(a) Methyl Hydrazine (CH6N2)	1.26E-05	9.31E-08
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	1.48E-06	1.10E-08
	(a) Methyl Naphthalene (2-C11H10)	4.78E-11	3.54E-13
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	2.59E-06	1.92E-08
	(a) Methylene Chloride (CH2Cl2, HC-130)	2.15E-05	1.59E-07
	(a) Molybdenum (Mo)	4.80E-08	3.55E-10
	(a) Naphthalene (C10H8)	1.00E-06	7.41E-09
	(a) Nickel (Ni)	1.76E-04	1.30E-06
	(a) Nitrogen Oxides (NOx as NO2)	1.40E+00	1.04E-02
	(a) Nitrous Oxide (N2O)	5.14E-02	3.80E-04
	(a) Organic Matter (unspecified)	8.45E-04	6.25E-06
	(a) Particulates (PM 10)	1.56E-06	1.16E-08
	(a) Particulates (unspecified)	9.04E-01	6.69E-03
	(a) Pentane (C5H12)	5.18E-06	3.83E-08
	(a) Phenanthrene (C14H10)	2.00E-07	1.48E-09
	(a) Phenol (C6H5OH)	1.18E-06	8.77E-09
	(a) Phosphorus (P)	3.97E-07	2.94E-09
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	3.23E-13	2.39E-15
	(a) Propane (C3H8)	5.75E-07	4.25E-09
	(a) Propionaldehyde (CH3CH2CHO)	2.81E-05	2.08E-07
	(a) Pyrene (C16H10)	2.44E-08	1.81E-10
	(a) Selenium (Se)	9.63E-05	7.12E-07
	(a) Silicon (Si)	1.18E-07	8.70E-10
	(a) Sodium (Na)	6.97E-07	5.16E-09
	(a) Styrene (C6H5CHCH2)	1.85E-06	1.37E-08
	(a) Sulfur Oxides (SOx as SO2)	1.35E+00	1.00E-02
	(a) Tetrachloroethylene (C2Cl4)	3.18E-06	2.36E-08
	(a) Toluene (C6H5CH3)	1.81E-05	1.34E-07
	(a) Trichloroethane (1,1,1-CH3CCl3)	1.48E-06	1.10E-08
	(a) Vanadium (V)	2.88E-06	2.13E-08
	(a) Vinyl Acetate (C4H6O2)	5.63E-07	4.16E-09
	(a) Xylene (C6H4(CH3)2)	2.75E-06	2.04E-08
	(a) Zinc (Zn)	1.03E-06	7.65E-09
	Total (g)		3.80E+02

		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	7.81E-01	5.78E-03

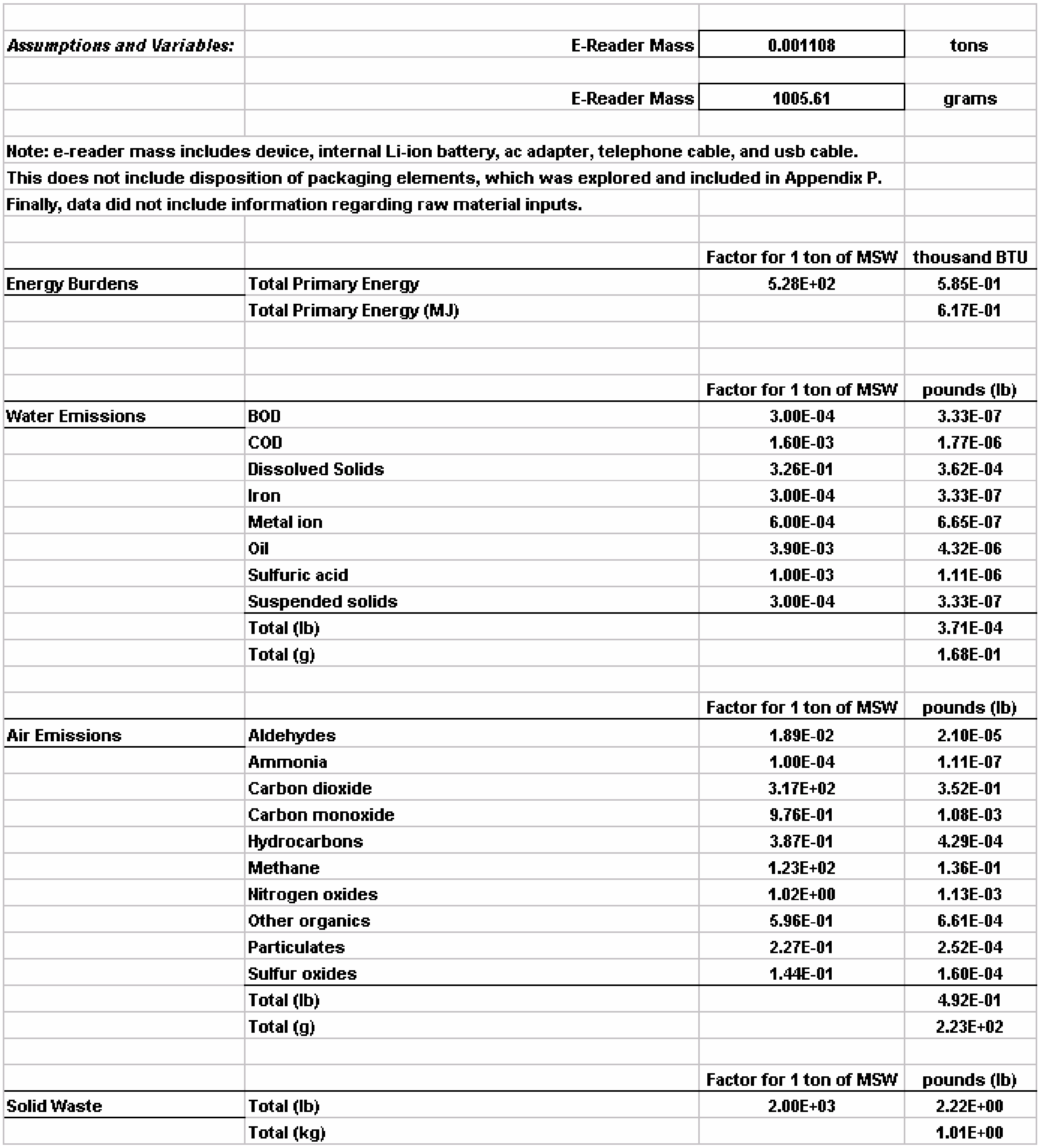
APPENDIX V
LCI DATA
E-READER USE

Appendix V: E-Reader Use

Assumptions and Variables:	Energy Requirement:	50.49	MJ
		Factor for 1 MJ	kilograms (kg)
Raw Materials	(r) Bauxite (Al2O3, ore)	2.46E-07	1.24E-05
	(r) Coal (in ground)	1.48E-01	7.49E+00
	(r) Limestone (CaCO3, in ground)	1.17E-02	5.91E-01
	(r) Natural Gas (in ground)	9.17E-04	4.63E-02
	(r) Oil (in ground)	2.99E-03	1.51E-01
	(r) Sand (in ground)	1.51E-07	7.61E-06
	(r) Sodium Chloride (NaCl, in ground or in sea)	6.92E-08	3.49E-06
	(r) Uranium (U, ore)	7.17E-07	3.62E-05
	Total		8.28E+00
Note: Raw material requirements exclude water usage, which equals		3.03E+00	liters
		Factor for 1 MJ	MJ
Energy Burdens	E Feedstock Energy	3.94E-01	1.99E+01
	E Fuel Energy	4.47E+00	2.26E+02
	E Non Renewable Energy	4.85E+00	2.45E+02
	E Renewable Energy	7.96E-03	4.02E-01
	Electricity	1.50E-02	7.57E-01
	E Total Primary Energy	4.86E+00	2.45E+02
		Factor for 1 MJ	grams (g)
Water Emissions	(w) Acids (H+)	1.06E-09	5.36E-08
	(w) Aluminum (Al3+)	7.83E-07	3.96E-05
	(w) Ammonia (NH4+, NH3, as N)	1.89E-04	9.52E-03
	(w) AOX (Adsorbable Organic Halogens)	2.07E-12	1.04E-10
	(w) Aromatic Hydrocarbons (unspecified)	4.84E-10	2.44E-08
	(w) Barium (Ba++)	1.55E-09	7.82E-08
	(w) BOD5 (Biochemical Oxygen Demand)	1.04E-03	5.25E-02
	(w) Cadmium (Cd++)	1.61E-12	8.15E-11
	(w) Chlorides (Cl-)	3.75E-02	1.89E+00
	(w) Chromium (Cr III, Cr VI)	3.46E-10	1.75E-08
	(w) COD (Chemical Oxygen Demand)	8.78E-03	4.43E-01
	(w) Copper (Cu+, Cu++)	3.23E-11	1.63E-09
	(w) Cyanide (CN-)	2.26E-12	1.14E-10
	(w) Dissolved Matter (unspecified)	4.28E-03	2.16E-01
	(w) Fluorides (F-)	1.08E-04	5.46E-03
	(w) Halogenated Matter (organic)	6.46E-13	3.26E-11
	(w) Hydrocarbons (unspecified)	2.41E-06	1.22E-04
	(w) Iron (Fe++, Fe3+)	2.11E-07	1.06E-05
	(w) Lead (Pb++, Pb4+)	6.46E-12	3.26E-10
	(w) Mercury (Hg+, Hg++)	7.42E-15	3.75E-13
	(w) Metals (unspecified)	6.37E-05	3.22E-03
	(w) Nickel (Ni++, Ni3+)	3.23E-12	1.63E-10
	(w) Nitrate (NO3-)	2.59E-05	1.31E-03
	(w) Nitrogenous Matter (unspecified, as N)	8.71E-11	4.40E-09
	(w) Oils (unspecified)	6.61E-04	3.34E-02
	(w) Organic Matter (unspecified)	2.79E-09	1.41E-07
	(w) Phenol (C6H5OH)	1.99E-05	1.01E-03
	(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)	3.22E-09	1.63E-07
	(w) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)	7.75E-12	3.91E-10
	(w) Salts (unspecified)	8.92E-06	4.51E-04
	(w) Sodium (Na+)	4.83E-02	2.44E+00
	(w) Sulfate (SO4--)	2.33E-05	1.18E-03
	(w) Sulfide (S--)	6.02E-10	3.04E-08
	(w) Suspended Matter (unspecified)	4.74E-03	2.40E-01
	(w) TOC (Total Organic Carbon)	4.84E-09	2.44E-07
	(w) Toluene (C6H5CH3)	7.10E-11	3.59E-09
	(w) Water: Chemically Polluted	5.69E+00	2.87E+02
	(w) Zinc (Zn++)	9.93E-11	5.01E-09
	Total (g)		2.92E+02
		Factor for 1 MJ	grams (g)
Air Emissions	(a) Acenaphthene (C12H10)	3.78E-08	1.91E-06
	(a) Acenaphthylene (C12H8)	1.85E-08	9.35E-07
	(a) Acetaldehyde (CH3CHO)	4.22E-05	2.13E-03
	(a) Acetophenone (C8H8O)	1.11E-06	5.61E-05
	(a) Acrolein (CH2CHCHO)	2.15E-05	1.08E-03
	(a) Aldehyde (unspecified)	7.58E-03	3.83E-01
	(a) Aluminum (Al)	1.36E-07	6.85E-06
	(a) Ammonia (NH3)	5.11E-05	2.58E-03
	(a) Anthracene (C14H10)	1.56E-08	7.85E-07
	(a) Antimony (Sb)	1.51E-06	7.62E-05
	(a) Aromatic Hydrocarbons (unspecified)	2.90E-10	1.47E-08
	(a) Arsenic (As)	1.30E-04	6.57E-03
	(a) Barium (Ba)	9.72E-08	4.91E-06
	(a) Benzene (C6H6)	2.59E-04	1.31E-02
	(a) Benzo(a)anthracene	5.93E-09	2.99E-07
	(a) Benzo(a)pyrene (C20H12)	2.82E-09	1.42E-07
	(a) Benzo(b)fluoranthene	3.86E-12	1.95E-10
	(a) Benzo(bjk)fluoranthene	8.14E-09	4.11E-07
	(a) Benzo(ghi)perylene	2.00E-09	1.01E-07
	(a) Benzo(k)fluoranthene	3.86E-12	1.95E-10
	(a) Benzyl Chloride (C7H7Cl)	5.18E-05	2.62E-03
	(a) Beryllium (Be)	1.49E-05	7.54E-04
	(a) Bromoform (CHBr3)	2.89E-06	1.46E-04
	(a) Butane (C4H10)	4.18E-06	2.11E-04
	(a) Cadmium (Cd)	8.42E-06	4.25E-04
	(a) Calcium (Ca)	1.18E-07	5.94E-06
	(a) Carbon Dioxide (CO2, biomass)	2.97E-05	1.50E-03
	(a) Carbon Dioxide (CO2, fossil)	3.77E+02	1.90E+04
	(a) Carbon Disulfide (CS2)	9.62E-06	4.86E-04
	(a) Carbon Monoxide (CO)	1.62E-01	8.18E+00
	(a) Chlorides (Cl-)	1.16E-05	5.88E-04
	(a) Chlorine (Cl2)	6.00E-11	3.03E-09
		Factor for 1 MJ	grams (g)
Air Emissions (cont.)	(a) Chloroacetophenone (2-C8H7ClO)	5.18E-07	2.62E-05
	(a) Chlorobenzene (C6H5Cl)	1.63E-06	8.22E-05
	(a) Chloroform (CHCl3, HC-20)	4.37E-06	2.21E-04
	(a) Chromium (Cr III, Cr VI)	2.17E-04	1.10E-02
	(a) Chrysene (C18H12)	7.41E-09	3.74E-07
	(a) Cobalt (Co)	7.61E-06	3.84E-04
	(a) Copper (Cu)	7.73E-08	3.90E-06
	(a) Cumene (C9H12)	3.92E-07	1.98E-05
	(a) Cyanide (CN-)	1.85E-04	9.34E-03
	(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	5.40E-06	2.73E-04
	(a) Dibenzo(a,h)anthracene	2.70E-12	1.36E-10
	(a) Dichlorobenzene (1,4-C6H4Cl2)	2.39E-09	1.21E-07
	(a) Dimethyl Benzanthracene (7,12-C20H16)	3.02E-11	1.53E-09
	(a) Dimethyl Sulfate (C2H6O4S)	3.55E-06	1.79E-04
	(a) Dinitrotoluene (2,4-C7H6N2O4)	2.07E-08	1.05E-06
	(a) Dioxins (unspecified)	1.20E-09	6.05E-08
	(a) Diphenyl ((C6H5)2)	1.26E-07	6.35E-06
	(a) Ethane (C2H6)	6.17E-06	3.12E-04
	(a) Ethyl Benzene (C6H5C2H5)	6.96E-06	3.51E-04
	(a) Ethyl Chloride (C2H5Cl)	3.11E-06	1.57E-04
	(a) Ethylene Dibromide (C2H4Br2)	8.88E-08	4.49E-06
	(a) Ethylene Dichloride (C2H4Cl2)	2.96E-06	1.50E-04
	(a) Fluoranthene	5.26E-08	2.65E-06
	(a) Fluorene (C13H10)	6.74E-08	3.40E-06
	(a) Fluorides (F-)	1.82E-06	9.18E-05
	(a) Formaldehyde (CH2O)	3.16E-05	1.60E-03
	(a) Furan (C4H4O)	5.57E-09	2.81E-07
	(a) Halogenated Hydrocarbons (unspecified)	1.61E-15	8.15E-14
	(a) Halon 1301 (CF3Br)	2.81E-12	1.42E-10
	(a) Hexane (C6H14)	8.54E-06	4.31E-04
	(a) Hydrocarbons (except methane)	1.39E-02	7.01E-01
	(a) Hydrocarbons (unspecified)	2.68E-02	1.35E+00
	(a) Hydrogen Chloride (HCl)	8.88E-02	4.49E+00
	(a) Hydrogen Fluoride (HF)	1.11E-02	5.61E-01
	(a) Hydrogen Sulfide (H2S)	2.13E-05	1.08E-03
	(a) Indeno (1,2,3,c,d) Pyrene	4.52E-09	2.28E-07
	(a) Iron (Fe)	2.62E-07	1.32E-05
	(a) Isophorone	4.29E-05	2.17E-03
	(a) Lead (Pb)	1.29E-04	6.51E-03
	(a) Magnesium (Mg)	8.14E-04	4.11E-02
	(a) Manganese (Mn)	2.42E-04	1.22E-02
	(a) Mercury (Hg)	8.08E-06	4.08E-04
	(a) Metals (unspecified)	1.76E-09	8.90E-08
	(a) Methane (CH4)	6.60E-01	3.33E+01
	(a) Methyl Bromide (CH3Br)	1.18E-05	5.98E-04
	(a) Methyl Chloride (CH3Cl)	3.92E-05	1.98E-03
	(a) Methyl Cholanthrene (3-C21H16)	3.58E-12	1.81E-10
	(a) Methyl Chrysene (5-C19H15)	1.63E-09	8.22E-08
	(a) Methyl Ethyl Ketone (MEK, C4H8O)	2.89E-05	1.46E-03
	(a) Methyl Hydrazine (CH6N2)	1.26E-05	6.35E-04
	(a) Methyl Methacrylate (CH2C(CH3)COOCH3)	1.48E-06	7.48E-05
	(a) Methyl Naphthalene (2-C11H10)	4.78E-11	2.41E-09
	(a) Methyl tert Butyl Ether (MTBE, C5H12O)	2.59E-06	1.31E-04
	(a) Methylene Chloride (CH2Cl2, HC-130)	2.15E-05	1.08E-03
	(a) Molybdenum (Mo)	4.80E-08	2.42E-06
	(a) Naphthalene (C10H8)	1.00E-06	5.06E-05
	(a) Nickel (Ni)	1.76E-04	8.88E-03
	(a) Nitrogen Oxides (NOx as NO2)	1.40E+00	7.08E+01
	(a) Nitrous Oxide (N2O)	5.14E-02	2.60E+00
	(a) Organic Matter (unspecified)	8.45E-04	4.27E-02
	(a) Particulates (PM 10)	1.56E-06	7.90E-05
	(a) Particulates (unspecified)	9.04E-01	4.56E+01
	(a) Pentane (C5H12)	5.18E-06	2.61E-04
	(a) Phenanthrene (C14H10)	2.00E-07	1.01E-05
	(a) Phenol (C6H5OH)	1.18E-06	5.98E-05
	(a) Phosphorus (P)	3.97E-07	2.00E-05
	(a) Polycyclic Aromatic Hydrocarbons (PAH, unspec.)	3.23E-13	1.63E-11
	(a) Propane (C3H8)	5.75E-07	2.90E-05
	(a) Propionaldehyde (CH3CH2CHO)	2.81E-05	1.42E-03
	(a) Pyrene (C16H10)	2.44E-08	1.23E-06
	(a) Selenium (Se)	9.63E-05	4.86E-03
	(a) Silicon (Si)	1.18E-07	5.94E-06
	(a) Sodium (Na)	6.97E-07	3.52E-05
	(a) Styrene (C6H5CHCH2)	1.85E-06	9.34E-05
	(a) Sulfur Oxides (SOx as SO2)	1.35E+00	6.83E+01
	(a) Tetrachloroethylene (C2Cl4)	3.18E-06	1.61E-04
	(a) Toluene (C6H5CH3)	1.81E-05	9.12E-04
	(a) Trichloroethane (1,1,1-CH3CCl3)	1.48E-06	7.48E-05
	(a) Vanadium (V)	2.88E-06	1.45E-04
	(a) Vinyl Acetate (C4H6O2)	5.63E-07	2.84E-05
	(a) Xylene (C6H4(CH3)2)	2.75E-06	1.39E-04
	(a) Zinc (Zn)	1.03E-06	5.22E-05
	Total (g)		1.96E+04
		Factor for 1 MJ	kilograms (kg)
Solid Waste	Waste (total)	7.81E-01	3.94E+01

APPENDIX W
LCI DATA
E-READER DISPOSITION

Appendix W: E-reader Disposition



Assumptions and Variables:	E-Reader Mass	0.001108	tons
	E-Reader Mass	1005.61	grams
Note: e-reader mass includes device, internal Li-ion battery, ac adapter, telephone cable, and usb cable.			
This does not include disposition of packaging elements, which was explored and included in Appendix P.			
Finally, data did not include information regarding raw material inputs.			
		Factor for 1 ton of MSW	thousand BTU
Energy Burdens	Total Primary Energy	5.28E+02	5.85E-01
	Total Primary Energy (MJ)		6.17E-01
		Factor for 1 ton of MSW	pounds (lb)
Water Emissions	BOD	3.00E-04	3.33E-07
	COD	1.60E-03	1.77E-06
	Dissolved Solids	3.26E-01	3.62E-04
	Iron	3.00E-04	3.33E-07
	Metal ion	6.00E-04	6.65E-07
	Oil	3.90E-03	4.32E-06
	Sulfuric acid	1.00E-03	1.11E-06
	Suspended solids	3.00E-04	3.33E-07
	Total (lb)		3.71E-04
	Total (g)		1.68E-01
		Factor for 1 ton of MSW	pounds (lb)
Air Emissions	Aldehydes	1.89E-02	2.10E-05
	Ammonia	1.00E-04	1.11E-07
	Carbon dioxide	3.17E+02	3.52E-01
	Carbon monoxide	9.76E-01	1.08E-03
	Hydrocarbons	3.87E-01	4.29E-04
	Methane	1.23E+02	1.36E-01
	Nitrogen oxides	1.02E+00	1.13E-03
	Other organics	5.96E-01	6.61E-04
	Particulates	2.27E-01	2.52E-04
	Sulfur oxides	1.44E-01	1.60E-04
	Total (lb)		4.92E-01
	Total (g)		2.23E+02
		Factor for 1 ton of MSW	pounds (lb)
Solid Waste	Total (lb)	2.00E+03	2.22E+00
	Total (kg)		1.01E+00