Subcontractor Report

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U.S. LCI Database Project—Phase I Final Report

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U.S. LCI Database Project
Phase I Final Report

1 Introduction

The Athena Sustainable Materials Institute, in association with Franklin Associates, Ltd. and Sylvatica, was retained by the National Renewable Energy Laboratory (NREL) to undertake Phase I of the U.S. Life-Cycle Inventory (LCI) Database Project.[1] Dr. Bo Weidema (Denmark) served as a consultant to the project team. This Phase I final report reviews the process and provides a plan for the execution of subsequent phases of the database project, including recommended data development priorities and a preliminary cost estimate.

The development of the *U.S. LCI Database Project Development Guidelines*[2]*: Phase I Final Version*, also called the *Guidelines*, provided as a companion to this document, was a critical part of the process that is described. This report includes specific recommendations for additional related work.

1.1 Background

It is widely recognized that the environmental performance of products must be viewed on a system-wide basis, considering a broad range of interactions with the environment both in time and space. In other words, there has to be a holistic environmental assessment approach. Life-cycle assessment (LCA) is just such an approach. In fact, LCA is viewed as the quantitative assessment component of industrial ecology. The cornerstone of LCA is the LCI, which is the quantification of material and energy (resources and wastes) flows associated with a product system under study. No matter how well a specific impact measure is crafted, nor how well a software tool is designed, the quality of results can never exceed the quality of the underlying LCI data.

The development of reliable LCI data typically requires considerable expert time inputs and expense, requirements that have generally impeded the application of LCA in North America. The lack of widely available, critically reviewed, comprehensive LCI databases for at least common processes is the main reason LCAs are frequently dismissed here as too expensive and time consuming. The development of a national LCI database will remedy this situation and considerably enhance the usability of LCA in general.

Although there are a few LCI databases on the market today, access to the information contained in them is generally restricted or protected by copyright agreements, or the data are otherwise not verifiable. The consultants who have developed databases are often reluctant to reveal much detail, partly to protect their own commercial interests, and partly because the databases were developed under confidentiality agreements with specific companies or industries. Perpetuation of this situation is inconsistent with the free, transparent, and open exchange of information required for reliable and verifiable

[1] U.S. LCI Database Project information is available at: http://www.nrel.gov/lci
[2] Formerly the U.S. LCI Database Project Research Protocol

technical and scientific investigations or assessments of products. A national LCI database, maintained by a reputable agency and available to all, will correct this serious deficiency.

Environmental issues associated with clean air, clean water, clean land, global climate change, toxic emissions, hazardous wastes, recycling, and other topics are constantly in the public eye. Clearly, the public's collective concern surrounding these and other issues is driving much of industry's interest in sustainable development, industrial ecology, and design for the environment. Organizations such as the World Business Council for Sustainable Development and others are actively establishing standards for metrics to characterize the eco-efficiency of industries and products, which must include life-cycle metrics. Since the LCI is fundamental to all life-cycle assessments, such data increasingly underlies various decision-support tools. The tools make it easier for researchers, manufacturers, designers, process engineers and virtually anyone else in the relevant supply chains to use LCI information. The creation of a national LCI database is again supportive of these efforts and must be applicable to the tool developers as well as to other potential users.

The ultimate requirement, then, is to establish a national database that meets stated criteria and is designed to serve the needs of a wide spectrum of potential data users. The criteria for this project include, but are not necessarily limited to, the following:

- Consistent with ISO standards and U.S. guidelines for LCA;
- Meeting specific transparency criteria;
- Uniform treatment of all materials and products;
- Regional differentiation to the extent required to properly reflect critical regional variations within and across industry sectors; and
- Full accessibility in a format(s) designed to maximize use.

The task in this first phase of the project has been to establish a guideline for data collection efforts and to develop a rational, cost-effective work program for at least the initial years of what should be an ongoing process.

1.1.1 Objectives

1.1.2 Overall Project Objective

The project represents a public/private research partnership designed to produce publicly available LCI databases for commonly used materials, products, and processes. The underlying intent is to support public and private sector efforts to develop environmentally oriented decision support systems and tools; to provide regional benchmark data for generating or assessing company, plant or new technology data; and to provide a firm foundation for subsequent life-cycle assessment tasks such as characterization, normalization, and impact assessment.

1.1.3 Phase I Objectives

The specific Phase I objectives were to develop a research guideline and establish research parameters, including products, processes, data categories and data quality, such that the resulting database would be credible and useful to interested parties.

1.2 Report Structure

The balance of this report is structured as follows:

Section 2 deals with the process followed during Phase I;

Section 3 focuses on the *Guidelines*, one of the critical outcomes of this phase;

Section 4 details the recommended *Work Program for Phase II* of the project; and

Section 5 discusses data dissemination issues.

2 Phase I Process

2.1 Meeting of Interests

Although the project formally started on May 1, 2001, the first public introduction of the project was at a Meeting of Interests hosted by Ford Motor Company on May 22 at its Dearborn, Michigan, research center. The purpose was to explain the database project, discuss related issues and concerns, and seek the support of a broad spectrum of relevant organizations.

In response to an invitation from Dr. John Sullivan of Ford, 37 representatives of industry, government, consulting organizations, universities, and research institutes, attended the meeting. The meeting included introductory comments from Ford, the U.S. Department of Energy (DOE), NREL and the U.S. Environmental Protection Agency (EPA), an overview of the project presented by the consulting team, and moderated discussion among all of the participants of a variety of issues, including the following topics:

- The nature and scope of data to be included;
- The quality of the data obtainable;
- The meaning of "peer review";
- The form of the data model and how the data will be stored;
- The format of the database;
- Transparency versus confidentiality issues;
- Where the database will reside, and who will take responsibility for its maintenance;
- Costs and cost sharing; and
- How new modules are to be added.

A full report on the Meeting of Interests is available from the project Web site at http://www.nrel.gov/lci.

2.2 Formation of Advisory Group

Prior to the Meeting of Interests we had identified a core group of people who had expressed interest in providing advice and guidance during Phase I of the project. Following the meeting, the advisory group was expanded to include 45 representatives of manufacturers, potential data users, LCA experts, and other public and private sector interests.

There were changes in the group composition over the course of Phase I, but most of the members worked with us throughout as explained in more detail below. The members of the advisory group are listed with their affiliations in Appendix A.

2.3 Working Papers

In preparation for a planned advisory group workshop, the consulting team prepared a series of seven working papers dealing with the following topics:

1. A survey of research Guidelines;
2. Data quality, data variability and uncertainty;
3. Common energy and transportation databases;
4. Materials and products definition;
5. Transformation process modules;
6. Transparency, data access and formats; and
7. Substance (e.g. environmental intervention) definition.

The working papers were circulated to the advisory group and formed the basis for the workshop discussions detailed below. All the working papers were subsequently posted to the project Web site where they can be reviewed and downloaded (see Section 2.1, above).

2.4 Workshop

The Advisory Group workshop, held at the NREL office in Washington, D.C., on July 24, 2001, was attended by about 30 members of the advisory group as well as the consulting team. The workshop objective was to establish the work program for the rest of Phase I. The workshop was structured to first ensure that all participants started with an understanding of the objectives and approach to the database project as a whole. Members of the consulting team then presented the basic working paper topics noted in the preceding sub-section as background information. The discussion during and after the presentations was intended to identify issues and establish Phase I priorities, not necessarily to resolve issues.

The following extracts from the workshop report, which is available at the project Web site, provide an overview of the issues and key conclusions.

Strategic Issues

Several overriding strategic issues dominated, especially the questions of who is likely to use the database and for what purpose. It was agreed that the answers to those questions would, at least in part, determine how to resolve other interrelated issues, such as the following:

- The rationale for developing LCI data at a unit process versus a rolled-up product level;
- How to establish an appropriate link between inventory and impact assessment in an LCI-only project where there is uncertainty about final users and uses of the data;
- Establishing priorities in terms of products, materials and processes to be studied;
- How to recognize or take account of the fact that industries, especially extractive industries, face specific physical realities which may not be fully understood or appreciated by users of LCI data that reflects flows per unit of output; and
- Ensuring the relevance of the data to appropriate functional units from a user perspective.

One important conclusion following from the discussion of strategic issues was the absolute necessity of making very clear the limitations of any database that is developed and the uses to which it can appropriately be put. There were also strong recommendations that the project be developed with a clear recognition of the following realities:

- The needs and priorities of supporting industries and agencies;
- The evolving nature of LCA practice; and
- The fact this is a building block process that should set the stage for continual database expansion and improvement.

The last point argued for establishing clear data gathering and analysis priorities, and for caution in terms of the level of detail expected from initial Phase II activities, whether in temporal, spatial, or other terms.

Guideline-related Issues
A second series of issues related more directly to elements of the *Guidelines*, such as:

- How to identify and deal with small flows that may be environmentally significant;
- The inclusion of feedstock energy;
- Linking data quality measure to specific data points or sets;
- The treatment of recyclability versus recycling;
- Co-product allocation rules and their application;
- Carbon-cycle issues and assumptions about carbon sequestration; and
- The development of data for electricity grids.

The wide-ranging discussion of these and similar issues previewed the work to be done in developing the Guidelines and provided a valuable starting point for working group deliberations.

Scope-related Issues
The third category of priority issues related to the Phase II project scope, with general agreement that it should be expanded to include common end-of-life process modules (e.g., scrap collection and baling, combustion). There was also concern that biodiversity and other site-specific effects somehow be taken into account.

Following the discussion of issues, the meeting focus shifted to the approach and work program needed to meet the Phase I objectives. The generally agreed upon work program included the formation of work groups, the subsequent review of the Guidelines, the basic communication process, and timing. The advisory group activities were critical to the process, as discussed below. The subsequent development of the Guidelines is covered in detail in Section 3: Guideline Development.

2.5 Advisory Group Activities

At the workshop, the advisory group agreed with the formation of five working groups, each with nine advisory group members and led by a member of the consulting team.

The five groups subsequently dealt with the following topics:

Group 1 — the assimilation of work group outputs and material from other sources to create a draft of the Guidelines;

Group 2 — data quality, uncertainty, and variability, as well as the definition of basic transformation processes;

Group 3 — transparency, data access, and data format issues;

Group 4 — the definition of substances to be tracked and the assessment of existing database availability; and

Group 5 — the development of a common database for fuel combustion and pre-combustion, including electricity generation and transportation, as well as identification of the products or materials to be studied in Phase II, and definition of the appropriate 'gates'.

An initial assignment of advisory group members to specific work groups had been prepared in advance of the workshop to ensure a reasonable balance of manufacturer, data user, and LCA expertise within each group. But members were given the opportunity to modify the assignments if necessary to better reflect individual interests and/or areas of expertise. The final composition of the work groups can be seen on the project Web site.

The working group contributions in the four months following the workshop were invaluable in development of the Guidelines (Section 3) and of the Work Program for Phase II (Section 4).

3 Guideline Development

Development of the Guidelines has proved more complex than originally expected, with the document going through 12 drafts to reach its current final Phase I version. Much of the challenge stems from the fact that LCI is as much an accounting process as it is a scientific or analytical process. Many of the LCI accounting conventions are subject to interpretation or are contentious, including many embedded in the ISO standard that is the LCA touchstone. As a result, the consulting team frequently found itself reliving the ISO 14040-14041 standard development process, a process that originally took several years.[3]

The current version of the Guidelines reflects the findings of an independent critical review team (see Section 3.2), as well as comments from other members of the advisory group. However, given the time constraints and the importance of starting the Phase II work, we have not tried to incorporate all of the suggestions nor to resolve some that conflict and would benefit from more careful analysis. We are therefore recommending tasks for Phase II that could result in revisions or extensions to the Guidelines. This is consistent with the fact emphasized during the workshop: that LCA practice is evolving and we are embarked on a building block process that should set the stage for continual database expansion and improvement. And as stated in the *Review Panel Report of the U.S. LCI Database Project Development Guidelines*, "a good test of the Guidelines will be its ability to be flexible enough to deal with less than ideal data …."

The Guidelines are being provided as a companion to this report and will be posted to the project Web site. The focus of this section is therefore on the process of developing the Guidelines and some of the key Guidelines-related tasks recommended for Phase II (see Section 3.3), rather than on re-stating what is in the Guidelines. The one exception is the basic description of the project goal, a critical topic that dominated much of the workshop discussion. Because understanding the goal is fundamental to understanding not only the Guidelines but also much of what follows in this report, we have duplicated relevant sections of the Guidelines in sub-section 3.1, below.

3.1 Goal Definition *(quoted from the Guidelines)*

<u>From Section 1 of the Guidelines</u>

> As discussed in the following section on goal and scope definition, the U.S. LCI Database Project differs from typical life-cycle assessments of individual products, processes, or systems. Those differences affect this document in certain fundamental ways that are made clear in various sections of the Guidelines. We especially have to anticipate a much broader range of potential uses and users of the LCI data, with attendant variety in the manner in which, and degree to which, the LCI data will be used for full LCA purposes.

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[3] ISO 14040:1997(E) Environmental management — Life-cycle assessment — Principles and framework

ISO 14041:1998(E) Environmental management — Life-cycle assessment — Goal and scope definition and inventory analysis

This document is intended for the use of LCA practitioners or others who will be directly involved in development of the LCI data modules, and for interested observers/reviewers of the project. As a result, we have assumed a basic level of understanding about LCA principles and practices, including the ISO 14000 series of standards and technical reports, and have not attempted to explain or justify all of the procedures or Guidelines.

Section 2.1 of the Guidelines

The basic goal of Phase II of the database project is to establish and maintain LCI modules that can be readily accessed, combined, and augmented to develop more complex LCIs or full LCAs.

The goal is not to carry out full product LCIs in this project, but rather to make the creation of such LCIs easier, while reducing the level of data inconsistency and incompatibility that currently plagues the LCA field in general. Accordingly, database modules will provide data on many of the processes needed by others for conducting LCIs, but will not contain data characterizing the full life cycles of specific products. For example, LCI data on electricity generation, transportation fuel use and emissions, and energy production is required for virtually all LCIs and will be provided as a series of modules. Other modules could include mining and quarrying activities, commodity metals production, the production of basic building block petrochemicals, etc. Data documentation released by the project must make the above goal clear.

It is also important to carefully distinguish the concept of publicly available data from the idea of data for use by the general public. While the data modules developed through this project will be made publicly available, they will not be intended for use by the general public in the way that full product LCIs might be used. The modules will typically be used in combination with each other, and with other data to be developed or provided by data users.

It is expected that users of the database are likely to include the following groups:

- Manufacturers, researchers, policy analysts, and others undertaking LCAs of specific products or processes;
- Developers and users of tools for LCA practitioners;
- Developers of tools for non-practitioners which typically do not allow the user to modify embedded databases; and
- Organizations or individuals engaged in product assessment and labeling at various levels of system complexity, from relatively simple consumer products to complex systems like buildings and automobiles.

There are two common threads running through this list:

1. An assumed level of knowledge and sophistication on the part of the anticipated users, and

2. The fact that the database will provide a resource base for LCAs, rather than presenting completed cradle-to-grave LCA comparisons of individual product life cycles.

It is important to recognize that point 2, above, dictates adoption of the highest feasible data development standards. Since we do not know in advance precisely how or why individual database modules will be used, these Guidelines assume the most stringent requirements in terms of data categories, transparency, review, and other factors that are normally determined by the starting goal and scope statement of a study as described in ISO 14041. In general, that means assuming the data will be used in full LCAs for the purpose of making public comparative assertions.

A critical proviso with regard to the use of the database modules is that they will be developed principally for use in attributional LCAs, which seek to establish the burdens associated with the production and use of a product, or with a specific service or process, at a point in time (typically in the recent past). The modules will not be developed at the outset to serve the needs of those undertaking consequential LCAs, which seek to identify the environmental consequences of a proposed change in a system under study. Consequential LCAs can impose different requirements from a LCI perspective (e.g., marginal electricity generation may be more important for a consequential LCA than average generation), and it is not clear at this point that the data modules can be developed to serve both needs equally well. We have therefore opted to focus first on the needs of attributional studies, leaving the data requirements of consequential studies for future assessment as the database evolves.

3.2 Critical Review

Participants at the advisory group workshop agreed that it would be essential to have a thorough review of the draft research Guidelines, not only by the full advisory group but also by people with strong LCA experience and credentials who had not been involved with the project as a member of either the consulting team or the advisory group. A final review draft was therefore developed and submitted to Dr. Patrick Hofstetter, who had agreed to chair a review committee.

As well as being a research fellow at the U.S. EPA offices in Cincinnati, Ohio, Dr. Hofstetter is a Visiting Scientist at Harvard School of Public Health. He was joined on the committee by Keith Weitz at Research Triangle Institute and by two members of the advisory group, Gregory Keoleian at the University of Michigan and John Sullivan at Ford Motor Company. All shared their expertise and gave of their time without compensation.

The final review draft of the Guidelines was also made available to all members of the advisory group with an invitation to submit any comments to Dr. Hofstetter. He in turn undertook to take notice of any such comments and to reproduce them in an appendix to the review report, but without necessarily considering them explicitly in the report.

The *Review Panel Report of the U.S. LCI Database Project Development Guidelines* was provided to the consulting team on December 12, 2001 with work since then devoted to producing the Phase I final version of the Guidelines, taking into account the many comments and suggestions. That process included a lengthy teleconference between members of the consulting team and Dr. Hofstetter. The review report and appendix will be posted to the project Web site along with the final review draft of the Guidelines—the latter being necessary to properly understand many of the comments. Any interested party can then compare the review draft with the Phase I final version of the Guidelines to see how comments were taken into account and the considerable number of changes that resulted from the review process.

3.3 Guidelines-related Recommendations for Phase II

A number of issues surfaced during the July 24, 2001 Washington workshop and dominated much of the discussion throughout the entire Guidelines development process, including the review. Examples are the appropriate methods for co-product allocation, and allocation for materials that are reused or recycled. In part, issues such as these are controversial because different industries can be affected differently by alternative approaches, in part because LCA experts themselves may strongly disagree on the choice of methodologies, and in part because there can be different approaches to LCA (e.g., attributional versus consequential) which may dictate different methods to a task like co-product allocation.

We have generally tried to maintain close adherence to the ISO 14041 standard for LCI work, but even that guide fails us at times because aspects of the standard may be open to different interpretations, and because the U.S. database project will not be dealing with complete LCAs, or even complete LCIs. As noted in the quotes from the Guidelines in Section 3.1, above, the project will be focusing on unit-process modules that will not encompass the full life cycle of materials or products. In fact, they may seldom deal with a final product. As a result, the ISO rules for recycling and reuse, for example, are not applicable in a straightforward manner.

One conclusion is that the Guidelines cannot be cast in stone as an all-encompassing and rigid or static guide. It will have to evolve and change as experience is gained during Phase II. There are some who disagree with this conclusion, arguing that it will leave too much in the hands of the analysts and potentially frustrate the overall project objectives. However, those making that case represent a very small minority of the advisory group, and we see no reasonable alternative. Moreover, we think it very important that the Phase II process have sufficient flexibility to make maximum use of existing databases as starting points at least for data modules. All of this argues for a Phase II approach that will facilitate orderly application and further development of the Guidelines.

> ***Recommendation:*** *that the first round of data collection work in Phase II be immediately preceded by a one-day workshop attended by selected analysts to review the Guidelines and discuss issues related to its applicability to the first round of studies. There should then be a follow-up exchange, although not necessarily a full workshop, to ensure that lessons learned during the first round of studies are properly incorporated in the Guidelines.*

It is equally important that there be a structured review process for data modules prior to their release. Specification of a review process is required under ISO as part of the goal and scope definition process when a study is going to result in publicly disclosed comparative assertions. However, at this stage we can only recommend the establishment of a suitable process by NREL.

> ***Recommendation:*** *that NREL structure and make public an appropriate review process for data modules to ensure adherence to the Guidelines; and, further, that a scientific panel be put in place to provide advice and guidance and, if necessary, make decisions with regard to any contentious or questionable aspects of the Guidelines in specific applications.*

The above recommendation focuses on "adherence to the Guidelines" because we believe that the best review of the data itself will be by those most familiar with it — typically the organizations that provide basic data and those that have done similar studies. The act of making the data modules public is therefore the most important element of a review process.

> ***Recommendation:*** *that there be stated mechanisms for others to comment on, or challenge, specific data; for reviewing and deciding the merits of any challenge; and for changing datasets, whether as a result of a challenge or because better data has been developed.*

As noted in the Section 3.1 quote from the Guidelines, the database will be developed to support attributional LCAs, which are presently the most commonly performed type of LCA. However, interest is growing throughout the LCA community in the consequential approach to LCA, and it may be possible to support consequential applications of the data by simply recording key types of "meta-data" (data about the data) during data gathering and documentation. This would greatly increase the utility and value of the database at minimal incremental cost. Perhaps more important is the potential to avoid major costs later, in the event that interest in consequential LCA continues to grow.

> ***Recommendation:*** *that the potential for collecting meta-data to support consequential LCAs using the U.S. LCI database modules be investigated early in Phase II and, if feasible and practical, that the procedures and data collection requirements be specified in operational detail including any modifications to the database characteristics that would either be required or would facilitate consequential LCA modeling.*

The remaining Guidelines-related recommendations deal with more specific aspects of the Guidelines where more detailed guidelines, tests, or background data are warranted. The relevant Guidelines section is shown in each case.

> ***Recommendation:*** *that a tool or guidelines be developed to help analysts screen for missing inputs to a product class and identify the relevance or potential environmental significance of small inputs to a unit process and to test for the potential influence of missing flows (Sections 3.2 and 7).*

> ***Recommendation:*** *that a Guidelines annex be developed detailing standard substance nomenclature and reporting guidelines for selection and reporting of elementary flows (Section 6).*

> ***Recommendation:*** *that an annex be developed to guide the use of economic allocation methods where appropriate, including recommendations regarding sources for pricing data, methods to be followed where there are market distortions, averaging to smooth the effects of the business cycle and price volatility, the selection of a base year, etc. (Section 14).*

4 Recommended Work Program for Phase II

This section details the recommended Work Program for Phase II, including the unit process priorities for study, a discussion of key available databases and their applicability, and the suggested management approach. To set the stage, it is useful to comment briefly on the underlying philosophy that we believe should guide the Phase II effort.

First and foremost is the fact that Phase II will only start a process that must be ongoing. Here we focus on a recommended two-year program with the objective of developing and making available critical LCI data that will be valuable in its own right, but more importantly will demonstrate the value of the database project as a whole and foster its continued evolution. That evolution should encompass steady expansion of the database to incorporate more unit processes as well as continual review, modification and improvement of unit-process data already in place.

For a project of this nature, there will always be practical limits in terms of available funding and time. As a result, it will be important to take a pragmatic approach rather than seeking the ultimate in coverage and detail for each unit process. To the extent practical, existing databases should be accessed and validated, thus reducing the need for collecting original data. Some unit processes may have to be combined to avoid disclosure of confidential data, or because data is simply not available except in aggregated form. As discussed in more detail in Section 5.3, there may be cradle-to-gate and gate-to-gate modules for different unit processes that contribute to a given process tree. In some instances data sets may also be rolled up to provide cradle-to-gate LCIs for a larger system.

4.1 Initial Assessment of Unit-Process Priorities

With the input of the process-definition working group, we established the following broad categories to set the first order of priorities.

1. Fuels, Energy, and Transportation
2. Products and Materials
    a. Building and Construction
    b. Automotive and Durable Goods
    c. Commodity Chemicals and Materials
    d. Packaging
3. Transformation Processes
4. End-of-Life (Recycling, Landfill, etc.)

Since each of these priority groupings covers a large number of separate unit processes, only the highest priorities can initially be considered for Phase II, given the likely funding and time limits as well as the management implications of undertaking too many LCI studies concurrently. As discussed below, we consider the entire fuels, energy and transportation category a priority area. Within the sub-groups of the products and materials category, we have set high, medium, and low priorities, as detailed later. In the case of the transformation and end-of-life categories, we have identified a smaller number of higher priority modules. However, even this initial priority setting results in a far larger number of data modules than might be reasonably funded and managed in a two-year project. We have therefore refined the lists on the basis of a data availability survey as discussed in Section 4.2.

4.1.1 Fuels, Energy, and Transportation, Excluding Electricity

Virtually every unit process, and therefore every LCA, involves the use of some form of energy, whether for transportation or stationary purposes. The fuels, energy, and transportation database must therefore be the top priority for Phase II. In fact, we consider energy and transportation to be the single most important common database requirement. As other database modules are developed, they can then be linked to the common data sets for the production and consumption of fuels used for process and transportation energy. Otherwise, differences between products are clouded by differences in the underlying energy data. This is currently a major problem in comparing results from different LCI sources. For example, the energy and emissions profile for the use of 100 kWh, or kilowatt-hour, of electricity can vary widely depending on the fuel grid used, the data for the production and consumption of each fuel, and the generating efficiency and transmission and distribution losses modeled.

The energy and transportation data sets must include not only the *combustion* energy and emissions for each type of fuel used for process or transportation energy, but also the *pre-combustion* energy and emissions: that is, the energy and emissions to extract, process, and deliver each type of fuel or energy.

The following data categories must be included in the fuels and energy database.

Process energy and emissions and transportation requirements per 1,000 fuel units for extraction and processing of:

- Coal
- Natural gas
- Residual fuel oil
- Distillate fuel oil
- Gasoline
- Liquefied petroleum gas (LPG)
- Fuel-grade uranium

Transportation fuel requirements (in fuel units and energy units/ton-mile for various transportation modes)

Energy factors for various fuels (in energy units/1,000 fuel units)

Total pre-combustion fuel use and fuel-related emissions per 1,000 fuel units for production of:

- Coal
- Natural gas
- Residual oil
- Distillate oil

- Gasoline
- Liquefied petroleum gas (LPG)
- Fuel-grade uranium

The modules listed above will provide a series of data sets that can be selectively used without fear of double counting. However, we believe it advisable to also provide a rolled up data set for total primary energy and emissions, including combustion and pre-combustion effects. Database users will then be able to go directly to the aggregated module for the wide range of fuel combustion scenarios outlined below. It will be critical to distinguish this rolled up data set from the modules used in its construction, and to make the distinction and uses of the different datasets clear in the user's guide (see Section 5.3).

Primary energy use and environmental emissions (pre-combustion and combustion) per 1,000 fuel units for:

- Combustion of Coal in Utility Boilers
- Combustion of Coal in Industrial Boilers
- Combustion of Residual Oil in Utility Boilers
- Combustion of Residual Oil in Industrial Boilers
- Combustion of Distillate Oil in Utility Boilers
- Combustion of Distillate Oil in Industrial Boilers
- Combustion of Natural Gas in Utility Boilers
- Combustion of Natural Gas in Industrial Boilers
- Combustion of Natural Gas in Industrial Equipment
- Diesel-Powered Industrial Equipment
- Gasoline-Powered Industrial Equipment
- Combustion of Liquefied Petroleum Gas in Industrial Boilers
- Combustion of Fuel-Grade Uranium
- Combustion of Wood in Industrial Boilers
- Tractor-Trailer Gasoline-Powered Trucks
- Tractor-Trailer Diesel-Powered Trucks
- Single Unit Gasoline-Powered Trucks
- Single Unit Diesel-Powered Trucks
- Diesel-Powered Locomotives
- Barges
- Ocean Freighters
- Air Cargo

4.1.2 Electricity Generation

The electricity grid is highly interconnected, both physically and economically, so that voltage drops propagate over large geographic regions and contracts for power supply range up to international and nearly continental scopes. In an attributional LCA, models are built following accounting conventions related to physical sources and destinations of input flows at some point in time, and average electricity generation is characterized at some geographic level, the choice of which is quite flexible.

Fortunately, electricity data are available in the United States at various levels of detail, from national and regional grids to state- and even plant-specific data. For example, the U.S. EPA has assembled data on four air emissions (NO_x, SO_2, CO_2, Hg) for all fossil fuel-based generating plants on an individual plant basis in a tool called e-GRID (***E***missions and ***G***eneration ***R***esource ***I***ntegrated ***D***atabase). The availability of E-GRID has opened up some new possibilities. Since e-GRID gives plant-by-plant data for selected air emissions, this source makes possible the following levels of detail for fossil fuel- based generation (coal, gas, oil): plant level; state; Power Control Areas (PCAs) (133 PCAs in the U.S.); North American Electric Reliability Council (NERC) regions (10 plus Alaska and Hawaii); and national. This database also makes it possible to compile data by fuel type and technology, a capability that could be very useful. However, solid wastes, water effluents and all other air emissions are not available in E-GRID and would have to be provided from other sources.

The U.S. EPA is also creating an "emissions profile tool" for the purpose of enabling individual electricity consumers to calculate the "environmental footprint" of their energy consumption. It will have two tracks, corresponding to attributional and consequential modeling. The attributional system will provide system average emissions for 26 different regions of the United States, where each region is composed of one or more PCAs. The EPA project manager indicated that this somewhat arbitrary selection of regions represents a manageable midrange between the 133 PCAs and the 10 NERC regions in the contiguous states, plus Alaska and Hawaii.

In deciding on an appropriate regional breakdown for the U.S database project, we have to take account of the likely regional breakdown of other manufacturing data as well as the characteristics of the electricity regions. Some of the NERC regions (such as the Electric Reliability Council of Texas, Inc., in Texas) are economically self-contained, for instance, while others exchange significant shares of their power generation capacity on an annual basis (e.g., those east of the Mississippi).

On balance, the NERC regions provide a manageable set of geographic divisions for the development of average LCI models for use in attributional LCI modeling, and we recommend the use of those regions for Phase II database development. When the location of a unit process using electricity is known to be within a NERC region, it should be modeled as using electricity from that region. In cases where unit-process data cannot be related to specific NERC regions, the national grid should be used. It is also customary to use specific industry data in special cases where electricity is a major issue, such as in electro-process industries. Otherwise, fuel use for self-generated electricity is generally included in the process energy reported for a unit process.

A complete profile for the electricity database would include the fuel sources listed below.

Primary energy consumption and emissions for the generation and delivery of one composite Kilowatt-Hour (in fuel units and energy units)

Conventional Sources

- Coal
- Natural Gas
- Fuel Oil (Residual and Distillate)
- Uranium (Nuclear)
- Hydro

Emerging Sources

- Biomass – Natural Sources (e.g., grass, trees, etc.)
- Biomass – Municipal Solid Waste
- Wind
- Photovoltaics
- Geothermal
- Fuel Cells

Transmission and distribution line losses must also be included.

The cost of developing this database can be reduced by limiting detail (e.g., electricity plant level data) or excluding emerging technologies that contribute little to regional and national grids.

4.1.3 Products and Materials

Four detailed lists of products and materials — those used in the manufacture of automobiles and other durables, those used in building and construction, basic commodity chemicals and materials, and packaging materials — were developed by examining a variety of existing databases. Sub-groupings in each list were then prioritized into three categories: highest priority, medium priority, and lowest priority, based upon feedback from the products and materials working group. These detailed, priority-ranked lists are presented in Appendix B.

It is probable that the cost of collecting data for even the highest priority items in each sub-group would exceed the budget limitations for Phase II, particularly since other process priorities are still to be considered in Sections 4.1.4 and 4.1.5. Therefore, while the full lists are presented in the appendix for the sake of completeness, the priorities are further refined in Section 4.2 in the context of looking at available databases.

4.1.4 Transformation Processes

Of the hundreds of transformation processes, the following were mentioned specifically by automotive industry representatives as high priority concerns.

Transformation of Metals

- Stamping, Press Forming, and Drawing
- Casting
- Extruding
- Welding

- Cladding (e.g., galvanized sheet metal production)
- Fluid-cooled Machining
-

Transformation of Plastics
- Injection Molding
- Blow Molding
- Compression Molding

Painting Processes (Automotive)

All of these transformations have relevance to many other industries and would therefore represent a good starting point for the database. A detailed, but still not necessarily exhaustive, list of transformation processes is provided in Appendix C.

4.1.5 End-of-Life

The primary focus of the U.S. LCI database is cradle-to-gate unit processes for products and materials. Users of the unit-process modules can then add specific manufacturing and use-phase data to construct more complete LCIs, based on their knowledge of specific products and their applications. Presumably users will also add specific end-of-life data for products in order to assess the full life cycle. The LCI database can assist by including some common end-of-life data modules that users can access or modify to represent recycling or other final disposition of product systems. Highest priority end-of-life data modules include the following.

Recycling
- Plastics
- Metals
- Paper
- Wood products
- Glass

Combustion
- With energy recovery (plastics, paper and wood products)
- Without energy recovery

Composting (paper and wood products)

Landfill

4.2 Data Availability

An important Phase I task was to identify relevant databases and approach data developers and industry associations to assess data availability, identify gaps, and solicit cooperation for subsequent phases of the project. We intended to then further assess available databases to determine the degree of consistency with the Guidelines and the consequent requirement for new database development work. While we were able to carry out the first of these tasks, we were unfortunately not in a position to undertake the second in as thorough a manner as intended. It was not possible to gain full access to all of the identified databases and the underlying methodologies, given the time available and the level of cooperation of some database owners.

However, the results of the initial assessment have provided a basis for further refining the list of high priority products and materials listed in Appendix B; this step in turn allows us to meet the primary work program planning objective. The remainder of this sub-section presents the results of the data availability assessment and the consequent refinement of priorities for Phase II.

The overview of the databases considered for use in the project, presented below, includes the database source, its approximate age, and the material or product coverage. There is no intent to imply that these are the only North American databases that might be considered for eventual inclusion in, or as building blocks for, the U.S. database project, but these are the databases that appear to offer the best immediate potential.

In most cases, we were able to discuss the databases with representatives of the source organizations and gain a reasonable understanding of the potential for their cooperation in Phase II. In those discussions, we were especially concerned about transparency and the ability to disaggregate the databases so that the common energy and transportation modules identified in Sections 4.1.1 and 4.1.2 can be applied. In other words, a Phase II analyst should be able to identify the amounts of transportation, end-use electricity, and fuel use by type for a given product or material module, and to then develop all of the related primary energy use and emission profiles using the common databases. If that is not possible, it does not necessarily rule out a database for use in the project, but it does mean that it will have to be carefully assessed, especially in terms of the critical project transparency requirements.

Other issues, such as co-product allocation methods and functional unit definition, are more difficult to assess without the opportunity to fully explore the relevant methodologies. At this stage, it seems best to adopt a pragmatic stance and to at least tentatively accept databases for detailed consideration if they meet the following criteria:

- The source organizations appear likely to cooperate;
- The basic disaggregation criterion can be met as discussed above; and
- The project is likely to have access to sufficient documentation to identify and assess the implications of any inconsistencies with the project Guidelines.

The following list is organized by source organization in priority order with the most promising databases first.

Consortium for Research on Renewable Industrial Materials (CORRIM)

Coverage:	Unit-process data for forest management, logging and structural wood products manufacturing (softwood lumber, plywood, OSB, and eventually selected engineered structural products).
Vintage:	1999

Region: Pacific Northwest and Southeast producing areas

Transparency: Good

Cooperative: Yes

Comments: This database would provide good coverage of basic wood building materials for two key regions, as well as a firm foundation for extension to other producing regions. It can be disaggregated as needed and may also be useful as a basis for adapting other Athena Institute wood products data for U.S. regions (see Athena Institute, below).

Portland Cement Association

Coverage: A limited range of concrete products, with a potential for providing separate cement manufacturing unit-process data (under discussion)

Vintage: 1998 (with update underway)

Region: Data currently available as national averages, but a potential for developing weighted average data by census region

Transparency: Acceptable to good, depending on whether cement data is separately identified

Cooperative: Yes

Comments: This database deals with an essential construction material. It can be disaggregated as needed and may also be useful as a basis for adapting other Athena Institute concrete products data for U.S. regions (see Athena Institute, below).

The Aluminum Association, Inc.

Coverage: North American primary and secondary ingot production, treated as single unit processes

Vintage: 1995

Region: North American averages

Transparency: Good

Cooperative: Yes

Comments: Association representative has indicated that the database can be disaggregated as needed for applying common energy and transportation databases.

The ATHENA™ Sustainable Materials Institute (Canada)

Coverage: All of the individual construction and building products listed in Appendix B

Vintage: mid-1990s to 2001

Region: Regional averages for six Canadian regions

Transparency: Good

Cooperative: Yes

Comments: The databases already draw on common energy and transportation modules that can be readily replaced with U.S. modules. Most of the individual product data sets were developed with the cooperation of associations or companies that operate in both countries, and are for processes that use essentially common technology. Most can therefore be readily adapted for U.S. regions, especially in cases like wood, concrete, and perhaps steel, where U.S. databases could be used to develop adjustment factors. The data sets for steel were updated in 2001 with specific adjustments to at least partially account for U.S. conditions.

Nickel Development Institute

Coverage: Class I nickel metal, and Class II ferronickel and nickel oxide

Vintage: Late 1990s

Region: Western hemisphere averages

Transparency: Uncertain

Cooperative: Yes

Research Triangle Institute

Coverage: Various "end-of-life" modules

Vintage: Late 1990s

Region: Uncertain

Transparency: Uncertain

Cooperative: Yes

Comments: We have had preliminary conversations and understand that data modules have been developed for municipal solid waste collection, transfer station operations, a materials recovery facility, waste combustion, mixed and yard waste composting, and landfill.

American Plastics Council (APC)

Coverage: Uncertain

Vintage: Uncertain

Region: Uncertain

Transparency: Uncertain

Cooperative: Yes, on a limited basis as explained below

Comments: An early 1990s extensive petrochemical database created by APC is now out-of-date, but the association has indicated a willingness to assist in adapting the Association of Plastics Manufacturers in Europe (APME) LCI data to U.S. conditions by backing out various European stationary and mobile equipment unit process data so that common U.S. unit-process data can be substituted. The acceptability of this approach is highly dependent upon the ability to determine the degree of data transparency of the APME LCI profiles.

The American Iron and Steel Institute / The International Iron and Steel Institute

Coverage:	Hot rolled steel produced in a basic oxygen furnace and bar steel produced in an electric arc furnace Vintage: Late 1990s
Region:	North American averages
Transparency:	Uncertain
Cooperative:	Under consideration by the association
Comments:	This database is known to exist but has been only selectively released for review or use by others. We therefore have limited knowledge with regard to coverage, transparency, the potential for disaggregation or other concerns. If it is made available it could provide an important contribution. At the very least it could be used to verify or adjust Athena Institute data for steel products.

4.3 Recommended Unit-Process Priorities

Based on the preceding, we believe the following data modules should be treated as the priority areas for Phase II. The modules are listed below in the basic categories established in Section 4.1. While this results in some overlaps (in the case of steel for construction and automotive/durables uses, for example) it seems preferable to maintain the categorization so that different groups can more readily assess how their interests might be met by the proposed priorities.

Fuels, Energy, and Transportation

All fuels and uses, including electricity generation, as described in Sections 4.1.1 and 4.1.2

Building & Construction

Wood structural
Steel structural
Glazing
Insulation and vapor barrier
Concrete structural
Cladding
Gypsum wallboard (various types and thicknesses)
Window frame materials
Floor coverings
Paint finishes
Residential roofing
Commercial/industrial roofing

Automotive/Durables

Steel (cold rolled sheet, hot dip galvanized, high strength)
Aluminum (primary and secondary ingots, primary sheet)
Non-ferrous metals (lead, nickel, copper)

Plastic resins (nylon 6, 6, polypropylene, polyethylene, polyurethane, polyvinyl chloride, thermoplastic polyolefin, polyethylene terephthalate, styrene butadiene rubber, polystyrene)

Commodity Chemicals & Materials

Limestone
Lime
Salt
Sodium hydroxide
Chlorine
Sulfur
Sulfuric acid
Cotton
Corn
natural rubber

Transformation Processes

Metals (stamping, casting, welding, machining, etc.)
Plastics (blow molding, injections molding, etc.)

End-of-Life

Collection and processing
Incineration with and without energy recovery
Composting
Landfill

In the review of data availability, there were no identified sources for the relatively long list under Commodity Chemicals and Materials. However, the listed items all reflect areas dealt with by Franklin Associates in past studies, and we therefore have a high level of confidence in the availability of information and the costs of developing these critical modules, all of which are used in various processes. The same is true, although to a lesser extent, with regard to the list of plastic resins.

In the case of transformation processes, we can identify a number that would be priorities for both metal and plastics, but suggest caution until some initial work has been done. The issue is the extent to which broad transformation types (e.g., stamping or injection molding) can be sub-divided into meaningful and manageable ranges, applications and other characteristics (pressures, temperatures, sizes, etc.).

Notably missing from the above list are paint systems, other than building materials, and painting transformation for automotive and similar applications. Our concern, subject to further investigation, is that there may be problems developing representative paint formulation, getting industry to provide the appropriate data, and properly categorizing the variety of processes.

4.3.1 Estimated Cost

As indicated in Section 4.2, there are still some significant unknowns with regard to existing databases and we can therefore only provide preliminary cost estimates based on what is known about the existing databases and past experience in developing similar LCI data.

A preliminary cost estimate range is shown in Table 1 for each of the data categories, in total, with specific assumptions noted in the final column.

Table 1: Estimated Cost of the U.S. LCI Database

	Estimated Cost ($'000)		
Category	**Low**	**High**	**Assumptions**
Fuels, Power & Transportation	200	300	Includes electricity generation
Building & construction	180	370	Use Athena Institute data as basic starting point for all products
Automotive/Durables	300	650	Use Franklin Associates data as starting point for plastic resins
Commodity chemicals & materials	100	150	Based on updating Franklin Associates data
Transformation processes	275	330	From $25K to $30K per process; assumes 8 metal, 3 plastic processes
End-of-life	15	20	Assume use of existing Research Triangle Institute data with modest adjustment to fit Guidelines
Totals	**1,070**	**1,820**	

We believe the estimated $1.1 to $1.8 million shown in the table is realistic for a two-year program of this nature, although there could be variations in the actual amounts for whole categories as well as for the category component estimates used to generate these numbers.

The budget estimates shown include research, data collection, data quality documentation, and modeling. Additional funding may be required to make the data available as part of a software program (see Section 5 on Data Dissemination). Additional funding will be required for other recommended Phase II tasks, such as the development of a user's guide, guidelines for conducting economic allocation, development of a tool for screening small inputs for environmental significance, etc. However, all of these activities together are unlikely to exceed 10% of the high estimate.

It is also important to recognize that the work program, and therefore the commitments to cost, can be undertaken incrementally. While we would strongly recommend undertaking all of the fuels, power and transportation work as the highest priority, modules could be selectively dropped from other categories if budgets dictate. They can also be added later if more funding is available. In the case of the building and construction category, for example, the module cost estimates range from $5K to $30K per element on the low-end up to $10 to $50K on the high-end. In the case of the automotive/durables category, the plastic resins alone account for about two-thirds of the total on both ends of the range.

4.4 Recommended Approach

Extensive LCI database projects of the kind recommended here have too often failed in the past because of the basic approach, not technically, but in the sense of who does what. For example, broad ranging projects have not usually been successful when they have depended on industry groups to provide the data at their own expense. Companies or their associations may join a project with good intentions, only to find that corporate priorities or financial fortunes change, or that the process is not exactly as they expected or would have wished. As a result, a well-intentioned effort may proceed in a halting fashion at best, or be simply abandoned after considerable time and expense.

Another problem with this type of approach is the inability to properly monitor and direct research activity as it progresses. It is critical that there be consistency in the application of the Guidelines and in the inevitable series of decisions that will have to be made as research proceeds on various fronts.

At the same time, this is not the kind of project that should be contracted to one organization. Few, if any, would have a sufficiently broad range of skills and a large enough staff to develop all of the data modules identified in Section 4.2 within a reasonable time frame. Moreover, assigning the entire project, including all of the data collection and analysis functions, to one entity is a high-risk approach from the perspective of those providing the funding.

In light of the preceding, and assuming that NREL would not intend to directly undertake tasks except in an oversight capacity, we recommend the following fundamental approach:

1. All data collection and analysis to be undertaken on a contract basis by various organizations or individuals experienced in and knowledgeable about LCA and the relevant industry sectors;
2. A central research management team as prime contractor to NREL, with a responsibility for developing terms of reference, accepting proposals from prospective contractors, letting and monitoring contracts, managing private sector contributions to the project, and generally serving as the client from the perspective of third parties;
3. Funding from a core budget, with funding from private as well as public sources, but with any private sector funding independent of ownership rights to specific data modules (e.g., a company would not specifically fund and <u>own</u> a study, although a company might provide funding to the management team with a stipulation that a certain module be developed as part of the project); and

4. Encouragement of direct involvement of industry associations and their member companies as data sources and for review of final data reports, either through the prime contractor or through individual project contractors.

Point 2, above, is essential to ensuring consistency, a critical concern expressed in the -review panel report of the Guidelines. As suggested in that report, consistency can also be facilitated by frequent communication and by providing all project analysts with a standardized electronic data format (see Section 5, below) and a spreadsheet with a pre-set list of resource and elementary flow names, as well as a pre-defined, and routinely updated, list of process names. The spreadsheet might also have provision for calculations required to meet various criteria in the Guidelines (see Guidelines sections 6 and 7, for example).

5 Data Dissemination

5.1 Web Site

The Web provides an ideal means for disseminating the U.S. LCI databases, and information about the data, to potential users worldwide at very modest cost, and a site has already been established by NREL (www.nrel.gov/lci) for the U.S. LCI database project, as noted previously. This site currently contains general information about the project, as well as access to information on the consultant team, sponsors, collaborators, working groups, working papers, various reports, and the Guidelines. The same Web site will be the source for dissemination of the LCI data sets as they are developed.

The database users and uses specified in Section 3.1 of this report dictate the following three main functions of the Web site:

1. Communication about the data, including its scope, intended uses, and limitations, as well as full documentation about the data elements and the life-cycle inventory models;
2. Provision of unit-process data for use by experienced LCA practitioners in developing their own models; and
3. Provision of cradle-to-gate LCI results to any unit-process point in the database, especially for intermediate and finished products, for use by developers of LCA-based decision support tools.

Communication about the data includes two main aspects: data documentation and separate information resources.

Data documentation (that is, documentation at the level of each LCI system, unit process, and process flow) will be accomplished using the ISO 14048 data documentation format discussed in Section 5.2, below.

Information resources to be freely downloadable from the Web site should include the following (at a minimum):

- A user's guide to accessing the data via the Web site, including the scope of the database at that point in time;
- A guide to use of the data in LCA or other decision support tools; and
- A description of the U.S. LCI database project, including the consultants, critical review processes, and other background information.

For provision of the data, the Web site will need to serve as a database browser, enabling users to survey database contents, view metadata, and select either individual unit processes or rolled up cradle-to-gate systems for download. An example of the latter was given for primary energy use and emissions in Section 4.1.1, above.

Users who download such system data will receive cradle-to-gate inventory results based upon the allocation methods and other parameters arising from application of the database Guidelines. While these allocation methods will be clearly documented, and users will therefore know what was done, users of rolled-up system data will not be able to change allocations or other procedures. They will have to take the rolled-up data as presented. However, users who download data at the unit-process level will have sufficient information to change allocations and generally construct rolled-up system LCIs as they see fit.

In the longer term, the Web site could conceivably include software that allows this kind of work to be done on-line, which would make the Web site and database an even more powerful tool. For that reason we urge monitoring of other database publishing efforts elsewhere in the world where researchers have completed, or are in the process of developing, Web interface systems for LCI data publishing (e.g., the Swiss and Italians). In fact, it may be possible to adopt or adapt software commissioned by others into a system meeting the requirements of the U.S. database project.

5.2 Data Formats

Data documentation (that is, documentation at the level of each unit process, process flow and LCI system) will be accomplished using the ISO 14048 data documentation format as specified in the Guidelines. This standard for data documentation was recently completed after a lengthy process that merged the best features of the competing data formatting systems available at the time. Use of the 14048 data documentation format helps ensure that the data documentation information will be imported and preserved alongside the data elements in all the major LCI software tools.

The major LCI software developers are now incorporating ISO 14048 read/write capability into the next versions of their tools. Therefore, by publishing unit-process details and documenting the data according to the ISO 14048 documentation format, this project will go a long way towards making the data efficiently usable in a variety of software tools and by a wide community of users. As more and more database projects publish their data using the ISO 14048 documentation format, this will help ensure that not only the data, but the metadata as well, will translate among tools and users.

5.3 User's Guide

The final critical Phase II task that deserves separate mention is development of the data user's guide that is frequently referenced in the research Guidelines.

The overriding concern with a user's guide must be to ensure that users fully understand the data and its limitations. The guide should illustrate the proper use of cradle-to-gate and gate-to-gate data modules in constructing full cradle-to-grave LCIs. That means including sample calculations, process trees, metadata and any other examples that will help ensure that users are aware of all contributing unit processes when they build their own process trees, while at the same time avoiding inadvertent double counting.

It will be especially important that the user's guide provide guidance and examples for modeling such difficult LCA steps as co-product allocation and material recycling and reuse. It can also provide guidance on modeling the use and end-of-life phases of the life cycle.

Appendix A
List of Advisory Group Members

Name	Organization
Allen, Derry	U.S. EPA
Bare, Jane	U.S. EPA
Bauer, Diana	AAAS Fellow at EPA
Bhatia, Pankaj	World Resources Institute
Bourassa, André	ICME/ICMM
Canton, Eric	Eco-Innovation Fund
Cobas-Flores, Elisa	Graduate School of Business Administration EGADE ITESM
Cooper, Joyce	University of Washington
Crawley, Drury	U.S. Dept. of Energy
Curran, Mary Ann	U.S. EPA, Sustainable Technology Division
Dooley, Richard	NAHB Research Center
Dubreuil, Alain	Natural Resources Canada
Eubank, Huston	Rocky Mountain Institute
Fitch, Peder	University of Washington, Ford Motor Co.
Haaf, William	Dupont
Howard, Nigel	U.S. Green Building Council
Kainz, Robert	Daimler Chrysler
Keoleian, Greg	University of Michigan
Levy, Mike	American Plastics Council
Lindsey, Gail	Design Harmony Inc.
Lippiatt, Bobbie	NIST, Building and Fire Research Laboratory
Malin, Nadav	Environmental Building News
Mann, Margaret	NREL
Martchek, Kenneth	ALCOA
McKean, Bruce	Nickel Development Institute
McLennan, Jason	BNIM Architects
Overcash, Michael	North Carolina State University
Park, JiHyung	Korea Institute of Science and Technology
Paster, Mark	DOE
Peterson, Pete	U.S. Steel
Rodenburg, Eric	U.S. Geologic Survey
Schultz, Jim	American Iron and Steel Institute
Shaw, Ian	Dofasco
Sparks, John	U.S. EPA
Spengler, John	Harvard University, School of Public Health
Stephens, Robert	General Motors
Sullivan, John	Ford Motor Company

Todd, Joel Ann	Independent consultant
Van Geem, Martha	Construction Technology Laboratory Inc.
Vehar, Chris	ASME International
Webber, Kevin	Toyota
Weidt, John	The Weidt Group
Wilson, Jim	CORRIM II, Oregon State University
Winn, Keith	Herman Miller, Inc.

Appendix B
Prioritized Products and Materials List

Materials used in the manufacture of automobiles and other durables

- STEEL
  - Highest Priority
    - Cold rolled
    - Hot dip galvanized
    - High strength steel
    - Stainless steel
  - Medium Priority
    - Electrolytic zinc plated
    - Billet
    - Various specialty alloys
- ALUMINUM
  - Highest Priority
    - Primary ingot
    - Primary sheet
    - Secondary ingot
    - Secondary die casting
    - Extrusion
  - Medium Priority
    - Various alloys
- NON-FERROUS METALS
  - Highest Priority
    - Lead
    - Nickel
    - Copper
    - Magnesium
    - Titanium
  - Medium Priority
    - Tin
    - Silicon
  - Lowest Priority
    - Zinc
- PRECIOUS METALS
  - Highest Priority
    - Platinum
  - Medium Priority
    - Silver
    - Gold
    - Palladium
    - Rhodium
- PLASTIC RESINS
  - Highest Priority
    - Nylon 6, 6
    - PP - polypropylene
    - PE - polyethylene
    - PUR - polyurethane
    - PVC - polyvinyl chloride
    - TPO - thermoplastic polyolefin
    - PET - polyethylene terephthalate
    - SBR - styrene butadiene rubber
    - PS - polystyrene
  - Medium Priority
    - EPDM ethylene propylene diene monomer
    - Nylon 6
    - ABS - acrylonitrile butadiene styrene
    - PET textiles
    - PP textiles
  - Lowest Priority
    - EP resin - ethylene propylene
    - NBR - nitrile butadiene rubber
    - MDI
    - TDI
    - Polyol
- PAINT SYSTEMS
  - Highest Priority
    - Solvent-based
    - Powder
    - Water-based
  - Lowest Priority
    - Fillers
- MINERALS
  - Highest Priority
    - Glass
    - Glass fibers
  - Medium Priority
    - Carbon

Building and construction products

\WOOD STRUCTURAL
- Highest Priority
  - Softwood lumber, green and kiln dried
  - Softwood plywood
  - Oriented strand board
  - Glue laminated beams
  - Wood “I” joists
  - Pressure treated lumber
- Medium Priority
  - Parallel strand lumber
  - Laminated veneer lumber
  - Parallel/pitched chord light frame trusses
- Lowest Priority
  - Composite wood/steel open web joists

STEEL STRUCTURAL
- Highest Priority
  - Galvanized studs
  - Galvanized decking
  - Hot and cold rolled sheet
  - Galvanized sheet
  - Reinforcement bar
- Medium Priority
  - Welded wire mesh and ladder wire
  - Nails and fasteners
  - Trusses (bar joists)
  - Hollow structural steel
  - Heavy and light sections
- Lowest Priority
  - Composite steel/wood joist components
  - Tubing

GLAZING SYSTEMS
- Highest Priority
  - Standard double glazed
  - Tin-coated glass
  - Tin-coated glass, argon filled
- Medium Priority
  - Silver-coated glass, argon filled

INSULATION AND VAPOR BARRIER
- Highest Priority
  - Fiberglas batt
  - Cellulose
  - Polystyrene rigid expanded (EPS) and extruded (XPS)
  - Polyethylene
  - Polyisocyanurate
- Medium Priority
  - Rock wool (mineral) batt

CONCRETE STRUCTURAL
- Highest Priority
  - Ready mixed
  - Standard concrete blocks
  - Cement mortar
- Medium Priority
  - Precast hollow deck
  - Precast “double T” beams

CLADDING
- Highest Priority
  - Wood bevel siding
  - Wood tongue and groove siding
  - Wood shiplap siding
  - Sheet steel cladding
  - Common clay brick
  - Vinyl siding
- Medium Priority
  - Modular brick
  - Concrete brick
  - Cementitious stucco
- Lowest Priority
  - Face brick
  - Glazed face brick
  - Silicate (sandlime) brick

GYPSUM WALLBOARD (various thicknesses)
- Highest Priority
  - Regular paper faced
  - Type X (fire resistant)
  - Moisture resistance
- Medium Priority
  - Mobile home board
  - Gypsum fiber board
  - Drying type ready-mixed joint compound
  - Setting type dry joint compound
- Lowest Priority
  - Shaftliner board
  - Paper joint tape

WINDOW FRAME MATERIALS
- Highest Priority
  - Wood
  - PVC
  - Aluminum
  - Steel doors and frames
- Medium Priority
  - PVC clad wood

FLOOR COVERINGS
- Highest Priority
  - Hardwood
  - Ceramic tile
  - Vinyl
  - Carpeting

PAINT FINISHES
- Highest Priority
  - Latex acrylic
  - Oil alkyd
- Medium Priority
  - Oil alkyd varnish

RESIDENTIAL ROOFING
- Highest Priority
  - Organic felt-based asphalt shingles
  - Fiberglas mat-based asphalt shingles
  - #15 saturated underlayment felt
  - #30 saturated underlayment felt
- Medium Priority
  - Mineral surface roll roofing
- Lowest Priority
  - Clay roofing tiles
  - Concrete roofing tiles

COMMERCIAL/INDUSTRIAL ROOFING
- Highest Priority
  - Roofing asphalt
  - SBS modified bitumen
  - EPDM membrane
  - PVC membrane
- Medium Priority
  - TPO membrane

Commodity chemicals/materials

CHEMICAL/MINERAL
- Highest Priority
  - Limestone
  - Lime
  - Salt
  - Sodium hydroxide
  - Chlorine
  - Sulfur
  - Sulfuric acid
- Medium Priority
  - Hydrochloric acid
  - Surfactants-various
  - EVA
  - EVOH
  - Talc
  - Titanium dioxide
- Lowest Priority
  - Ammonia
  - Ethylene glycol
  - Propylene glycol
  - Vinegar
  - Mineral oil
  - Drinking/tap water

AGRICULTURAL
- Highest Priority
  - Cotton
  - Corn
  - Cornstarch
  - Natural rubber
  - Glucose
- Medium Priority
  - Phosphate fertilizer
  - Nitrate fertilizer
  - Potash fertilizer
  - Potatoes
  - Potato starch
  - Soybeans
  - Palm oil
  - Coconut oil
- Lowest Priority
  - Soy oil
  - Soy protein
  - Corn stover
  - Soy beans
  - Hog manure
  - Cow manure
  - Chicken manure
  - Ethanol from corn grain

Common packaging materials

PAPER AND PAPERBOARD
- Highest Priority
  - Bleached kraft
  - Bleached virgin
  - Bleached recycled
  - Unbleached kraft
  - Unbleached virgin
  - Unbleached recycled
  - Corrugated

COATINGS
- Medium Priority
  - Clay
  - Wax
  - PE

PLASTIC
- Highest Priority
  - Films (various resins)
  - Blow molded (various resins)
  - Injection molded (various resins)
  - Extruded (various resins)
  - Thermoformed (various resins)
  - Polystyrene Foam
- Medium Priority
  - Calendared

PALLETS
- Medium Priority
  - Wood
  - Plastic

DRUMS
- Highest Priority
  - Steel
- Medium Priority
  - Paperboard
- Lowest Priority
  - Plastic

MISCELLANEOUS
- Highest Priority
  - Cellophane
  - Printing inks
  - Adhesives
- Medium Priority
  - Aseptic packaging
  - FoilsAPPENDIX C

Appendix C
Transformation Processes for Possible Inclusion in the U.S. LCI Database

Compiled by **Joyce Smith Cooper**, Assistant Professor of Mechanical Engineering, University of Washington

1. Shape Modification

1.1 Shape Casting

- Centrifugal Casting
- Centrifugally-Aided Casting
- Ceramic mold Casting
- CLA/CLV Casting
- CO2/Silicate Casting
- Cosworth Casting
- Die Casting
- Evaporative Pattern Casting, Automated
- Evaporative Pattern Casting, Manual
- Ferro Die Casting
- Gravity Die Casting
- Green Sand Casting, Automated
- Green Sand Casting, Manual
- Investment Casting, Automated
- Investment Casting, Manual
- Low Pressure Die Casting
- Plaster mold Casting
- Replicast Casting
- Semi-Centrifugal Casting
- Shell Casting
- Squeeze Casting

1.2 Composite Forming

- Autoclave molding
- BMC molding
- Centrifugal molding
- Cold Press molding
- Continuous Laminating
- Filament Winding
- Hand Lay-Up
- Pultrusion
- RTM
- SMC molding
- Spray-Up
- Vacuum/Pressure Bag

1.3 Deformation

Ceramic Extrusion
Cold Closed Die Forging
Cold Heading And Upsetting
Cold Shape Rolling
Deep Drawing
Electromagnetic Forming
Explosive Forming
Hot Closed Die Forging
Hot Extrusion
Hot Open Die Forging
Hot Shape Rolling
Impact Extrusion
Micro-Blanking
Press Forming
Roll Forming
Shape Drawing
Spinning
Stamping
Swaging
Wire Drawing
Superplastic Forming

1.4 Molding

Calendering
Compression molding
Extrusion Blow molding
Injection molding(Thermoplastics)
Injection molding(Thermosets)
Injection Blow molding
Polymer Casting
Polymer Extrusion
Reaction Injection molding
Rotational molding
Thermoforming
Transfer molding

1.5 Powder Methods

Cold Isostatic Pressing
Die Pressing and Sintering
HIPing, Large-Scale
HIPing, Small-Scale
HIPing, Tertiary, Large-Scale
HIPing, Tertiary, Small-Scale
Hot Pressing
P/M Forging

Powder Extrusion
Powder Injection molding
Powder Rolling
Pressureless Sintering
Repressing
Slip Casting
Spark Sintering
Spray Deposition
Tape Casting

1.6 Rapid Prototyping

3D Printing
Ballistic Particle
Fused Deposition
Laminated Object
Laser Sintering
Solid Ground Curing
Stereolithography

2. Secondary Operations

2.1 Surface Treatments

Anodizing
Explosive hardening
Precipitation hardening
Solution treatment

Coating, Plating, and Painting

Chemical bath immersion	Coating and plating
Chemical vapor deposition	Coating and plating
Chemical wipes	Coating and plating
Cladding	Coating and plating
Coil coating	Coating and plating
Conversion coating	Coating and plating
Electroless plating	Coating and plating
Electroplating	Coating and plating
Impact plating	Coating and plating
Porcelain enameling	Coating and plating
Sputtering	Coating and plating
Thermal spraying	Coating and plating
Vacuum deposition	Coating and plating
Automatic spraying	Painting: Application
Dipping	Painting: Application
Hand spraying	Painting: Application
Hot spraying	Painting: Application
Powder coating	Painting: Application
Heat tunnel drying	Painting: Drying
Infared drying	Painting: Drying
Oven drying	Painting: Drying
Electrostatic spray finishing	Painting: Finishing

Machining	
Flood cooling	Cutting fluid application
Mist cooling	Cutting fluid application
High pressure cutting fluid systems	Cutting fluid application
Abrasive water-jet machining	Bulk removal
Abrasive-jet machining	Bulk removal
Standard machining	Bulk removal
Centreless microgrinding	Bulk removal
Chemical machining/ blanking	Bulk removal
Electrical-discharge grinding	Bulk removal
Electrical-discharge machining	Bulk removal
Electrochemical grinding	Bulk removal
Electrochemical machining/ polishing	Bulk removal
Electron-beam machining	Bulk removal
Flame cutting	Bulk removal
Knurling	Bulk removal
Laser machining	Bulk removal
Micro and nano machining	Bulk removal
Planing, shaping, and broaching	Bulk removal
Plasma arc cutting	Bulk removal
Water-jet machining	Bulk removal
Belt sanding or belt grinding	Polishing and burr removal
Buffing	Polishing and burr removal
Honing	Polishing and burr removal
Lapping	Polishing and burr removal
Laser peening	Polishing and burr removal
Roller burnishing or surface rolling	Polishing and burr removal
Shot peening	Polishing and burr removal
Vibratory, barrel finishing, or tumbling	Polishing and burr removal
Water-jet peening	Polishing and burr removal
Wire brushing	Polishing and burr removal
Polishing, Cleaning, and Burr Removal	
Acid pickling	Chemical methods
Alkaline cleaning	Chemical methods
High pressure hot water washers	Chemical methods
Hot caustic paint strippers	Chemical methods
Salt-bath paint stripping	Chemical methods
Solvent cleaning	Chemical methods
Solvent paint stripping	Chemical methods
Ultrasonic cleaning	Chemical methods
Vapor degreasing	Chemical methods
Abrasive-flow deburring/ machining	Mechanical methods
Blast media paint stripping	Mechanical methods
Chemical deburring	Mechanical methods

Dry ice blasting paint stripping	Mechanical methods
Electrochemical deburring	Mechanical methods
Power brushing	Mechanical methods
Power sanding	Mechanical methods
Spindle finishing	Mechanical methods
Thermal energy deburring	Mechanical methods
Ultrasonic deburring	Mechanical methods
Water-jet paint stripping	Mechanical methods
Burn-off paint stripping systems	Thermal/ energy methods
Cryogenic paint stripping	Thermal/ energy methods
Flashlamp paint stripping	Thermal/ energy methods
Laser paint stripping	Thermal/ energy methods

2.2 Joining

Adhesives

Adhesive Bonding

Mechanical Fasteners

Mechanical Fasteners

Welding

Torch brazing	Brazing
Furnace brazing	Brazing
Induction brazing	Brazing
Resistance brazing	Brazing
Dip brazing	Brazing
Infrared brazing	Brazing
Diffusion brazing	Brazing
Oxyacetylene flame welding	Fusion
Shielded metal arc welding	Fusion
Gas metal arc welding	Fusion
Electrogas welding	Fusion
Electroslag welding	Fusion
Thermit welding	Fusion
Laser beam welding	Fusion
Electron beam welding	Fusion
Torch soldering	Soldering
Furnace soldering	Soldering
Induction soldering	Soldering
Resistance soldering	Soldering
Dip soldering	Soldering
Infrared soldering	Soldering
Ultrasonic soldering	Soldering
Reflow (paste) soldering	Soldering
Wave soldering	Soldering
Cold Welding	Solid State
Friction Welding	Solid State
Inertia Friction welding	Solid State
Linear Friction welding	Solid State

Friction Stir Welding	Solid State
Resistance spot welding	Solid State
Resistance seam welding	Solid State
High frequency resistance welding	Solid State
Resistance projection welding	Solid State
Flash welding	Solid State
Stud welding	Solid State
Percussion welding	Solid State
Explosion welding	Solid State
Ultrasonic Welding	Solid State
Diffusion Bonding/ Welding	Solid State

3. Waste Recovery and Treatment

Metal scrap collection	Material collection
Used peen material collection	Material collection
Fluids collection	Material collection
Activated carbon adsorption	Fluids purification
Basket strainers	Fluids purification
Centrifugation	Fluids purification
Cyclone separators	Fluids purification
Distillation	Fluids purification
Filtration	Fluids purification
Precipitation	Fluids purification
Molecular sieves	Fluids purification
Pasteurization/ distillation	Fluids purification
Reverse osmosis	Fluids purification
Settling/ drag out	Fluids purification
Solvent extraction	Fluids purification
Ion exchange	Fluids purification
Evaporation	Fluids purification
Gas stripping	Fluids purification
Crystallization/ cryogenic	Fluids purification
Electrodialysis	Fluids purification
Ultrfiltration	Fluids purification
Used paint recycling	Fluids purification
Metal scrap recycling	Solids recycling
Used peen material recycling	Solids recycling

References:

1 Granta Design Limited, Cambridge Engineering Selector, Version 3.1.
Further information is available at http://www.grantadesign.com/products/overview.htm
2 Tlusty, G., Manufacturing Processes and Equipment, Prentice Hall, 1999.
3 Kalpakjian, S., S.R. Schmid, Manufacturing Engineering and Technology, Prentice Hall, 200
4 Creese, R.C. Introduction to Manufacturing Processes and Materials, Marcel Dekker, 1999.
5 DeGarmo, E.P., J.T. Back, R.A. Kohser (eds.), Materials and Processes in Manufacturing,

John Wiley & Sons, 1997.

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This Phase I final report reviews the process and provides a plan for the execution of subsequent phases of the database project, including recommended data development priorities and a preliminary cost estimate. The ultimate goal of the project is to develop publicly available LCI Data modules for commonly used materials, products, and processes.

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