DISSERTATION

Life-Cycle Assessment and Life-Cycle Costs: A Framework with Case Study Implementation Focusing on Residential Heating Systems

Submitted by

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WE RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY SCOTT A. GLICK ENTITLED LIFE-CYCLE ASSESSMENT AND LIFE-CYCLE COSTS: A FRAMEWORK WITH CASE STUDY IMPLEMENTATION FOCUSING ON RESIDENTIAL HEATING SYSTEMS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

Life-Cycle Assessment and Life-Cycle Costs: A Framework with Case Study Implementation Focusing on Residential Heating Systems

In 2004 the U.S. residential housing industry accounted for an estimated 21% of total carbon dioxide emissions for an average of 11.3 metric tons of carbon dioxide per single family home. One of the main contributors to these emissions is the residential heating system.

Traditionally heating systems are chosen by owners and designers based on first costs. This does not provide a complete picture of total costs. To better understand the total costs of owning and using a building, life-cycle cost methodology can be used to identify, monitor, and decrease energy cost over a buildings' life-cycle. However this methodology does not consider the environmental consequences of system choice. Life-cycle assessment can increase the understanding of the environmental consequences attributable to a specific product, process, or system choice. This research uses both methodologies in the decision making process relating to heating system choice and design.

This research created frameworks for performing life-cycle environmental and economic assessment using existing free online tools. Both frameworks were used in a comparative case study of two residential heating systems, gas forced air and radiant solar, for inclusion in a home in Fort Collins, Colorado, U.S.A. The proposed home consists of 3000 square feet, has excellent solar access, has 2x6 walls with superior insulation, is located at an elevation of 5000-6000 feet, and is in a four season climate.

The results of an analysis of the life-cycle cost and life-cycle assessment data initially indicated the gas forced air system was the better choice both environmentally and economically. The data were then used to pinpoint solar radiant system components for replacement trying to reduce both costs and environmental impacts. This analysis indicated the replacement of the solar collectors with a gas fired boiler in the solar radiant system improved both system costs and environmental impacts. The new system had similar environmental impacts to the gas forced air system, and fewer environmental impacts than the solar radiant system. This substitution had less impact on the life-cycle cost making the modified system still cost-prohibitive when compared to the gas forced air system.

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CHAPTER ONE: INTRODUCTION

This study creates a framework outlining the use of two commonly accepted methods for exploring the economic and environmental impacts of residential heating systems. The methods are Life-Cycle Assessment (LCA) for environmental and energy measurement and Life-Cycle Cost for the economic impacts. The framework is demonstrated by a case study analysis of the two heating systems being considered by the owner for inclusion into a new residential home in Fort Collins, Colorado.

The impact of the residential housing market on U.S. emissions is significant. An analysis of 1997 data revealed that the new single-unit residential sector accounted for 5% of the U.S. Global Warming Potential (GWP) (Hendrickson & Horvath, 2000). This study is grounded in the environmental aspect of the construction industry, specifically residential construction, the choice of a residential heating system, and the consequences of that choice in environmental and economic terms. The background explains the concerns about global warming from a global, national, state, and local perspective focusing on emissions from fossil fuels in the residential housing industry, current methods of analysis, ratings programs, and analysis tools. Following is the statement of the problem which describes the focus of this research. Next are the purpose of the research, definitions, general research questions, and the delimitations of the study. The chapter concludes with a discussion of the limitations, assumptions, and the researcher's perspective relative to the research.

Background

Global Environmental Concern

Global warming is a topic of international study and debate. It is believed that global warming is the result of greenhouse gases (GHG) which trap heat in the atmosphere, raising the earth's temperature and "there is new and stronger evidence that most of the warming over the past 50 years is attributable to human activity" (Global Warming-Climate, nd.). The U.S. Environmental Protection Agency (EPA) has identified the principle GHGs resulting from human activity: Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), and Fluorinated Gases (Greenhouse Gas Emissions, 2006). Global Warming (GW) is the term used to describe the increased temperature in the earth's atmosphere caused by GHGs. Each GHG has a different life span and potential for increasing temperatures; this is referred to as global warming potential (GWP) (Greenhouse Gas Emissions, 2006).

Out of all global GHG emissions, CO_2 is the predominant GHG contributing 74% of all global GHG emissions in 2000 (The Significance of Methane and the U.S. Activities to Reduce Methane Emissions, nd.). The combustion of fossil fuels is the largest source of CO_2 and the United States is the world leader in CO_2 emissions (kt) (thousands) and metric tons per capita, Table 1. In 2005, the United States produced 24% of global CO_2; an amount five times the world average of CO_2 emissions per capita.

Table 1. CO_2 Emissions and Emissions per Capita from select countries 2005

	CO_2 Emission (kt)(thousand)	**CO_2 Emissions Metric Ton per Capita**
World	24355	4
United States	5834	20
China	3507	3
India	1219	1
Russian Federation	1431	10
Germany	850	10
Mexico	843	4
United Kingdom	543	9
France	358	5

Data Source: (Worldbank-Environment)

United States Environmental Concern

In 2002, a national policy was adopted with a stated goal of reducing the greenhouse gas intensity by 18% over 10 years providing a cumulative reduction of over 500 million metric tons of emissions (National Goal to Reduce Greenhouse Intensity, 2006). This goal will be accomplished by reducing the ratio of emissions per million dollars in Gross Domestic Product (GDP). The construction industry in the United States is very significant and accounts for approximately 4.7 % of the GDP in 2004, with the residential sector making up about 50% (calculated) of that amount (Gross-Domestic-Product-by-Industry Accounts, 2006). If the residential construction sector reduced emissions in proportion to its share of the 2004 GDP, it could result in an estimated reduction in emissions of approximately 882.5 (thousand) metric tons for 2004 (calculated number, Glick).

The Census Bureau estimates that there were 124.5 million homes in the U.S. in 2005 (Cumulative Percent Change of Housing Unit Estimates for the United States and States Rankings: April 1, 2000 to July 1, 2005, 2006). With the population expected to grow to an estimated 363.5 million by 2030 or 63.5 million more than in 2006, 14.54

million new homes will need to be built based on an average family size of 2.5 persons (Interim Projections, 2005). According to a Co-Director of the Metropolitan Institute at Virginia Tech, in addition to the new homes needed based on the population projections there is an average annual rate of home reconstruction and/or replacement of 0.7% (Arthur C. Nelson, personal communication, 10-29-06). The estimated number of housing units needed to be reconstructed or replaced to meet the population growth by 2030 is 30 million. The total for estimated new and replaced/reconstructed homes combined is 44.54 million housing units.

CO_2 is also the dominant GHG in the United States and accounted for 84.6% of total GHGs in 2004 with 21% coming from the residential sector (Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004, 2004). The average annual CO_2 emissions for a single family home in 2001 was 11.3 metric tons/per yr. (Unit Conversion, Emission Factors, and Other Reference Data, 2004). Using this average (11.3 metric tons) 270 million metric tons of new CO_2 emissions per year would be generated if the estimated 23.9 million new homes are built out.

The 2001 Residential Energy Review identified 60.5 million households (57%) in the U.S. that heat with natural gas either as a primary or secondary heat source resulting in the consumption of 3,231 billion cubic feet of natural gas (Natural Gas Consumption and Expenditures in U.S. Households by End Uses and Census Region, 2001). Combustion of natural gas in furnaces results in the emissions of nitrogen oxides (N_2O), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nitrous oxide, volatile organic compounds (VOC), sulfur dioxide, and particulate matter (Natural Gas Combustion, nd.). With a lb CO_2/ft^3 factor of .12 (Unit Conversion, Emission Factors, and Other Reference Data, 2004), this equates to 1.759 million metric tons of CO_2 from residential heating systems in 2001 [{(3,231*.12=387.72 billion lbs) /2000=3.877mil tons}* .9072=1.759MMT] (Natural Gas Consumption and Expenditures in U.S. Households by End Uses and Census Region, 2001).

Colorado Environmental Concern

In Colorado, the 2002 CO_2 emissions from fossil fuel consumption in the residential sector amounted to 7.49 million metric tons (CO_2 Emissions from Fossil Fuel Combustion Million Metric Tons CO_2 ($MMTCO_2$), nd.). This number could increase significantly if Colorado's new residential construction continues to outpace the national average. From April 1, 2000 to July 1, 2005, the estimated increase in housing units in Colorado increased 13.5%; the national average was 7.4% for the same period (Cumulative Percent Change of Housing Unit Estimates for the United States and States Ranking: April 1, 2000 to July 1, 2005, 2006). The population in Colorado is projected to grow by 1.491 million people by 2030 from the 2000 Census number (Interim Projections, 2005). Based on the average family size of 2.5 people, this equates to 569,400 new homes by 2030. Since 244,820 new homes are estimated to have been built in Colorado during the first 5 years of the time period (2000-2030), it appears that the estimates for new homes through 2030 may be low (Cumulative Percent Change of Housing Unit Estimates for the United States and States, and States Geographic's, 2006).

Economic Valuation of Construction Projects

First cost analysis of a construction project is the historical standard for the industry. First costs are used to determine the estimated costs for the building and include all system costs. This method does not consider the time value of money and can be used as a starting point for the first cut in a project feasibility analysis. If a project is feasible, then potential profit can be calculated from a sale, rental income can be determined and rents set, and financing can be arranged for the project.

With the increasing awareness of energy costs, both builders and purchasers of residential housing units are adopting analysis methods used by building owners to analyze ongoing operation costs (Bull, 2003). The traditional first costs format is being augmented with more sophisticated analysis tools that estimate the life-cycle costs (LCC) associated with the construction, operation, maintenance, and disposal of the building. For this additional in depth financial analysis, the three most commonly used financial tools are simple payback, Internal Rate of Return (IRR), and Net Present Value (NPV) (Bull, 2003).

Environmental Valuation of Construction Projects

The assessment of the environmental impact of a system choice is possible through a process called LCA. "The assessment includes the entire life cycle of the product, process, or activity encompassing extracting and processing of raw materials; manufacturing, transportation, and distribution; use/re-use/maintenance; recycling; and final disposal" (Fava, Dennison, Jones, Curran, Vigon, Selke, & Barnum, 1991, pg.1). A shortcoming of LCA is the system boundary that limits the impact analysis to a predetermined area, usually the construction project. A new LCA methodology, Economic Input/Output LCA (EIO-LCA) was developed to enhance the traditional methodology. EIO-LCA expands the study boundary to include the entire upstream supply chain impacts within the US economy. EIO-LCA is being touted as being faster than the traditional LCA, hours or days, not months, it is cheaper since free internet software is available, and it is better due to the inclusion of the entire national economy (Hendrickson, Lave, & Matthews, 2006).

Residential Rating Programs

Recent practice has commercial designers, building owners, and builders looking at ways to make buildings more efficient and sustainable. This trend has been driven in part by several criteria-based assessment methods around the world: Green Globes in Canada, Green Building Initiative in the U.S., and Leadership in Energy and Environmental Design (LEED™) in the U.S. Each of these programs has metrics driven by regional needs assessments, politics, supply and demand, public demand, and costs. These diverse programs have become known as "green building" or "sustainable" building programs, each having its own unique set of criteria to determine what is necessary to carry the green label.

The LEED rating system was recently named by the General Services Administration as the most "credible green rating system" among five systems analyzed: Building Research Establishment's Environmental Assessment Method (BREEM), Comprehensive Building Environmental Efficiency (CASBEE), GBTool, Green Globes US., and LEED (USGBC in the News, 2006). In 2004, the USGBC created a task force "LCA into LEED" to determine if LCA would be a useful addition in the next version of LEED (Cassidy, 2005). LEED also recently created a checklist for new home construction that is in the pilot phase. A review of the LEED for Homes Pilot Project Checklist found no mention of environmental requirements for heating ventilation and air conditioning (HVAC) systems (LEED for Homes Pilot Project Checklist, 2006.). This may change if the USGBC adopts LCA as a rating requirement.

Analysis Tools

As the interest in sustainable building increases, so do the number of tools available to help decision makers make more informed decisions. On the environmental side, some tools focus on green product comparisons: Building for Environmental and Economic Sustainability (BEES), ECOTECT, GaBi, and websites like EIO-LCA.net that are available for hybrid LCA. (For in depth discussions see Guggemos, 2003). Other tools focus on the entire building as a system: Energy Pro is a California Title 24 compliance software, Design Builder looks at early pre-design and early-stage design energy code compliance (Materials Components: HVAC Systems, nd.). For cost consideration and LCC, tools like Building Life-Cycle Costing Program (BLCC5) were developed and are supported by the National Institute of Standards and Technology (Building Life Cycle Cost (BLCC) Programs, nd.).

Problem Statement

There currently is no LCA and LCC framework available that describes the life-cycle costs and impacts of residential heating systems. As residential green building grows, practitioners will need to provide both costs and environmental impact data for their customers. One area of particular concern is the choice of residential heating systems. "The average single-family home adds more than twice as much greenhouse gas (CE) emissions to the atmosphere as the average passenger vehicle" (Unit Conversion, Emission Factors, and Other Reference Data, pg.6, 2004). The traditional economic analysis used in construction looks at first costs and, in some cases, the LCC of the project. The downside to LCC is that it doesn't quantify and account for the emissions generated during manufacturing, construction, use, maintenance, and the disposal of the heating system components.

There is a need for homeowners and residential construction and design professionals to understand all life cycle consequences of the heating systems that are installed in new and remodeled residential housing units. Once a problem is identified, it can be analyzed and a solution can be crafted to solve the problem. In the case of residential heating systems, not quantifying and analyzing the environmental consequences of different heating systems is the problem, not just individual residential heating systems but the culmination of the existing and yet to be built residential heating systems.

It is in the design phase where decisions are made that impact every phase in the residential construction process. “With virtually every decision made over the life cycle of a building having performance and environmental consequences of both long and short term, the decision makers need information to assess the consequences of each decision in a timely, cost effective, and practical way” (Morrissey, O’Donnell, Keane & Bazjanac, pg. 7, 2004). By measuring the environmental impacts of the two heating systems the owner is considering, the owner will be able to determine if the perceived “greenness” of the solar radiant heating system warrants the potential increased first cost expenditure.

Market research has shown that at least 80% of the people would prefer to have environmentally friendly products if they were free and/or the same cost as traditional products and 10-20% would pay for green products (Schenck, 2005). For the people willing to pay for green products, the use of these tools by design professionals and contractors would help the consumer determine the best way to spend their environmental dollars. "Not measuring environmental performance could mean that you are spending money and effort on things that don't matter" (Schenck, pg. 5, 2005).

The framework put forth in this research was demonstrated using a case study focusing on the selection of a heating system for a new residence being constructed in Fort Collins, Colorado. While several heating system choices were available, the homeowner/builder wanted to choose between a solar radiant heat system (SRS) in an attempt to go off the grid and a traditional gas forced air system (GFA), a system widely used in this geographic area. The first costs were substantially different and the life cycle costs were estimated to be substantially different as well. In addition, the environmental costs associated with each alternative were assumed to be quite different since the solar system is a perceived "green" system. A comparative case study of the two proposed systems will provide data on the environmental and economic life cycle costs of each system, data that was used by the homeowner/builder to choose a heating system. The use of this data for other projects is covered in the discussion chapter.

Purpose of the Research

The purpose of this research was to create a framework for performing LCA and LCC that is easy to understand and use by the average construction practitioner. A case study has been performed to demonstrate and test the framework. The case study determined the estimated total life cycle environmental and economic impacts of a GFA and SRS for a proposed residential building in Fort Collins, Colorado. The results of the LCC portion of the study and those of the LCA portion of the study provided the data discussed with the builder/homeowner as to which system should be used based on using multiple assessment methods and owner preferences. This data also expands the LCA research base and explore different ways to interpret and use the results of a LCA study as called for by the Society of Environmental Toxicology and Chemistry (SETAC) in 1991 (Fava, Dennison, Jones, Curran, Vigon, Selke, & Barnun, 1991).

Developing the Framework

The framework was developed based on using tools readily available on the web that incorporate industry standard methodologies for LCA and LCC. It details the information requirements and steps needed to perform an LCA using the web-based tool EIO-LCA.net and LCC using BLCC5.3, a tool also available for free on the web. The framework includes detailed steps on how to use the web-based tool eio.lca.net. A case study was performed to demonstrate the framework and to provide calculation details and backup sources. For example, the LCA framework listed the phases that were analyzed, the method of analysis, and the appropriate tool for analysis. Within each phase, the required input information was identified, quantified, and analyzed into estimated environmental impacts shown as GWP. This process was done for each heating system alternative and the data sources are shown in appendices.

The LCC analysis provides information identifying the web-based analysis tool, the data needed for input, and an analysis of the results. The data sources and calculations are shown in appendices.

Definition of Terms

Adaptive Reuse is defined as a process that adapts buildings for new uses while retaining their historic features (Architecture Glossary, n.d.).

Carbon Dioxide is defined by the United States Environmental Protection Agency as follows:

> A naturally occurring gas, and also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1. (Glossary of Climate Change Terms, 2006).

Climate Change is defined by the United States Environmental Protection Agency as follows:

> Climate change refers to any significant change in measures of climate (such as temperature, precipitation, or wind) lasting for an extended period (decades or longer). Climate change may result from:
>
> Natural factors, such as changes in the sun's intensity or slow changes in the Earth's orbit around the sun;
>
> Natural processes within the climate system (e.g. changes in ocean circulation); human activities that change the atmosphere's composition (e.g. through burning fossil fuels) and the land surface (e.g. deforestation, reforestation, urbanization, desertification, etc.) (Glossary of Climate Change Terms, 2006).

Conceptual Cost is defined as the owner's preliminary estimate of the total cost of design and construction.

Cost of Capital is defined by Investopedia.com as the required return necessary to make a capital budgeting project worthwhile (Cost of Capital, n.d.).

Design Phase is defined as the initial project design where the owner's thoughts and ideas are solidified. It is at this point where decisions are made concerning all aspects of materials and methods as well as system choices and finishes.

Discount Rate is defined by Investopedia.com as the interest rate used in determining the present value of future cash flows (Discount Rate, n.d.).

Economic Input/Output Life–Cycle Assessment (EIO-LCA) A model that "provides the complete supply chain of economic activity needed to manufacture any good or service in the economy" (Matthews & Small, 2001).

Ecosystem is defined by the United States Environmental Protection Agency as follows:

> Any natural unit or entity including non-living parts that interact to produce a stable system through cyclic exchange of materials (Glossary of Climate Change Terms, n.d.).

Embodied Energy is defined by the Australian Government as follows:

> Embodied energy is the energy consumed by all of the processes associated with the production of a building, from acquisition of natural resources to product delivery. This includes the mining and manufacturing of materials and equipment, the transport of the materials and the administrative functions. Embodied energy is a significant component of the lifecycle impact of a home (Embodied energy, n.d.).

First Costs is defined as the initial costs of a project in current dollars.

Functional Unit is defined as a unit of analysis which allows for comparisons to be made if the functional unit of each choice is the same.

Global Warming is defined by the United States Environmental Protection Agency as follows:

> Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human-induced. In common usage, "global warming" often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities (Glossary of Climate Change Terms, n.d.).

Global Warming Potential (GWP) is defined by the United States Environmental Protection Agency as follows:

> The cumulative radiative forcing effects of a gas over a specified time horizon resulting from the emission of a unit mass of gas relative to a reference gas. The GWP-weighted emissions of direct greenhouse gases in the U.S. Inventory are presented in terms of equivalent emissions of carbon dioxide (CO_2), using units of teragrams of carbon dioxide equivalents (Tg CO_2 Eq.).
> Conversion: Tg = 10^9 kg = 10^6 metric tons = 1 million metric tons (Glossary of Climate Change Terms, n.d.).

Green House Gases (GHG) is defined by the United States Environmental Protection Agency as follows:

> Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the UNFCCC deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) (Glossary of Climate Change Terms, n.d.).

Green House Gas Intensity is defined by the United States Environmental Protection Agency as the ratio of greenhouse gas emissions to economic output (National Goal to Reduce Emissions Intensity, 2006).

Housing Units are defined by the Unites States Census Bureau as follows:

> A housing unit is a house, an apartment, a mobile home or trailer, a group of rooms, or a single room that is occupied, or, if vacant, is intended for occupancy as separate living quarters. Separate living quarters are those in which the occupants live separately from any other persons in the building and which have direct access from the outside of the building or through a common hall (Terms and Definitions, 2006).

Internal Rate of Return is defined as the percentage earned on the amount of capital invested each year of the project life after allowing for the repayment of the sum originally invested (Bull, 2003).

International Organization for Standardization (ISO) is a network of the national standards institutes of 157 countries, on the basis of one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system (Overview of the ISO System, nd.).

Kiloton (kt) is a unit of measure equal to 1000 metric tons.

Life-Cycle Assessment is defined by SETAC as follows:

> "Life-cycle assessment is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impacts of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process, or activity, encompassing extraction and processing of raw materials, manufacturing and distribution, use/reuse/maintenance, recycling, and final disposal"
> (Fava, Denison, Jones, Curran, Vigon, Selke, & Barnum, 1991, pg. 1).

Life-Cycle Cost is defined in Section 707 of Executive Order 13123 as follows:

> The sum of present values of investment costs, capital costs, installation costs, energy costs, operating costs, maintenance costs, and disposal costs over the lifetime of the project, product, or measure (Executive Summary, 2005).

Monetization is defined as assigning values in dollars (Boardman, Greenberg, Vining, & Weimer, 2001)

Net Present Value is defined as the sum of money that needs to be invested today to meet all future requirements as they arise throughout the life of the investment (Bull, 2003).

Process is defined as a flow of materials that transforms raw materials to finished goods. It could be referred to as an input/output model.

Process Model is defined as the pictorial representation of the flow of goods or services within a related system to help understand the series of events that lead to the desired outcome.

Simple Payback is defined as the time it takes for the return on an investment to repay the investment (Bull, 2003).

Society of Environmental Toxicology and Chemistry (SETAC) defines itself as follows:

> A nonprofit, worldwide professional society comprised of individuals and institutions engaged in: the study, analysis, and solution of environmental

> problems; the management and regulation of natural resources; environmental education; research and development (Welcome to SETAC.org, nd.).

Sustainable Development as defined by The World Commission of Environment and Development is:

> "Humanity has the ability to make development sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (pg 8). Within this context there is an increasing awareness that economic prosperity and environmental protection are inextricably linked (World Commission on Environment and Development, 1987).

Time Value of Money is defined by Investopedia.com as the idea that money available at the present time is worth more than the same amount in the future, due to its potential earning capability. This core principle of finance holds that, provided money can earn interest, any amount of money is worth more the sooner it is received (Time Value of Money, n.d.).

Research Questions

The research questions are:

1. What are the life-cycle environmental impacts of a residential gas-forced air system heating system?
2. What are the life-cycle environmental impacts of a residential solar hot water radiant heat system?
3. What are the life-cycle costs of a residential gas-forced air heating system?
4. What are the life-cycle costs of a residential solar hot water radiant heat system?

Delimitations

The delimitations of this study are: geographic location, system choices, and phases. One of the delimiting characteristics of the home is the geographic location and the climatic conditions. This affects the estimates of solar access, building insulation, fuel type, and costs. Related delimitations are the size of the structure, occupant loads, estimates of future energy costs, and the initial system costs.

The consideration of only two heating systems delimited the study to GFA and SRS heat systems. Neither system includes a provision for air conditioning; additionally, the SRS also excludes the domestic hot water component in order to maintain the same functional unit needed for comparison. Domestic hot water would be considered an additional load and system component of the solar system. The design of the solar radiant heat system assumes 100% of the heating needs for this home can be met using solar energy. Typically, this is not practical due to heat buildup in the stored water during the summer months requiring a heat dump.

Limitations

One of the limitations of this study is the 20-year projected life cycle of the GFA system. This affects both assessment tools and is not unique to this study alone. However, the Department of Energy publishes annual energy price indices and discount factors for life cycle costs analysis which are widely-used assumptions within the federal government. Even with this resource, the prediction of energy costs in the context of the current geopolitical situation is uncertain at best. The uncertainty is the same for the discount rate estimation.

Using national averages for residential energy use is a limitation even though these are broken down by fuel type, usage, and census region. Averages do not consider life style choices or individual conservation efforts. Technology also limits the choice of fuel to run the heating system, electricity for pump and blower circulation, and natural gas for air heating in the GFA-use phase. The introduction of bio-fuels could change the assumptions significantly in the future.

Concerning the LCA-portion of the study, there is a limitation on how to determine the cost wholesalers pay to the manufacturer and the manufacturer's profit margin. The cost to produce is the cost that is used in EIO-LCA calculations, not the cost to the retail consumer.

The study is further limited by the accuracy of the data available to the creators of the eiolca.net website which was used for the analysis of environmental impacts of the entire supply chain. Uncertainty could result from several sources as discussed by Hendrickson, Lave, & Matthews: survey errors, use of old data, incomplete data, missing data, aggregation of data, and imports (2006). The results of the eialca.net model give averages and will not show differences in superior products or services. The data is limited to the information acquired by the Department of Commerce and in some cases missing data is estimated and included in the model (Hendrickson, Lave, & Matthews, 2006).

Assumptions

The major assumption of this case study was that using two methods to assess the two heating system choices over the life cycle of the building would be more accurate and informative than doing an individual LCA or LCC on one system. This assumption is supported by Hendrickson, Lave, & Matthews who say that "deciding which of two products or processes is more environmentally desirable will be less uncertain than characterizing the impact of any single product" (2006, pg. 47). It was further assumed that even though the assessment process had several delimitations and limitations due to the newness of EIO-LCA and future projections, that the information gleaned from this study will help others in the future do comparative studies of building products, processes, and systems.

Researcher's Perspective

My experience in the construction industry is predominately residential-based and spans 30 years in the field. I have always been self-employed and 100% at risk for all business development, estimates, procurement, scheduling, and quality. I have done both remodeling and new construction and, in several cases, built homes by myself with the exception of dirt work or concrete, although I have done both of these trades as well. My business philosophy is "Do what you say you will do, when you say you will do it and for the quoted price." This philosophy has served me well and I take pride in the fact that I have never had a call back to fix workmanship-related problems.

While doing this case study, I have the unique perspective of being a student in an interdisciplinary PhD program while teaching in a construction management program as an adjunct faculty and being a home builder/owner and land developer, all at the same time. It is the homebuilder/owner that is interested in which system is better suited to balance my concern for the environment with economic costs considerations. It is my desire as a developer to understand the real estate market and try to determine what people will pay for both now and in the next five years. It is the combination of these perspectives that encourages me to look at different valuation techniques that will help in making a balanced decision based on the best information available in the design stage of this home as to which heating system will be installed.

Concerning the environment and the number of new houses that will be built nationwide over the next 25 years, I am encouraged by the methods that are available to evaluate the environmental impact of our industry. The residential building industry could make a significant positive impact on the environment if they become proactive as a group and use these methods in ways that provide better building envelopes, better and more efficient system choices, and better designs based on all systems working together within a home.

I would also like to state my opinion regarding the fledgling state of environmental analysis in residential construction. I feel that any study that uses new methods, creates or modifies these methods, or uses multiple methods is worthwhile and adds an increment to our understanding of how residential construction affects the environment, how residential construction can better the environment and how residential construction can be a leader in educating consumers and those in other emphasis areas of construction.

CHAPTER 2: LITERATURE REVIEW

Background

History

LCA was introduced in the 1960s as a tool to look at extended product systems, and specifically, energy requirements through "fuel cycle" studies by the Department of Energy (Curran, 1996, pg. 1.3). Following the energy crisis of the 1970s LCA became the tool of choice for looking at environmental issues. LCA was used in the manufacturing sector to determine how green a company was. This "green" labeling was driven in the U.S. by mandates to quantify and reduce emissions from manufacturing facilities (Hundal, 2002; Curran, 1996). One of the first studies in this area was done by Coca-Cola looking at resource consumption and emissions associated with beverage containers (Jensen, Hoffman, Moller, Schmidt, dk-TEKNIK Energy & Environment Denmark, Christiansen, et al., 1997). During this time, similar packaging studies were being carried out in Europe (Curran, 1996).

During the 1980s the Green movement in Europe looked to LCA in relation to recycling. "As a result, environmental releases were routinely added to energy, raw materials, and solid waste considerations" (Curran, 1996, pg. 1.3). From this rich history, LCA emerged as the leading model to quantify environmental outputs from products, processes, and activities.

Life-Cycle Thinking

Life-cycle is a way of thinking about a product, process, or system that looks at the overall impact of the selection of use of any product, process, or system. This way of thinking espouses the total life-cycle of any decision to include all impacted areas related to a decision. In the financial markets, life-cycle costs have been the standard for decades. Environmental concerns are pushing life-cycle assessment to the forefront. Unfortunately, the life-cycle and systems thinking movement is hindered by several market conditions.

Lutzenhiser & Janda point out that life-cycle and systems thinking in residential construction is in its infancy since the "industry is complex and highly differentiated or heterogeneous along a number of dimensions." In regards to energy efficiency in homes, "innovation toward energy efficiency (as well as some other forms of innovation that promise to be more economically efficient, socially beneficial and environmentally sustainable) has been quite gradual" (1999, pg. 4).

Professor Roland Clift (U.K.) argues that "It is key that life-cycle thinking be fostered throughout organisations, and be adopted as part and parcel of the organisation's philosophy, mission, and day-to-day operations. This makes it essential that life-cycle thinking also be applied to corporate educational processes" (Jensen, Hoffman, Moller, Schmidt, dk-TEKNIK Energy & Environment Denmark, Christiansen, et al., 1997, pg. 21). The educational process cannot begin at the corporate level. Students of all ages should by educated and informed about the environmental consequences associated with their decisions from an early age. If this is not done, there is a risk that environmental awareness may become generational and fade from the public forum as that generation passes on.

Cole summarizes the initial roadblocks faced by a transition to sustainable building practices:

> "Environmental issues are inevitably at odds with those generally subscribed to by society as a whole and those implicit in building owner's priorities and expectations, the predominately short-term mentality among financial institutions and developers, and an outmoded regulatory framework which creates little incentive for environmentally responsible building practices. Moreover, limited time, budget, and skills together with a host of other regulatory and code restrictions will continue to limit the ability of architects and other design professionals to assimilate all pressing or relevant issues into a specific design project" (Cole, 1998, pg. 4).

Understanding the issues associated with incorporating environmental awareness into the mainstream building process makes it easier to overcome them incrementally by refining tools and regulations in a manner that incorporate life-cycle and systems thinking into the construction industry.

Projections for LCA in the Future

As the use of LCA increases in the construction industry, "there will be more commonality and greater data availability, market pressure will push greater benchmarking against industry averages, there will be more widely accepted standards and methodologies, LCA will be seen as an integral part of the environmental management tool kit, but will also find new applications in areas such as corporate strategy" (Jensen, Hoffman, Møller, Schmidt, dk-TEKNIK Energy & Environment Denmark, Christiansen, et al., 1997, pg. 28). The potential incorporation of LCA into the LEED requirements for green building certification is a good example of a corporate strategy to capitalize on the environmental aspects of construction and its integration into the decision making process of building design.

Life-Cycle Assessment

What is Life-Cycle Assessment

LCA is referred to as both a tool and a methodology that has been defined many ways: "Cradle-to-Grave (LCA 101-Introduction to LCA, 2001); "In ISO 14040, LCA is defined as the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (Guinee, 2002, pg. 5); and "LCA is a tool that can be used to evaluate the environmental effects of a product, process or activity" (Curran, 1996, pg. 2.1).

SETAC has a more comprehensive definition: "life-cycle assessment is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impacts of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process, or activity, encompassing extraction and processing of raw materials, manufacturing and distribution, use/reuse/maintenance, recycling, and final disposal" (Fava, Dennison, Jones, Curran, Vigon, Selke, & Barnum, 1991, Executive Summary).

Two groups took the initiative to provide some standardization for LCA: SETAC and the International Organization for Standardization (ISO). SETAC took the lead in 1990 holding a workshop in Vermont and then a year later holding a similar workshop in Belgium. The two SETAC groups, European and North America, do have divergent views of LCA. The Europeans focused on methodology development and the North Americans focused on limitations and improper use. It is from the European group that the ISO developed its 14040 series standards relating to LCA starting in 1994 (Guinee, 2002).

The key components of the LCA for SETAC are: "Life-Cycle Inventory, Life-Cycle Impact Analysis, and Life-Cycle Improvement Analysis" (Fava, Dennison, Jones, Curran, Vigon, Selke, & Barnum, 1991). The ISO uses similar categories: Principles and Framework (ISO14040), Goal and Scope Definition and Inventory Analysis (ISO14041), Life Cycle Impact Assessment (ISO14042), and Life Cycle Interpretation (IOS14043) (ISO.org, nd.). The main difference is the wording of the last step; SETAC uses "Impact" assessment and "Interpretation" is used by ISO.

In a presentation at the first conference on Life-Cycle Management, Copenhagen, Norris points out that there are two benefits of LCA; one to individual users and one to society. Individual users of LCA may be concerned with specific issues such as costs associated with an impact. Society benefits in a more indirect manner. If LCA is used to reduce pollution that results from construction-related decisions then the amount of health related illnesses could decline. In one case, the individual bears the cost and in the other, society as a whole benefits from costs borne by a few (Norris, 2000).

LCA Weaknesses

Even though LCA has emerged as the legitimate accepted method of choice for comparing competing alternative products in the building industry (Shen & Feeser, 1997; Treloar, Love, Faniran, & Iyer-Raniga, 2000; Peuportier, 2001; Zachariah, 2003), there are some limitations to this approach (Suh, Lenzen, Treloar, Hondo, Horvath, Huppes, et al., 2004; Heiskanen, 2001; LCA 101- Introduction to LCA, 2001, Guinee ed., 2002):

A. Inventory process diagrams are constrained by the system boundaries assuming upstream impacts have only minor effects.
B. LCA is based on societal norms, values, and assumptions that affect the study boundary.
C. Data is not always available and accurate.
D. Time is a factor and may hold up a decision process.
E. Economic resource commitment is large.
F. It is difficult to accurately identify all impacts of a process.
G. There are multiple processes that may lead to competing answers.
H. Local impacts are not addressed.
I. LCA is not dynamic in nature, so future changes in technology are not considered.
J. LCA is based on non-linear modeling.
K. Although the focus of an LCA is on the environment, usually as potential impacts, it ignores for the most part the economic and social characteristics.

The weakness of data availability is interesting and problematic in that both LCA and EIO-LCA websites that rely on government data are at the mercy of when that data is released and how accurate it is. The eiolca.net web site is still using the 1997 reference data in 2006. In a 2002 publication, Ochoa, Hendrickson, and Matthews stated "we choose 1997 reference data due to availability issues" (2002, pg. 134). There was no reference to what effects this dated data would have on their research, if any.

Since the 1992 data is available, a comment could be made on the change over time of the reference data from 1992 to 1997 and possible effects of any significant changes to the data. One of the changes that could be looked at is the introduction of new technologies into the manufacturing sector. This alone, in theory, would decrease cost and emissions. If a large enough investment was made by a sector in newer technology this could change the averages for that sector of the economy.

Methodological Debates

There are several key steps in the impact assessment stage: selection and definition of Impact Categories, Classification, Characterization, Normalizing, Grouping, Weighting, and Evaluation and Reporting (LCA 101- Introduction to LCA, 2001). It is in classification where the inventory results are assigned to impact categories. These impacts are then modeled within impact categories using science-based conversion factors. The weighting function (valuation) is where the values issue becomes a concern due to the subjective weights assigned to the impacts (Azapagic, 1999).

Hertwich, Hammitt and Pease thesis is that LCA is not value-free in the impact assessment area "because it draws into question what LCA is, what criteria are employed to evaluate its results and its methods, and how arguments are made" (2000, pg. 19). They also argue that LCA should be considered a decision support tool and that the issue of values extends to the goal and scope as well as the inventory processes of LCA. By making LCA part of the decision making process, they believe that a “consistent criteria for the evaluation of LCA methods and results can be developed” (2000, pg. 15).

Owens raises similar concerns relating to the constraints placed on the inventory as they relate to the impacts and assessment portions of the LCA. These constraints are value judgments placed on the study in the goal and scope portion. Others are concerned with the term “impact assessment” as it sounds predictive in nature. Owens argues that the “impact assessment results are largely directional environmental indicators” due to the limitations placed on the inventory (1997, pg. 37).

Some studies are silent on the values matter in the methodological discussions of the impact stage (Miettinen & Hämäläinen, 1997; Alsema, 2000; Burgess & Brennan, 2001). There are studies that do not mention the impact stage at all in the methodology section (Horvath, 1997; Guggemos, 2003; Zachariah, 2003). There also are studies that only make reference to the use of a particular website for their methodology (Ochoa Franco, 2004) and those that make a cursory mention prior to explaining a computer model (Cicas, 2005).

I agree with the Hertwich, Hammitt, and Pease thesis that values are an issue but the argument that Owens makes about impact results being indicators makes this concern a moot point to me. To me, the question becomes: what do you want from the LCA? Do you need value-free scientifically-sound data or do you need data that provides answers to specific questions while considering the direction of the environmental indicators? This is a value judgment itself in assessing the need for information from doing an LCA. I would argue that in order to get industry practitioners in residential construction to use LCA, you need the latter.

As an observation, it appears that the reference to and possibly the understanding of the specific underlying components of a LCA are not being directly addressed as the databases and software tools proliferate. This observation is based on the dates and the method discussions of the literature that were reviewed above and the reference to specific Hybrid LCA websites.

Economic Input/Output Life-cycle Assessment

There are two commonly used methods for creating an inventory analysis, "process analysis and input-output analysis" (Suh, Treloar, Hondo, Horvath, Huppes, et al., 2004, pg. 658). The process analysis is done in LCA and input-output analysis is used in economic input-output (EIO). The introduction of EIO models to LCA has addressed several of the weaknesses of the traditional LCA process: time requirements, costs, increased system boundaries, inclusion of linear modeling, and it is somewhat dynamic as data changes over time will reflect changes in technology.

The shortcomings in available traditional approaches to LCA have motivated the development of EIO-LCA models (Matthews & Small, 2001, pg. 8). One of these shortcomings as argued by Suh, Lenzen, Treloar, Hondo, Horvath, Huppes, et al. is that "compliance with ISO standards is practically impossible without models containing loops" (2004, pg. 658). Following this argument, the inventory in a LCA would "exhibit inherent system incompleteness" since it would not consider the input of capital goods (Suh, Lenzen, Treloar, Hondo, Horvath, Huppes, et al., 2004, pg. 658).

This argument makes sense when you consider the limitations placed on a study by the selection of a system boundary for the traditional LCA. By not including upstream materials from the supply chain you are, in fact, excluding the flow of capital goods into the process, one of the attributes of using the IO model. One explanation to challenge this argument would be that an LCA is a snapshot of a point in the process and, as such, only the products in the picture need to be considered.

Another point of view is the realization that LCA had limits due to data availability and costs when it was first developed as a method. However, this was not always a weakness; the data is getting better, allowing newer methods to be developed. If the weakness argument were applied to the EIO-LCA model we should not be using it due to the amount of data aggregation. And if LCA is so bad, why is it included in the hybrid process as a way to disaggregate data for more precise results?

Another important consideration in using EIO-LCA methodology is the context in which the information gleaned from an LCA will be used. The traditional LCA is time and cost-prohibitive to many applications in residential construction, e.g. the comparison of two heating systems. In some construction-related issues, a decision needs to be made in a short period of time. It is in these instances where a simplified LCA that focuses on problem identification and differences between products should be sufficient in providing information for decision makers (Jensen, Hoffman, Møller, Schmidt, dk-TEKNIK Energy & Environment Denmark, Christiansen, et al., 1997).

The use of EIO models has a rich history dating back to its development in 1941 by Leontief, W. (Matthews & Small, 2001; Bjorn, Declercq-Lopez, Spatari, & MacLean, 2005; Hendrickson, Lave, & Matthews, 2006). This type of analysis assumes that there is a linear relationship between inputs into a system and the outputs from that system. One of the highest volume LCA tools in the world (Matthews & Small, 2001) is the EIO-LCA website put together by Carnegie Mellon's Green Building Initiative. This tool uses

1997 reference data from the U.S. Department of Commerce: the data originally used was from 1992. Unlike the bottom-up approach of LCA, EIO-LCA is a top-down approach using the entire economy as the boundary of the study which creates a stable boundary for all studies using this approach (Joshi, 2000; Matthews & Small, 2001; Suh, Lenzen, Treloar, Hondo, Horvath, Huppes, et.al, 2004).

While EIO-LCA has performed well when compared to study results using traditional LCA (Lankey & McMichael, 2000; Lave, MacLean, Hendrickson, & Lankey, 2000; Horvath & Hendrickson, 1998; Joshi, 2000), a potential exists that a traditional LCA will not account for all the indirect impacts found along the supply chain. One reason for this weakness may be the limit of the boundary on the inventory, called a truncation error, a result of missing data from upstream sources. In some cases, these errors can be as much as 50% (Lenzen, 2001). For this reason, the addition of the EIO component to the traditional LCA appears to add additional strength to study results (Bjorn, Declercq-Lopez, Spatari, & MacLean, 2005).

EIO Weaknesses

The use of economy-wide data as used for the EIO-LCA model has its own set of weaknesses. The data used is aggregated for each commodity sector so the product of interest is an approximation of average values. While the narrowness of the boundary problem of LCA is expanded to include all upstream supply chain flows, there is still no data available for the end-of-life decisions (Joshi, 2000; Hendrickson, Lave, & Matthews, 2006).

There are also issues about current data since the Department of Commerce only publishes IO data every 5 years and they are not always on schedule. The timeliness of data releases by governments may not be a U.S. issue alone. Bjorn, Declercq-Lopez, Spatari, and MacLean report that in Canada "the values in recently published matrices are deflated and reported in 1997 dollars to allow for comparability between different years" (2005, pg. 20). This statement implies that some data may be newer than 1997 and that data could become the new base.

As previously mentioned, the U.S. data used in the eiolca.net website is from 1997. The 2002 benchmark preliminary estimates were released in 2005 but the revisions will not be made public and finalized until summer 2007. The preliminary numbers show an average yearly increase for the construction sector of 6.1% from 1997 to 2002. This data will be five years old upon final release so the increase for the five years from 2002 to 2007 will not be included.

An additional issue may arise from the proposed combining of industries with $3 billion or less and declining gross revenues with larger similar industries. This will result in more aggregated data affecting primarily the agriculture, and manufacturing sectors (Stanley-Allen, Empey, Meade, Rzeznik, Streitwieser, & Strople, 2005).

One of the steps users of the eiolac.net tool must do is to use the Consumer Price Index (CPI) to deflate current U.S. dollars into 1997 base year dollars. Doing this conversion could create an entire set of new challenges for comparability of studies over time. The CPI is a market basket of goods and they may change periodically as consumer preferences change; consumer preference is a value (Bureau of Labor Statistics, nd.). One problem is that the CPI numbers are released monthly and they are used to deflate prices to some point in time, in this case to 1997. The further back in time you go with this process the more current values are treated as being equal with the values from the benchmark input-output data year, 1997.

The release of benchmark numbers significantly after the fact does not appear to concern Carter (1970) as cited in Hendrickson, Lave and Matthews. Carter did a study of the U.S. economy for the 22 years prior to 1966 using five different input-output tables and found the results varied only 3/8% (2006). This supporting data may be of little use in the marketplace today due to the increase in global markets and policies like the North American Free Trade Association (NAFTA). This may not be viewed as an issue but no other studies have been located that support the findings of Carter.

Other concerns include imports being treated as U.S. products and the difficulty of applying the CPI to an open economy that does not have domestic products with which to compare to a high number of imports (Hendrickson, Lave, & Matthews, 2006).

Hybrid Model

The use of EIO information on products becomes problematic when the product does not fit into a predefined sector or the data is too aggregated to be useful. In this case, the process method, bottom-up approach, of the traditional LCA can be used to disaggregate the data to a level where the IO data and the EIO-LCA model can be applied. By using the positive attributes of each model, LCA and EIO-LCA the weaknesses are minimized (Hendrickson, Lave, & Matthews, 2006).

The use of the hybrid model is described by Udo de Haes, Heijungs, Suh, and Huppes as the use of models that are not totally compatible, i.e. LCA and EIO-LCA. The use of compatible models is not always necessitated and this requirement is set forth in the scope and goal of the study as a level of precision. As long as the variables in one model act in ways that don't significantly alter the other model, the hybrid model use is acceptable (2004).

LCA with other Methods

The use of LCA as the predominant method for measuring the environmental impacts of processes, products, and services is widely accepted. However, it is important to use the LCA results in perspective to other issues that also play important roles in decision making. SETAC views LCA as "one tool to help identify, assess, and solve environmental concerns associated with products, processes, and activities" (Fava, Dennison, Jones, Curran, Vigon, Selke, & Barnum, 1991, Executive summary). The EEA shares this view and believes that LCA cannot be used as the only decision support tool in environmental management (Jensen, Hoffman, Møller, Schmidt, dk-TEKNIK Energy & Environment Denmark, Christiansen, et al., 1997, pg. 39). The EPA and Science Applications International Corporation are more specific in their view of LCA's limitations in being used as a stand alone tool: "LCA does not take into account technical performance, cost, or political and social acceptance. Therefore, it is recommended that LCA be used in conjunction with these other parameters" (LCA 101- Introduction to LCA, 2001, pg. 25). The weakness of LCA as a stand-alone is widely acknowledged in the literature with recommendations that it be used as one of multiple tools in decision making (Guinee, Huppes, Lankreijer, Udo de Haes, Sleeswijk, et al.,1992; Miettinen & Hämäläinen, 1997; Owens, 1997; Burgess & Brennan, 2001; NAHB Research Center, Inc., 2001; Guinee, 2002).

I strongly believe that multiple methods are necessary for decision making situations especially when the methods being used are newer and still being developed, EIO-LCA, or well-established and being modified to include areas that are not traditional to their use, LCC. Although the information from either an LCC or LCA are valuable, they are measuring very different outcomes and treating either outcome as a stand-alone metric on which to base a decision which excludes other criteria that should be considered. Hence the reason that the individual tool itself was created: to provide information where none existed prior to that method's development.

Energy-Related LCA Studies

The use of LCA in assessing the use of solar photovoltaic (PV) systems, a building-related component, was one area examined as LCA began its crossover into the building industry. These studies are commonly referred to as Life-Cycle Energy Analysis (LCEA) and focus on energy as the only environmental impact (Fay, Treloar, & Iyer-Raniga, 2000). These studies looked at the energy payback time of PV modules. The emphasis of these studies was on the product design phase as an area where environmental considerations could be used to lower impacts on the environment as a result of PV production. Lewis and Keoleian did some work drawing tight boundaries around the manufacturing process of PV modules and worked with the PV industry to help acquire data for their study (Lewis & Keoleian, 1996; Keoleian & Lewis, 1997). Additional studies were performed in Europe and Asia using the same production boundaries and excluded the operation and disposal phases for lack of impact and data (Alsema, 1998; Alsema, Frankl, & Kato, 1998).

More recent studies of PV modules still focus on the energy payback time but they include discussions of balance of system (BOS) components like support racks, inverters, etc., system boundaries, and mention recycling prospects for end-of-life considerations (Knapp & Jester, 2001; Krauter, 2003).

One of the important points made in these articles was the difference in location of the actual PV modules and how that affected the data collected for use in the energy payback time calculations. Another interesting issue was how the boundaries were expanded to include national boundaries and the inclusion of the use and disposal phases in the discussions as time passed. This may reflect the improved information availability and model use in respect to LCA.

LCA Construction Studies

The use of LCA in construction is still relatively new with some work being done in both commercial and residential applications. Horvath used EIO-LCA and looked at three different areas of design and material use: asphalt and concrete pavements, steel and concrete bridge girders, and wood and light gauge metal framing in residential construction. In this case, the environmental burdens were higher in the manufacturing phase than in the use and recycle phase for all three areas. The asphalt, concrete girders, and wood were the more environmentally friendly in the three categories (Horvath. 1997).

It is not always the case where the use phase dominates the emissions from a given product or process. Guggemos looked at the construction phase of three buildings and focused on structural frames. It was found that the manufacturing, construction, and maintenance phases could also contribute significantly to emissions generation. The importance of product selection, equipment choice, and extended producer responsibility were significant outcomes of this study (Guggemos, 2003).

There was an in-depth discussion by Guggemos (2003) and Horvath (1997) concerning data quality and uncertainty, age, completeness, missing, and aggregation. The data Horvath used was from 1987 while Guggemos used data from1997. It would be interesting to redo one or both of these studies using more current data to determine if the results were similar. Such a replication process could help with validity issues. One of the arguments for using data collected by the government in the EIO-LCA was that it is probably the same data that would be given to private researchers since it is already required by the government. It was also pointed out that using environmental information as the only means on which to compare products is difficult. Guggemos also identifies as an issue the boundary selection and data availability as hindrances in comparability of studies.

A LCA and full-cost evaluation study of nine different commercial wall systems made of, wood, steel, and concrete, used an interesting approach to future costs. The future environmental costs were not discounted; the current costs were used for the entire study period. This approach was justified based on the time value of money making the cost of pollution avoidance today not worth investing in over the very long term (Lucuik, Eng, & Meil, 2004). Unfortunately, there was no follow up discussion as to what impacts this decision had on the study results. Running two scenarios and presenting both discounted and non-discounted results would have strengthened the argument for not discounting the environmental pollutants.

Blanchard and Reppe used a similar method of disclosing both discounted and non-discounted future cost in their study of an energy-efficient house in Ann Arbor, Michigan. For this LCA, the home was modeled using different materials with various levels of embodied energy to determine which combination had the lowest life cycle energy use and global warming potential over a fifty-year expected life. A 4% discount rate was employed when determining the range of energy costs during the use phase of the home. It was determined that the energy-efficient home used less energy overall than the standard home with the use phase having the highest energy use (1998).

This presentation was helpful as it shows the reader the effects of the time value of money. However, a discussion of the importance of the use phase geared toward the homeowner would have added more to this study. Additional discount rates using a 30-year mortgage would have been a good presentation to bring the importance of material choice into perspective for homeowners highlighting the fact that first costs are not always the best indicator of life cycle outcomes.

Zachariah used a case study to look at walls, floors, windows, cladding, and insulation in a residential application for a home in Ottawa, Canada. Using a base case house design, several design scenarios were run to determine the most efficient design in terms of environmental impact and life cycle costs. The options that were looked at included the following building envelope components: concrete walls and floors, steel walls and floors, and wood walls and floors. One of the main findings in this study was the use phase needs to be targeted in the design phase. "The operational energy accounts for 82% of the life cycle energy, 74% of the emissions to the air, 86% of the emissions to the water. Yet, the operational cost is only 12% of the total life cycle cost" (2003, pg. 101).

A study commissioned by the Canadian Wood Council (CWC) asked the Athena Institute to look at three structural framing systems: wood, light gauge steel, and insulated concrete forms (ICF). The 2400 sq.ft. home was built for the Toronto market and the purpose of it was to show the environmental implications of typical building systems used in the Toronto market. The importance of functional equivalent units was important to this case study due to the different material types. The need for LCA data sets to be used by practitioners was also mentioned so they don't have to become LCA experts to acquire environmental information related to their decisions. A concluding comment pointed out that even though much has been done there is still more to do, especially in the U.S. (Trusty & Meil, nd.).

Three residential homes were looked at by Ochoa Franco in a case study format using EIO-LCA methodology, RS Means for estimating material, and the Home Energy Saver software for quantifying use phase energy requirements. The use phase in all three cases was found to be the most important in energy use. In a significant departure from LCA and EIO-LCA formats, this study was done as a cross-sectional analysis for 1997; not a standard 50-year time period. The costs for the EIO-LCA model were derived from RS Means minus 10% for markup. However, this may not reflect the true cost to the producers of materials which is the number that should be used for the EIO-LCA model inputs (2004).

A LCA of residential heating systems in a home located in Montreal, Canada, was done by Yang to determine the life cycle energy, life cycle green house gasses, life cycle exergy (p.137) destruction, and life-cycle costs. The study focused on a gas forced air and electric hot water baseboard systems. The lack of manufacturer information was identified as a major weakness of this study in determining the boiler life-cycle inventory. To compensate for this weakness, a payoff matrix was used to determine the necessary information to use in the LCA. The pipe and duct work were estimated for the house based on manufacturer obtained data. The payoff matrix established 120 different alternatives for a heating system which were not calculated due to lack of information (2005).

In a review of the different database tools Yang identified OPTIMISE which stood out since it incorporated Canadian input/output (I/O) data into its calculations. The Canadian input/output data set has 58 commodity sectors which is far less than the 485 the U.S. tracks. It was determined that using the I/O data would result in the underestimation of greenhouse gases. Due to the lack of information, the study was limited to the production, construction, and operation phases. The assumptions were laid out in a transparent fashion but did not include variations in energy usage over time. This study found that the use phase consumed the most energy.

The hot water heating system is comprised of an electric boiler and fin type baseboard radiators for heat dispersion. The gas forced air system used natural gas for heat and an electric motor/blower to distribute the heat. The results of the study found the electric boiler used the least energy but had the highest level of embodied energy in the manufacturing phase. The opposite was found for the gas forced air system. The CO_2 emissions for the gas forced air system were found to be three times higher than the gas forced air system prior to operation. The emissions for the hot water system were less than the gas forced air during use; the lower CO_2 emissions were further helped by the amount of hydroelectric power used in Quebec. The life-cycle costs were found to be less for the hot water heat system in the use phase but the overall life-cycle costs was found to be similar for both systems over the 30-year study period. The maintenance, retrofit, and demolition were excluded from the study.

It is interesting that Yang found the I/O data would not include the GHG emissions and, therefore, understated these emissions in the data. The use of I/O data in the U.S. increases the boundaries of the study in an effort to more accurately reflect the emissions from the entire supply chain. Yang's position may have stemmed from concerns relating to data aggregation to a level that the emissions shown in the entire economy will not be representative of the emission source being studied. Overall this study varied in the location of the house (Montreal), type of heating source for the hot water, use of models for estimating costs and energy use, and availability of data since the study was done in Canada (2005).

Life-Cycle Cost

Interest in LCC

The interest in LCC in construction dates back to the 1950s when building maintenance personnel and owners started to realize the large ongoing expenses associated with the building's use phase (Bull, 1993). The application of LCC to capital investment projects looks at the trade-offs between potentially higher first costs to achieve lower life cycle costs (Fuller, n.d.). Kohler, Barth, Heitz, and Hermann identify several reasons to use LCC: "comparing competing projects, long range planning and budgeting, select among competing bidders, controlling an ongoing project, comparing logistical concepts, deciding on the replacement of aging equipment" (1997, pg. 1). Increased consumer awareness is another reason to use LCC. The energy crisis of the

1970s highlighted the role of the energy used to operate appliances over their lifetime (Hutton & Wilkie, 1980). This concern is valid for energy use in residential homes today.

LCC with Other Methods

It is no more appropriate to use LCC as a stand-alone methodology than it is to use LCA as a stand-alone methodology. The use of LCC should be complemented with additional methodologies to complement the economic data the LCC creates (Gluch & Baumann, 2004). I strongly agree that the use of multiple methods is necessary in order to make an informed decision. Not only should methods be used for specific tasks, in most cases they should not be modified in an attempt to displace another specialized methodology.

LCC Discount Rate

The basic economic principle behind LCC methodology is that things have a monetary value and dollars in different time periods cannot be compared unless the time value of money is accounted for (Gluch & Baumann, 2004). The choice of a discount rate is very important to LCC; however there are different views on how to set this rate. Most LCC studies set this rate to reflect an investor's minimum rate of return when compared to alternative investments (Fuller, n.d.; Fuller & Petersen, 1995). The U.S. DOE sets the discount rates used for energy and water conservation investments in federal buildings each year (Fuller & Petersen, 1995).

Gluch and Baumann argue that discount rates should be multi-tiered to reflect different levels of environmental effects. There would be a red level that would not discount any item that negatively affects the environment in the future in the same way it does today. A yellow level would be used for things that have uncertain effects on the environment and green would be used for those things that have no affect on the environment. Their argument is that a higher discount rate would more accurately reflect important costs that are close in time. Discounting red items at a high rate makes the present value of these items look cheap in today's dollars, so why try to limit the pollution (2004). All these arguments are accurate and highlight the values that go into the choice of the discount rate.

Importance of the Study

The need for LCA-related studies is well-documented. The National Association of Home Builders (NAHB) prepared a report for the U.S. Department of Housing and Urban Development citing the need for case studies to "quantify the benefits of green building products" (NAHB Research Center, Inc., 2001, pg. ii). Cole identifies several benefits resulting from environmental assessments of buildings: building team expertise, reference source, building occupant education, organization of complex information to help manage the building, and as a way to measure the environmental efforts a building owner has undertaken (1998).

Recently Fava and Cooper reviewed the capacity of North America relating to LCA and found that they are catching up with the Europeans in the areas of "skills, datasets, tools and knowledge needed to more fully incorporate life-cycle information into private and public-decision making processes" (2004, pg. 8). Even with these advances, they identify three areas where increased awareness is needed: new product development and innovation, increased knowledge through pilot LCA studies to incorporate into the decision making process, and product branding and position development with customers (Fava & Cooper, 2004).

This study will provide information about solar hot water radiant heat systems and gas forced air heating systems in residential construction for a specific region of the Unites States using both LCA and LCC methodologies. A key difference between this study and existing studies is that this one is taking place during the design phase so the homeowners can choose the system that best fits their needs, budget, concern for the environment, and future resale market conditions. Yang did focus on a residential heating system but it was in an existing home, in a different climate, used different system components, a hydroelectric energy source was available, a different analysis tool was used and the goal of the study was sufficiently different to justify further studies. Although the LCA component information from this study will be site-specific, the transparent nature of the framework will allow others to replicate or conduct similar studies on their own.

CHAPTER 3: RESEARCH METHODOLOGY

Research Design

The built environment impacts the world's ecosystems, natural resources, water resources and air quality. Therefore, it is becoming increasingly necessary to expand the current economic decision making criterion to include the measurement of the non-monetary impacts of construction related decisions. To this end, the construction industry adopted LCA from the manufacturing sector to help identify and better understand the environmental effects of construction projects.

An alternative to the traditional LCA methodology is Economic Input/Output Life-Cycle Assessment (EIO-LCA) that uses data from the entire supply chain, not just data from a specific project within a set boundary, which increases the impacts measured to include the entire economy. The boundary expansion increases the understanding of the total environmental impact of a product, process, or system choice. A combination of the traditional LCA and EIO-LCA models is referred to as a Hybrid model. The use of LCA and EIO-LCA in conjunction with the existing LCC methodologies, IRR and NPV, help decision makers strike a balance in designing and building structures that are both economically and environmentally responsible.

Environmental Analysis

Life-Cycle Assessment

LCA provides a systematic framework for the quantification of the environmental outputs of a product, process, or system choice based on the system boundary and related inventory components. This results in an impact assessment, Figure 1. All the inflow and outflow streams are identified in the inventory analysis and mass-balance calculations (inputs equal outputs) are applied to them (Guggemos, 2003). Mass balance calculations are used to validate the unit process flows and may identify the presence of an unknown emission if inputs do not equal outputs (Hendrickson, Lave, & Matthews, 2006).

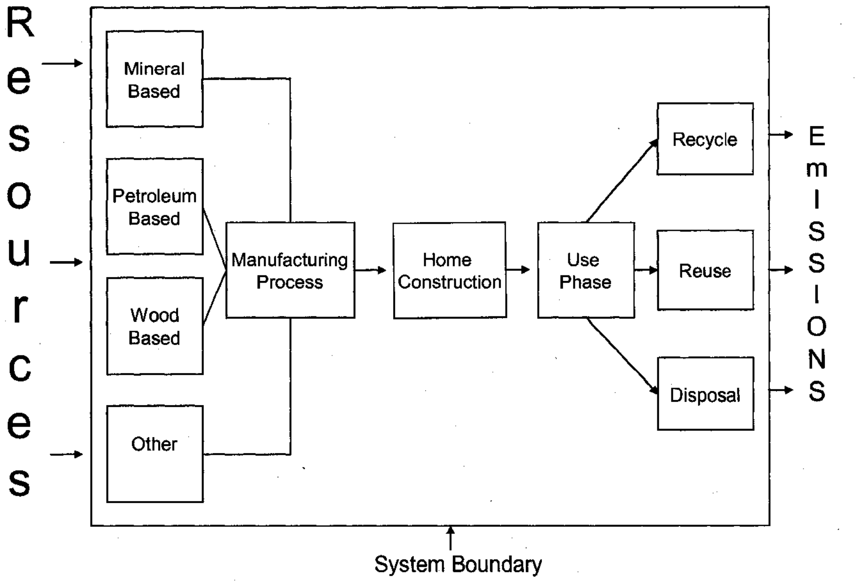

Figure* 1. A Conceptual Model of a Residential LCA *Outline

The LCA examines every identifiable stage in a product life-cycle: material resource extraction, conversion, manufacturing, use and maintenance, and disposal/recycle/reuse (Fava, Dennison, Jones, Curran, Vigon, Selke, & Barnum, 1991; Curran, 1996; Tibor & Feldman, 1996) (Figure 2). Some of the applications of LCA include product comparison, new product design, determining where problems originate, and trying to look at variations to improve the product (Guinee, Huppes, Lankreijer, Udo de Haes, Sleeswijk, et al., 1992).

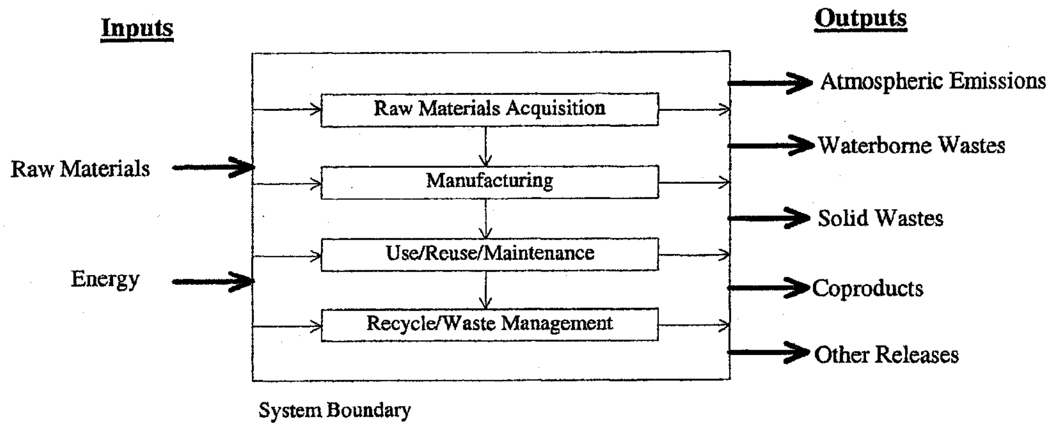

Figure **2. Life-Cycle Stages of a Product or Process.** Source: SETAC, 1991.

Once the LCA is completed, an additional step of improvement analysis may be undertaken to minimize the environmental impacts of a decision(s). Some of the major organizations promoting the use of LCA are: the International Organization for Standardization (ISO), the U.S. Environmental Protection Agency (EPA), The Society for Environmental Toxicology and Chemistry (SETAC), American Center for Life Cycle Assessment, National Institute of Standards and Technology (NIST), and the United Nations Environment Program, Division of Technology, Industry and Economics (Professional Interest Groups, 2005).

The LCA Process

The LCA consists of several major steps with each having its own ISO standard: inventory analysis, impact assessment, and improvement assessment. ISO standards are used here as they are similar to the SETAC methodology (Azapagic, 1999). ISO 14041 addresses the goal and scope of the study and inventory analysis, ISO 14042 addresses impact assessment and ISO 14043 governs improvement assessment (The ISO Family of Standards, Guides and Technical Reports-including drafts, nd.).

Inventory Analysis

In this step, the "goal definition/scope and inventory analysis" (LCI) (Sayre, 1996, pg. 41) of the study are defined. What goals and scope are chosen for a LCA usually are in response to a question that is posed by an individual, group, or a governmental body (Curran, 1996). For example which heating system is better over the life cycle, both environmentally and economically? The scope determines if the study will include all products in a group (forced air heating systems) or a specific model(s) (Trane Model 200 and the Buderus 1102). The boundaries of the study are then established to determine what is included and excluded from the model. Once these parameters are established the process of creating an inventory may begin.

There are two commonly used methods for creating an inventory analysis, "process analysis and input-output analysis" (Suh, Lenzen, Treloar, Hondo, Horvath, Huppes, et al., 2004, pg. 658). The process diagram begins with the creation of a flow chart depicting the overall process as defined in the goal/scope step. Inputs and outputs from each life-cycle stage are identified as well as the related products, equipment, and processes. From this flow chart, detailed process diagrams are created showing the necessary levels of processes that enable the researcher to fulfill the scope requirements of the study. These detailed diagrams form the basis that guides the data collection efforts of the researcher (Ciambrone, 1997). Previous studies have found, without a significant impact on the study findings, that due to time and costs considerations it is only necessary to identify key processes and products for inclusion into the overall process diagram (Guggemos, 2003).

Impact Assessment

The impact assessment process is where comparisons of different products or processes take place (Rahimi & Weidner, 2004). It is in this stage that the inventory items previously identified are assessed and the environmental impacts of each phase of the products life cycle are determined. This determination is based on information that is available on publicly accessible data bases.

Improvement Assessment

The improvement assessment is used to look at alternatives that may be available other than those proposed that will reduce the impacts to the environment. If other LCAs were done or available, those results could be compared to the current study if the goals and scope of the existing studies are similar. The final result is the making of recommendations that meet the intent of the goal and scope of the study and ultimately those of the people asking the initial question.

EIO-LCA

The purpose of a traditional process-based LCA is to focus on the environmental effects of a specific product, process, or service within a set boundary; it does not include the whole supply chain. This shortcoming was identified by researchers who argued that economy-wide environmental implications of products could not be fully ascertained unless the economic implications were represented in the LCA model (Hundal, 2002). Using input-output models developed by Wassily Leontiff and the information available from the U.S. government, researchers at Carnegie Mellon University's Green Design Institute developed an EIO-LCA model that encompasses the entire supply chain for 480 sector final demands of the economy (Hendrickson, Lave, & Matthews, 2006). By using this information, the boundary of a process being studied is increased to encompass the entire supply chain adding the indirect effects to the direct effects of using a product, process, or system.

Advantages and Disadvantages of LCA and EIO-LCA Methodologies

As shown in Table 2, there are both advantages and disadvantages to LCA and EIO-LCA. Other limitations to LCA have also surfaced (Suh, Lenzen, Treloar, Hondo, Horvath, Huppes, et al., 2004; Heiskanen, 2001; LCA 101- Introduction to LCA, 2001; Guinee ed., 2002):

A. Inventory process diagrams are constrained by the system boundaries assuming upstream impacts have only minor effects.

B. LCA is based on societal norms, values, and assumptions and affect the study boundary.

C. Data is not always available and accurate.

D. Data may be hard to collect.

E. Time is a factor and may hold up a decision process.

F. Economic resource commitment is large.

G. It is difficult to accurately identify all impacts of a process.

Table 2. Advantages and Disadvantages of Two Life-Cycle Assessment Approaches.
Source: (Hendricks, Lave & Matthews, 2006, pg. 25)

	Process Models	*EIO-LCA*
Advantages	Detailed Process-specific analysis	Economy-wide, comprehensive assessments (all direct and indirect environmental effects included
	Specific product comparisons	System LCA: industries, products, services, national economy
	Process improvement, weak point analysis	Sensitivity analysis, scenario planning
	Future product development assessments	Publicly available data, reproducible results
Disadvantages	System boundary-setting subjective	Some product assessment contain aggregate data
	Tend to be time-intensive and costly	Process assessment difficult
	New process design difficult	Difficulty linking dollar values to physical units
	Use of proprietary data	Economic and environmental data may reflect past practices
	Cannot be replicated if confidential data are used	Imports treated as U.S. products
	Uncertainty in data	Difficult to apply to an open economy (with substantial non-comparable imports)
		Non-U.S. data availability a problem

H. There are multiple processes that may lead to competing answers.

I. Local impacts are not addressed.

J. LCA is not dynamic in nature so future changes in technology are not considered.

K. LCA is based on non-linear modeling.

L. Although the focus of an LCA is on the environment, usually as potential impacts, it ignores for the most part the economic and social characteristics.

Hybrid LCA Approach

Having considering these issues LCA and EIO-LCA are useful methodologies and were used to help determine which of the two residential heating systems appears to be the best choice environmentally. In the cases where data is too aggregated in the EIO-LCA model, process diagrams helped identify the material flows (Figure 3). The combination of using EIO-LCA and the traditional LCA process diagrams is referred to as the hybrid approach: a combination of the strengths of the two methods. This information adds to the knowledge base for others doing LCA and EIO-LCA in the construction industry.

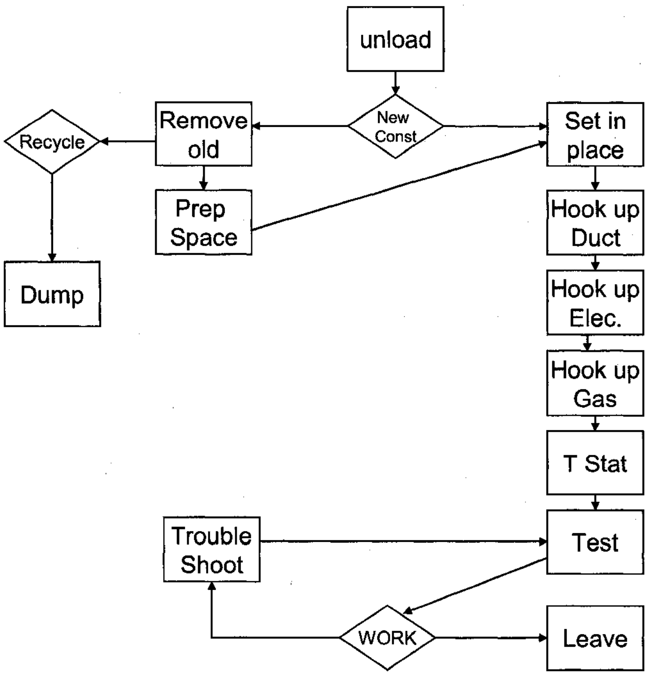

Figure **3. Process Diagram for a Furnace Installation**

Economic Analysis

First costs are a common parameter for decision making in construction for a conceptual cost figure. The three most commonly used financial tools for more in-depth analysis in the building sector are simple payback, Internal Rate of Return (IRR), and Net Present Value (NPV) (Bull, 1993). These tools are divided into two distinct categories. The first costs and simple payback tools do not take into account the time value of money. Both the NPV and IRR tools consider the time value of money and are considered LCC tools. This type of analysis presents a more accurate picture of the true costs of owning a building and allows the decision makers the ability to make better informed decisions in the design phase.

First Costs

First costs are used to determine the estimated costs for the building and include all systems costs. This method can be a first cut analysis for the owner to determine the feasibility of a project. Once the feasibility of a project is determined the use for this method varies. A developer that intends to sell the building immediately upon completion uses the numbers to determine the potential profit they may expect to realize. For owners who intend to occupy the building they may wish to do additional analysis to determine if they want to spend more money up front to purchase more efficient systems that will lower their cost of ownership over the life of the building.

Simple Payback

The simple payback method indicates the amount of time that it will take to recover the investment. An example of this analysis is the decision to replace the lighting fixtures in a building to attain lower utility bills. If the costs to replace the fixtures are $5,000 and the predicted savings on electricity are $1,000 per year then it will take you 5 years (5000/1000) to recover your investment. This method does not consider the time value of money.

Life Cycle Costs

The concept of Life-Cycle Costs looks at the costs throughout all phases of a building or a system's entire expected useful life. It "can be described as a means of auditing the financial consequences of a decision" (Bull, 1993, pg. 2). "A life cycle cost indicates that the first cost alone is not enough to evaluate fully an article or system but that all costs incurred over the life cycle must be considered" (Howlett & Ramesh, 1995, pg. 125). The common phases analyzed are manufacturing, construction, use and maintenance, and disposal. Depending on the building or system type this time period could span up to 50 years or longer if adaptive reuse of the building is an option. Once costs are identified, they are placed into a timeline indicating where in the future they are expected to take place. The next step is to analyze these costs using IRR or NPV, two of the more commonly accepted analysis methods used to consider the time value of money.

Internal Rate of Return

The IRR determines the amount that needs to be earned on the investment to provide a zero NPV. This figure is then compared to other investment choices to determine which projects, if any, to invest in. "Defined as the percentage earned on the amount of capital invested in each year of the life of the project after allowing for the repayment of the sum originally invested" (Bull, 2003, pg. 3).

Net Present Value

In the NPV method, a discount rate is chosen based on the cost of capital or minimum expected return and the resulting calculations show the amount of money needed today, the NPV, to meet all future known costs associated with an investment. The NPV method "can only be used as a tool in the design process to evaluate the financial differences between a finite number of mutually exclusive schemes" (Bull, 2003, pg. 9).

Advantages and Disadvantages of LCC

As shown in Table 3 there are both advantages and disadvantages to LCC.

Table 3. LCC-oriented Tools Advantages and Disadvantages. Source: (Adapted from Gulch and Baumann, 2004).

Advantages	Disadvantages
Uses a familiar unit, money	Fails to handle decisions under uncertainty
Gives an indication on which aspects to consider	Fails to handle irreversible decisions
Limits the information flow by simplifying multi-attributed alternatives	Neglects items without an owner, such as the environment
May entail learning by participating in the calculation process	Over-simplifies environmental problems into monetary dimension
Has a life cycle perspective	Underrates future environmental costs
	Suffers from poor availability and reliability of data
	Relies on many estimated variables due to the complexity of the building and building process
	Results in bias towards the decision maker's personal values
	May restrain learning if too mechanically used
	Is beset with conceptual confusion due to many similar LCC-oriented tools and inconsistent life cycles

Choice of Methodologies

The hybrid LCA and NPV of LCC methodologies will be followed since they are the standard methodologies for this type of research. The LCA provides an evaluation of the entire environmental impact during a product, process, or systems life-cycle, from cradle to grave (Thomas, Theis, Lifset, Grasso, Kim, Koshland, et al., 2003). Based on its inclusiveness, LCA is the legitimate accepted method of choice for comparing competing alternative products in the building industry according to Shen and Feeser (1997); and Peuportier (2001). Hendrickson, Lave, and Matthews remind us that EIO-LCA results are still controversial and they should not be represented as just dollars. It is important to remember that these results are estimates of the possible environmental impacts based on differing situations (2006). LCC is the preferred method to assess costs in construction-related decision making (Cole & Sterner, 2000).

The goal of both LCA and LCC is to look at specific costs over the life-cycle of a product, process, or service. Although the goals are similar, there are important differences in both purpose and approach. The combined use of both methods is part of the tool box approach described by Udo de Hes, Heijungs, Suh, and Huppes where different tools that complement each other are used to support a policy or business decision while maintaining separate results (2004). The LCA is trying to answer questions concerning environmental implications of different products providing the same utility or function. LCC compares the economics of different investments (Norris, 2001). A summary developed by Norris of these methodological differences can be found in Table 4. In the case of selecting a residential heating system, LCA and LCC provide the decision maker with additional and better information on which to base the decision of which system to select.

One of the major differences Norris points out is the timing aspect of the information used in the two types of analysis. The LCC uses time in the accounting sense where the economic life of a product is usually determined by the Internal Revenue

Service through the tax code. In sharp contrast, LCA makes no distinction about the timing of events relating to a product (2001).

Table 4. How LCA and LCC Differ in Purpose and Approach. Source: (Norris, 2001)

Tool/Method	LCA	LCC
Purpose	Compare relative environmental performance of alternative product systems for meeting the same end-use function, from a broad, societal perspective	Determine cost effectiveness of alternative investments and business decisions, from the perspective of an economic decision maker such as a manufacturing firm or consumer
"Life Cycle" Activities	All processes causally connected to the physical life cycle of the product; including the entire pre-usage supply chain; use and the process supplying use; end-of-life and the processes supplying end-of-life steps	Activities causing direct costs or benefits to the decision maker during the economic life of the investment, as a result of the investments
Flows Considered	Pollutants, resources, and inter-process flows of materials and energy	Cost and benefit monetary flows directly impacting decision maker
Units for tracking flows	Primarily mass and energy; occasionally volume, other physical units	Monetary units (e.g. dollars, euro, etc.)
Time treatment and scope	The timing of processes and their release or consumption flows is traditionally ignored; impact assessment may address a fixed-time window of impacts (e.g.,100-year time horizon for assessing global warming potentials) but future impacts are generally not discounted	Timing is critical, present valuing (discounting) of costs and benefits; specific time horizon scope is adopted, and any costs or benefits occurring outside that scope are ignored

Validity and Reliability

The issue of validity and reliability are important to any type of research. The case study will use the hybrid approach combining traditional LCA and EIO-LCA and NPV of LCC. There are two free analysis tools available online: eiolca.net for EIO-LCA and Building Life Cycle Cost (BLCC5.3) for LCC. The use of computer-based tools may be problematic for the researcher if the logic process, assumptions, values, and data incorporated into the tool or program are not disclosed to the user. Norris and Yost remind us that "the databases should make the results of an LCA repeatable and verifiable" (2002, pg. 16). Tool validity can be established by running multiple studies of several products and examining the results looking for similarities in the results. For example, several contractors may be considering using heating systems for new home construction similar to those in this study. Each of them should be able to use the same tools and assumptions, modified for geographic, home size, fuel type, and family size differences, and obtain results similar to those of this study. If these results appear to be reasonable, then the tool is probably valid and reliable.

In the case of LCA tools, the independent scientific testing of individual tools is problematic: "Given the approach of the tool developers, it can be very difficult to disprove outputs of LCA tools" (NAHB Research Center, Inc., 2001, pg. 16). The use of multiple tools to perform a LCA, EIO-LCA, or LCC may not produce the intended results of typical triangulation of data unless the tool user can access the logic of each tool prior to use to determine any necessary adjustments that would make the tool results comparable. The use of three or more tools to verify the results may provide different answers which are technically correct based on the internal logic and data. However, it still may be beneficial to compare results across models due to the high level of uncertainty in LCA (Hendrickson, Lave, & Matthews, 2006).

As previously mentioned the areas of uncertainty for EIO-LCA are numerous and can affect the validity of such studies: survey errors, old data, incomplete data, missing data, aggregation, and imports. The overall uncertainty from LCA studies is estimated to be about 10-20% since multiple errors in both the economic and environmental coefficients cancel out in the computation process (Hendrickson, Lave, & Matthews, 2006). Of importance to validity and reliability in this study is the similarity of the products being compared; two heating systems. Hendrickson, Lave, and Matthews point out that the comparison of two products is less subject to uncertainty since the similarities are positively correlated resulting in a more accurate impact estimation than either product studied alone (2006).

The one common issue that plagues all methodologies that look into the future is the use of estimates, predictions, approximations, and assumptions as how some future event will unfold. Energy usage is difficult to predict in the design phase of a building even using a simulation program. Energy price projections are difficult due to the political conflicts in oil-rich countries, increasing world demand, the introduction of alternative sources of energy, conservation efforts, and new technology. Non-fuel operating costs are difficult to estimate and may vary from one building to the next even if they are identical. The discount rate used in LCC is of particular importance due to time value of money and the affect the discount rate has on the cash flows. All this uncertainty can affect the validity of the study since estimated and actual values may vary (Fuller, n.d.).

Reliance on estimates, predictions, approximations, and assumptions for data creation and analysis are subject to values. The thought process used in a LCA or LCC to predict future uses or costs may be perfectly valid in the case where a single person has control over the entire life-cycle. In reality, this is very seldom the case and, in the instances where it does happen, there are external factors that cannot be controlled, e.g. politics, economic conditions, conflicts, product availability, technology.

Although each methodology (LCA, EIO-LCA, and LCC) has inherent weaknesses, it is better to use a methodology and disclose its weaknesses than to not have any methods to use at all. The use of multiple methods adds another level of balance to the decision process. Methods that measure the same outcome can be used for triangulation adding certainty to the decision. Methods that measure specific concerns associated with decisions let decision makers assimilate a balanced approach to product, process, and system selection decisions. The key in using one or more methods is the transparency of the process. If a study can be replicated and the results are the same or very similar, then the reliability of the study information and claims increases. If the data used is subject to confirmation, then the validity of the process increases.

Data Collection

The concept of using a hybrid approach is to achieve the best of both worlds by using both the LCA and EIO-LCA approaches. While the LCA method uses process diagrams to disaggregate data and get more detail than that available for EIO-LCA, using EIO-LCA overcomes the boundary limitations of process analysis (Hendrickson, Lave, & Matthews, 2006). Figure 4 illustrates the hybrid approach. In cases where the EIO-LCA data is too aggregated or the eiolca.net model does not support an appropriate North American Industry Classification System (NAICS) category, a process model can be used to identify detailed information for placement into an appropriate NAICS category for EIO-LCA processing (Hendrickson, Lave, & Matthews, 2006).

An example of this would be the construction and end-of-life phases for which there is no NAICS classification. In these phases, the hybrid model would be employed and process models would be used to identify the material and equipment flows. Once identified, these flows would be loaded with environmental burdens from other studies or by using NAICS and the eiolca.net software.

The potential weakness in this approach is that the NAICS categories represent the U.S. economy, not imports. If the solar collectors are made in China for example, then a process diagram would be used to identify differences in manufacturing technology, transportation effects, and any other aspect of manufacturing or delivery that would not be accurately measured by using the EIO-LCA process: the hybrid approach.

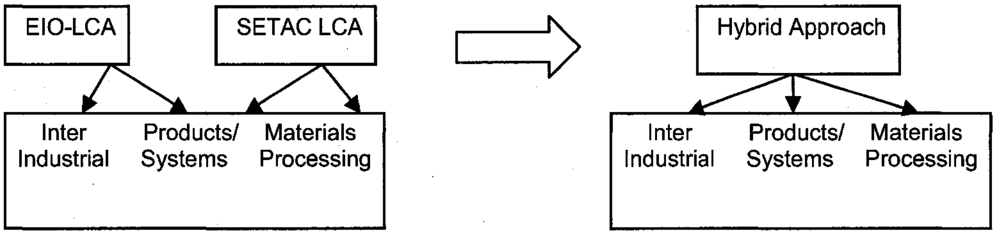

Figure 4. Application Areas of EIO-LCA, Process LCA, and Hybrid Approaches. Source: (Hendrickson, Lave, & Matthews, 2006, pg. 28).

The areas in which process analysis is typically used are construction and end-of-life (Figure 5); however, the hybrid model incorporates the process diagram information to provide the basis for the information processed by the eiolca.net tool in both the construction and use phases. EIO-LCA could be used in the construction phase but the data is aggregated and the use of the hybrid approach will yield better data. There is no NAICS category for the disposal phase so this would be analyzed using a hybrid-based LCA.

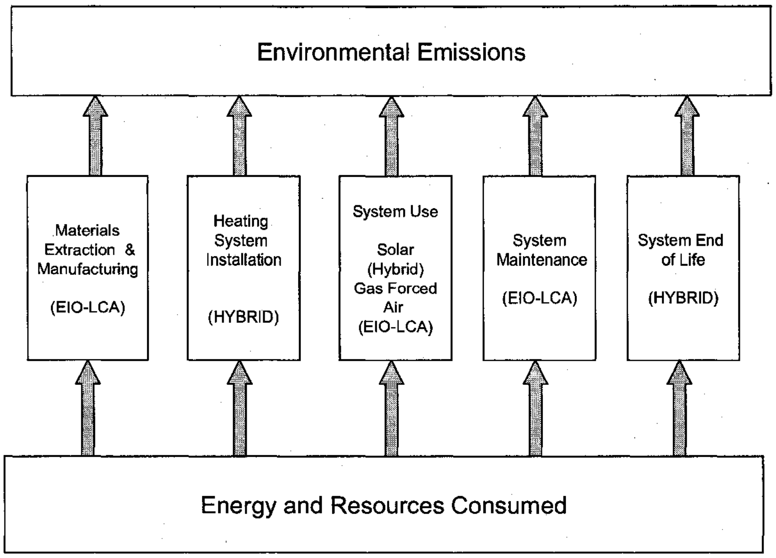

Figure **5. Residential Heating Systems Life-Cycle Phases.** Source: (Adapted from Guggemos, 2003).

Hybrid LCA Data

The information necessary for EIO-LCA are producer costs, consumer price index to convert current dollar costs to base year (1997) dollars to match the current eiolca.net data set, NAICS categories for the main components of each system, and the percentages of each component in relation to the price paid to the producer to calculate the individual NAICS percentages. Both the solar and gas heating systems consist of prefabricated component parts that are assembled on the job site; thus, there is little, if any, manufacturing of parts on the job site. This will make the manufacturing phase somewhat straightforward for both systems to run the EIO-LCA using eiolca.net.

Data will be collected from several sources. RS Means and hard bids will provide costs data and job durations. Material markup information may come from a supplier, estimate, or government figures. Transportation from the supplier, recycler, and landfill will be actual mileage and worker transportation will be estimated mileage from government sources like the Federal Highway Administrations NT-5 average vehicle trip lengths. Emissions factors and other data for the traditional LCA will come from various government and private sources: U.S. EPA "Unit Conversions, Emissions Factors, and other Reference Data," U.S. EPA "CO_2 Emissions from Fossil Fuel Combustion Million Metric Tons CO_2," and salary estimates will come from websites like PAS1 (PAS1.com, n.d.) that specialize in construction salary surveys. If historical data is available, it will be used.

LCC Data

The LCC process is data intensive, time consuming, and has several specific areas of focus: economic or profitability, physical or actual time the building may be occupied, technical or obsolescence due to new technologies, and utility or the time period the building can meet performance expectations (Gluch & Baumann, 2004). Once the focus of the LCC is chosen, the data needed for the study can be identified and collected. Some of the key data types are shown in Table 5.

Once the data requirements are identified the data can come from historical costs, forecasts, estimated standards, or average building use (Gluch & Baumann, 2004).

Data for the initial investment costs will come from RS Means and hard bids. Data sources available for the use and maintenance phases include historical records, service records, and manufacturer requirements. Historical records of the owner relating to energy usage may be a good indicator of lifestyle preferences and expected future

Table 5. Examples of Input Data Needed to Perform an LCC for a Building. Source: (Gluch & Baumann, 2004).

Investment cost data	Operation and maintenance data	Project specific data
Building costs	Administration	Type of building
Site costs	Energy	Type of design
Design fees	Water	Type of building material
Salvage value	Waste water	Location
Demolition costs	Material	Lifetime periods
Other	Cleaning	Other specific data
	Maintenance	
	Insurance costs	
	Rates	
	Taxes	
	Other	

usages of fuel and electricity. Service technicians can provide information for maintenance based on service calls for specific models in the region. Manufacturer requirements and recommendations are also good sources and provide information on required service intervals. Salvage values can be determined from local installers, salvagers, and perhaps from websites specializing in used equipment.

Local utilities provide costs for electric, water, and gas and may have long-term projections to share for expected future costs. The Energy Information Administration's "Natural Gas Consumption and Expenditures in U.S. households by End Uses and Census Region" provide average consumption data by housing unit type, fuel type, and census region. The future energy cost escalation figures are imbedded in the BLCC software that will be used for the LCC calculation and those costs are based on fuel type and current cost in this area. They are also listed in the annual supplement to the NIST Handbook 135 which is the Department of Energy's guide to performing Life-Cycle Cost Analysis.

Data Analysis

Research using the LCA methodology is also referred to as an "embedded" case study. The embedded case study has four main focuses: levels of knowledge, ways to synthesize the information, knowledge integration in the case study, and types of knowledge integration (Scholz & Tietje, 2002). At the first level, the case, a baseline understanding of the case is developed. This is done through the goal definition and scope process of the LCA. The knowledge synthesis process in the embedded case study is done in the inventory analysis process of the LCA by placing the components into real world processes and impacts: process mapping.

The importance of the embedded case study to this research is the use of mixed methods. The LCA and LCC methodologies create a lot of data that is presented in tables, charts, and figures. The power of the qualitative description of these data cannot be discounted. If the information from the LCA and LCC cannot be understood by the reader or practitioner, then the data will not be used in the decision making process of heating system selection in residential buildings. The embedded case study will bridge any gaps that users of this information may have concerning the data interpretation.

It is important that the researcher not make statements about facts for which there is no support. For example, one could not say that based on an LCA, solar heating systems are always more environmentally-friendly than a gas-forced air heating system. One could state that given the same scope and use, some materials in a solar hot water heating system appear to be more environmentally-friendly than those in a gas-forced air heating system. The same could be said for the use of LCC. One could not say that the solar hot water heat system is always more expensive than the gas forced air system.

This could be true for a specific house on a specific lot but not for all houses of the same size. A different setting may result in more concrete mass in the foundation which could serve as heat storage reducing the economic costs of the solar heat system.

The focus of the LCA portion of the study will be on GHG emissions and GWP and energy use. The quantitative data analysis will be done using the free software EIO-LCA tool developed by Carnegie Mellon's Green Design Institute, eiolca.net for the phases using EIO-LCA. This tool has six categories of analysis if additional information is needed for specific analysis: Energy, Green House Gasses, Toxic Releases, Economic Activity, Conventional Air Pollutants, and Employment. The process-based LCA information will be analyzed manually using data from sources previously noted.

The focus of the LCC portion of the study will be on the NPV of the LCC obtained from the previously noted sources. The LCC quantitative data will be analyzed using the free Building Life Cycle Cost (BLCC5.3) program, version 5.3-07 available for download from the Department of Energy. The quantitative portion will be followed by a qualitative discussion of the results in a manner that addresses the research questions.

The use of LCC as a financial tool is widely practiced in both private and public sectors. The use of LCA, EIO-LCA, in the hybrid format for estimating the environmental impacts of construction-related decisions appears logical. By combining LCC and LCA, there will be additional information to consider along with real estate market conditions, demographics, political climate, and budget considerations when deciding which heating system to use.

CHAPTER 4: DATA COLLECTION AND RESULTS

EIO-LCA Framework

Overview

For the manufacturing, use, and maintenance phases, the macro level steps needed to assimilate and organize the information necessary to perform an EIO-LCA on the materials needed to manufacture, use, and maintain any number of residential heating systems is shown in Figure 6. However, there are important differences between the manufacturing and use/maintenance phases. One important difference between the manufacturing and use/maintenance phases are the estimated use of energy, replacement parts, inspections, and repairs. Unlike a bid or construction estimate that covers a short time horizon, the use/maintenance phase estimates cover the expected life of the product, process, or system being studied; in this case a residential heating system. The information for these phases may come from one or more of the following sources: past experience, estimates, industry averages, and programs using discounted cash flow analysis. In all cases, the collection of data should be well-documented for future reference.

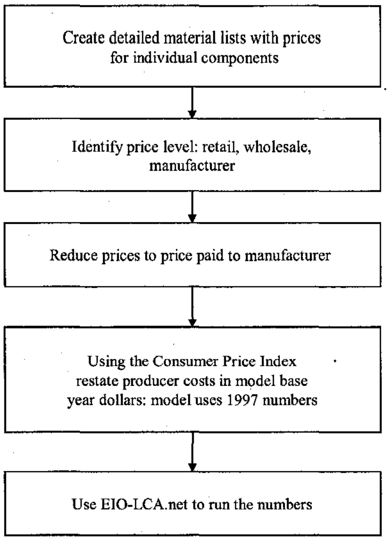

Figure 6. **Data Collection Steps for EIO-LCA Modeling of Residential Heating Systems Materials.**

Once a system or systems are chosen for emission and/or costs evaluation, the framework moves to a micro level enabling the user to access existing websites and create the needed information for analysis.

GFA and SRS LCA Data Collection for Manufacturing, Use, and Maintenance Phases

The framework for doing an EIO-LCA using the web based eiolca.net tool is presented in Figure 7. This framework is at the micro level and provides a step-by-step process for users of the online tool eiolca.net to follow to create and evaluate data for all project, process, or system phases being analyzed using the EIO-LCA method outlined in chapter three.

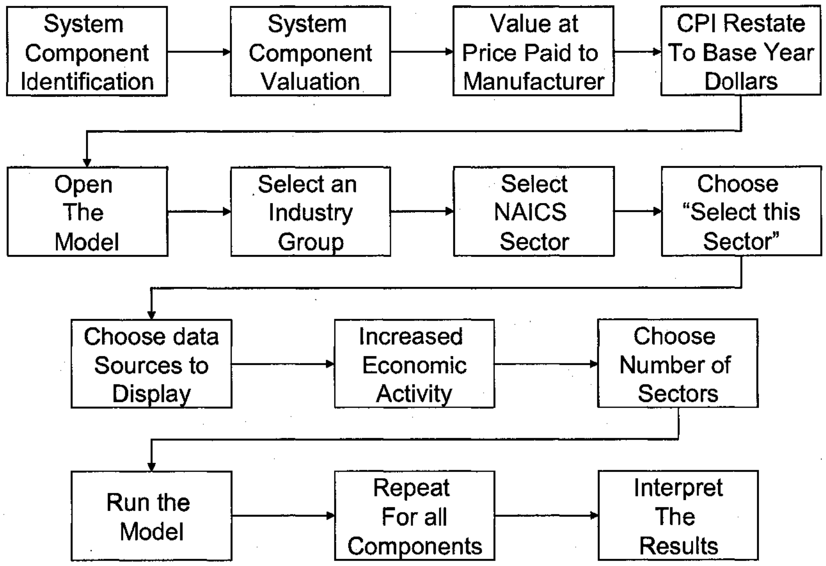

***Figure* 7. Framework for Performing an EIO-LCA using EIO-LCA.net**

The amount of information needed to perform an LCA on individual or multiple residential heating systems creates a lot of data. In an effort to make this process easier, the framework user may want to consider creating a simple Excel spread sheet. This will help in the documentation process while ensuring that no steps are left out of the LCA process. The following explanations of the framework steps found in Figure 7 will help in the development of this spreadsheet.

System Component Identification

The information needed for the system component identification comes from a material list. This list originates from either a detailed estimate which breaks down system components and their individual costs, an estimate done using a resource such as RS Means residential costs data, or an estimate with a fixed-dollar bid where the detail is created using a source like RS Means to estimate the individual system components. A reference like Means can be used to reduce a fixed-dollar bid price to the component level showing individual parts and quantities with a reasonable level of certainty. The detailed estimate is the easiest to use and also the most indicative of the actual quantity of materials used in the system. However, any assumptions used in this process should be clearly stated for future reference and variance analysis where appropriate. The materials can now be priced and grouped with similar items, if warranted.

System Component Valuation

The prices come from the same sources as the materials lists previously mentioned: a lump sum bid or a detailed bid giving detailed component prices. Getting a detailed bid may be difficult since the profit margin is usually closely held information. An explanation to the subcontractor may help with this request and the amounts can be in similar categories: pumps, electronic controls, duct work, etc. If a lump sum bid is given, the individual component prices may be determined using Means or a similar estimating source at the same time the materials lists is compiled.

Value at Price paid to the Manufacturer

Next, the associated price paid to the manufacturer for each material needs to be determined either by manufacturer's data, industry averages, or an estimate, if necessary. If you purchase at a retail level, there are markups from the retailer to you. These must be estimated if not known to reduce the costs to what the retailer paid the wholesaler. If you purchase at the wholesale level, this price includes a markup from the wholesaler to you and it, too, must be estimated if not known to reduce the costs to what the wholesaler paid the manufacturer.

CPI Restate to Base Year Dollars

The price paid to the manufacturer now needs to be reduced to the base year data set used in the eiolca.net tool. The eiolca.net tool as of this writing uses data from 1997 which is referred to as the base year. This means that all costs incurred after 1997 to purchase materials need to be converted to base year dollars. The use of the Consumer Price Index (CPI) is an acceptable method to accomplish this task (Bureau of Labor Statistics, n.d.). You will need two numbers, the base year CPI value and the current year CPI value. Take the base year CPI number and divide it by the current year CPI number; the resulting percentage is multiplied with the price paid to the manufacturer value calculated in the previous step. This deflated price paid to the manufacturer is the dollar amount that will be entered into the eiolca.net tool.

Select Industry Group

The next step is the choice of an industry group and the eiolca.net tool needs to be open for this step. Once at the website click on "use the model." The column on the left of the screen titled "Industry Group List" is the broadest level of North American Industry Classification Standard (NAICS) codes. It is important to note that not all broad categories contain the economic sectors that one would think. Therefore, it is important to browse through all the choices at this level to become familiar with the content. The goal is to pick a group that best represents each of the specific components, materials, or parts identified in the material list step. Once you choose a group, the detailed industry sectors for that group come up in the box to the right, giving you more NAICS sector choices.

Select NAICS Sector

The NAICS reference numbers used in this study were gleaned from the EIO-LCA.net model last accessed 10-26-07. Appendix A shows the home page of the eiolca.net tool. This needs to be done to ensure that the NAICS category chosen accurately describes and includes the system components that are being studied. Once the first category is chosen from the industry group list, the related "industry sectors" list will appear to the right. Once an industry sector is chosen, a drop-down list of the related manufacturing sectors is displayed under the "select a sector" icon on the right of the screen under industry group. Be sure to review this list prior to hitting the "select this sector" icon to ensure that you are measuring the appropriate product and industry-related data.

Choose Data Sources to Display

After a sector is selected, a new screen will appear with a question asking "which data sources would you like to display? The model lets you choose from five levels of data source impacts: Economic Activity, Conventional Air Pollutants, Greenhouse Gases, Energy, and Toxic Releases.

Increased Economic Activity

The next question is "for what level of increased economic activity in the selected sector?" The million dollar unit of measure is the default. The drop-down menu gives you the choice of dollars, thousands, millions, and billions. The dollars level should be chosen if any of the material costs are less than one thousand dollars. Once you choose the correct dollar level measurement, you then enter the base year dollar value calculated previously in the CPI step.

Choose Number of Sectors

The next step is to choose the amount of sectors to display. The choices are 5, 10, 25, 50, 100, and all. Usually the top Five are sufficient as it will give you the total supply chain impacts for the entire sector as well as the top five contributing sectors to the total. Once all the choices are made, the user selects "Run the Model" and outputs are displayed based on the choices made for economic activity, impacts, and sector.

Once you run the model, you can look at other data source categories or change the number of sectors to display. At the top of the screen, two icons appear, giving you these choices. If you choose this option, you can add the additional data to your Excel spreadsheets in additional workbooks.

Once you run the model, the EIO-LCA program provides a display showing a column for Sector. The other columns show the emissions calculated in total and individually. The rows start with "Total for all sectors." The following rows are identified by the NAICS number to the left and then the NAICS sector description. The model results are displayed in tables showing amounts for each output analyzed. For "Greenhouse Gases," the outputs are GWP, CO_2, CH_4, N2O, and CFCs. For "Energy," the outputs are Total Terajoules (TJ), Electricity, Coal, Natural Gas, Liquefied Petroleum Gas (LPG), Motor Gas (MotGas), Distillate, Kerosene (Kero), Jet Fuel, and Residual. The value for "Total for all sectors" is the figure that is representative of the entire supply chain impacts for that NAICS sector. These numbers can be transferred to your Excel spreadsheet using the cut and paste command.

Repeat for All Components

These steps will be repeated for each product, material, or part identified in the material lists until all impacts of interest are known. For example, if you are comparing three heating systems it will be necessary to do each of the fourteen steps three times for the manufacturing, use, and maintenance phases. It is important not to group too many similar materials together as that will make the analysis and material substitution process more difficult in the improvement process.

Once you model each material, material group, or product, the impacts calculated in EIO-LCA can be totaled and analyzed. The development of a single spread sheet focusing on one impact category is recommended to start with. Once the processes are developed and checked, then additional sheets can be copied to analyze additional systems or products.

Traditional LCA Framework

GFA Construction Phase Hybrid LCA

In the construction phase, the available data for EIO-LCA in most activities are too aggregated or non-existent so process diagrams were created to identify the expected sources of pollution. Figure 8 shows the process diagram for the construction-related activities for the gas-forced air system and includes both on-site and off-site activities. Each item on the diagram displays a code identifying the type of emissions related to that step. It is important that the boundary, the entire U.S. economy, of the EIO-LCA for the manufacturing phase coincide with the boundary, all transportation on goods to the construction site, of the traditional LCA for the construction phase to ensure that data is not excluded from the study. Any assumptions that are made when acquiring the data should also be documented. An example would be worker transport. This figure needs to be round trip from home to work, from home to the job site, or from work to the job site to accurately account for the transport emissions.

The creation of the process diagrams for the GFA and SRS heating systems both include the following assumptions. In both cases the system design was assumed to be done in the contractors' office using a computer based model requiring one person to input the data. In both cases the data collected for the design function came from eiolca.net based on the selection of an NAICS sector that appeared to represent this function accurately. In all transport activities the liquid waste (2) impact was assumed to be immaterial due to unknown service schedules. All tool usage for the system installation assumes that battery powered hand tools are used on site and the electricity for recharging the battery is estimated in kWh daily. The bleeding of NG from the gas piping to the GFA furnace is assumed to be immaterial as is the water used to fill the distribution piping in the SRS system. It was also assumed that the environmental impacts from the production of the hand tools used on site were immaterial. This assumption was based on the unknown tool lists, expected tool life, and tool costs.

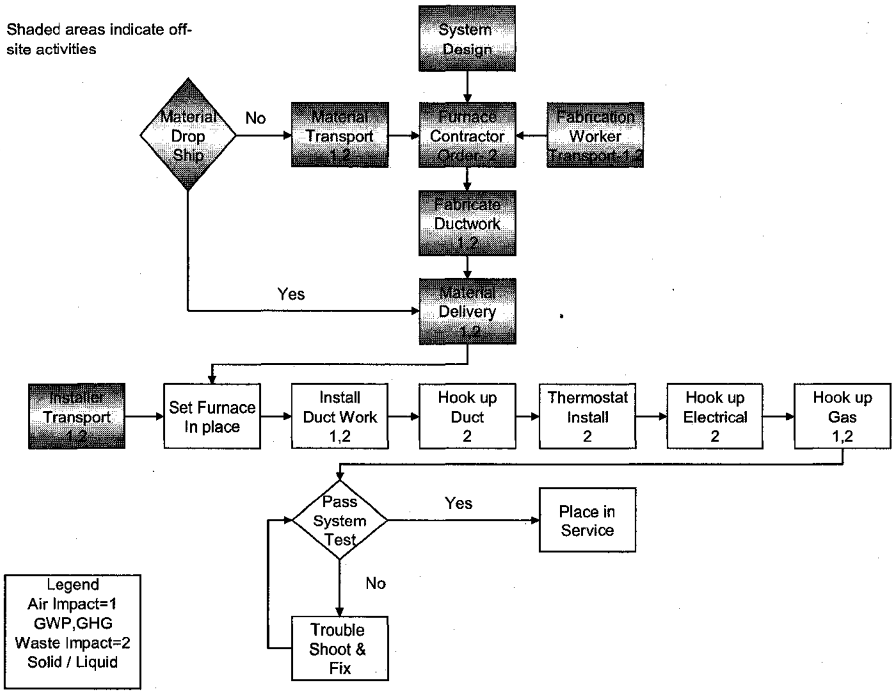

***Figure* 8. Gas-Forced Air Heating System Construction Phase Process Diagram**
Source: (Glick & Guggemos, 2007).

SRS Construction Phase Hybrid LCA

A process diagram for the construction phase of the SRS system was also created. Figure 9 shows the construction phase activities for the solar radiant floor heating system including both on-site and off-site activities. Each item on the diagram displays a code identifying the type of emissions related to that step.

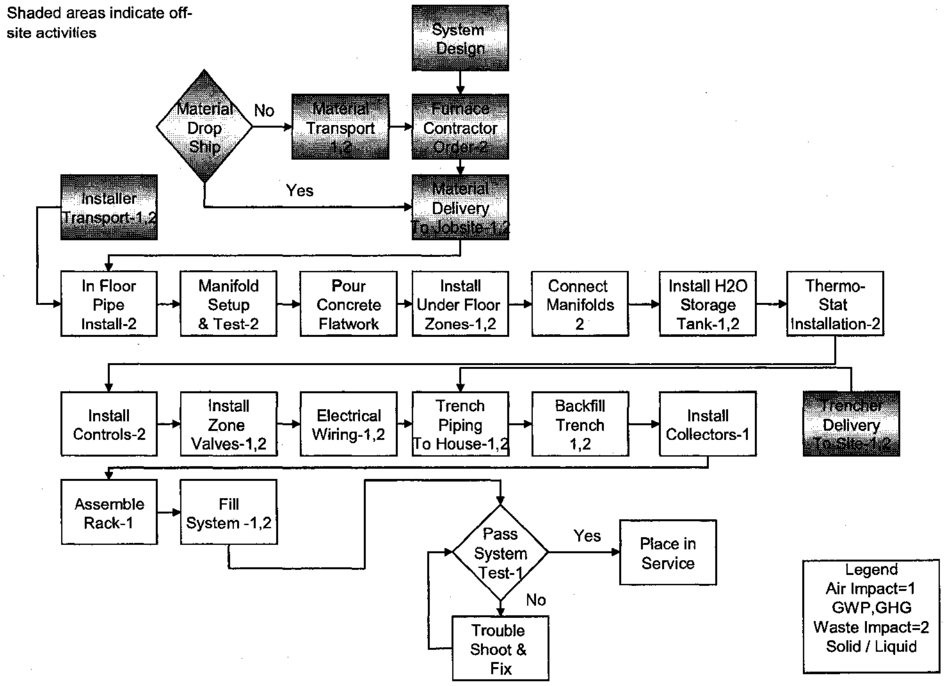

***Figure* 9. Solar Radiant Floor Heating System Construction Phase Process Diagram**
Source: (Glick & Guggemos, 2007).

GFA End-of-Life Phase Hybrid LCA

Figure 10 shows the end-of-life activities for the gas forced air heating system based on the assumption that both the building and the heating system are at the end of their useful lives. The steps identified in this diagram are based on current technology and demands for recycled materials. Acceptable items for recycling 20 years from now may vary significantly.

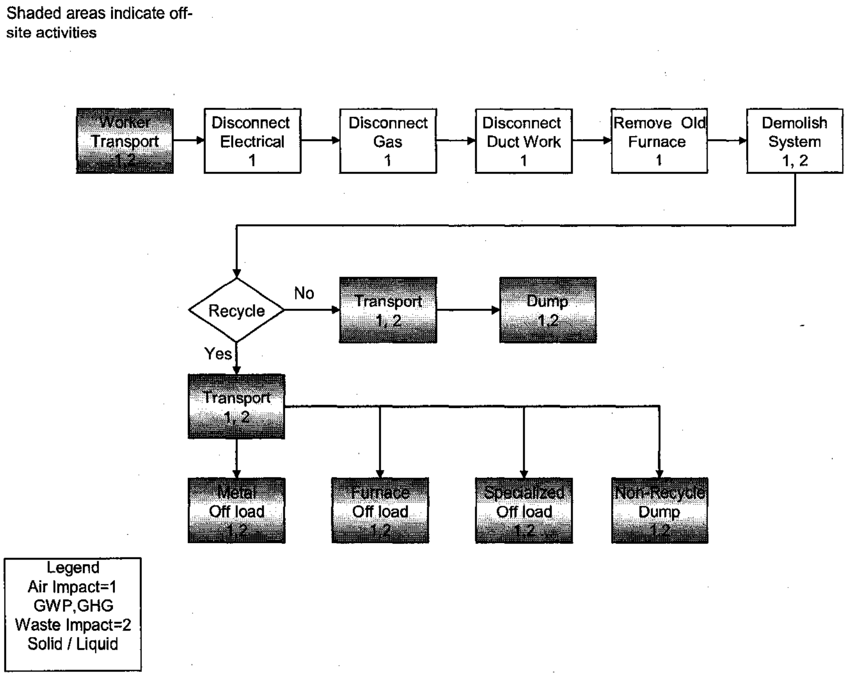

***Figure* 10. Gas-Forced Air Heating System End-of-Life Phase Process Diagram**
Source: (Glick & Guggemos, 2007).

SRS End-Of-Life Phase Hybrid LCA

Figure 11 shows the end-of-life activities for the solar radiant system based on the assumption that both the building and the heating system are at the end of their useful lives. The steps identified in this diagram are based on current technology and demands for recycled materials. Acceptable items for recycling and component reuse 20-30 years from now may vary significantly.

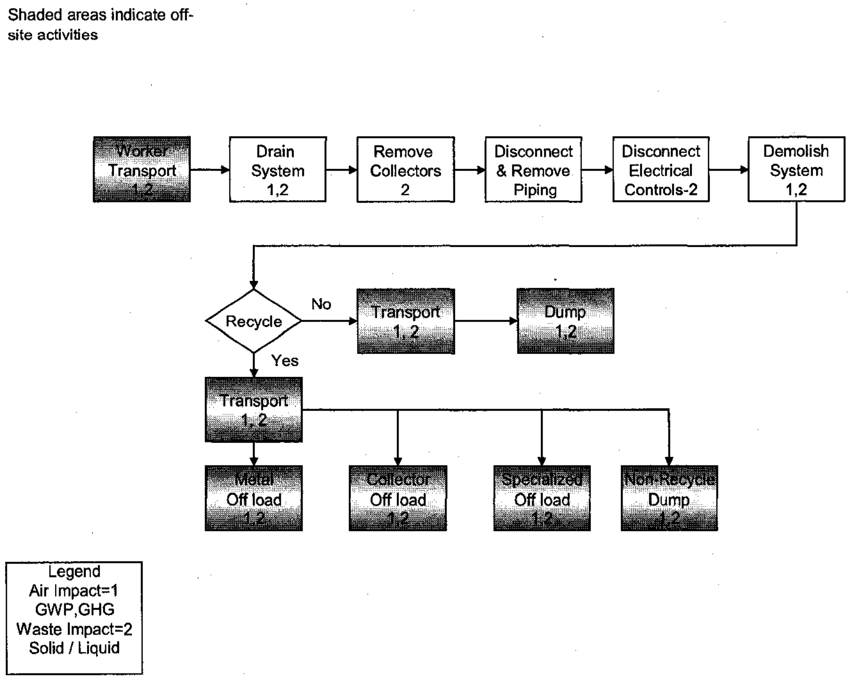

***Figure* 11. Solar Radiant System End-of-Life Phase Process Diagram** Source: (Glick & Guggemos, 2007).

LCC Framework

The use of the BLCC5.3 tool to perform a LCC requires information about several future events. In most cases where prediction is required, the more forward-looking the time frame, the greater the risk of error. There are several steps necessary to accumulate the information needed to perform a Life-Cycle Cost analysis using BLCC5.3. First go to the web and download this free analysis tool (Building Life-Cycle Costs Programs, n.d.). Once installed on your computer, you can do analysis web-free. When you open the program, click on “New” and select FEMP Energy Analysis, New Project. There are three tabs at the top: General Information, Key Dates, and Add Alternative. Additional reference material can be found in the NIST handbook 135 (Fuller & Petersen, 1995) and in the current year supplement to the handbook at the same website.

You will need a discount value unless you want to use one of the default values BLCC provides. The choices are constant dollar (no inflation) or current dollar (with inflation). Fill in the general information first and select end-of-year discounting and current dollar analysis. Next select the "Key Dates" icon. You will need to have the expected life of the system. This can be based on local supplier or installer expertise, manufacturer data, or historical information you may have access to. This will be entered as the "length of study." Use xx y, for years and xx m for months. On the bottom of each screen, there are tips that prompt you and answer questions. Select the "Add Alternative" icon and fill in the requested information; this becomes the base case.

If comparing two or more systems, the study period needs to be the same for all systems. If this is not the case, then assumptions will need to be made about the salvage value of the longer-lived system. The value for the additional life will be entered into the residual value of the capital expenditure; this is as a percentage of the initial costs, not a dollar value.

Once you create an alternative, you will need to enter energy costs, water costs, and capital component cost if necessary. If historical data is not available, you will need to estimate the cost of water, electricity, and fuel. It is important to have this done prior to using the BLCC software. You can use national averages for prices but in most cases the costs information will be available from the local utility provider. If no historical usage is available, then space heating energy expenditures and energy consumption by census region are available (Natural Gas Consumption and Expenditures in U.S. Households by End Uses and Census Region, 2001). The Energy Information Administration (EIA) provides these statistics. The current website is: www.eia.doe.gov; a keyword search for residential, space heat, energy expenditures, and energy consumption should be sufficient. You will need annual consumption in kWh, gallons, Btu, or cubic feet or some other common unit of measure. Conversion factors can be found in Unit Conversions: Emissions Factors, and Other Reference Data (November, 2004).

You will need to know the heating season length in order to calculate the expected energy usage. This will vary by region and the local utility company should be able to help with this information if there is no personal history to use. There will also be estimates for both recurring and non-recurring expenses for all systems. Recurring expenses may include yearly inspections, filters, cleaning, etc. The current costs will also be needed for the program. Non-recurring expenses could include pump replacement, antifreeze, belts, hoses, blower motors, heat exchangers, vent caps, and duct cleaning. You will need the current costs for the materials and the labor.

Keep good documentation of your assumptions for future reference and variance analysis, if needed. This will make other projects easier and cut down on time commitments. Adding an additional alternative will also be easier.

Environmental and Costs Implications of Heating System Choice, a Case Study

In this portion of the chapter a gas forced air heating system and a solar hot water radiant heating system were compared for a residential home, based on their respective environmental effects, GHG and energy, and LCC. The two examples were chosen based on the homeowner's criteria. Traditionally, system choice may be determined based on prior experience, costs, availability, aesthetics, material performance, market acceptance, resale value, operating costs, intent of building owner (i.e. to occupy, to sell, or to rent/lease, etc). In the future, regulatory requirements stemming from a recent U.S. Supreme Court ruling mandating that the U.S. EPA regulate CO_2 emissions may also affect the decision making process relating to residential heating systems.

The home consists of 3,000 square feet of finished space on three levels; basement (1200), main floor (1200), and half story attic space (600). The walls were constructed using 2x6 studs, 16" o.c. with blown in R23 insulation. The solar orientation is 10-20 degrees west of south providing excellent solar exposure and day-lighting year around. The home is located in Fort Collins, Colorado where there are four seasons each typically mild. The energy sources are electric and NG.

Both the systems chosen were functionally equivalent in nature. Equivalent means that both heating systems are able to heat the residential building in a manner that makes the occupants of the building comfortable. For example, the solar heating system delivers the heat to the inside of the residence through a series of liquid filled plastic distribution lines placed in the floor systems while the gas forced air system delivers heated air through a series of metal duct work; both systems regulate the indoor air temperature to a predetermined level.

Using the framework previously outlined, the case study was performed using the hybrid approach described in chapter 3. The analysis for the manufacturing, use, and maintenance stages used the EIO-LCA methodology and the construction and disposal phases used the traditional LCA methodology based on process diagrams. The LCC was performed using the free BLCC5.3 tool. The steps used in the analysis of each phase are outlined as follows:

Whatever resource is used, it is important that each system component, or the materials making up system components, be reduced to levels that are properly represented in the NAICS categories. If this is not possible, the traditional LCA methodology using process diagrams may be required either in whole or in part until the NAICS format can be properly used. An example of this would be the furnace component in a gas forced air heating system. The furnace consists of sheet metal, a heat exchanger, gas piping, a blower motor and fan, and electronic controls. Although each of these components is manufactured in a separate process, the data used in the NAICS format is too aggregated to focus on the individual furnace components so the proper level of analysis would be the Industry Group titled Engines and Machinery. Within this group, there is a sector of the economy titled AC and warm air heating equipment. The examples given in this sector include furnaces, warm air (i.e., forced air) manufacturing which accurately depicts our equipment and the related materials. The NAICS category matches the heating system component furnace, so the NAICS number used would be 333415.

EIO-LCA Analysis

The materials for both heating systems are well-represented by existing NAICS categories. In addition to determining the GHG for each specific sector based on the increment of demand as stated in base year dollars, the GWP for each specific sector as a percentage of that total sector can be calculated. The manufacturing phase materials for the gas forced air system are presented first followed by the materials for the solar hot water radiant system.

Manufacturing Phase

Gas-Forced Air LCA

The "system component identification" and "system component valuation" steps were done simultaneously. Transportation costs could have been included in the construction phase but is shown here. All the costs are at the wholesale level and purchases of system components were made in 2007. The CPI index for 2007 and 1997 were 205.5 and 160.5 respectively. The markup percentage from the wholesale sales price to the price paid to the manufacturer was estimated to be 33%. The component costs were at the wholesale level resulting in one cost adjustment to reach the cost paid to the manufacturer. The difference between the total material costs and the bid price are labor, profit, and overhead. Table 6 presents a breakdown of the GFA system component costs and 1997 base year dollar values. The hard bid amount was $6,200.00.

Table 6. GFA System Component Costs and Base Year Values.

Material Description	NAICS Sector	Whsle 2007 $	Base yr 1997 $
Furnace	333415	$1,974.65	$1,056.22
Duct work	332322	$457.09	$244.49
Floor registers	332323	$21.63	$11.57
Ceiling registers	332323	$62.83	$33.60
Return air grill	332323	$24.21	$12.95
Thermostat	334512	$5.40	$2.89
Transportation	484121	$39.40	$31.37
		$2,585.21	$1,393.10

As previously stated the "system component identification", furnace, and "valuation", $1,974.65 were done simultaneously. The 33% profit, "value at cost to manufacture", at the wholesale and manufacture levels lowered this cost to $1,326.70. The CPI index of .78, "CPI restate to base year dollars", lowered it to the base year dollar of $1,056.22. For the GFA system furnace, the industry group, "select industry group", Engines and Machinery was chosen. Within this group, the industry sector, "select NAICS Sector", Air-Conditioning and Warm Air Heating Equipment, NAICS 333415 was used. The increment of demand "increased economic activity", in 1997 base year dollars was $1,056.22. As shown in Appendix B, this sector is made up of one or more NAICS sectors. A review of the Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing sector identified a specific reference to warm air furnace manufacturing (i.e., forced air). Based on this information, this sector is the best representation of warm air furnace manufacturing equipment. This process is repeated for each system component, for each system, and for each Phase using EIO-LCA.

The duct work is represented by the industry group Cutlery, Hand Tools, Structural & Metal Containers. Within this group, the industry sector Sheet Metal Work Manufacturing, NAICS 332322 was used. The increment of demand in 1997 base year dollars was $244.49. As shown in Appendix C, this sector is made up of one or more NAICS sectors. A review of the Sheet Metal Work Manufacturing sector identified a specific reference to ducts, sheet metal, and manufacturing and is, therefore, the best representation of furnace duct work.

The floor registers, ceiling grills, and return air grills are represented by the industry group Cutlery, Hand Tools, Structural & Metal Containers. Within this group, the industry sector Ornamental and Architectural Metal Work Manufacturing, NAICS 332323 was used. The increment demand in 1997 base year dollars is $11.57, $33.60, and $12.95 respectively. Although all sheet metal products listed here are represented by the same NAICS code, they were listed separately to allow for easy modification. As shown in Appendix D this sector is made up of one or more NAICS sectors. A review of the Ornamental and Architectural Metal Work Manufacturing sector found a specific reference to grills and grillwork manufacturing and grillwork, ornamental metal manufacturing, therefore, it is the appropriate choice for these materials.

The thermostat control is represented by the industry group Semiconductors, Electrical Equipment, and Media Reproduction. Within this group, the industry sector Automatic Environmental Control Manufacturing, NAICS 334512 was used. The increment demand in 1997 base year dollars is $2.89. As shown in Appendix E, this sector is made up of one or more NAICS sectors. A review of the Automatic Environmental Control Manufacturing sector found specific reference to thermostats (e.g., air-conditioning, appliance, comfort heating, refrigeration) manufacturing, therefore, it is the appropriate choice for these materials.

Transportation for the materials from the manufacturer to the wholesale outlet is difficult to accurately determine due to the global nature of manufacturing and assembly of parts into components or complete products. To define the study boundary, a requirement that all system materials come from North America was specified by the owner. The decision should not have a major impact on prices since all component parts are available within this boundary. A complete description of the assumptions and freight calculations used in this study can be found in Appendix F. Transportation is represented by industry group Truck Transportation, NAICS Sector 484. This sector is made up of more than one sector and there are four levels of sub-sector headings that are used for specificity. The sub-sector General Freight Trucking, long-distance, less than truckload, NAICS 484122, was used. The increment demand in 1997 base year dollars is \$31.37. As shown in Appendix G, this sub-sector has one NAICS sector code. A review of the General Freight Trucking, long-distance, less than truckload sector identified the type of transportation system used by many wholesalers to move inventory from a manufacturer to their warehouse. This system allows multiple shippers to consolidate their loads into a single long-haul load to ensure the fullest possible truck. Once at the central destination, the individual items are delivered using a fleet of more localized carriers; therefore it is the appropriate sector choice for this service.

Table 7 displays the estimated supply chain impacts for manufacturing each component material of a GFA heating system. Figure 12 shows the GWP for the GFA heating system by NAICS Sectors. The GWP is the combination of the individual GHG component levels of Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (NO_2), and Chlorofluorocarbons (CFC). Each of these GHGs is represented in metric ton CO_2 equivalents ($MTCO_2E$). Note that the furnace contributes 70% of the GWP.

Table 7. Total Estimated Supply Chain GWP for GFA Heating System in the Manufacturing Phase. Source: (eiolca.net)

Materials	NAICS Sector	**GWP MTCO$_2$E**	**CO$_2$ MTCO$_2$E**	**CH$_4$ MTCO$_2$E**	**N$_2$O MTCO$_2$E**	**CFCs MTCO$_2$E**
Furnace	333415	**0.71**	0.58	0.07	0.01	0.06
Duct work	332322	0.19	0.06	0.01	0.00	0.02
Floor Registers	332323	0.01	0.01	0.00	0.00	0.00
Ceiling Registers	332323	0.03	0.03	0.00	0.00	0.00
Return Air Grill	332323	0.01	0.01	0.00	0.00	0.00
Thermostat	334512	0.00	0.00	0.00	0.00	0.00
Transportation	484121	0.07	0.06	0.00	0.00	0.00
	TOTAL	1.02	0.75	0.08	0.01	0.08

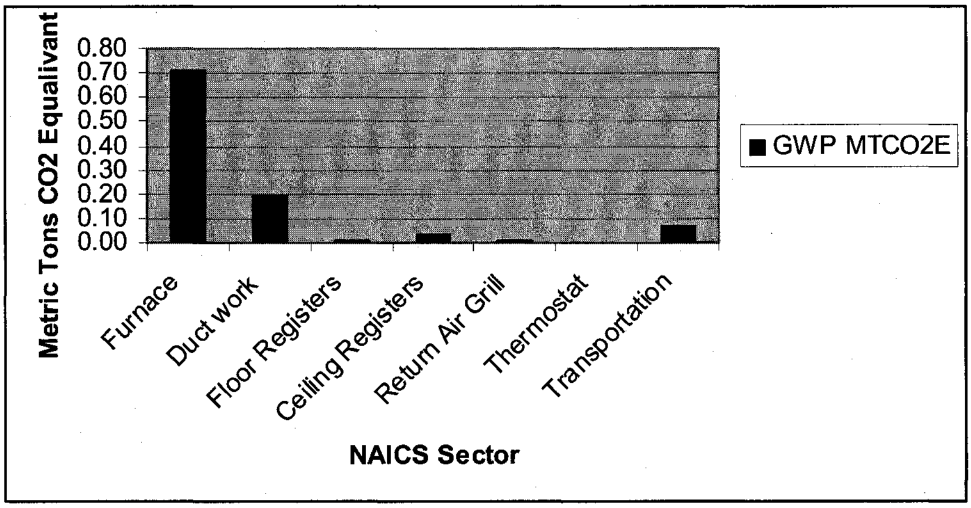

***Figure* 12. Total Supply Chain GWP for GFA Heating System Components in the Manufacturing Phase.** Source: (Table 7)

Solar-Radiant System LCA

The "system component identification" and "system component valuation" steps were done simultaneously. Transportation costs could have been included in the construction phase but is shown here. All the costs are at the wholesale level and purchases of system components were made in 2007. The CPI index for 2007 and 1997 were 205.5 and 160.5 respectively. The markup percentage from the wholesale sales price to the price paid to the manufacturer was estimated to be 33%. The component costs were at the wholesale level resulting in one cost adjustment to reach the cost paid to the manufacturer. The difference between the total material costs and the bid price are labor, profit, and overhead. Table 8 presents a breakdown of the SRS system component costs and 1997 base year dollar values. The hard bid amount was $45,688.00.

Table 8. SRS System Component Costs and Base Year Values.

Material Description	NAICS Sector	Whsle 2007 $	Base yr 1997 $ EIO-LCA
Solar FP collector	333414	$14,608.00	$7,665.39
Plastic pipe	326122	$1,656.00	$868.97
Metal valves	332911	$174.00	$91.30
Hydronic control	334512	$2,206.00	$1,157.58
Collector stand	332323	$1,036.00	$543.63
Transportation	484122	$232.00	$181.20
Aluminum plates	331316	$502.00	$263.42
Storage tank	332420	$7,616.00	$3,996.41
Expansion tank	332420	$218.00	$114.39
Pumps	333911	$141.00	$73.99
Copper tubing	331421	$989.00	$518.97
Fittings	332913	$498.00	$261.32
Manifolds/brass	331522	$1,052.00	$552.03
		$30,928.00	$16,288.60

For the SRS, the solar collectors are represented by the industry group Engines and Machinery. Within this industry group, the industry sector Heating Equipment (except warm air furnaces) Manufacturing, NAICS Sector 333414, was chosen. The increment of demand in 1997 base year dollars is $7665.39. As shown in Appendix H, this sector is made up of one or more NAICS sectors. A review of the Heating Equipment (except warm air furnaces) Manufacturing sector found a specific reference to solar energy heating equipment manufacturing. Based on this information, this sector is the best representation of solar collector manufacturing.

The plastic distribution piping is represented by the industry group Plastic, Rubber and Non-metallic Mineral products. Within this industry group, the industry sector Plastics Pipe and Pipe Fitting Manufacturing, NAICS Sector 326122, was chosen. The increment of demand in 1997 base year dollars was $868.97. As shown in Appendix I, this sector is made up of one or more NAICS sectors. A review of the Plastics Pipe and Pipe Fitting Manufacturing sector identified a specific reference to pipe, rigid plastics, manufacturing and therefore is the best representation of the plastic piping.

The metal valves are represented in the industry group Ordinance and Other Metal products. Within this industry group the industry sector Metal Valve Manufacturing, NAICS Sector 332911, was chosen. The increment of demand in 1997 base year dollars was $91.30. As shown in Appendix J, this sector is made up of one or more NAICS sectors. A review of the Metal Valve Manufacturing sector found a specific reference to ball valves, industrial, manufacturing; check valves, industrial type; manufacturing, and safety (i.e., pop-off) valves, industrial-type, manufacturing and appears to be the best representation of these types of materials.

The hydronic control equipment is represented by the industry group Semiconductors, Electrical Equipment, and Media Reproduction. Within this group, the industry sector Automatic Environmental Control Manufacturing, NAICS Sector 334512, was used. The increment demand in 1997 base year dollars is $1157.58. As shown in Appendix E, this sector is made up of one or more NAICS sectors. A review of the Automatic Environmental Control Manufacturing sector found specific reference to hydronic circulator control, automatic, manufacturing; and hydronic limit, pressure, and temperature controls, manufacturing; therefore, it is the appropriate choice for these materials.

The solar collector stands are represented in the industry group Cutlery, Hand Tools, Structural and Ornamental Containers. Within this group, the industry Ornamental and Architectural Metal Work Manufacturing, NAICS Sector 332323, was used. The increment demand in 1997 base year dollars is $543.63. As shown in Appendix D, this sector is made up of one or more NAICS sectors. A review of the Ornamental and Architectural Metal Work Manufacturing sector found a specific reference to architectural and ornamental metalwork manufacturing; therefore, it is the appropriate choice for these materials.

The transportation supporting data is shown in Appendix F as previously mentioned. Transportation is represented by industry group Truck Transportation, NAICS Sector 484. This sector is made up of more than one sector and there are four levels of sub-sector headings that are used for specificity. The sub-sector General Freight Trucking, long-distance, less than truckload, NAICS 484122, was used. The increment demand in 1997 base year dollars is $181.20. As shown in Appendix G, this sub-sector has one NAICS sector code. A review of the general freight trucking, long-distance, less than truckload sector identified the type of transportation system used by many wholesalers to move inventory from a manufacturer to their warehouse. This system allows multiple shippers to consolidate their loads into a single long haul load to ensure the fullest possible truck. Once at the central destination, the individual items are delivered using a fleet of more localized carriers; therefore, it is the appropriate sector choice for this service.

The aluminum plates are represented in the industry group Ferrous and Nonferrous Metal Production. Within this industry group, the industry sector Aluminum Extruded Product Manufacturing, NAICS 331316, was used. The increment of demand in 1997 base year dollars was $263.42. As shown in Appendix K, this sector is made up of one or more NAICS Sectors. A review of the Aluminum Extruded Product Manufacturing sector found a specific reference to the extrusion process for aluminum and appears to be the best representative sector for this product.

The storage and expansion tanks are represented by the industry group Cutlery, Hand Tools and Metal Containers. Within this industry group, the industry sector Metal Tank (heavy gauge) Manufacturing, NAICS 332420, was used. The increment of demand in 1997 base year dollars was $3996.41 and $114.39 for the storage and expansion tanks, respectively. They are listed separately to make changes easier if prices or quantities are changed. As shown in Appendix L, this sector is made up of one or more NAICS sectors. A review of the Metal Tank (heavy gauge) Manufacturing sector identified a specific reference to water tanks, heavy gauge, manufacturing; and tanks, heavy gauge manufacturing and, therefore, adequately represent these two tank types.

The pumps are represented in the industry group Engines and Machinery. Within this industry group, the industry sector Pump and Pumping Equipment Manufacturing, NAICS Sector 333911, was used. The increment of demand in 1997 base year dollars was $73.99. As shown in Appendix M, this sector is made up of one or more NAICS sectors. A review of the Pump and Pumping Equipment Manufacturing sector identified a specific reference to pumps, sump or water, residential, manufacturing, and pumps, industrial or commercial-type, general purpose, manufacturing and is, therefore, the best representation of pumps.

The copper tubing is represented by the industry group Ferrous and Nonferrous Metal Production. Within this industry group, the industry sector Copper Rolling, Drawing, and Extruding, NAICS 331421, was used. The increment of demand in 1997 base year dollars was $518.97. As shown in Appendix N, this sector is made up of one or more NAICS sectors. A review of the Copper Rolling, Drawing, and Extruding sector found a specific reference to pipe, extruded and drawn, brass, bronze, and copper, made from purchased copper or in integrated secondary processes and appears to be the best representative sector for this product.

The fittings are represented by the industry group Ordinance and Other Metal Products. Within this industry group, the industry sector Metal Valve Manufacturing was chosen. The specific NAICS sector chosen here was plumbing fixture fitting and trim manufacturing, NAICS 332913. The increment of demand in 1997 base year dollars was $261.32. As shown in Appendix J, this sector is made up of one or more NAICS sectors. A review of the Plumbing Fixture Fitting and Trim Manufacturing sector found a specific reference to plumbing fittings and couplings, (e.g., compression fittings, metal elbows, metal unions) manufacturing and appears to be the best representation of these types of materials.

The manifolds/brass used in the SRS system is represented by the industry group Ferrous & Nonferrous metal production. Within this industry group, the industry sector Nonferrous (except aluminum) Die-casting Foundries, NAICS 331522, was used. The increment of demand in 1997 base year dollars was $552.03. As shown in Appendix O, this sector is made up of one or more NAICS sectors. A review of the Nonferrous (except aluminum) Die-casting Foundries sector found a specific reference to bronze die-castings, unfinished, manufacturing and appears to be the best representative sector for this product.

Table 9 displays the estimated supply chain impacts for each component material of a SRS heating system. Note the contributions of the solar collector and storage tanks, 64% of the total GWP. Figure 13 shows the GWP for the SRS for each NAICS sector. The GWP is the combination of the individual GHG component levels of Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (NO_2), and Chlorofluorocarbons (CFC).

Table 9. Total Estimated Supply Chain GWP for SRS Heating in the Manufacturing Phase. Source: (eiolca.net)

Material	NAICS Sector	**GWP**	**CO_2**	**CH_4**	**N_2O**	**CFCs**
Description		**$MTCO_2E$**	**$MTCO_2E$**	**$MTCO_2E$**	**$MTCO_2E$**	**$MTCO_2E$**
Solar collector	333414.0	**4.1**	3.5	0.4	0.0	0.2
Plastic pipe	326122.0	1.0	0.8	0.1	0.0	0.0
Metal valves	332911.0	0.0	0.0	0.0	0.0	0.0
Hydronic control	334512.0	0.5	0.4	0.0	0.0	0.0
Collector stand	332323.0	0.5	0.4	0.0	0.0	0.0
Transportation	484122.0	0.4	0.4	0.0	0.0	0.0
Aluminum Plates	331316.0	0.5	0.4	0.0	0.0	0.1
Storage Tank	332420.0	**3.3**	2.8	0.3	0.0	0.1
Expansion tank	332420.0	0.1	0.1	0.0	0.0	0.0
Pumps	333911.0	0.0	0.0	0.0	0.0	0.0
Copper tubing	331421.0	0.5	0.4	0.0	0.0	0.0
Fittings	332913.0	0.1	0.1	0.0	0.0	0.0
Manifolds/brass	331522.0	0.5	0.4	0.0	0.0	0.1
	TOTALS	11.6	9.8	0.9	0.1	0.7

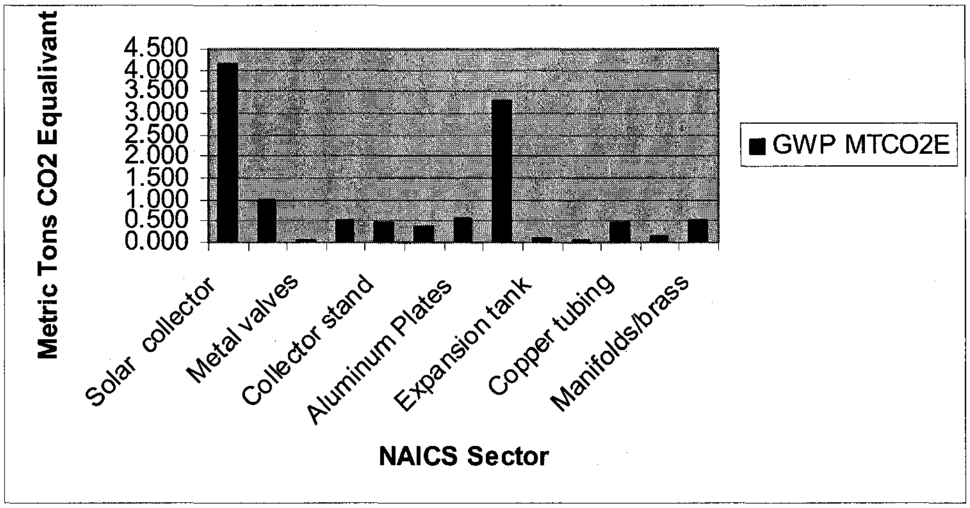

Figure **13. Total Estimated Supply Chain GWP for SRS Heating Components in the Manufacturing Phase.** Source: Table 9.

Construction Phase

Gas-Forced Air Hybrid LCA

The process diagram presented for the GFA construction phase identified the information that needed to be gathered in this phase. The diagram can be modified to represent the installation of another heating system as required.

The off-site activity System Design includes using system parameters to create the heating system design and perform heat-loss calculations. The GFA system design process is included in the heating contractor's overhead. This process is estimated to take two hours for data entry and processing once the designer is given the necessary building and window information by the customer. It is common for this process to be done by a salaried salesperson. The RS Means residential costs data reference does not contain salaries for positions classified as overhead (R.S. Means, 2005). A Google search of "construction salary survey" was done with excellent results. The website www.pas1.com was chosen since it was free and contained detailed descriptions about the construction industry.

The categories reviewed were Mechanical Estimator I ($51,702) and Sales Representative ($51,115) with an averaged annual salary of $51,408.50 or $24.76 per hour. This hourly rate was then converted to base year dollars using the CPI for a base year wage of $49.52 per hour. The NAICS sector 541410 was chosen and a complete description of this sector is in Appendix P. The estimated $MTCO_2E$ for the system design activity was .005298. The Shop Fabricator category was also included in the NAICS sector here for one-half day at $99.04 for an estimated $MTCO_2E$ of .174232.

The transportation of materials from the various manufacturers to the furnace contractor's place of business in Fort Collins, Colorado, was included in the manufacturing phase data. As identified in the process diagram for the construction phase, there are three types of transportation, installer, fabricator, and material, with each activity having potential air (1) and waste (2) impacts. All transport activities will be treated as air impacts (1) due to the uncertainties associated with estimating liquid wastes from oil, antifreeze, and other fluids subject to unknown service intervals. All transport will be counted as a round trip in terms of energy use and associated emissions. The material and installer transport from the furnace contractor to the job site will be based upon truck capacity, job duration, and productivity. The fabricator, installer, and additional crew transport from their home to the furnace contractor will be counted as round trips also.

The average distance for worker transport from home to place of business is 10.6 miles each way or 21.2 miles daily per worker (Federal Highway Administration, 2005).

The duration for the job was estimated at four days for rough in and one day for trim out using a two-person Q-9 crew (R.S. Means, 2005). Based on this, the estimated commuting mileage from home to work and back is 212 miles. The shop fabricator was estimated to work on this job one-half day to make any non-standard or non-stock sheet metal pieces the installation crew may need. The result is an additional 10.6 commuting miles.

The distance from the furnace contractor's shop to the job site is 5.7 miles one-way or 11.4 miles round trip. The materials for the job will come in the same vehicle as the installers; no material will be drop shipped to the job site. Two round trips to the shop from the job site were added to the mileage to account for unforeseen needed parts and materials. An additional mileage figure for off-site lunches is 6 miles round trip per day to the shopping center nearest the job site. The resulting mileage for the installer and material delivery including lunch is 109.8 miles.

The solid waste (2) generated during the install ductwork, hook up duct, thermostat, electrical, and gas sequences will be collected either in recycle containers (metal duct) or trash and taken to the local landfill and metal recycler. The distance from the job site to the landfill is approximately 12.5 miles one-way or 25 miles round trip. The metal recycler is located on this route so no additional mileage is required for metal recycling. The landfill and recycle trip can be combined with other aspects of construction; however, it is all entered here to ensure the impacts will not be underrepresented.

The electrical use for the equipment on the job site is estimated at 10kWh per day to cover battery charges and grid-operated equipment. The resulting estimated GWP

$MTCO_2E$ is .03436. Table 10 summarizes all mileage, electrical, and overhead impacts in $MTCO_2E$ terms for the GFA construction phase with supporting calculations in Appendix Q. The final outcome of Place in Service is shown as a milestone for completeness but the energy use and emissions from this activity are outside the construction phase boundary and will occur during the use phase.

Table 10. Summary of CO_2 Emissions by Source for Gas Forced Air Construction Phase.

	Commute	Miles Job	Dump	Electrical Usage	Project Estimate	Shop Fab Time
$MTCO_2E$	0.1060	0.0055	0.0125	0.0344	0.0053	0.0106

TOTAL $MTCO_2E$	0.1742

Solar-Radiant System Hybrid LCA

The process diagram for the SRS heating system was the guide to data collection in this phase. This diagram is an example and can be modified to fit other heating system installation processes as necessary.

The off-site activity “System Design”, identified in the process diagram, is similar to that previously described in the GFA design and the same assumptions for time and labor will be used here for the heating system design and heat-loss calculations. The same NAICS sector was used, resulting in the same $MTCO_2E$ estimate of .005298.

The transportation of materials from the various manufacturers to the plumbing supplier’s place of business in Fort Collins, Colorado, was included in the manufacturing phase data. As identified in the process diagram for the construction phase, there are three types of transportation: installer, trencher, and material, with each activity having potential air (1) and waste (2) impacts. All transport activities will be treated as air impacts (1) due to the uncertainties associated with estimating liquid wastes from oil, antifreeze, and other fluids subject to unknown service intervals. All transport will be counted as a round trip in terms of energy use and associated emissions. The material transport from the plumbing supplier to the job site is based on one truck load. The installer and trencher transport will be based on actual mileage numbers and will be counted as round trips also.

The installer for the SRS estimates the installation of the complete system will take 21 days. This is based on three days for in-floor system loops, testing, and concrete placement oversight. The additional time will be spent once the rough framing is completed and the project is dried in. The installer works from home and commutes to the job in a vehicle that gets 30 mpg. The commute is 4.2 miles one-way or 8.4 miles round trip for a total commuting distance of 177.2 miles. In addition, it is anticipated that one trip will be made daily to a supply house for unforeseen materials. The closest supply house is the plumbing wholesaler and it is 11.4 miles round trip for a total of 239.4 miles. The same mileage for lunch will apply here as in the GFA construction at 6 miles per day round trip for a total of 126 miles. The total mileage for installer, parts trips, and lunch is 542.6.

The trenching and backfilling will be done with a walk-behind unit with a small gas engine. The rental location is 5.3 miles from the job for a round trip of 10.6 miles. A truck and trailer will be used to transport the trencher and the installer's historical mileage of this vehicle combination is 6 mpg.

The usage of tools and equipment to install this system generate emissions either from directly burning fossil fuel (i.e. for trenching equipment) or indirectly from using electricity to run tools or charge batteries to power hand tools; both impacts are shown in the process diagram. The potential solid waste (2) generated for the SRS system comes from several installation processes. The piping for the in-floor and under-floor zones as well as connecting the solar collectors to the interior controls is plastic and is cut to length from 500-or 1000-foot rolls which reduce solid waste. Additional processes for solid waste creation are: manifold setup and connection, water tank and collector connections, thermostat, electronic control, electrical, and zone valve installation, as well as rack assembly. The pour concrete process is shown for activity sequencing only and outside the boundary of this study as it would be placed regardless of heating system choice. Any waste generated will be segregated into metal and plastic recycling and waste. The metal recycler is on the way to the landfill and the landfill has collection points for plastic recycling for the pipe. The mileage to the landfill and recycler is the same (25 miles) for the SRS as the GFA as is the assumption concerning the full assignment of emissions to this phase and system.

The electrical use for the equipment on the job site is estimated at 10kWh per day to cover battery charges and grid-operated equipment. Many of the tools for plastic piping are hand-operated and the fittings are a compression type. The resulting estimated GWP $MTCO_2E$ is .144313. Table 11 summarizes all mileage, electrical, and overhead impacts in $MTCO_2E$ terms for the SRS construction phase with supporting calculations in Appendix R. The commissioning process instructs the home owner in the proper operation and maintenance of the heating system. The final outcome of Place in Service is shown as a milestone for completeness but the energy use and emissions from this activity are outside the construction phase boundary and will occur during the use phase.

Table 11. Summary of CO_2 Emissions by Source for Solar Radiant System Construction Phase.

	Commute	Miles Job	Dump	Trencher	Electrical Usage	Project Estimate	Trench Use
$MTCO_2E$	0.1592	0.0057	0.0125	0.0155	0.1443	0.0053	0.0504

TOTAL $MTCO_2E$	0.3929

Use and Maintenance Phase

Gas-Forced Air LCA

For the GFA system furnace, the industry group Engines and Machinery was chosen to represent the replacement blower. Within this group, the industry sector Air-Conditioning and Warm Air Heating Equipment, NAICS 333415, was used. The increment of demand in 1997 base year dollars was $83.39. As shown in Appendix B, this sector is made up of one or more NAICS sectors. A review of the Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing sector identified a specific reference to warm air furnace manufacturing (i.e., forced air). Based on this information, this sector is the best representation of warm air furnace manufacturing equipment.

For the natural gas, the industry group Mining & Utilities was chosen. Within this group, the industry sector Natural Gas Distribution, NAICS 221210, was used. The increment of demand in 1997 base year dollars was $3921.04. As shown in Appendix S, this sector is made up of one or more NAICS sectors. A review of the Natural Gas

Distribution sector identified a specific reference to natural gas distribution systems. Based on this information this sector is the best representation of distributing natural gas to end users.

The electricity was represented by the industry group Mining and Utilities. Within this group, the industry sector Power Generation and Supply, Electric Power Generation, Transmission, and Distribution, NAICS 221112, was used. The increment of demand in 1997 base year dollars was $62.86. As shown in Appendix T, this sector is made up of one or more NAICS sectors. A review of the Electric Power Distribution sectors specifically mentioned electrical power generation, making this a representative sector for power creation and distribution.

For maintenance, the industry group Construction was chosen. Within this group, the industry sector Plumbing, Heating, and Air Conditioning Contractors, NAICS 235110, was used. The increment of demand in 1997 base year dollars was $1549.82. As shown in Appendix U, this sector is made up of one or more NAICS sectors. A review of the Plumbing, Heating, and Air Conditioning Contractors identified a specific reference to servicing heating equipment, making this a representative sector for GFA service.

For the filters, the industry group Wood, Paper, and Printing was chosen. Within this group, the sector All Other Converted Paper Product Manufacturing, NAICS 322299, was used. The increment of demand in 1997 base year dollars was $375.57. As shown in Appendix V, this sector is made up of one or more NAICS sectors. A review of the All Other Converted Paper Product Manufacturing sector identified a specific reference to paper filters, making this a representative sector for filters.

For the GFA heating system use/maintenance, Table 12 is a summary of the increment of demand for each material sector for both the 2007 wholesale price and the 1997 base year dollar value.

Table 12. Summary of Dollar Value Calculations, Current Year vs. Base Year, for Gas Forced Air.

Use/Maint expenses	NAICS	Wholesale 2007 $	Base yr 1997 $
Electricity	221122	$88.73	$62.86
Natural Gas	221210	$5,534.99	$3,921.04
Yearly Maint	235110	$1,549.82	$1,052.56
Furnace	333415	$158.91	$83.39
Filters	322299	$375.57	$280.84
		$7,708.02	$5,400.69

Table 13 displays the estimated supply chain impacts for each component material of a GFA heating system. Figure 14 shows the GWP for the GFA system by NAICS Sectors. The GWP is the combination of the individual GHG component levels of Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (NO_2), and Chlorofluorocarbons (CFC). Each of these GHGs is represented in metric ton CO_2 equivalents ($MTCO_2E$). Appendix W shows the supporting assumptions for the use/maintenance phase for the GFA system.

Table 13. Total Estimated Supply Chain GWP for GFA Heating System in the Use/Maintenance Phase. Source: (eiolca.net)

Material Description	NAICS Sector	GWP MTCO$_2$E	CO$_2$ MTCO$_2$E	CH$_4$ MTCO$_2$E	N$_2$O MTCO$_2$E	CFCs MTCO$_2$E
Electricity	221122	0.7	0.6	0.0	0.0	0.0
NG distribution	221210	8.7	3.3	5.4	0.0	0.0
Maintenance	235110	0.9	0.8	0.1	0.0	0.0
Furnace	333415	0.1	0.0	0.0	0.0	0.0
Filters	322299	0.2	0.2	0.0	0.0	0.0
	Totals	10.6	5.0	5.5	0.0	0.1

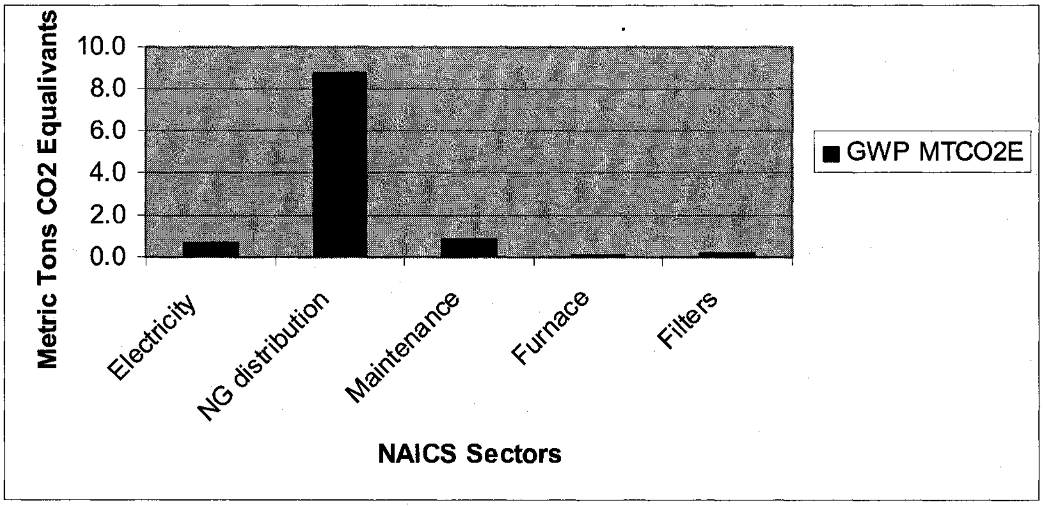

***Figure* 14. Total Estimated Supply Chain GWP for GFA Heating System Components in the Use/Maintenance Phase.** Source Table 13

Solar-Radiant System LCA

The electricity was represented by the industry group Mining and Utilities. Within this group, the industry sector Power Generation and Supply was chosen. The specific NAICS sector here is fossil fuel power generation, NAICS 221112. The increment of demand in 1997 base year dollars was $62.86. As shown in Appendix T, this sector is made up of one or more NAICS sectors. A review of the Electric Power

Distribution sectors specifically mentioned electrical power generation, making this a representative sector for power creation and distribution.

The pumps are represented in the industry group engines and machinery. Within this industry group, the industry sector pump and pumping equipment manufacturing, NAICS 333911, was used. The increment of demand in 1997 base year dollars was $36.92. As shown in Appendix M, this sector is made up of one or more NAICS sectors. A review of the pump and pumping equipment manufacturing sector identified a specific reference to pumps, sump or water, residential; manufacturing and pumps, industrial or commercial-type; and general purpose, manufacturing and is, therefore, the best representation of pumps.

For maintenance, the industry group construction was chosen. Within this group, the industry sectors other maintenance and repair construction was chosen. The NAICS sector chosen here was plumbing, heating, and air conditioning contractors, NAICS 235110. The increment of demand in 1997 base year dollars was $934.35. As shown in Appendix U, this sector is made up of one or more NAICS sectors. A review of the plumbing, heating, and air conditioning contractors identified a specific reference to servicing heating equipment, making this a representative sector for GFA service.

For antifreeze, the industry group Paint, Coating, Adhesives, Cleaning and Other Chemicals was chosen. Within this group, the industry sector All Other Miscellaneous Chemical Product and Preparation Manufacturing, NAICS 325998, was used. The increment of demand in 1997 base year dollars was $135.24. As shown in Appendix X, this sector is made up of one or more NAICS sectors. A review of the All Other

Miscellaneous Chemical Product and Preparation Manufacturing sectors identified a specific reference to antifreeze, making this a representative sector for GFA service.

For the SRS heating system materials, Table 14 is a summary of the increment of demand for each material sector for both the 2007 wholesale price and the 1997 base year dollar value. All GWP for GHG are measured in metric ton CO_2 equivalents ($MTCO_2E$). All chosen GWP values are based on the 1997 base year dollar value.

Table 14. Summary of Dollar Value Calculations, Current Year vs. Base Year, for Solar Radiant System.

Use/Maint expenses	NAICS	Wholesale 2007 $	Base yr 1997 $
Electricity	221122	$88.73	$62.86
Maintenance	235110	$1,375.76	$934.35
Pumps	333911	$70.35	$36.92
Antifreeze	325998	$173.16	$135.24
		$1,708.00	$1,169.37

Table 15 displays the estimated supply chain impacts for each component material of a SRS heating system. Figure 15 shows the GWP for the SRS by NAICS Sectors. The GWP is the combination of the individual GHG component levels of Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (NO_2), and Chlorofluorocarbons (CFC). Each of these GHGs is represented in metric ton CO_2 equivalents ($MTCO_2E$).

Table 15. Total Estimated Supply Chain GWP for SRS Heating System in the Use/Maintenance Phase. Source: eiolca.net

Material Description	NAICS Sector	**GWP $MTCO_2E$**	**CO_2 $MTCO_2E$**	**CH_4 $MTCO_2E$**	**N_2O $MTCO_2E$**	**CFCs $MTCO_2E$**
Electricity	221122	0.7	0.6	0.0	0.0	0.0
Maintenance	235110	0.8	0.7	0.1	0.0	0.0
Pumps	333911	0.0	0.0	0.0	0.0	0.0
Antifreeze	325998	0.2	0.1	0.0	0.0	0.0
	Totals	1.6	1.5	0.1	0.0	0.0

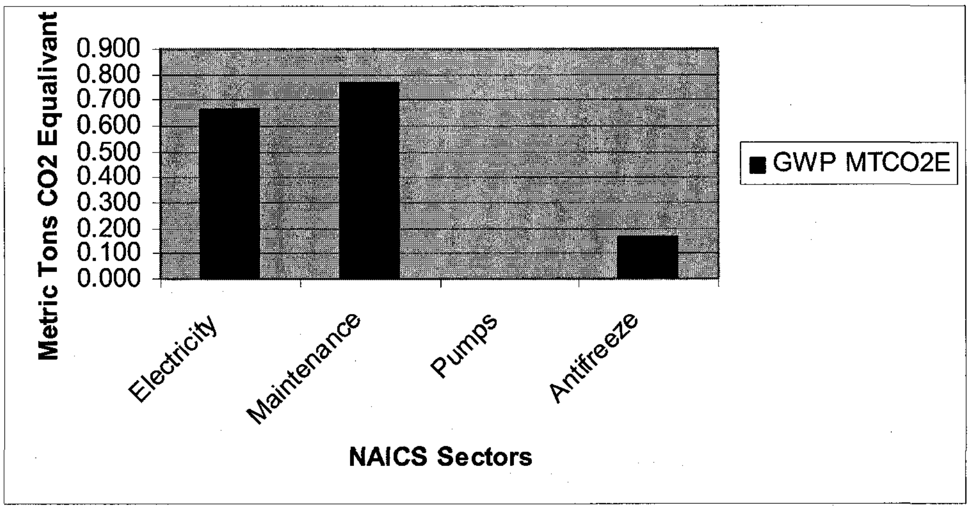

***Figure* 15. Total Estimated Supply Chain GWP for SRS Components in the Use/Maintenance Phase.** Source: Table 15.

End-of-Life Phase

For both systems, the user must decide if they will attempt to recycle all or part of the heating system. One of the greatest concerns with the end-of-life phase is the cost effectiveness with recycling parts of a building subject to total removal. Currently, concrete and asphalt enjoy a high level of recycling in the commercial sector; a status based on volume and price of materials. In the case of residential housing, it is unlikely that someone would come in and remove a complete system that is at the end of its useful life for free. This may change if scrap prices continue to increase and new technology makes currently unwanted scrap recycling profitable.

The assumptions for recycling are based on current recycling technology and demand for recycled products. If no recycling is chosen, all materials will be delivered to a landfill unless subjected to mandatory disposal requirements. If recycling is chosen, several different recyclers may be used and there will still be some residual materials that cannot be recycled and will therefore be sent to a landfill. Current technology and practice allows several components to be recycled.

Gas-Forced Air Hybrid LCA

The process diagram for the End-of- Life phase was the guide to identifying the impacts related to the SRS system deconstruction. This diagram can be modified to represent other systems.

For this case study, it is assumed that the following GFA system components will be recycled as scrap metal: furnace, duct work, and register covers. The gas line and electrical will not be included in the case study since they were outside the construction phase boundary except for the small time commitment to hook onto existing stubs. Power will not be required to disconnect the electrical or the gas piping, only hand tools. The removal of the duct work most likely will be done with wrecking bars to increase productivity. The furnace itself can be loaded onto a truck by a two-person crew.

The estimated time for GFA deconstruction is estimated to take one day using a two-person crew and a pickup truck. Without knowing a place of business address, the assumption will be made that the workers will come from their homes to the job site. The average commuter mileage of 10.6 miles one way will be used (Highway Statistics, 2005). This will result in 42.4 miles for worker transportation to the job.

There is a metal recycler located three miles from the job site and it is estimated that three trips will be necessary, due to the bulk nature of the duct work in its installed form. This will result in an additional 18 trip miles. The resulting MTCO2E totals are shown in Table 16. The supporting data for this table can be found in Appendix Y. All residual material in the form of scraps will be taken to a land fill by a demolition contractor and is outside the scope of this study.

Table 16. Summary of CO_2 Emissions by Source for Gas Forced Air Disposal Phase.

	MILES		
	Commute	Recycle	Dump
$MTCO_2E$	0.0212	0.009	0
TOTAL $MTCO_2E$	0.0302		

Solar-Radiant System Hybrid LCA

The process diagram for the SRS End-of-Life phase was the guide showing the impacts relating to the SRS system deconstruction. The diagram can be modified to represent other systems.

For this case study, it assumed that the solar panels will be bought by a local entity for reuse at an unknown destination. The historical value of used flat plate collectors is about 20% of the new price; a number that will be used for a residual value in the LCC portion of the study. Since the purchaser is unknown, the assumption will be that two people will come to dismantle the collectors and stands and haul them off in two trips to their point of origin. The average commute to work is 10.6 miles (Highway Statistics, 2005). The round trip commute will generate 42.4 miles and the additional one trip to haul off the panels will add an additional 21.2 miles. No power tools will be needed for this process.

The plastic piping is not recyclable using current technology and will be taken to a land fill with the other residual components by a demolition contractor which is outside the scope of this study. If the pipe becomes recyclable, two issues will need to be solved prior to deconstruction. Some of the pipe is embedded in the concrete slabs and will still be part of that demolition. Secondly, the other pipe in this job is stapled up to the floor system and covered with drywall which will need to be removed.

The glycol water fluid mix from the solar system can be recycled through an automotive repair shop that does radiator service work. However, the volume of this fluid, 800+ gallons, would require a large pumping vehicle and excessive costs. The current antifreeze is non-toxic and can be discarded into an existing sewer system. It is assumed that the latter method of disposal will be used.

There are several electronic controls used with the SRS as well as brass manifolds and miscellaneous fittings that can be recycled. One person could remove these using hand tools in about a half-day. Here again, it is assumed that one round trip commute for this person would generate 21.2 miles. The recycler is three miles from the job site which adds another 6 miles. No deduction is taken for combining mileage to the recycler with the trip home since the destination is unknown. The resulting MTCO$_2$E totals are shown in Table 17. The supporting data for this table can be found in Appendix Y. All residual material in the form of scraps will be taken to a land fill by a demolition contractor and is outside the scope of this study.

Table 17. Summary of CO$_2$ Emissions by Source for Solar Radiant System Disposal Phase.

		Miles	
	Commute	Recycle	Dump
MTCO$_2$E	0.024874	0.003	0
TOTAL MTCO$_2$E	0.028		

The aggregated GWP data from each phase and heating system alternative is presented in Table 18 and Figure 16. The bold numbers in Table 18 represent the most efficient phase between the two heating systems.

Table 18. Summary of Total GWP by Heating System Choice and Life Cycle Phase.
Source: (eiolca.net)

Life Cycle Phase	GFA MTCO$_2$E GWP GFA	SRS MTCO$_2$E GWP SRS	GFA Difference
Manufacturing	1.0	**11.6**	-91%
Construction	0.2	**0.4**	-56%
Use/Maintenance	**10.6**	1.6	86%
Disposal	0.0	**0.0**	8%
Total	**11.8**	13.6	-12%

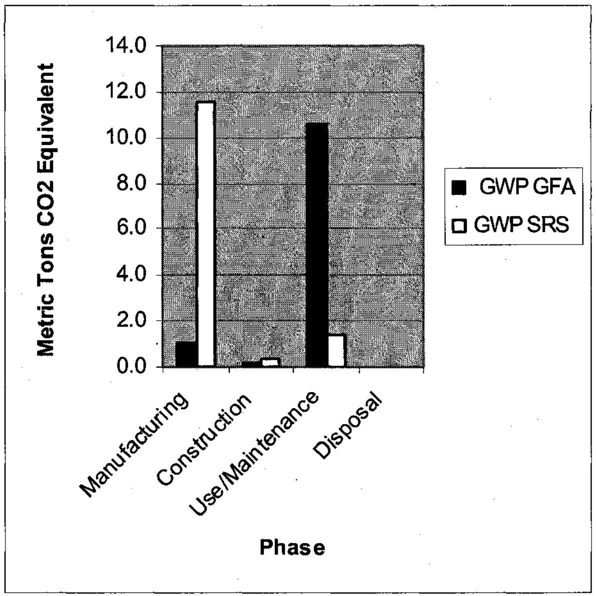

***Figure* 16. Summary of Total GWP by Heating System Choice and Life Cycle Phase.**
Source: (eiolca.net)

Note the impact of the SRS system in the manufacture phase, 11.6 MTCO$_2$E (85% of the total). The GFA has the larger impact in the Use/Maintenance phase, 10.6 MTCO$_2$E (90% of the total). The construction phase accounts for less than 5% of the MTCO$_2$E for either system and the End-of-Life phase accounts for less than 1% of the MTCO$_2$E for either system.

Energy Use

The energy information for the eiolca.net tool was updated on December 10, 2006 as of this writing. Tables 19 and 20 show the results for energy use for all phases for the GFA and SRS systems respectively. Note the GFA system used more electricity than the SRS system and the SRS used more total MJ than the GFS system.

Table 19. GFA Energy Use by Phase. Source: (eiolca.net)

Phase	Total MJ	Elec MkWh	Coal MJ	NatGas MJ	LPG MJ	MotGas MJ	Distillate MJ	Kero MJ	JetFuel MJ	Residual MJ
MFG	11.60	718.00	2.90	5.05	0.26	0.60	1.40	0.00	0.30	0.29
Const						2.49				
Use/Main	76.98	2.06	14.66	44.42	3.04	3.16	7.37	0.00	0.90	1.26
Disposal						0.43				
Totals	88.58	720.06	17.55	49.46	3.30	6.68	8.77	0.00	1.20	1.55

Table 20. SRS Energy Use by Phase. Source: (eiolca.net)

Phase	Total MJ	Elec MkWh	Coal MJ	NatGas MJ	LPG MJ	MotGas MJ	Distillate MJ	Kero MJ	JetFuel MJ	Residual MJ
MFG	103.55	6.32	26.16	45.97	2.46	6.46	10.74	0.00	2.22	2.49
Const						3.41				
Use/Main	19.97	0.34	7.64	4.89	0.90	0.71	4.64	0.00	0.31	0.46
Disposal						0.40				
Totals	123.52	6.66	33.80	50.86	3.36	10.58	15.38	0.00	2.53	2.95

Life Cycle Cost

The Life Cycle Cost was performed using the Building Life Cycle Cost (BLCC) program (Building Life Cycle (BLCC) Program, n.d.) developed for by the National Institute of Standards and Technology (NIST) for the Department of Energy's Federal Energy Management Program. This tool supports the NIST Handbook 135, Life-Cycle Costing Manual for the Federal Energy Management Program (Fuller & Petersen, 1995).

The program can be downloaded from the Department of Energy's Energy Efficiency and Renewable Energy website at www1.eere.energy.gov/femp/information/download_blcc.html. The NIST Handbook 135 and current supplements can also be downloaded from this web page.

The program is easy to use and offers several options for the type of analysis desired and for choosing discount rates. The input data listing report from BLCC can be found in Appendix Z. The information shown in this report can serve as a guide for collecting the needed data prior to using the BLCC program. The reports available from the BLCC program include a List of Inputs, Detailed LCC, Cash Flow, Summary LCC, Lowest LCC, and Comparative Analysis. For this LCC, the discounting convention "End of Year" was used. The discount rate chosen was for current dollar analysis. The nominal discount rate was 5% which included inflation of 1.9%. For key dates, the base date of June 1, 2007 was used.

The duration of the study period was 20 years and 0 months. This period was chosen based on the average life expectancy of the GFA system with expected maintenance. The SRS has an expected life of 30-plus years with expected maintenance. By choosing the 20-year period, the longer life expectancy of the SRS needed to be adjusted for the additional 10 years of system life. This was accomplished by increasing the salvage value of the SRS system from 8% to 25%. The 8% being the historical market value of the used solar collectors and the 25% reflecting the additional value of the collectors, system controls, pumps, and storage tanks.

For the base case, GFA, the energy costs used were the current rate paid by the homeowner of .08125 cents per kWh. The electrical usage was estimated at 1092 kWh. The natural gas consumption was estimated to be 53,200CuFt with a base price of $.008 per cubic foot. The investment base costs were $6,200.00. The recurring yearly service costs were estimated to be $99.00 and a non-recurring cost in year 12 of $325.00 for a new blower motor.

The alternative, SRS, used the same estimated energy costs as the GFA system. This was based on energizing three circulating pumps during the heating season less frequently that one GFA blower on a more frequent basis. There was no other fuel usage. The initial base cost was $45,688.00 with an expected study life of 20 years. The base date for this system was also June 1, 2007. There were recurring yearly inspection costs of $75. The non-recurring costs were in year 10 for replacement antifreeze at $550.00 and year 16 for a replacement pump at a cost of $145.00.

The Comparative Analysis report can be found in Appendix AA. The savings to investment ratio was .17 and the Internal Rate of Return was -3.91%. As shown in Table 21 there was a negative net savings of -$27,483.00 for the solar alternative based on the first cost differential. The SRS life cycle savings for natural gas usage was 1,063,854.3 CuFt. The total average annual CO_2 emissions for the GFA were 3,929.35kg and 966.63kg for the SRS.

Table 21. Key Comparative Analysis LCC results for GFA and SRS. Source: (NIST BLCC 5.3-07)

	GFA	SRS	Hybrid	Life Cycle Reduction
First Costs	**$6,200.00**	$45,688.00	$20,489.00	
Total Present Value LCC	**$14,795.00**	$42,278.00	$23,559.00	-$8,764.00
Avg NG Consumption	53,200CuFt	**0 CuFt**	53,200CuFt	1,063,854.3 CuFt
Avg Electric Consumption	3.7 MBtu	3.7 MBtu	3.7MBtu	0
NG savings Life Cycle	54.8MBtu	**0 MBtu**	54.8MBtu	1,096.4MBt
Average Annual Total CO2	3929.35kg	**966.63kg**	1033kg	59,246.31kg

CHAPTER 5: DISCUSSION

Initial LCA and LCC Findings

The findings for the LCA and the LCC performed for the GFA and SRS heating systems choices are somewhat contrary to many of the common conceptions of solar energy sources, costs effectiveness, sustainability, and green building. It is important to note that these findings are based on two heating system choices out of many and located in a specific region of the country. The initial case study questions asked:

1. What are the life cycle environmental impacts of a residential gas forced air system heating system?
2. What are the life cycle environmental impacts of a residential solar hot water radiant heat system?
3. What are the life cycle costs of a residential gas forced air heating system?
4. What are the life cycle costs of a residential solar hot water radiant heat system?

Focusing on the first two questions regarding the life-cycle impacts of the GFA and SRS heating systems we can see in Table 18 that the Total GWP $MTCO_2E$ for the GFA system is estimated to be 11.8. This number tells us the estimated total environmental supply chain impacts for the five phases: manufacturing, construction, use, maintenance, and disposal. Table 18 also indicates that for all five phases of the SRS the

GWP $MTCO_2E$ was estimated to be 13.6; an amount 1.8 $MTCO_2E$ higher than the GWP $MTCO_2E$ associated with the GFA heating system.

With the focus on the life-cycle costs, Table 21 shows that the present value of the 20-year life-cycle costs for the GFA system are $14,795.00 and the present value of the adjusted 20-year life-cycle costs for the SRS is $42,278.00. The additional present value costs difference is $27,483.00 or a 65% premium for the SRS. This cursory review of the LCA and LCC data indicate that the GFA system is the better of the two heating system choices. The initial first costs shown in Table 21 also support the decision to use the GFA ($6,200) versus the SRS ($45,688), an 86% savings for the building owner. However, this conclusion is based on aggregated data and may not adequately inform the decision makers about true environmental costs or any alternative designs that may be available within each heating system.

To better understand the results, a detailed analysis needs to be performed. The information in Table 18 indicates that the GWP for the SRS in the manufacturing phase is 10.6 $MTCO_2E$ greater than that for the GFA system; a result similar to Horvath, 1997. It also shows the GWP for the GFS system is 9 $MTCO_2E$ higher in the use/maintenance phase than that for the SRS. Based on this information, a review of the manufacturing and use/maintenance phase level data are warranted. This review should identify the individual component emissions that will be the focus of a more detailed review of individual system components. This component level review should be undertaken to determine what alternatives may be available to enhance the environmental performance of either heating system. The system alternatives could be as simple as identifying an alternative water storage vessel or designing a hybrid system.

Phase Level LCA Findings

The phase level data shown in Table 22, GFA, and in Table 23, SRS, summarize the estimated CO_2, CH_4, N_2O, and CFC emissions attributable to each of the five life cycle phases of the GFA and SRS systems respectively. These emissions are the components of the GWP shown in Table 18 and are shown for comparative analysis in an effort to determine what phase(s) is/are creating the 1.8 $MTCO_2E$ increase in GWP for the SRS.

Table 22. Summary of Detail Estimated Phase Emission for GFA Heating System Source: (eiolca.net)

GFA PHASE	GWP $MTCO_2E$	CO_2 $MTCO_2E$	CH_4 $MTCO_2E$	N_2O $MTCO_2E$	CFCs $MTCO_2E$
Manufacturing	1.0	0.8	0.1	0.0	0.1
Construction	0.2	0.0	NA	NA	NA
Use/Maintenance	10.6	5.0	5.5	0.0	0.1
Disposal	0.0	0.0	NA	NA	NA
Total	11.8	5.9	5.6	0.0	0.1

Table 23. Summary of Detail Estimated Phase Emissions for an SRS. Source: (eiolca.net)

SRS PHASE	GWP $MTCO_2E$	CO_2 $MTCO_2E$	CH_4 $MTCO_2E$	N_2O $MTCO_2E$	CFCs $MTCO_2E$
Manufacturing	11.6	9.8	0.9	0.1	0.7
Construction	0.4	0.3	NA	NA	NA
Use/Maintenance	1.6	1.5	0.1	0.0	0.0
Disposal	0.0	0.0	NA	NA	NA
Total	13.6	11.6	1.0	0.2	0.7

A review of each phase indicates that the aggregated 12% increase in GWP for the SRS is the result of both an increase and decrease in emissions in different phases. The SRS emits an estimated 9 $MTCO_2E$ more CO_2 emissions in the manufacturing phase. However, the GFA emits an estimated 3 $MTCO_2E$ more CO_2 and 5.4 $MTCO_2E$ more CH_4 emissions during the use/maintenance phase; a combination of these two numbers accounts for a large portion of the 1.8 MTCO_2E increase identified from the data in Table 18. To better understand what the increase in CO_2 and CH_4 emissions in the manufacturing and use/maintenance phases are telling us about the systems, the individual NAICS system components need to be looked at.

NAICS Sector LCA Findings

To help determine the SRS component parts that make up largest portion of the 9 MTCO2E greater CO_2 emissions created in the manufacturing phase, each NAICS sector needs to be reviewed. Using the emissions information in Table 7 and Table 9, the CO_2 emissions for the individual NAICS sectors in the manufacturing phase are shown in comparative form in Table 24 and Figure 17.

Table 24. Comparative CO_2 Emissions for both Heating Systems for the Manufacturing Phase by NAICS Sector. Source: eiolca.net

		GFA	SRS
Material	NAICS	**CO_2**	**CO_2**
Description	Sector	**$MTCO_2E$**	**$MTCO_2E$**
Solar FP collector	333414	0.0	**3.5**
Plastic pipe	326122	0.0	0.8
Metal valves	332911	0.0	0.0
Hydronic control	334512	0.0	0.4
Collector stand	332323	0.0	0.4
Transportation	484122	0.1	0.4
Aluminum Plates	331316	0.0	0.4
Storage Tank	332420	0.0	**2.8**
Expansion tank	332420	0.0	0.1
Pumps	333911	0.0	0.0
Copper tubing	331421	0.0	0.4
Fittings	332913	0.0	0.1
Manifolds/brass	331522	0.0	0.4
Furnace	333415	0.6	0.0
Duct work	332322	0.2	0.0
Floor Registers	332323	0.0	0.0
Ceiling Registers	332323	0.0	0.0
Return Air Grill	332323	0.0	0.0
Thermostat	334512	0.0	0.0
Totals		0.8	9.8

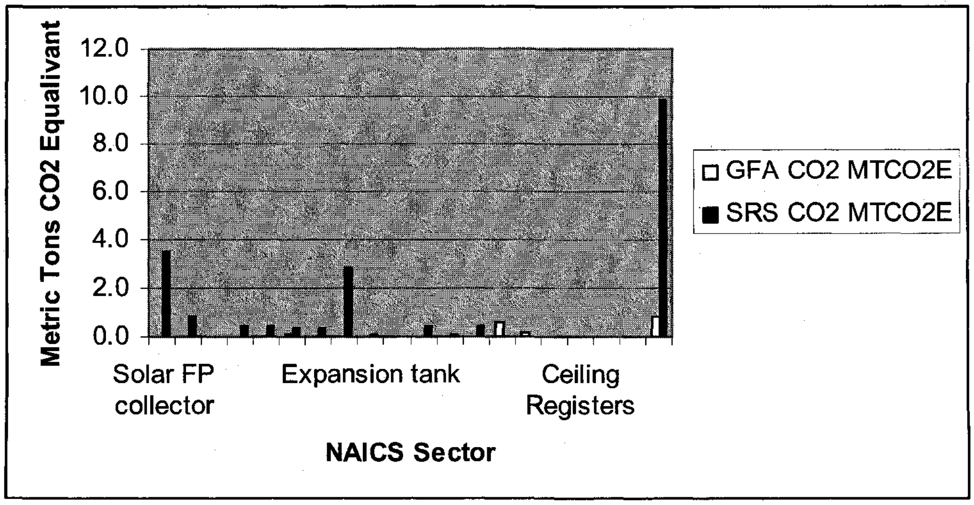

***Figure* 17. Comparative CO_2 Emissions for both Heating Systems for the Manufacturing Phase by NAICS Sector.** Source: Table 24.

The only common source of CO_2 emissions both systems share in the manufacturing phase are transportation related and account for about .3MTCO$_2$E. As previously mentioned transportation from the manufacturer to the supplier was included in this phase for convenience. It could be included in the construction phase; in either case care should be taken to ensure that transportation effects are accounted for. However, the two SRS system components that really stand out are the solar collectors and the storage tanks. The collectors contribute 3.5414 MTCO$_2$E and the tanks contribute 2.8494 MTCO$_2$E or 65% of the total MTCO$_2$E for the SRS manufacturing phase. The removal of the collector stands explains an additional .4115 MTCO$_2$E or another 4% of the manufacturing phase contribution to global warming.

Using the information from Tables 13 and 15, the CO_2 and CH_4 emissions created during the use/maintenance phase for each heating system are identified and shown in comparison form in Table 25 and Figure 18.

Table 25. Comparative CO_2 and CH_4 Emissions for both Heating Systems for the Use/Maintenance Phase by NAICS Sector. Source: (eiolca.net)

		GFA	SRS	GFA	SRS
Material Description	NAICS Sector	**CO_2 MTCO$_2$E**	**CO_2 MTCO$_2$E**	**CH_4 MTCO$_2$E**	**CH_4 MTCO$_2$E**
Electricity	221122	0.6	0.6	0.0	0.0
NG distribution	221210	3.3	**0.0**	5.4	**0.0**
Maintenance	235110	0.8	**0.7**	0.1	**0.1**
Furnace	333415	0.0	**0.0**	0.0	**0.0**
Filters	322299	0.2	**0.0**	0.0	**0.0**
Pumps	333911	**0.0**	0.0	0.0	0.0
Antifreeze	325998	**0.0**	0.1	**0.0**	0.0
	Totals	5.0	**1.5**	5.5	**0.1**

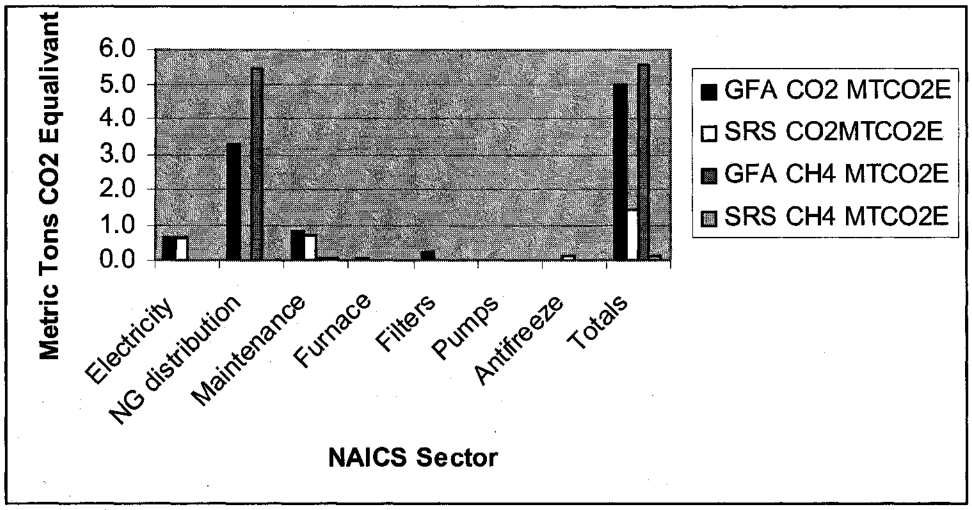

***Figure* 18. Comparative CO_2 and CH_4 Emissions for both Heating Systems for the Use/Maintenance Phase by NAICS Sector.** Source: Table 25.

The emissions for the electricity are the same which reflects the assumption that both systems will consume the same amount of energy during the use phase. The emissions from natural gas distribution appear to be the main causes for the overall increase in CO_2 and CH_4 emissions. This is due to the fact that the SRS system does not require additional energy from fossil fuels as a heat source during use. The common emission source for systems is the heating component; natural gas for the GFA and the solar collectors and storage tanks for the SRS. Without these components, both systems become more environmentally-friendly but cannot function as heating sources. Based on this detailed analysis, an additional research question emerges.

1. Can the detailed information identifying high-pollution emissions be used to develop a hybrid system that lessons the environmental impact (LCA) while staying within the budget (First Costs, LCC)?

The answer to the question is yes and it can be done running scenarios replacing the identified parts in the SRS with others thought to be more environmentally-friendly or efficient.

Improvement Assessment

Using the LCA and LCC information to create a new system or look at different scenarios based on using different component parts is a natural extension of the original comparative analysis. The detailed analysis of the original system choices pinpointed specific system components in both systems that increased either the GWP or costs of that system. For the GFA, there was the natural gas in the use/maintenance phase. The emissions for the SRS focused on the manufacturing, construction, and use/maintenance phases. The LCC and first costs both favored the GFA system. With this in mind, the solar collectors, mounting rack, and storage tanks could be exchanged for a hydronic boiler system creating a hybrid of the two original system choices.

The modeling of a new system choice is quite easy. In this case, the information in the Excel spreadsheet for the SRS was copied to a new workbook and modified. The modification included the deletion of the solar collectors, mounting racks, and storage tanks. In their place, a hydronic boiler was inserted for the heat source. For the LCC analysis, the BLLC file was modified to include another alternative, the hybrid system. The results of an LCA and LCC will indicate if this type of system could meet the owners' environmental and costs objectives. The results may also provide information regarding the adaptation of solar collectors in the future if prices and technology in the solar industry change.

The hybrid LCA detail for phase emissions is shown in Table 26. The total system GWP is shown in a comparative form for all three system choices in Table 27.

Table 26. Summary of Detail Estimated Phase Emissions for a Hybrid Heating System. Source: (eiolca.net)

Hybrid PHASE	**GWP MTCO$_2$E**	**CO$_2$ MTCO$_2$E**	**CH$_4$ MTCO$_2$E**	**N$_2$O MTCO$_2$E**	**CFCs MTCO$_2$E**
Manufacturing	4.5021	3.7254	0.3494	0.0684	0.3576
Construction	0.0174	0.0174	NA	NA	NA
Use/Maintenance	6.8714	3.0056	3.8174	0.0110	0.0377
Disposal	0.0302	0.0302	NA	NA	NA
Total	11.4201	6.7786	4.1669	0.0795	0.3952

Table 27. Summary of total GWP by Heating System Choice and Life Cycle Phase for Comparison with new Hybrid Option

Source: (eiolca.net)

Life Cycle Phase	GFA MTCO$_2$E GWP	SRS MTCO$_2$E GWP	Hybrid MTCO$_2$E GWP
Manufacturing	**1.0**	11.6	4.5
Construction	0.2	0.4	**0.0**
Use/Maintenance	10.6	**1.4**	6.9
Disposal	0.0	**0.0**	0.0
Total	11.8	13.4	**11.4**

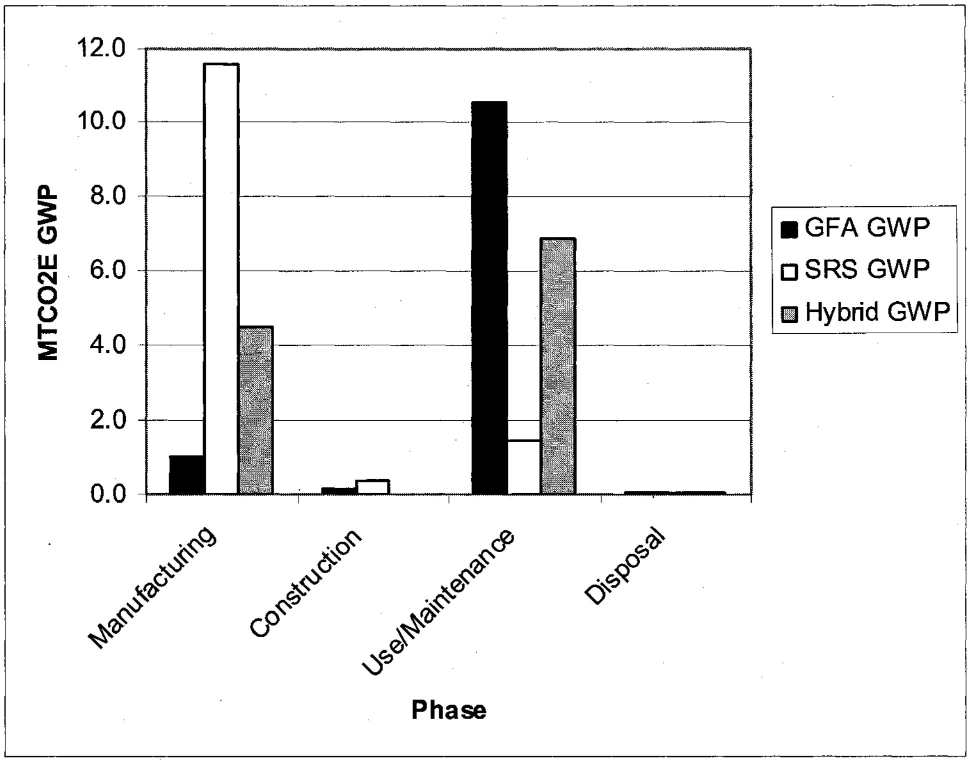

Figure **19. Summary of Total GWP by Heating System Choice and Phase**

A review of the hybrid system detail phase results with those of the original two systems choices found in Tables 26 and 27 shows that the change from using solar collectors, stands, and storage to a hydronic boiler lowered the emissions in the manufacturing phase compared to the SRS and raised it compared to the GFA system. This result is expected due to the base year cost of the hydronic boiler, which is midrange between the GFA furnace and the SRS solar components. The eiolca.net tool is linear in nature so the results for one thousand dollars will be 10 times the amount for one hundred dollars. The industry group was also the same even though the sector was different. The results in the use/maintenance phase are also similar and expected. The hybrid system is between the original two systems with lower maintenance costs and higher fuel costs.

The hybrid alternative was added to the original system BLCC file and a LCC was performed. The electrical use was kept constant with the original systems. The gas usage for the GFA was also used for the hybrid. The solar components were deleted from the SRS costs and the hydronic boiler cost was added. The maintenance costs for the hydronic system are minimal with a checkup in year 10 and a pump replacement in year 16. There is no need for antifreeze or filters. The residual value was stated at 35% to compensate for the 30+ year system life expectancy. The results of this additional system choice are shown in Appendix AB.

The LCC for the hybrid shows total life cycle costs of $23,559 compared to $42,278 for the SRS and $14,795 for the GFA. The total life cycle costs as an annual value were $1,884 for the hybrid compared to $3,380 for the SRS and $1,183 for the GFA. These results support the emissions findings from the LCA: a midrange value. In this case the creation of an acceptable heating system alternative to the original two system choices was successful using the LCA methodology but not using the LCC methodology. However, the apparent role costs play as a function of environmental impact is readily apparent and raises an additional research question.

1. Given the tradeoffs between the environment and economics, what are some of the costs concerns relating to LCA and LCC associated with making a heating system selection from the view of the decision making party?

The Role of Costs

The decision making party needs to understand the role of project costs, not only first costs, but how costs may affect the LCA results. The amount of calculated emissions using the EIO-LCA methodology is a function of costs and is linear in nature. The cost to manufacture a product is assumed to be representative of some amount of emissions based on industry averages for the base year data. Two important issues associated with this assumption are the timing of the costs and base year emissions.

The timing of the costs refers to the time difference between the current and base years. The greater the timing difference, the greater the risk of using a discounting mechanism, in this case the CPI. The CPI is based on the market basket approach (for a complete description of market basket, see www.bls.gov/cpi/cpifaq.htm). The index represents the spending patterns of urban shoppers and may reflect both the economic and political climate from that point in time. However, the base year may not be indicative of current shopping patterns, the economy, or political climate. The user of the information needs to understand the risks associated with using the CPI, the length of time between purchase and base dollars, and the differences in costs.

The adjustment of current cost to base year data is based on the assumption that the prices for goods and services increase. While technically correct, there are cases where prices of products may decrease due to increased demand and technological advances. When these lower prices are adjusted to base year dollar equivalents, the lower cost effect is compounded. Not only has the current price decreased, the discount further decreases the base year cost equivalent. This may result in an understatement of emissions in base year terms.

Solar collectors provide an example where the longer the time frame between the current and base year costs, the greater the risk for this potential understatement of emissions. The SRS solar collector component illustrates a case where demand or technology may decrease the cost of production over an extended time frame. If the cost of flat plate solar collectors decreased from $18,608.00 in 1997 to $14,608.00 in 2006, one could assume the $4,000.00 decrease is the result of either an increase in production or a technological advancement, or both as the reason. An increase in demand may decrease the emissions assigned to each unit by spreading the fixed costs portion over more units. A technological advancement would hopefully decrease the emissions assigned to the variable costs portion of the product as well. In either case, the lower costs represent the expected lower emissions in 2007. In addition to this decrease attributable to the current cost reduction, the current cost is then discounted to the base year, Table 28.

Table 28. Differences in Current Cost to Base Year Costs by Phase and System.
Source: Tables 6, 8, 12, and 14.

Phase	2007 $ Value	1997 Discount $ Value GFA	Percent Reduction GFA	2007 $ Value	1997 Discount $ Value SRS	Percent Reduction SRS
Mfg	$2,585.21	$1,404.13	46.00	$30,928.00	$16,288.60	47.33
Use/maint	$7,708.02	$5,400.69	30.00	$1,708.00	$1,169.37	31.55
Total		$6,804.82			$17,457.97	

As shown in Table 28, the dollar discount from current year dollars to base year dollars for the SRS is substantial (47.33%). The 47.33% reduction ($6,942.61) in the flat plate solar collectors 2007 cost to base year costs would also reflect a decrease in emissions relative to the base year data. The result would be a double counting of the emission reduction. Once for the reduction in the 2007 cost, $4,000 from 1997, and once for the CPI discount to base year dollars.

The representation of emissions as a function of costs may result in an understatement/overstatement of emissions. The time increment from the base year to the year of production also is a concern for technology matching to costs. This creates two additional research questions.

1. Are the emissions of each component accurately represented by the cost to manufacture that component?
2. Does the length of time between the base year data used in the eiolca.net tool and the time the product was manufactured affect the emissions as a function of costs?

The relationship between costs and impacts is an important one. Since all impacts are computed based on the cost to manufacture, the EIO-LCA methodology includes an inherent assumption that all costs are equal at all production facilities. An example of the weakness of this assumption could be two production facilities making the same product for the same company but located in different geographic regions of the U.S. If one plant is closer to the raw materials supplier their shipping costs may be lower then the other plant. The same could be true for the cost of labor. One plant could be in the Northeast and be unionized and the other could be in El Paso, Texas with a non-union shop. There could be a significant labor cost differential.

In either case, the cost to manufacture could be significantly different. The effect these costs differences have on the product purchaser are minimal as the increased profit resulting from lower shipping or labor cost within the company flow through the balance sheet as additional profit.

With respect to base year emissions, the older the base year data, the greater the risk that it may not accurately represent advancements in technology and cost savings achieved from economies of scale. Technology savings could come from more efficient smokestack scrubbers, new materials, more efficient manufacturing processes, better designs, or new product technology increasing product efficiency while reducing size. Greater economies of scale may result from mergers and acquisitions, increased market demand, lower price due to increased product efficiency, or improved worker or manufacturing productivity rates.

The risk that lower emissions and lower costs today are not represented in older base year data is real. The SRS in this case study used flat plate solar collector technology. As sustainable building increases in the market place, there will be more demand for renewable energy. As demand increases, the production costs should decrease driven by greater economies of scale, new technology, or both. Over the course of a ten-year period, the emissions for dollar spent could change drastically; a change that may not be reflected in the base year data that is ten years older than the technology. Therefore, the price emissions ratio may be skewed in the LCA as a function of costs, with the result of overstated emissions. The fact that costs are discounted to a base year does not account for any other factor except inflation.

There is also the question of who pays for long-term efficient heating systems. This is a function of how long someone will occupy a home. Most people do not stay in a house for the 20-to 30-year average life expectancy for various heating systems. Given the current economic situation in the residential real estate market, there is no substantial resale market premium for heating systems that lower or eliminate monthly bills. In 2005, Schenck brought up the point that people want these systems, but in most cases they are not willing to pay for them. If they are willing to pay a premium for an efficient system, the appraisal of the home must reflect this. If it does not, the buying party must come up with additional funds at closing for the premium above what the lender is willing to lend or the seller must lower the price.

Three other research questions emerged that focus on how this analysis process can help owners and practitioners make similar informed decisions in a timely and cost effective manner.

1. Can the results of this case study be generalized to other residential home projects considering the same system choices?

The results of this case study could be generalized to a residence in the same geographic region having the same number of solar days exposure. However, generalization would require a similar building envelope, insulation package, windows, and quality of construction and materials. Even if these steps are taken, there is no guarantee the heat loss calculations and system design loads would be similar, a function of the design software used for these calculations. It is more accurate to perform an LCA and LCC for each heating system based on the system design for that individual project and the framework outlined in chapter four.

2. What information needs to be collected by the homeowner or the builder in order to perform this type of analysis?

The information needed to perform the LCA and LCC calculations is straightforward and can be taken from detailed bids, utility bills, national averages for energy use, other studies, or other sources readily available that fit the project requirements. The LCC input data sheets used in this case study are available in Appendix Z. Supporting calculations are in Appendix W.

3. What other considerations need to be balanced in conjunction with an analysis using LCA and LCC?

LCA and LCC are two tools the building owner or designer has available for decision making regarding residential heating systems. There may be issues that change over time that favor one system over another. For example, building codes may be prescriptive and not performance-based. The availability of materials within a specific building window may be a deciding factor. The ability of people with the expertise to run and maintain a system and financial resources an owner has to hire someone to run or maintain a system may also be a concern.

Phase Level Energy Use Findings

The consideration of "Energy" as a metric in heating system choice is also appropriate. The energy used for each of the three phases: manufacturing, use, and maintenance, can be calculated at the same time as the impacts for GHGs. Table 29a and b and Figure 20 compares the results of Tables 19 and 20 for the phases with the greatest differences in energy use.

The SRS system uses 34.93 total MJ more energy than the GFA system and the Hybrid system uses 17.43 total MJ more than the GFA system (Table 29a). The use of the hybrid system results in a 50% reduction of total MJ used. The $MTCO_2E$ for the same three phases: manufacturing, use, and maintenance, shown in Table 30 are 10.6$MTCO_2E$ higher for the SRS than the GFA and 3.5 $MTCO_2E$ higher for the Hybrid over the GFA system. The adoption of the hybrid system cuts $MTCO_2E$ by 66%. There also appears to be a correlation between the manufacturing and use phases for both the

EIO-LCA and Energy data. In Table 29, the total MJ use for the SRS was 91.95 MJ more than the GFA and the hybrid used 40.94 total MJ more than the GFA. The use of the hybrid system would lower total MJ use in the manufacturing phase by 45%. Table 30 shows a similar trend with the SRS creating 10.6 $MTCO_2E$ more emissions than the GFA and the hybrid creating 3.5 $MTCO_2E$ more than the GFA. The reduction in choosing the hybrid system over the SRS system results in a 66% reduction in $MTCO_2E$ in the manufacturing phase. Looking at the use and maintenance phase, we can see in Table 29a that the GFA system used 75% more MJ than the SRS system. This is largely due to the burning of natural gas which is 89% higher for the GFA system, Table 29b. The $MTCO_2E$ shown in Table 30 indicates a similar pattern for the use/maintenance phase with the GFA system creating more $MTCO_2E$ than the SRS or hybrid system. The choice of the GFA over the SRS system will increase the $MTCO_2E$ by 10.6 and the choice of the hybrid over the SRS will increase the $MTCO_2E$ by 5.3. The choice of the hybrid over the GFA system would only increase the $MTCO_2E$ by 58% over the SRS system. The data in Table 13 indicates that this is largely due to the burning of natural gas; the GWP $MTCO_2E$ for natural gas is 82% of the total GWP $MTCO_2E$ for the GFA use/maintenance phase. This is similar to Table 29b which shows an increase in NG energy use in the use/maintenance phase for the GFA system and the hybrid system over the SRS system.

Table 29a&b. Energy Use by System Comparison for Phases with Greatest Difference. Source: Table 19 & 20

Phase	Total GFA Total MJ	Total SRS Total MJ	Total Hy Total MJ	Elec GFA Elec MkWh	Elec SRS Elec MkWh	Elec Hy Elec MkWh
MFG	11.60	103.55	52.54	0.72	6.32	3.64
Const						
Use/Main	76.98	19.97	53.47	2.06	0.34	1.78
Disposal						
Totals	88.58	123.51	106.01	2.77	6.66	5.42

Table 29b. Energy Use by system Comparison for Phases with Greatest Difference.
Source: Table 19 & 20

Phase	Coal GFA Coal MJ	Coal SRS Coal MJ	Coal Hy Coal MJ	NatGas GFA NG MJ	NatGas SRS NG MJ	Natgas Hy NG MJ	MotGas GFA MotGas MJ	MotGas SRS MotGas MJ	MotGas Hy MotGas MJ
MFG	2.90	26.16	14.12	5.05	45.97	21.42	0.60	6.46	2.75
Const							2.49	3.41	3.41
Use/Main	14.66	7.64	13.70	44.42	4.89	28.83	3.16	0.71	1.19
Disposal							0.43	0.40	0.40
Totals	17.55	33.80	27.83	49.46	50.86	50.25	6.67	10.98	7.75

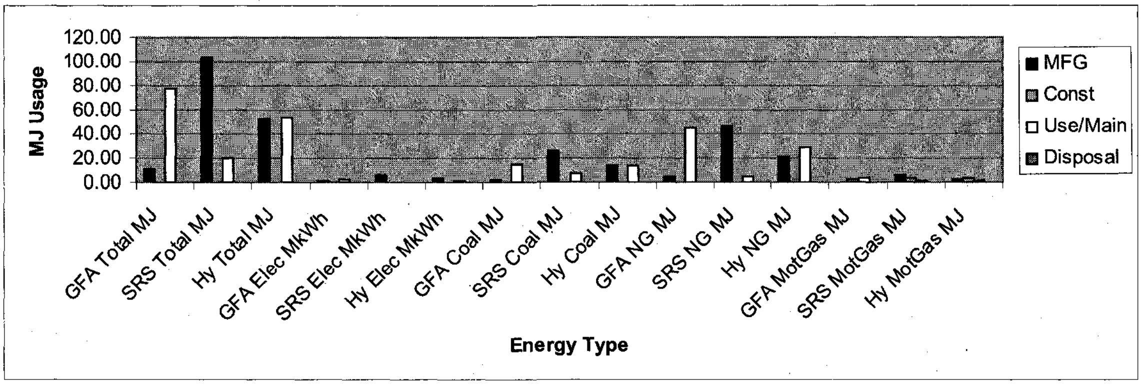

Figure **20. Comparison for Energy Use by System Phases with Greatest Difference.**
Source: Table 19 & 20

Table 30. Select EIO-LCA Phases for Comparison to Energy Usage Phases. Source: Table 27

Life Cycle Phase	GFA MTCO$_2$E GWP	SRS MTCO$_2$E GWP	Hybrid MTCO$_2$E GWP
Manufacturing	1.0	11.6	4.5
Use/Maintenance	10.6	1.6	6.9
Total	11.6	13.2	11.4

The construction and disposal phases' energy analysis was derived from the traditional LCA format and the results converted to MJ. The analysis for these phases used the data looking at commuter miles, work-related travel, fuel usage, and electrical consumption. Table 31 and Figure 21 shows the fuel consumption for the construction phase and Table 32 and Figure 22 does so for the disposal phase, and Figure 23 compares electrical use for the construction phase.

Table 31. Comparison of Gallons of Gas Fuel Use in the Construction Phase

	Commute	Materials	Dump	Transport	Trench	Total
GFA Fuel Used	12.05	6.24	1.42	0	0	19.71
SRS Fuel Used	10.1	8.65	1.42	1.77	5	26.94

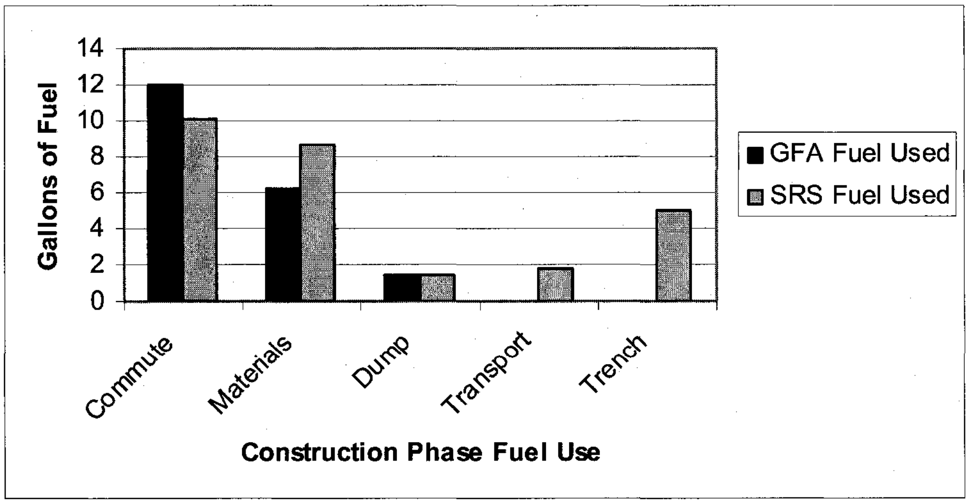

***Figure* 21. Comparison of Fuel Use in the Construction Phase.** Source: Appendix R & S

The overall fuel consumption shown in Table 31 and Figure 21 is higher for the SRS than the GFA system and is expected due to the difference in job durations with the SRS taking 21 days and the GFA taking 5 days. Additional factors in the fuel usage include the transport and running of the trencher. However, the installer of the SRS system does get 30 mpg, actual historical mileage, while the installer for the GFA uses an industry average of 17.6 mpg. The construction phase fuel use for the SRS system is higher due to daily trips to the supply house for unforeseen parts. Better material lists and project management could reduce this usage significantly. The dump use is equal and the GFA system does not need to transport and use a trencher.

The fuel consumption shown in Table 32 and Figure 22 is higher for the SRS due to the increased number of trips to the worker's house to transport the materials for reuse at some other site. The use of a larger truck for transport could cut this usage down. The important concept here is that the SRS components will be reused at another site; the transportation impacts for that usage would be included within the boundary of that site study.

Table 32. Comparison of Gallons of Gas Fuel Use in Disposal Phase.

	Commute	Recycle
GFA Fuel Used	2.41	1.02
SRS Fuel Used	2.83	0.34

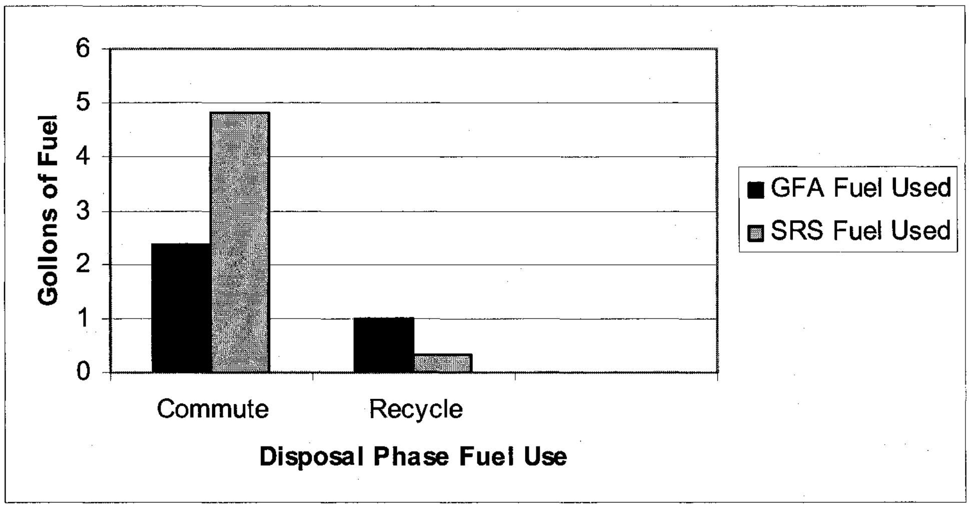

Figure **22. Comparison of Fuel Use in the Disposal Phase.** Source: Appendix R & S

The increased electrical use shown in Figure 23 is attributable entirely to the job duration as daily kWh , 10 kWh per day, usage is assumed to be the same. The GFA duration is expected to be 5 days, 50 kWh, and the SRS is expected to be 21 days, 210 kWh. This is a linear function of time and may not be the most accurate indication of electrical usage due to the unknown sequencing of the work. The tools used for each installation are similar in nature and typically are hand operated or run off battery packs.

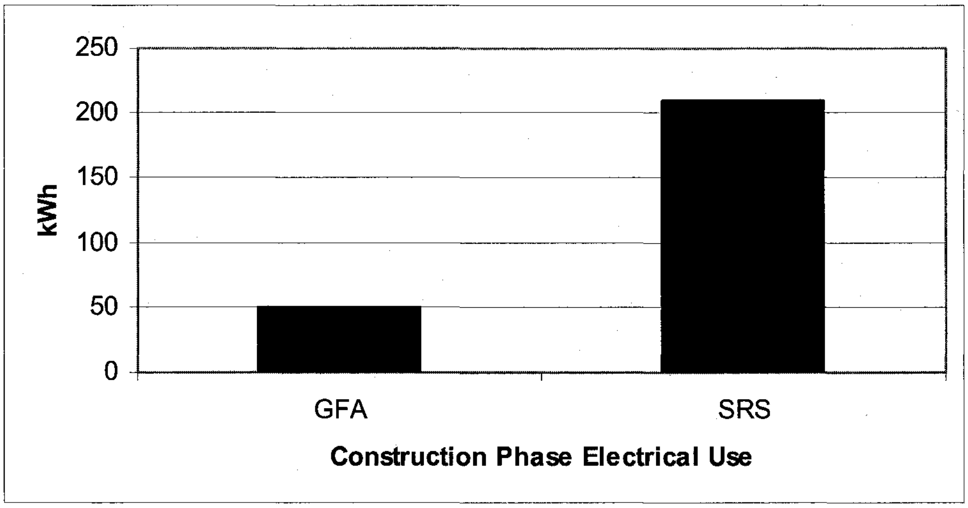

Figure **23. Comparison of Electrical Use in the Construction Phase.** Source: Appendix R & S

Previous Study Results Comparison

There are both similarities and differences between the results of this case study and others previously done in the construction field. Blanchard and Reppe used a 4% discount rate for their energy cost escalation in their study of energy efficient homes in Ann Arbor Michigan, an amount similar to the 5% discount rate used here. They performed an LCA on a home modeled with various energy efficiency features and a standard home. The result was that the energy-efficient home used the lowest amount of energy in the use phase compared to the standard home (1998).

The focus on the use phase does not allow for a comparison to other phases in a LCA. Both Horvath, 1997, and Guggemos, 2003, found other phase to be higher in emissions than the use phase. The results of this study support those findings. The GFA system was much more environmentally-friendly in the manufacturing phase than the SRS. That friendliness reversed itself during the use phase. This is an important concern as the GHG produced in all five phases of a home's life should be considered when designing, not just the use phase.

Zachariah focused on residential homes in Canada and also found that the use phase needs to be targeted in the design phase of a home (2003). Ochoa Franco had similar results finding that the energy use in the use phase was the highest. This study did depart from traditional LCA and EIO-LCA formats, however (2004). The use phase in the case study performed in this paper found that the SRS used substantially less energy than the GFA system in the use phase. Despite the use phase performance, the SRS system does not have the overall lower emissions in all five phases compared to the GFA system. A decision based solely on use phase results would yield inaccurate data on which to base heating system adoption. To determine if this system would be the best choice, then all energy use and emissions would need to be calculated and reviewed.

Yang studied GFA and hot water baseboard heating systems using a payoff matrix due to incomplete manufacturer data. This established a matrix with 120 different alternatives yet none were calculated due to lack of information. The hot water heating source in Yang's study was an electric boiler and fin-type baseboard radiators. This study used a 98% efficient NG boiler and radiant floor loops. Based on the information in Yang's study, the GFA components are similar. The results of Yang's study found that the emissions for the hot water system were less during the use phase than the GFA; a result similar to this study. The LCC were also found to be less in the use phase but were close to equal over the 30-year period of the study. This result is very different from this study where the LCC of the SRS were higher and did not reach equilibrium during the study period. Yang did not include maintenance, retrofit, and demolition items included in this case study.

Conclusions

LCA and LCC are valuable methods for decision making when their strengths and weaknesses are understood. The problem solving approach both methods take is rational and systematic in nature, but uses assumptions that are value-laden and contain a certain level of uncertainty. Neither method should be used as the sole basis for decision making. LCA has inherent weaknesses in both the traditional and EIO-LCA formats. Energy use uses the same base data the EIO-LCA method does so the weaknesses are similar. In addition, there are other assumptions to the energy number that are described in the eiolca.net tool assumptions disclosure. The energy results should mimic the EIO-LCA results in percentages since they use the same data set. LCC is weak in the prediction aspect of forecasting multiple variables future values.

Traditional LCA is time-consuming and information may be hard to obtain. The construction and disposal phase results in this case study are a small portion of the emission results from all phases. There may not be time or a need for the general building practitioner to achieve such detail for the decision makers. The EIO-LCA approach is relatively quick and provides emissions data that, on average, appear reasonable for the three highest emission producing phases relating to residential heating systems: manufacturing, use, and maintenance.

The increased use of LCA in construction is important, but it is not without problems. One barrier to EIO-LCA is the globalization of product manufacturing.

Unless the source of manufacturing is specified in the contract documents, a part could come from one of several plants, in most cases, located around the world. This globalization makes using the EIO-LCA problematic in the sense that the U.S. economy is no longer big enough; a problem similar to that of the tight boundaries of a traditional LCA.

The assumption that lower costs will result in lower emissions needs to be understood in the context of discounting, emissions averages, production costs, and time factors. It cannot be taken for granted that cost savings will come from a new technology. Cheaper labor or overhead cost in one plant may allow for additional profit by a manufacturer if all other things are equal. A new technology may increase the speed with which one unit can be produced but not lower the emissions except to spread the fixed-cost portion over more units. The passage of time between base year and current prices adds additional risk to the emissions calculation since base year rates may not reflect technological changes. The use of emissions averages for all sectors of the economy may understate or overstate emissions depending on the representativeness of the sector of interest to the overall supply chain.

There needs to be more work done at the national level to ensure data availability is current. In addition, the Department of Commerce needs to expand the NAICS categories in the construction industry sectors to fine-tune the impacts of this large and diverse industry. There also needs to be a concerted effort to identify and incorporate new categories that accurately represent new renewable technologies in all segments of the economy.

The use of the government supported BLCC 5.3-7 model is straight forward once the initial data is assembled and assumptions are made. If the LCC is being done simultaneously with an LCA, the LCA data for the use and maintenance phase is similar to that needed for the LCC. The ability to add alternatives to the base case scenario are invaluable. Unfortunately, the information used in this tool is also value-laden and contains a level of uncertainty.

The use of LCC focuses on financial metrics only. There is a need for long-term thinking in the environmental debate regarding who will ultimately pay for heating systems that take substantially longer to pay out than their alternatives. The question of "who pays and when" should be replaced with the question "what can be done so everyone shares equally in the costs and benefits of environmental stewardship?"

The framework created in this research addresses the problem identified in a study commissioned by the Canadian Wood Council and done by the Athena Institute. A concluding comment identified the need to create LCA data without having to become an LCA expert (Trusty & Meil, n.d.). The ability of a user to follow the framework supplied in this paper will increase the understanding of LCA and LCC as methodologies to develop data that can be used in decision making. The framework will also help interested parties access and use these models resulting in increased expertise as called for by Cole, 1998). The study results also reinforce the need to look at all phases in a LCA and LCC. It cannot be assumed that the usage phase will always be the highest energy user and emissions producer.

Future Research

There are several areas for continuing research in the field of LCA and LCC relating to the construction industry. Even though LCC has been used in construction decision making for years and LCA is gaining a foothold in the industry, the question of how to balance their information remains unanswered. Over time, solutions to data availability, multiregional manufacturing, and less aggregated data will be found.

In the case of the EIO-LCA.net web site, the base year data used is from 1997. Ochoa Franco, Hendrickson, and Matthews addressed the data availability point in the weaknesses of LCA section in the literature review. They stated that they chose 1997 data for the EIO-LCA.net website based on availability. The government is supposed to update this information in five-year cycles, 2002 and 2007. Once this information is available, it is critical to incorporate it into this web-based tool.

When the newer data is made available, it would be interesting to look at the effects the different time period base data has on the same project. For example, both the GFA and SRS systems case study could be replicated using 1992, 1997, 2002, and 2007 base year data to measure the effects of the time difference (CPI), the cost difference (first costs), and the differences in emissions from technological advancements (GWP).

There are several countries that have data sets for EIO-LCA. Each of these data sets uses the country's economy as the study boundary, similar to the U.S. With the globalization of manufacturing, it is increasingly important to identify which production facilities are most efficient. Once this is accomplished, the technology can be transferred to other facilities, supply chains could be streamlined, or facilities could be shut down. It may be shown that it is more environmentally-friendly to leave production at specific facilities and ship around the world instead of building new or retrofitting old facilities.

The aggregation of data allows the EIO-LCA model to expand the supply chain, but, at the same time, limits the focus that is achieved in the traditional LCA. As new alternatives to renewable energy are discovered and introduced to the marketplace, comparative studies of the EIO-LCA and LCA methods should be done. There is no reason to implement a new technology that is not what it purports to be. A traditional LCA could verify or dismiss the assumptions of the marketplace based on costs alone.

There needs to be additional studies of heating systems to determine if the construction and disposal phases contribute significant amounts of emissions to the environment. The development of baseline data sets for different heating systems will determine if the these phases need to be addressed in a streamlined LCA process aimed at providing quick and pertinent information to decision makers concerning heating system choice; a necessity for the adoption and use of LCA by owners and industry professionals. The increased data could also be used on a geographical basis to help local building authorities adopt performance based building codes.

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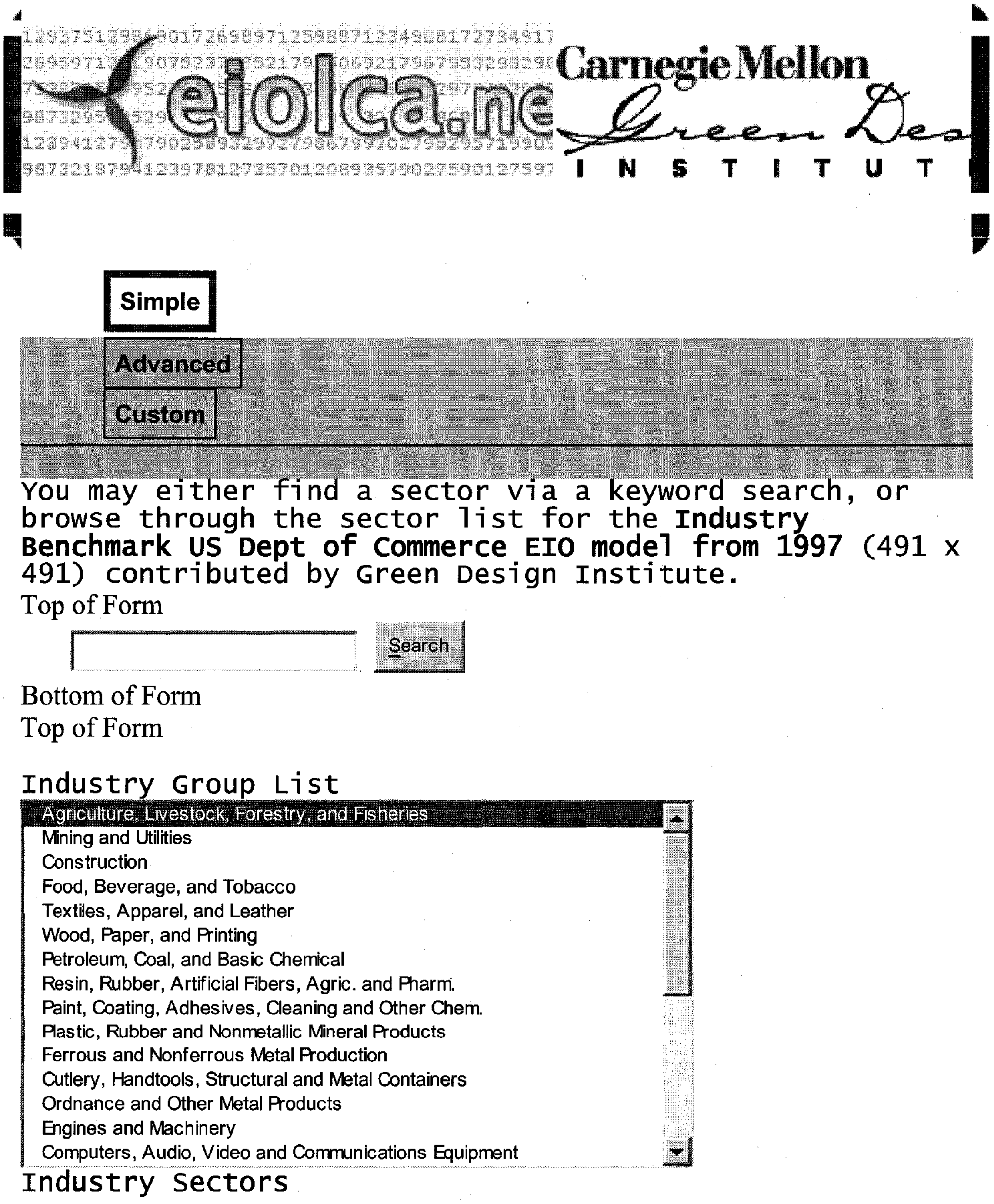
Appendix A

eiolca.net Home Page

Source: EIOLCA.net, downloaded 9-15-2007



You may either find a sector via a keyword search, or browse through the sector list for the **Industry Benchmark US Dept of Commerce EIO model from 1997** (491 x 491) contributed by Green Design Institute.

Top of Form

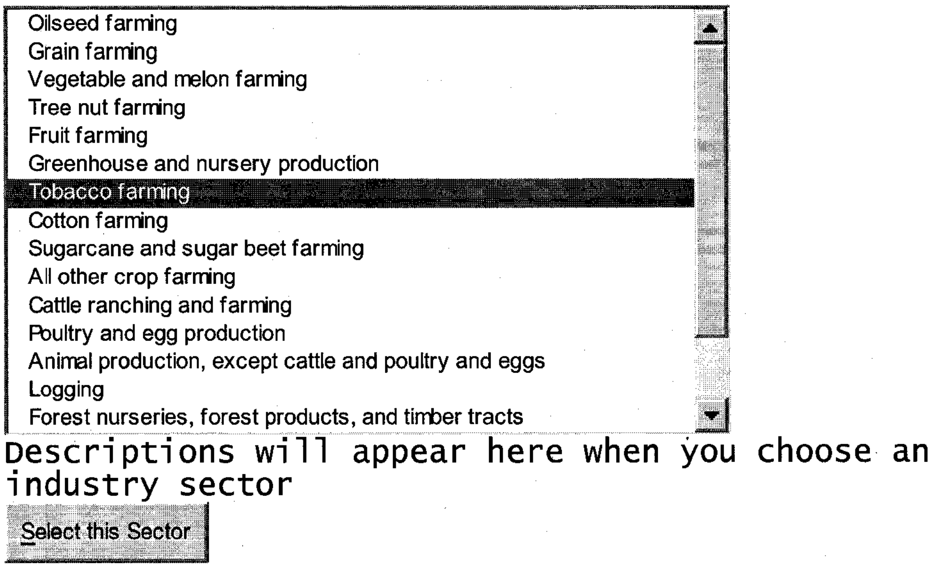
Bottom of Form

Top of Form

Industry Group List

- Agriculture, Livestock, Forestry, and Fisheries
- Mining and Utilities
- Construction
- Food, Beverage, and Tobacco
- Textiles, Apparel, and Leather
- Wood, Paper, and Printing
- Petroleum, Coal, and Basic Chemical
- Resin, Rubber, Artificial Fibers, Agric. and Pharm.
- Paint, Coating, Adhesives, Cleaning and Other Chem.
- Plastic, Rubber and Nonmetallic Mineral Products
- Ferrous and Nonferrous Metal Production
- Cutlery, Handtools, Structural and Metal Containers
- Ordnance and Other Metal Products
- Engines and Machinery
- Computers, Audio, Video and Communications Equipment

Industry Sectors



Oilseed farming
Grain farming
Vegetable and melon farming
Tree nut farming
Fruit farming
Greenhouse and nursery production
Tobacco farming
Cotton farming
Sugarcane and sugar beet farming
All other crop farming
Cattle ranching and farming
Poultry and egg production
Animal production, except cattle and poultry and eggs
Logging
Forest nurseries, forest products, and timber tracts

Descriptions will appear here when you choose an industry sector

This sector is comprised of one or more NAICS sectors, as described below:

11191 Tobacco Farming

111910 Tobacco Farming

This industry comprises establishments primarily engaged in growing tobacco.

Examples of activities in this sector:

- Tobacco farming, field and seed production

Bottom of Form

Appendix B

Air Conditioning & Warm Air Heating

NAICS Sector Air-Conditioning and Warm Air Heating Equipment

This sector is comprised of one or more NAICS sectors, as described below:

333415 Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing

This U.S. industry comprises establishments primarily engaged in (1) manufacturing air-conditioning (except motor vehicle) and warm air furnace equipment and/or (2) manufacturing commercial and industrial refrigeration and freezer equipment.

Examples of activities in this sector:

* Air-conditioners, unit (e.g., motor home, travel trailer, window), manufacturing
* Air-conditioning and warm air heating combination units manufacturing
* Air-conditioning compressors (except motor vehicle) manufacturing
* Air-conditioning condensers and condensing units manufacturing
* Air-conditioning equipment (except motor vehicle) manufacturing
* Beer cooling and dispensing equipment manufacturing
* Coolers, refrigeration, manufacturing
* Coolers, water, manufacturing
* Cooling towers manufacturing
* Counters and display cases, refrigerated, manufacturing
* Dehumidifiers (except portable electric) manufacturing
* Display cases, refrigerated, manufacturing
* Drinking fountains, refrigerated, manufacturing
* Electric warm air (i.e., forced air) furnaces manufacturing
* Evaporative condensers (i.e., heat transfer equipment) manufacturing
* Fountains, refrigerated drinking, manufacturing
* Freezing equipment, industrial and commercial-type, manufacturing
* Furnaces, warm air (i.e., forced air), manufacturing
* Heat pumps manufacturing
* Heating and air conditioning combination units manufacturing
* Heating equipment, warm air (i.e., forced air), manufacturing
* Humidifying equipment (except portable) manufacturing
* Ice making machinery manufacturing
* Lockers, refrigerated, manufacturing
* Refrigerated lockers manufacturing
* Refrigeration compressors manufacturing
* Refrigeration equipment, industrial and commercial-type,

manufacturing
* Refrigeration units, truck-type, manufacturing
* Room air-conditioners manufacturing
* Showcases, refrigerated, manufacturing
* Snow making machinery manufacturing
* Soda fountain cooling and dispensing equipment manufacturing
* Water (i.e., drinking) coolers, mechanical, manufacturing

Appendix C

Sheet Metal Work Manufacturing

NAICS Sector for Sheet Metal Work Manufacturing
This sector is comprised of one or more NAICS sectors, as described below:

332322 Sheet Metal Work Manufacturing

This U.S. industry comprises establishments primarily engaged in manufacturing sheet metal work (except stampings).

Examples of activities in this sector:

* Air cowls, sheet metal, manufacturing
* Awnings, sheet metal, manufacturing
* Canopies, sheet metal, manufacturing
* Casings, sheet metal, manufacturing
* Coal chutes, sheet metal, manufacturing
* Concrete forms, sheet metal, manufacturing
* Cornices, sheet metal, manufacturing
* Cowls, sheet metal, manufacturing
* Culverts, sheet metal, manufacturing
* Dampers, sheet metal, manufacturing
* Door hoods, sheet metal, manufacturing
* Downspouts, sheet metal, manufacturing
* Ducts, sheet metal, manufacturing
* Eaves, sheet metal, manufacturing
* Elbows for conductor pipe, hot air ducts, and stovepipe, sheet metal, manufacturing
* Flooring, sheet metal, manufacturing
* Flues, stove and furnace, sheet metal, manufacturing
* Flumes, sheet metal, manufacturing
* Forms, concrete, sheet metal, manufacturing
* Furnace casings, sheet metal, manufacturing
* Furnace flues, sheet metal, manufacturing
* Guardrails, sheet metal highway, manufacturing
* Gutters, sheet metal (except custom roll formed), manufacturing
* Hampers, laundry, sheet metal, manufacturing
* Highway guardrails, sheet metal, manufacturing
* Hoods, range (except household-type), sheet metal, manufacturing
* Irrigation pipe, sheet metal, manufacturing
* Joists, sheet metal, manufacturing
* Louvers, sheet metal, manufacturing
* Machine guards, sheet metal, manufacturing
* Mail chutes, sheet metal, manufacturing
* Pile shells, sheet metal, manufacturing
* Pipe, sheet metal, manufacturing

* Radiator shields and enclosures, sheet metal, manufacturing
* Roof deck, sheet metal, manufacturing
* Roofing, sheet metal, manufacturing
* Sheet metal work (except stamped) manufacturing
* Siding, sheet metal, manufacturing
* Skylights, sheet metal, manufacturing
* Spouts, sheet metal, manufacturing
* Stove boards, sheet metal, manufacturing
* Stove pipes and flues, sheet metal, manufacturing
* Studs, sheet metal, manufacturing
* Troughs, elevator, sheet metal, manufacturing
* Ventilators, sheet metal, manufacturing
* Wells, light, sheet metal, manufacturing

Appendix D

Ornamental & Architectural Metal Work

Ornamental and Architectural metal work manufacturing

This sector is comprised of one or more NAICS sectors, as described below:

332323 Ornamental and Architectural Metal Work Manufacturing

This U.S. industry comprises establishments primarily engaged in manufacturing ornamental and architectural metal work, such as staircases, metal open steel flooring, fire escapes, railings, and scaffolding.

Examples of activities in this sector:
* Acoustical suspension systems, metal, manufacturing
* Architectural metalwork manufacturing
* Balcony railings, metal, manufacturing
* Bank fixtures, ornamental metal, manufacturing
* Bannisters, metal, manufacturing
* Barn stanchions and standards manufacturing
* Brasswork, ornamental, manufacturing
* Chain ladders, metal, manufacturing
* Channels, furring metal, manufacturing
* Corrals, metal, manufacturing
* Elevator guide rails, metal, manufacturing
* Fences and gates (except wire), metal, manufacturing
* Fire escapes, metal, manufacturing
* Flagpoles, metal, manufacturing
* Flooring, open steel (i.e., grating), manufacturing
* Furring channels, sheet metal, manufacturing
* Gates, holding, sheet metal, manufacturing
* Gates, metal (except wire), manufacturing
* Gratings (i.e., open steel flooring) manufacturing
* Grills and grillwork, sheet metal, manufacturing
* Grillwork, ornamental metal, manufacturing
* Guards, bannisters, and railings, sheet metal, manufacturing
* Ladders, metal chain, manufacturing
* Ladders, permanently installed, metal, manufacturing
* Lath, expanded metal, manufacturing
* Ornamental metalwork manufacturing
* Partitions, ornamental metal, manufacturing
* Pipe bannisters, metal, manufacturing
* Pipe guards, metal, manufacturing
* Pipe railings, metal, manufacturing

* Purlins, metal, manufacturing
* Railings, metal, manufacturing
* Registers, metal air, manufacturing
* Scaffolds, metal, manufacturing
* Stair railings, metal, manufacturing
* Stair treads, metal, manufacturing
* Staircases, metal, manufacturing
* Stairs, metal, manufacturing
* Stalls, metal, manufacturing
* Treads, metal stair, manufacturing

Appendix E

Automatic Environmental Controls

NAICS Sector for Automatic Environmental Control Manufacturing for Residential, Commercial, and Appliance Use

This sector is comprised of one or more NAICS sectors, as described below:

334512 Automatic Environmental Control Manufacturing for Residential, Commercial, and Appliance Use

This U.S. industry comprises establishments primarily engaged in manufacturing automatic controls and regulators for applications, such as heating, air-conditioning, refrigeration and appliances.

Examples of activities in this sector:

* Air flow controllers (except valves), air-conditioning and refrigeration, manufacturing
* Appliance controls manufacturing
* Appliance regulators (except switches) manufacturing
* Building services monitoring controls, automatic, manufacturing
* Clothes dryer controls, including dryness controls, manufacturing
* Combination limit and fan controls manufacturing
* Combination oil and hydronic controls manufacturing
* Computerized environmental control systems for buildings manufacturing
* Damper operators (e.g., electric, pneumatic, thermostatic) manufacturing
* Electric air cleaner controls, automatic, manufacturing
* Electric heat proportioning controls, modulating controls, manufacturing
* Electric space heater controls, automatic, manufacturing
* Energy cutoff controls, residential and commercial types, manufacturing
* Fan controls, temperature responsive, manufacturing
* Flame safety controls for furnaces and boilers manufacturing
* Float controls, residential and commercial types, manufacturing
* Gas burner automatic controls (except valves) manufacturing
* Gradual switches, pneumatic, manufacturing
* Heating and cooling system controls, residential and commercial, manufacturing
* Heating regulators manufacturing
* Humidistats (e.g., duct, skeleton, wall) manufacturing

* Humidity controls, air-conditioning-type, manufacturing
* Hydronic circulator control, automatic, manufacturing
* Hydronic limit control manufacturing
* Hydronic limit, pressure, and temperature controls, manufacturing
* Ice bank controls manufacturing
* Ice maker controls manufacturing
* Ignition controls for gas appliances and furnaces, automatic, manufacturing
* In-built thermostats, filled system and bimetal types, manufacturing
* Incinerator control systems, residential and commercial-type, manufacturing
* Light responsive appliance controls manufacturing
* Limit controls (e.g., air-conditioning, appliance, heating) manufacturing
* Line or limit control for electric heat manufacturing
* Liquid level controls, residential and commercial heating-type, manufacturing
* Oven temperature controls, nonindustrial, manufacturing
* Pneumatic relays, air-conditioning-type, manufacturing
* Pressure controllers, air-conditioning system-type, manufacturing
* Pressurestats manufacturing
* Primary oil burner controls (e.g., cadmium cells, stack controls) manufacturing
* Refrigeration controls, residential and commercial-type, manufacturing
* Refrigeration thermostats manufacturing
* Refrigeration/air-conditioning defrost controls manufacturing
* Room thermostats manufacturing
* Sequencing controls for electric heating equipment manufacturing
* Static pressure regulators manufacturing
* Steam pressure controls, residential and commercial heating-type, manufacturing
* Surface burner controls, temperature, manufacturing
* Switches, pneumatic positioning remote, manufacturing
* Switches, thermostatic, manufacturing
* Temperature controls, automatic, residential and commercial-types, manufacturing
* Temperature sensors for motor windings manufacturing
* Thermocouples, glass vacuum, manufacturing
* Thermostats (e.g., air-conditioning, appliance, comfort heating, refrigeration) manufacturing
* Time program controls, air-conditioning systems, manufacturing
* Vapor heating controls manufacturing
* Water heater controls manufacturing

Appendix F

Transportation Supporting Documentation

The information about trucking freight charges came from personal correspondence with TDM Transport Inc., a truck transportation broker in Fort Collins, Colorado. (8-12-2007). It is assumed that all components came from North America as specified in the contracts. It is necessary to determine a dollar figure for freight in order to use EIOLCA.net. The freight charges for trucking are based on the weight of the item being shipped and travel zone(s) and vary widely nationwide. The figure of $2 per mile was determined to be a good estimate of an average trucking charge per mile across all freight zones. The maximum freight weight a truck can carry without a special use permit is 45K lbs. Based on this information, the individual component weights were estimated either from manufacturers specifications, from shipping labels, or by approximation. The combined weight for a system, either Gas Forced Air (GFA) or Solar Radiant System (SRS), was then proportioned to a full truckload of 45k lbs priced at $2 per mile.

Where specific manufacturing plants were identified from product literature or corporate websites, the mileage was approximated, and in the case of multiple plants, averaged to Fort Collins, Colorado. In the case where plants could not be identified but were clustered in a specific region(s) of the country an average was used from a central point in the region to Fort Collins, Colorado. All other components were estimated using an average trip length of 1000 miles.

For the GFA system components, the manufacturing facilities for the Trane furnace were identified from the corporate website and mileages were estimated between the individual plants and Fort Collins, Colorado. The plants were located in Arkansas, Texas, New Jersey, Georgia, and Monterrey, Mexico. The estimated mileages used were 984, 877, 1750, 1403, and 1250 respectively, resulting in an average distance of 1200 miles. The duct work sheet metal was assumed to come from the upper Midwest region of the U.S. with an estimated mileage factor of 940 miles. The other parts needed to assemble the GFA system were assumed to come from various parts of the U.S. and for these an estimated mileage factor of 1000 miles was used.

The weight for the furnace was estimated to be 200 pounds. The weight of the duct work was taken from the detailing of the initial estimate using RS Means factors and is estimated to weigh 528 pounds. The other items were estimated to weigh 150 pounds. Based on these estimates, the shipping cost for the GFA system materials to the wholesale distributor in Fort Collins, Colorado, are estimated to be $39.40 as shown below.

Material	MFG	Est. WGT	Est. miles	$ per lb	Est. $ ship
Furnace	varies	200	1200	0.053333	10.66667
Duct	MN	528	940	0.041778	22.05867
Misc.	varies	150	1000	0.044444	6.666667
					$ 39.39

The components for the SRS come mostly from the Northeast region of the U.S.: Rhode Island, Maine, New Hampshire, and New Jersey. The estimated miles from these production facilities to Fort Collins, Colorado, were 2000, 2100, 2000, and 1750 respectively. In cases where an individual component came from one plant, a specific estimated mileage was used. In cases where the materials could come from multiple plants in the Northeast the average mileage used was 1900 miles.

The specified solar collectors are manufactured in Warwick, Rhode Island and the estimated weight from the manufacturer's product information sheet is 600 pounds. The mounting racks are from the same manufacturer and are estimated to weigh 300 pounds. The storage tanks also come from the same source and are estimated to weigh 500 pounds each, for a combined weight of 1000 pounds. The other component parts are estimated to weigh 750 pounds and come from various parts of the same region so the estimated mileage used was 1900 miles. Based on these estimates, the shipping costs for the SRS system components are estimated to be $232.00 as shown below.

Material	MFG	Est. WGT	Est. miles	$ per lb	Est. $ ship
Solar collectors	Warwick RI	600	2000	0.088889	53.33333
Mount racks	Warwick RI	300	2000	0.088889	26.66667
Storage tanks	Warwick RI	1000	2000	0.088889	88.88889
Misc.	varies	750	1900	0.084444	63.33333
					$ 232.22

Appendix G

Truck Transportation

NAICS Sector for Truck Transportation

This sector is comprised of one or more NAICS sectors, as described below:

484 Truck Transportation

Industries in the Truck Transportation subsector provide over-the-road transportation of cargo using motor vehicles, such as trucks and tractor trailers. The subsector is subdivided into general freight trucking and specialized freight trucking. This distinction reflects differences in equipment used, type of load carried, scheduling, terminal, and other networking services. General freight transportation establishments handle a wide variety of general commodities, generally palletized, and transported in a container or van trailer. Specialized freight transportation is the transportation of cargo that, because of size, weight, shape, or other inherent characteristics require specialized equipment for transportation.

Each of these industry groups is further subdivided based on distance traveled. Local trucking establishments primarily carry goods within a single metropolitan area and its adjacent nonurban areas. Long distance trucking establishments carry goods between metropolitan areas.

The Specialized Freight Trucking industry group includes a separate industry for Used Household and Office Goods Moving. The household and office goods movers are separated because of the substantial network of establishments that has developed to deal with local and long-distance moving and the associated storage. In this area, the same establishment provides both local and long-distance services, while other specialized freight establishments generally limit their services to either local or long-distance hauling.

4841 General Freight Trucking

This industry group comprises establishments primarily engaged in providing general freight trucking. General freight establishments handle a wide variety of commodities, generally palletized, and transported in a container or van trailer. The establishments of this industry group provide a combination of the following network activities: local pickup, local sorting and terminal operations, line-haul, destination sorting and terminal operations, and local delivery.

48411 General Freight Trucking, Local

484110 General Freight Trucking, Local

This industry comprises establishments primarily engaged in providing local general freight trucking. General freight establishments handle a wide variety of commodities, generally palletized and transported in a container or van trailer. Local general freight trucking establishments usually provide trucking within a metropolitan area which may cross state lines. Generally the trips are same-day return.

Examples of activities in this sector:
* Bulk mail truck transportation, contract, local
* Container trucking services, local
* General freight trucking, local
* Motor freight carrier, general, local
* Transfer (trucking) services, general freight, local
* Trucking, general freight, local

48412 General Freight Trucking, Long-Distance

This industry comprises establishments primarily engaged in providing long-distance general freight trucking. General freight establishments handle a wide variety of commodities, generally palletized and transported in a container or van trailer. Long-distance general freight trucking establishments usually provide trucking between metropolitan areas which may cross North American country borders. Included in this industry are establishments operating as truckload (TL) or less than truckload (LTL) carriers.

484121 General Freight Trucking, Long-Distance, Truckload

This U.S. industry comprises establishments primarily engaged in providing long-distance general freight truckload (TL) trucking. These long-distance general freight truckload carrier establishments provide full truck movement of freight from origin to destination. The shipment of freight on a truck is characterized as a full single load not combined with other shipments.

Examples of activities in this sector:
* Bulk mail truck transportation, contract, long-distance
* Container trucking services, long-distance
* General freight trucking, long-distance, truckload
* Motor freight carrier, general, long-distance, truckload

- Trucking, general freight, long-distance, truckload

484122 General Freight Trucking, Long-Distance, Less Than Truckload

This U.S. industry comprises establishments primarily engaged in providing long-distance, general freight, less than truckload (LTL) trucking. LTL carriage is characterized as multiple shipments combined onto a single truck for multiple deliveries within a network. These establishments are generally characterized by the following network activities: local pickup, local sorting and terminal operations, line-haul, destination sorting and terminal operations, and local delivery.

Examples of activities in this sector:

- General freight trucking, long-distance, less-than-truckload (LTL)
- LTL (less-than-truckload) long-distance freight trucking
- Motor freight carrier, general, long-distance, less-than-truckload (LTL)
- Trucking, general freight, long-distance, less-than-truckload (LTL)

4842 Specialized Freight Trucking

This industry group comprises establishments primarily engaged in providing local or long-distance specialized freight trucking. The establishments of this industry are primarily engaged in the transportation of freight which, because of size, weight, shape, or other inherent characteristics, requires specialized equipment, such as flatbeds, tankers, or refrigerated trailers. This industry includes the transportation of used household, institutional, and commercial furniture and equipment.

48421 Used Household and Office Goods Moving

484210 Used Household and Office Goods Moving

This industry comprises establishments primarily engaged in providing local or long-distance trucking of used household, used institutional, or used commercial furniture and equipment. Incidental packing and storage activities are often provided by these establishments.

Examples of activities in this sector:

- Furniture moving, used
- Motor freight carrier, used household goods

* Trucking used household, office, or institutional furniture and equipment
* Used household and office goods moving
* Van lines, moving and storage services

48422 Specialized Freight (except Used Goods) Trucking, Local

484220 Specialized Freight (except Used Goods) Trucking, Local

This industry comprises establishments primarily engaged in providing local, specialized trucking. Local trucking establishments provide trucking within a metropolitan area that may cross state lines. Generally the trips are same-day return.

Examples of activities in this sector:
* Agricultural products trucking, local
* Automobile carrier trucking, local
* Boat hauling, truck, local
* Bulk liquids trucking, local
* Coal hauling, truck, local
* Dry bulk trucking (except garbage collection, garbage hauling), local
* Dump trucking (e.g., gravel, sand, top soil)
* Farm products hauling, local
* Flatbed trucking, local
* Grain hauling, local
* Gravel hauling, local
* Livestock trucking, local
* Log hauling, local
* Milk hauling, local
* Mobile home towing services, local
* Refrigerated products trucking, local
* Rubbish hauling without collection or disposal, truck, local
* Sand hauling, local
* Tanker trucking (e.g., chemical, juice, milk, petroleum), local
* Top soil hauling, local
* Tracked vehicle freight transportation, local
* Trucking, specialized freight (except used goods), local
* Waste hauling, hazardous, local
* Waste hauling, nonhazardous, local

48423 Specialized Freight (except Used Goods) Trucking, Long-Distance

484230 Specialized Freight (except Used Goods) Trucking, Long-Distance

This industry comprises establishments primarily engaged in providing long-distance specialized trucking. These establishments provide trucking between metropolitan areas that may cross North American country borders.

Examples of activities in this sector:
* Automobile carrier trucking, long-distance
* Boat hauling, truck, long-distance
* Bulk liquids trucking, long-distance
* Dry bulk carrier, truck, long-distance
* Farm products trucking, long-distance
* Flatbed trucking, long-distance
* Forest products trucking, long-distance
* Grain hauling, long-distance
* Gravel hauling, long-distance
* Livestock trucking, long-distance
* Log hauling, long-distance
* Mobile home towing services, long-distance
* Radioactive waste hauling, long-distance
* Recyclable material hauling, long-distance
* Refrigerated products trucking, long-distance
* Refuse hauling, long-distance
* Rubbish hauling without collection or disposal, truck, long-distance
* Sand hauling, long-distance
* Tanker trucking (e.g., chemical, juice, milk, petroleum), long-distance
* Tracked vehicle freight transportation, long-distance
* Trash hauling, long-distance
* Trucking, specialized freight (except used goods), long-distance
* Waste hauling, hazardous, long-distance
* Waste hauling, nonhazardous, long-distance

Appendix H

Heating Equipment, Except Warm Air Furnaces

NAICS Sector for Heating Equipment (except warm air furnaces) Manufacturing

This sector is comprised of one or more NAICS sectors, as described below:

333414 Heating Equipment (except Warm Air Furnaces) Manufacturing

This U.S. industry comprises establishments primarily engaged in manufacturing heating equipment (except electric and warm air furnaces), such as heating boilers, heating stoves, floor and wall furnaces, and wall and baseboard heating units.

Examples of activities in this sector:
* Baseboard heating equipment manufacturing
* Boilers, heating, manufacturing
* Burners, heating, manufacturing
* Fireplace inserts (i.e., heat directing) manufacturing
* Furnaces (except forced air), heating, manufacturing
* Furnaces, floor and wall, manufacturing
* Gas burners, heating, manufacturing
* Gas fireplaces manufacturing
* Gas space heaters manufacturing
* Gas-oil burners, combination, manufacturing
* Heaters, space (except portable electric), manufacturing
* Heaters, swimming pool, manufacturing
* Heating equipment, hot water (except hot water heaters), manufacturing
* Heating units, baseboard, manufacturing
* Hydronic heating equipment manufacturing
* Kerosene space heaters manufacturing
* Logs, gas fireplace, manufacturing
* Oil burners, heating, manufacturing
* Radiators (except motor vehicle, portable electric) manufacturing
* Room heaters (except portable electric) manufacturing
* Solar energy heating equipment manufacturing
* Solar heating systems manufacturing
* Space heaters (except portable electric) manufacturing
* Steam heating equipment manufacturing
* Swimming pool heaters manufacturing
* Unit heaters (except portable electric) manufacturing
* Wood stoves manufacturing

Appendix I

Plastics Pipe

NAICS Sector for Plastics Pipe, Pipe Fitting, and Unsupported Profile Shape Manufacturing

This sector is comprised of one or more NAICS sectors, as described below:

32612 Plastics Pipe, Pipe Fitting, and Unsupported Profile Shape Manufacturing

This industry comprises establishments primarily engaged in manufacturing plastics pipes and pipe fittings, and plastics profile shapes such as rod, tube, and sausage casings.

326121 Unsupported Plastics Profile Shape Manufacturing

This U.S. industry comprises establishments primarily engaged in converting plastics resins into nonrigid plastics profile shapes (except film, sheet and bags), such as rod, tube, and sausage casings.

Examples of activities in this sector:
* Casings, sausage, nonrigid plastics, manufacturing
* Profile shapes (e.g., rod, tube), nonrigid plastics, manufacturing
* Rod, nonrigid plastics, manufacturing
* Sausage casings, plastics, manufacturing
* Tube, nonrigid plastics, manufacturing

326122 Plastics Pipe and Pipe Fitting Manufacturing

This U.S. industry comprises establishments primarily engaged in converting plastics resins into rigid plastics pipes and pipe fittings.

Examples of activities in this sector:
* Fittings and unions, rigid plastics pipe, manufacturing
* Fittings, rigid plastics pipe, manufacturing
* Pipe fittings, rigid plastics, manufacturing
* Pipe, rigid plastics, manufacturing
* PVC pipe manufacturing

Appendix J

Metal Valve Manufacturing

NAICS Sector for Metal Valve Manufacturing

This sector is comprised of one or more NAICS sectors, as described below:

33291 Metal Valve Manufacturing

This industry comprises establishments primarily engaged in manufacturing one or more of the following metal valves: (1) industrial valves; (2) fluid power valves and hose fittings; (3) plumbing fixture fittings and trim; and (4) other metal valves and pipe fittings.

332911 Industrial Valve Manufacturing

This U.S. industry comprises establishments primarily engaged in manufacturing industrial valves and valves for water works and municipal water systems.

Examples of activities in this sector:

* Angle valves, industrial-type, manufacturing
* Automatic (i.e., controlling-type, regulating) valves, industrial-type, manufacturing
* Ball valves, industrial-type, manufacturing
* Boiler gauge cocks, industrial-type, manufacturing
* Butterfly valves, industrial-type, manufacturing
* Check valves, industrial-type, manufacturing
* Compressed gas cylinder valves manufacturing
* Control valves, industrial-type, manufacturing
* Cross valves, industrial-type, manufacturing
* Fire hydrant valves manufacturing
* Fire hydrants, complete, manufacturing
* Gas valves, industrial-type, manufacturing
* Gate valves, industrial-type, manufacturing
* Globe valves, industrial-type, manufacturing
* Nuclear application valves manufacturing
* Plug valves, industrial-type, manufacturing
* Pressure control valves (except fluid power), industrial-type, manufacturing
* Safety (i.e., pop-off) valves, industrial-type, manufacturing
* Solenoid valves (except fluid power), industrial-type, manufacturing
* Steam traps, industrial-type, manufacturing
* Stop valves, industrial-type, manufacturing

* Straightway (i.e., Y-type) valves, industrial-type, manufacturing
* Thermostatic traps, industrial-type, manufacturing
* Valves for nuclear applications manufacturing
* Valves for water works and municipal water systems manufacturing
* Valves, industrial-type (e.g., check, gate, globe, relief, safety), manufacturing
* Waterworks and municipal water system valves manufacturing

332912 Fluid Power Valve and Hose Fitting Manufacturing

This U.S. industry comprises establishments primarily engaged in manufacturing fluid power valves and hose fittings.

Examples of activities in this sector:
* Control valves, fluid power, manufacturing
* Electrohydraulic servo valves, fluid power, manufacturing
* Fluid power aircraft subassemblies manufacturing
* Fluid power hose assemblies manufacturing
* Fluid power valves and hose fittings manufacturing
* Hose couplings and fittings, fluid power, manufacturing
* Hydraulic aircraft subassemblies manufacturing
* Hydraulic hose fittings, fluid power, manufacturing
* Hydraulic valves, fluid power, manufacturing
* Pneumatic aircraft subassemblies manufacturing
* Pneumatic hose fittings, fluid power, manufacturing
* Pneumatic valves, fluid power, manufacturing
* Pressure control valves, fluid power, manufacturing
* Solenoid valves, fluid power, manufacturing
* Tube and hose fittings, fluid power, manufacturing
* Valves, hydraulic and pneumatic, fluid power, manufacturing

332913 Plumbing Fixture Fitting and Trim Manufacturing

This U.S. industry comprises establishments primarily engaged in manufacturing metal and plastics plumbing fixture fittings and trim, such as faucets, flush valves, and shower heads.

Examples of activities in this sector:
* Antiscald bath and shower valves manufacturing
* Backflow preventors, plumbing, manufacturing
* Cocks, drain, plumbing, manufacturing
* Drain cocks, plumbing, manufacturing
* Faucets, plumbing, manufacturing
* Flush valves, plumbing, manufacturing

* Plumbing fittings and couplings (e.g., compression fittings, metal elbows, metal unions) manufacture
* Plumbing fixture fittings and trim, all materials, manufacturing
* Shower heads, plumbing, manufacturing
* Spigots, plumbing fixture fitting, manufacturing
* Stopcock drains, plumbing, manufacturing
* Supply line assemblies, plumbing (i.e., flexible hose with fittings), manufacturing
* Traps, water, manufacturing
* Water traps manufacturing

332919 Other Metal Valve and Pipe Fitting Manufacturing

This U.S. industry comprises establishments primarily engaged in manufacturing metal valves (except industrial valves, fluid power valves, fluid power hose fittings, and plumbing fixture fittings and trim).

Examples of activities in this sector:
* Aerosol valves manufacturing
* Boiler couplings and drains, plumbing and heating-type, manufacturing
* Breakers, vacuum, plumbing, manufacturing
* Couplings, hose, metal (except fluid power), manufacturing
* Elbows, pipe, metal (except made from purchased pipe), manufacturing
* Flanges and flange unions, pipe, metal, manufacturing
* Hose couplings, metal (except fluid power), manufacturing
* Lawn hose nozzles and lawn sprinklers manufacturing
* Nozzles, fire fighting, manufacturing
* Nozzles, lawn hose, manufacturing
* Plumbing and heating inline valves (e.g., check, cutoffs, stop) manufacturing
* Sprinklers, lawn, manufacturing
* Steam fittings, metal, manufacturing
* Unions, pipe, metal (except made from purchased pipe), manufacturing
* Valves, inline plumbing and heating (e.g., cutoffs, stop), manufacturing

Appendix K

Aluminum Extruded Product Manufacturing

NAICS Sector for Aluminum Extruded Product Manufacturing

This sector is comprised of one or more NAICS sectors, as described below:

331316 Aluminum Extruded Product Manufacturing

This U.S. industry comprises establishments primarily engaged in (1) extruding aluminum bar, pipe, and tube blooms or extruding or drawing tube from purchased aluminum; and/or (2) recovering aluminum from scrap and extruding bar, pipe, and tube blooms or drawing tube in integrated mills.

Examples of activities in this sector:

* Aluminum bar made by extruding purchased aluminum
* Aluminum bar made in integrated secondary smelting and extruding mills
* Aluminum pipe made by extruding purchased aluminum
* Aluminum pipe made in integrated secondary smelting and extruding mills
* Aluminum rod made by extruding purchased aluminum
* Aluminum rod made in integrated secondary smelting and extruding mills
* Aluminum tube blooms made by extruding purchased aluminum
* Aluminum tube blooms made in integrated secondary smelting and extruding mills
* Aluminum tube made by drawing or extruding purchased aluminum
* Aluminum tube made in integrated secondary smelting and drawing plants
* Aluminum tube made in integrated secondary smelting and extruding mills
* Bar made by extruding purchased aluminum
* Bar, aluminum, made in integrated secondary smelting and extruding mills
* Pipe made by extruding purchased aluminum
* Pipe, aluminum, made in integrated secondary smelting and extruding mills
* Rod made by extruding purchased aluminum
* Rod, aluminum, made in integrated secondary smelting and extruding mills
* Tube blooms made by extruding purchased aluminum
* Tube blooms, aluminum, made in integrated secondary smelting and extruding mills

* Tube made by drawing or extruding purchased aluminum
* Tube, aluminum, made in integrated secondary smelting and drawing plants
* Tube, aluminum, made in integrated secondary smelting and extruding mills

Appendix L

Metal Tank Manufacturing

NAICS Sector for Metal Tank (heavy gauge) Manufacturing

This sector is comprised of one or more NAICS sectors, as described below:

33242 Metal Tank (Heavy Gauge) Manufacturing

332420 Metal Tank (Heavy Gauge) Manufacturing

This industry comprises establishments primarily engaged in cutting, forming, and joining heavy gauge metal to manufacture tanks, vessels, and other containers.

Examples of activities in this sector:

* Absorbers, gas, manufacturing
* Accumulators, industrial pressure vessels, manufacturing
* Acetylene cylinders manufacturing
* Air receiver tanks, heavy gauge metal, manufacturing
* Annealing vats manufacturing
* Autoclaves, industrial-type, manufacturing
* Bulk storage tanks, heavy gauge metal, manufacturing
* Caissons, underwater work, manufacturing
* Columns, fractionating, manufacturing
* Cryogenic tanks manufacturing
* Cylinders, pressure, manufacturing
* Digesters, industrial-type, manufacturing
* Farm storage tanks, heavy gauge metal, manufacturing
* Fermentation tanks, heavy gauge metal tanks, manufacturing
* Gas storage tanks, heavy gauge metal, manufacturing
* Kettles, heavy gauge metal, manufacturing
* Liquefied petroleum gas (LPG) cylinders manufacturing
* Liquid oxygen tanks manufacturing
* Nuclear waste casks, heavy gauge metal, manufacturing
* Oil storage tanks, heavy gauge metal, manufacturing
* Petroleum storage tanks, heavy gauge metal, manufacturing
* Pots (e.g., annealing, melting, smelting), heavy gauge metal, manufacturing
* Retorts, heavy gauge metal, manufacturing
* Septic tanks, heavy gauge metal, manufacturing
* Smelting pots and retorts manufacturing
* Stills, heavy gauge metal, manufacturing
* Storage tanks, heavy gauge metal, manufacturing
* Tanks, heavy gauge metal, manufacturing

* Vacuum tanks, heavy gauge metal, manufacturing
* Vats, heavy gauge metal, manufacturing
* Vessels, heavy gauge metal, manufacturing
* Water tanks, heavy gauge metal, manufacturing

Appendix M

Pump & Pumping Equipment Manufacturing

NAICS Sector for Pump and Pumping Equipment Manufacturing

This sector is comprised of one or more NAICS sectors, as described below:

333911 Pump and Pumping Equipment Manufacturing

This U.S. industry comprises establishments primarily engaged in manufacturing general purpose pumps and pumping equipment (except fluid power pumps and motors), such as reciprocating pumps, turbine pumps, centrifugal pumps, rotary pumps, diaphragm pumps, domestic water system pumps, oil well and oil field pumps and sump pumps.

Examples of activities in this sector:
* Centrifugal pumps manufacturing
* Oil-well and oil-field pumps manufacturing
* Pumps (except fluid power), general purpose, manufacturing
* Pumps for railroad equipment lubrication systems manufacturing
* Pumps, industrial and commercial-type, general purpose, manufacturing
* Pumps, oil field or well, manufacturing
* Pumps, sump or water, residential-type, manufacturing
* Sump pumps, residential-type, manufacturing

Appendix N

Copper Rolling, Drawing & Extruding

NAICS Sector for Copper Rolling, Drawing, and Extruding

This sector is comprised of one or more NAICS sectors, as described below:

331421 Copper Rolling, Drawing, and Extruding

This U.S. industry comprises establishments primarily engaged in (1) rolling, drawing, and/or extruding shapes (e.g., bar, plate, sheet, strip, tube (except bare or insulated copper communication or energy wire) from purchased copper; and/or (2) recovering copper from scrap and rolling, drawing, and/or extruding shapes (e.g., bar, plate, sheet, strip,tube (except bare or insulated copper communication or energy wire in integrated mills.))

Examples of activities in this sector:

* Bar, copper and copper alloy, made from purchased copper or in integrated secondary smelting and
* Brass products, rolling, drawing, or extruding, made from purchased copper or in integrated seco
* Bronze products, rolling, drawing, or extruding, made from purchased copper or in integrated sec
* Cartridge cups, discs, and sheets, copper and copper alloy, made from purchased copper or in int
* Copper foil made from purchased metal or scrap
* Copper products (except communication wire, energy wire) made by drawing purchased copper
* Copper products (except communication wire, energy wire) made by rolling, drawing, or extruding
* Copper products (except communication wire, energy wire) made in integrated secondary smelting a
* Copper products (except communication wire, energy wire) made in integrated secondary smelting m
* Foil, copper, made from purchased metal or scrap
* Pipe, extruded and drawn, brass, bronze, and copper, made from purchased copper or in integrated
* Plate, copper and copper alloy, made from purchased copper or in integrated secondary smelting a
* Rod, copper and copper alloy, made from purchased copper or in integrated secondary smelting and
* Sheet, copper and copper alloy, made from purchased copper or in integrated secondary smelting a
* Strip, copper and copper alloy, made from purchased copper or in

integrated secondary smelting a
* Tubing, copper and copper alloy, made from purchased copper or in integrated secondary smelting
* Wire, mechanical, copper and copper alloy, made from purchased copper or in integrated secondary

Appendix O
Nonferrous Die-Casting Foundries

NAICS Sector for Nonferrous (except aluminum) Die-Casting Foundries

This sector is comprised of one or more NAICS sectors, as described below:

331522 Nonferrous (except Aluminum) Die-Casting Foundries

This U.S. industry comprises establishments primarily engaged in introducing molten nonferrous metal (except aluminum), under high pressure, into molds to make nonferrous metal die-castings. Establishments in this industry purchase nonferrous metals made in other establishments.

Examples of activities in this sector:

- Beryllium die-castings, unfinished, manufacturing
- Brass die-castings, unfinished, manufacturing
- Bronze die-castings, unfinished, manufacturing
- Copper die-casting foundries
- Copper die-castings, unfinished, manufacturing
- Die-castings, nonferrous metals (except aluminum), unfinished, manufacturing
- Foundries, die-casting, nonferrous metals (except aluminum)
- Lead die-castings, unfinished, manufacturing
- Magnesium die-castings, unfinished, manufacturing
- Nickel alloy die-castings, unfinished, manufacturing
- Nickel die-castings, unfinished, manufacturing
- Nonferrous (except aluminum) die-casting foundries
- Titanium die-castings, unfinished, manufacturing
- Zinc die-castings, unfinished, manufacturing

331525 Copper Foundries (except Die-Casting)

This U.S. industry comprises establishments primarily engaged in pouring molten copper into molds to manufacture copper castings. Establishments in this industry purchase copper made in other establishments.

Examples of activities in this sector:

- Brass foundries (except die-casting)
- Bronze foundries (except die-casting)
- Castings (except die-castings), unfinished, copper, manufacturing
- Copper alloy castings (except die-castings), unfinished,

manufacturing
* Copper foundries (except die-casting)
* Foundries, brass, bronze, and copper (except die-casting) manufacturing
* Foundries, copper (except die-casting)
* Investment castings, copper (except die-castings), unfinished manufacturing
* Permanent mold castings, copper, unfinished, manufacturing
* Sand castings, copper and copper-base alloy, unfinished, manufacturing
* Ship and boat propellers, cast brass, bronze and copper (except die-casting), unfinished, manufacturing

331528 Other Nonferrous Foundries (except Die-Casting)

This U.S. industry comprises establishments primarily engaged in pouring molten nonferrous metals (except aluminum and copper) into molds to manufacture nonferrous castings (except aluminum die-castings, nonferrous (except aluminum) die-castings, aluminum castings, and copper castings). Establishments in this industry purchase nonferrous metals, such as nickel, lead, and zinc, made in other establishments.

Cross-References. Establishments primarily engaged in--

Manufacturing aluminum die-castings--are classified in U.S. Industry 331521, Aluminum Die-Casting Foundries;

Manufacturing nonferrous (except aluminum) die-castings--are classified in U.S. Industry 331522, Nonferrous (except Aluminum) Die-Casting Foundries;

Pouring molten aluminum into molds to manufacture aluminum castings--are classified in U.S. Industry 331524, Aluminum Foundries (except Die-Casting);

Manufacturing copper castings--are classified in U.S. Industry 331525, Copper Foundries (except Die-Casting); and

Manufacturing nonferrous castings and further manufacturing them into finished products--are classified based on the specific finished product.

Examples of activities in this sector:
* Beryllium castings (except die-castings), unfinished manufacturing

* Castings (except die-castings), nonferrous metals (except aluminum, copper), unfinished manufacturing
* Foundries (except die-casting), nonferrous metals (except aluminum, copper)
* Investment castings, nonferrous metal (except aluminum, copper), unfinished, manufacturing
* Lead castings (except die-castings), unfinished, manufacturing
* Magnesium castings (except die-castings), unfinished, manufacturing
* Nickel castings (except die-castings), unfinished, manufacturing
* Nonferrous metals (except aluminum, copper) foundries (except die-casting)
* Nonferrous metals (except aluminum, copper) unfinished castings (except die-castings) manufacturing
* Permanent mold castings, nonferrous metal (except aluminum, copper), unfinished, manufacturing
* Sand castings, nonferrous metals (except aluminum, copper), unfinished, manufacturing
* Titanium castings (except die-castings), unfinished, manufacturing
* White metal castings (except die-castings), unfinished, manufacturing
* Zinc castings (except die-castings), unfinished, manufacturing

Appendix P

Specialized Design Services

This sector is comprised of one or more NAICS sectors, as described below:

5414 Specialized Design Services

This industry group comprises establishments providing specialized design services (except architectural, engineering, and computer systems design).

54141 Interior Design Services

541410 Interior Design Services

This industry comprises establishments primarily engaged in planning, designing, and administering projects in interior spaces to meet the physical and aesthetic needs of people using them, taking into consideration building codes, health and safety regulations, traffic patterns and floor planning, mechanical and electrical needs, and interior fittings and furniture. Interior designers and interior design consultants work in areas, such as hospitality design, health care design, institutional design, commercial and corporate design, and residential design. This industry also includes interior decorating consultants engaged exclusively in providing aesthetic services associated with interior spaces.

Examples of activities in this sector:
* Decorating consulting services, interior
* Interior decorating consultant services
* Interior decorating consulting services
* Interior design consulting services
* Interior design services
* Interior designer services

54142 Industrial Design Services

541420 Industrial Design Services

This industry comprises establishments primarily engaged in creating and developing designs and specifications that optimize the use, value, and appearance of their products. These services can include the determination of the materials, construction, mechanisms, shape, color, and surface finishes of the product, taking into consideration human characteristics and needs, safety, market appeal, and efficiency in production, distribution, use, and maintenance. Establishments providing automobile or furniture industrial design services or industrial design consulting services are included in this industry.

Examples of activities in this sector:
* Automobile industrial design services
* Furniture design services
* Handtool industrial design services
* Industrial design consulting services
* Industrial design services
* Packaging industrial design services
* Tool industrial design services

54143 Graphic Design Services

541430 Graphic Design Services

This industry comprises establishments primarily engaged in planning, designing, and managing the production of visual communication in order to convey specific messages or concepts, clarify complex information, or project visual identities. These services can include the design of printed materials, packaging, advertising, signage systems, and corporate identification (logos). This industry also includes commercial artists engaged exclusively in generating drawings and illustrations requiring technical accuracy or interpretative skills.

Examples of activities in this sector:
* Art services, commercial
* Art services, graphic
* Art studios, commercial
* Artists, independent commercial
* Artists, independent graphic
* Artists, independent medical
* Commercial art services
* Commercial artists, independent
* Commercial illustration services
* Commercial illustrators, independent
* Communication design services, visual
* Corporate identification (i.e., logo) design services
* Graphic art and related design services
* Graphic artists, independent
* Graphic design services
* Illustrators, independent commercial
* Medical art services
* Medical artists, independent

* Medical illustration services
* Medical illustrators, independent
* Silk screen design services
* Studios, commercial art

54149 Other Specialized Design Services

541490 Other Specialized Design Services

This industry comprises establishments primarily engaged in providing professional design services (except architectural, landscape architecture, engineering, interior, industrial, graphic, and computer system design).

Examples of activities in this sector:
* Clothing design services
* Costume design services (except independent theatrical costume designers)
* Fashion design services
* Fashion designer services
* Float design services
* Fur design services
* Jewelry design services
* Shoe design services
* Textile design services

Appendix Q

GFA Support

Supporting Calculations for GFA Construction Phase Activities

Transport est. CO_2 emissions

		MILES	
	Commute	Job	Dump
Est. miles	212	109.8	25
MPG est.	17.6	17.6	17.6
Gas used	12.05	6.24	1.42
CO_2lbs/gal	19.4	19.4	19.4
CO_2lbs produced	233.6818	121.0295	27.55682
short ton	0.116841	0.060515	0.013778
MTCO2E	0.105998	0.054899	0.0125

Notes

1. Estimated Commute mileage on 10.6 miles one way is form Federal Highway Administration, Highway Statistics 2005.
2. One gallon of gasoline produces 19.4 pounds of CO_2
3. To convert from a short ton to a metric ton multiply by .9072.

2 & 3 Source: Unit Conversions, Emissions Factors, And Other Reference Data, 2004.

Electrical CO_2 emissions

	Est. use	Lbs	
kWh	50		
CO_2/MWh		1515	
MWh/kWh			1000
CO_2lbs/kWh			1.515
$MTCO_2E$			0.03436

Notes

1. The CO_2 per MWh figure includes delivery to end electric user.
2. To convert from MWh to kWh multiply by 1000
3. There are 1515 lbs of CO_2 in every MWh of delivered electricity

Source: Unit Conversions, Emissions Factors, And Other Reference Data, 2004.

Appendix R

SRS Support

Supporting Calculations for SRS Construction Phase Activities

Transport est CO_2 emissions

		MILES			USE
	Commute	Materials	Dump	Trencher	Trench
Est miles	542.6	11.4	25	10.6	n/a
MPG est.	30	17.6	17.6	6	n/a
Gas used	18.09	0.65	1.42	1.77	5
CO_2lbs/gal	19.4	19.4	19.4	19.4	22.23
CO_2lbs produced	350.8813	12.56591	27.55682	34.27333	111.15
short ton	0.175441	0.006283	0.013778	0.017137	0.055575
$MTCO_2E$	0.15916	0.0057	0.0125	0.015546	0.050418

Notes

1. Estimated Commute mileage on 10.6 miles one way is from Federal Highway Administration, Highway Statistics 2005.
2. 17.6 MPG estimate is the light duty truck fleet average for 2001.

Source Emission Facts, EPA420-F-05-004, Feb 2005
htpp://www.epa.gov/otaq/climate/420f05004.htm

3. One gallon of gasoline produces 19.4 pounds of CO_2
4. To convert from a short ton to a metric ton multiply by .9072.
5. One gallon of diesel fuel produces 22.25 pounds of CO_2

3,4& 5 Source: Unit Conversions, Emissions Factors, And Other Reference Data, 2004.

Electrical CO_2 emissions

	Est use	Lbs	
kWh	210		
CO_2/MWh		1515	
MWh/kWh			1000
CO_2lbs/kWh			1.515
MTCO2E			0.144313

Notes

1. The CO_2 per MWh figure includes delivery to end electric user.
2. To convert from MWh to kWh multiply by 1000
3. There are 1515 lbs of CO_2 in every MWh of delivered electricity

Source: Unit Conversions, Emissions Factors, And Other Reference Data, 2004.

Appendix S
Natural Gas Distribution

NAICS Sector for Natural Gas Distribution

This sector is comprised of one or more NAICS sectors, as described below:

2212 Natural Gas Distribution

22121 Natural Gas Distribution

221210 Natural Gas Distribution

This industry comprises: (1) establishments primarily engaged in operating gas distribution systems (e.g., mains, meters); (2) establishments known as gas marketers that buy gas from the well and sell it to a distribution system; (3) establishments known as gas brokers or agents that arrange the sale of gas over gas distribution systems operated by others; and (4) establishments primarily engaged in transmitting and distributing gas to final consumers.

Examples of activities in this sector:

* Blue gas, carbureted, production and distribution
* Coke oven gas, production and distribution
* Distribution of manufactured gas
* Distribution of natural gas
* Gas, manufactured, production and distribution
* Gas, mixed natural and manufactured, production and distribution
* Gas, natural, distribution
* Liquefied petroleum gas (LPG) distribution through mains
* Manufactured gas production and distribution
* Natural gas brokers
* Natural gas distribution systems
* Natural gas marketers

Appendix T

Electrical Power Generation

NAICS Sector for Electrical Power Generation, Transmission, and Distribution

This sector is comprised of one or more NAICS sectors, as described below:

2211 Electric Power Generation, Transmission and Distribution

This industry group comprises establishments primarily engaged in generating, transmitting, and/or distributing electric power. Establishments in this industry group may perform one or more of the following activities: (1) operate generation facilities that produce electric energy; (2) operate transmission systems that convey the electricity from the generation facility to the distribution system; and (3) operate distribution systems that convey electric power received from the generation facility or the transmission system to the final consumer.

22111 Electric Power Generation

This industry comprises establishments primarily engaged in operating electric power generation facilities. These facilities convert other forms of energy, such as water power (i.e., hydroelectric), fossil fuels, nuclear power, and solar power, into electrical energy. The establishments in this industry produce electric energy and provide electricity to transmission systems or to electric power distribution systems.

221111 Hydroelectric Power Generation

This U.S. industry comprises establishments primarily engaged in operating hydroelectric power generation facilities. These facilities use water power to drive a turbine and produce electric energy. The electric energy produced in these establishment is provided to electric power transmission systems or to electric power distribution systems.

Examples of activities in this sector:
* Electric power generation, hydroelectric
* Power generation, hydroelectric

221112 Fossil Fuel Electric Power Generation

This U.S. industry comprises establishments primarily engaged in operating fossil fuel powered electric power generation facilities. These facilities use fossil fuels, such as coal, oil, or gas, in internal combustion or combustion turbine conventional steam process to produce electric energy. The electric energy produced in these establishments are provided to electric power transmission systems or to electric power distribution systems.

Examples of activities in this sector:
* Electric power generation, fossil fuel (e.g., coal, oil, gas)

- Power generation, fossil fuel (e.g., coal, gas, oil), electric

221113 Nuclear Electric Power Generation

This U.S. industry comprises establishments primarily engaged in operating nuclear electric power generation facilities. These facilities use nuclear power to produce electric energy. The electric energy produced in these establishments are provided to electric power transmission systems or to electric power distribution systems.

Examples of activities in this sector:

- Electric power generation, nuclear
- Power generation, nuclear electric

221119 Other Electric Power Generation

This U.S. industry comprises establishments primarily engaged in operating electric power generation facilities (except hydroelectric, fossil fuel, nuclear). These facilities convert other forms of energy, such as solar, wind, or tidal power, into electrical energy. The electric energy produced in these establishment is provided to electric power transmission systems or to electric power distribution systems.

Examples of activities in this sector:

- Electric power generation, (except fossil fuel, hydroelectric, nuclear)
- Electric power generation, solar
- Electric power generation, tidal
- Electric power generation, wind
- Power generation, electric (except fossil fuel, hydroelectric, nonhazardous solid waste, nuclear
- Power generation, solar electric
- Power generation, tidal electric
- Power generation, wind electric

22112 Electric Power Transmission, Control, and Distribution

This industry comprises establishments primarily engaged in operating electric power transmission systems, controlling (i.e., regulating voltages) the transmission of electricity, and/or distributing electricity. The transmission system includes lines and transformer stations. These establishments arrange, facilitate, or coordinate the transmission of electricity from the generating source to the distribution centers, other electric utilities, or final consumers. The distribution system consists of lines, poles, meters, and wiring that deliver the electricity to final consumers.

221121 Electric Bulk Power Transmission and Control

This U.S. industry comprises establishments primarily engaged in operating electric power transmission systems and/or controlling (i.e., regulatory voltage) the transmission of electricity from the generating source to distribution centers or other electric utilities. The transmission system includes lines and transformer stations.

Examples of activities in this sector:
  * Electric power control
  * Electric power transmission systems
  * Transmission of electric power

221122 Electric Power Distribution

This U.S. industry comprises electric power establishments primarily engaged in (1) operating electric power distribution systems (i.e., consisting of lines, poles, meters, and wiring) or (2) operating as electric power brokers or agents that arrange the sale of electricity via power distribution systems operated by others.

Examples of activities in this sector:
  * Distribution of electric power
  * Electric power brokers
  * Electric power distribution systems

Appendix U

Plumbing, Heating, & Air-Conditioning Contractors

This sector is comprised of one or more NAICS sectors, as described below:

233 Building, Developing, and General Contracting

Industries in the Building, Developing, and General Contracting sub sector comprises establishments primarily responsible for the entire construction (i.e., new work, additions, alterations, and repair) of building projects. Builders, developers, and general contractors, as well as land sub dividers and land developers are included in this sub sector. Establishments identified as construction management firms for building projects are also included. The construction work may be for others and performed by custom builders, general contractors, design builders, engineer-constructors, joint-venture contractors, and turnkey contractors, or may be on their own account for sale and performed by speculative or operative builders.

2331 Land Subdivision and Land Development

23311 Land Subdivision and Land Development

233110 Land Subdivision and Land Development

This industry comprises establishments primarily engaged in subdividing real property into lots and/or developing building lots for sale.

Examples of activities in this sector:
* Land sub dividers and developers (except cemeteries)
* Real property (i.e., land, except cemetery lots) development or subdivision

2332 Residential Building Construction

23321 Single Family Housing Construction

233210 Single Family Housing Construction

This industry comprises establishments primarily responsible for the entire construction (i.e., new work, additions, alterations, and repairs) of single family residential housing units (e.g., single family detached houses, town houses, or row houses where each housing unit is separated by a ground-to-roof wall and where no housing units are constructed above or below). This industry includes establishments responsible for additions and alterations to mobile homes and on-site assembly of modular and prefabricated houses. Establishments identified as single family construction management firms are also included in this industry. Establishments in this industry may perform work for others or on their own account for sale as speculative or operative builders. Kinds of establishments include single family housing custom builders, general contractors, design builders, engineer-constructors, joint-venture contractors, and turnkey contractors.

Examples of activities in this sector:
* Building alterations, single family, general construction contractors
* Building construction, single family, general construction contractors
* Cabin construction
* Construction management firms, single family
* Custom built house construction
* Designing and erecting combined, single family housing, general construction contractors
* Duplexes, single family, construction
* Home improvements, residential single-family, construction
* Houses, single family attached, construction
* Houses, single family detached, construction
* Houses, single family semi-detached construction
* Housing construction, single family
* Modular house assembly and installation on site, construction
* Modular house construction
* On-site mobile home repair construction
* On-site modular homes assembly construction
* On-site prefabricated homes assembly construction
* One family house construction--general construction contractors
* Operative builders of single family housing
* Prefabricated house construction
* Prefabricated house erection
* Premanufactured housing erection, single family
* Remodeling single family buildings
* Renovating single family buildings
* Repairing single family buildings
* Residential construction, single family
* Row house single family construction
* Single family construction management firms
* Town house construction

23322 Multifamily Housing Construction

233220 Multifamily Housing Construction

This industry comprises establishments primarily responsible for the entire construction (i.e., new work, additions, alterations, and repairs) of multifamily residential housing units (e.g., highrise, garden, and town house apartments where each unit is not separated by a ground-to-roof wall). The units may be constructed for sale as condominiums or cooperatives, or for rental as apartments. Establishments identified as multifamily construction management firms are also included in this industry. Establishments in this industry may perform work for others or on their own account for sale as speculative or operative builders. Kinds of establishments include multifamily housing general contractors, design builders, engineer-constructors, joint-venture contractors, and turnkey contractors.

Examples of activities in this sector:
* Apartments (e.g., garden, high-rise) construction
* Building alterations, residential (except single family), general construction contractors
* Building construction, residential (except single family), general construction contractors
* Condominiums, multifamily, construction
* Construction management firms, multifamily
* Cooperative construction
* Custom buildings, residential (except single family), general construction contractors
* Designing and erecting combined, residential (except single family housing), general constructio
* Dormitory construction, general construction contractors
* Duplexes, double (i.e., one unit above the other) multifamily, construction
* Home improvements, residential (except single family), construction
* Housing construction, multifamily
* Multifamily construction management firms
* Operative builders of multifamily housing
* Prefabricated apartment construction
* Prefabricated apartment erection
* Prefabricated building (except house) erection, residential
* Premanufactured housing (except single family) erection
* Remodeling residential (except single family) buildings
* Renovating residential (except single family) buildings
* Repairing residential (except single family) building
* Residential construction (except single family)

* Town house-type apartment construction

2333 Nonresidential Building Construction

23331 Manufacturing and Industrial Building Construction

233310 Manufacturing and Industrial Building Construction

This industry comprises establishments primarily responsible for the entire construction (i.e., new work, additions, alterations, and repairs) of manufacturing and industrial buildings (e.g., plants, mills, factories). Establishments identified as manufacturing and industrial building construction management firms are also included in this industry. Kinds of establishments include manufacturing and industrial building general contractors, design builders, engineer-constructors, joint-venture contractors, and turnkey contractors.

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Examples of activities in this sector:
* Aluminum plant construction, general construction contractors
* Assembly plant construction
* Building alterations, industrial, general construction contractors
* Building components manufacturing plant construction, general construction contractors
* Building construction, industrial, general construction contractors
* Cannery construction
* Clean room construction, general construction contractors
* Cold storage plant construction
* Construction management firms, manufacturing and industrial building
* Custom buildings, industrial, construction
* Designing and erecting combined, industrial, general construction contractors
* Dry cleaning plant construction
* Factory construction
* Food products manufacturing or packaging plant construction
* Grain elevator construction
* Industrial and manufacturing building construction contractors
* Industrial and manufacturing building construction management firms
* Industrial building construction, general construction contractors
* Industrial plant construction, general construction contractors

* Laboratories, manufacturing, construction
* Manufacturing and industrial building construction management firms
* Operative builders of manufacturing and industrial buildings
* Paper pulp mill construction
* Pharmaceutical manufacturing plant construction
* Prefabricated building erection, industrial
* Printing/publishing plant construction
* Remodeling industrial buildings
* Renovating industrial buildings
* Repairing industrial buildings
* Textile mill construction
* Truck and automobile assembly plant construction

23332 Commercial and Institutional Building Construction

233320 Commercial and Institutional Building Construction

This industry comprises establishments primarily responsible for the entire construction (i.e., new work, additions, alterations, and repairs) of commercial and institutional buildings (e.g., stores, schools, hospitals office buildings, public warehouses). Establishments identified as commercial and institutional building construction management firms are also included in this industry. Kinds of establishments include commercial and institutional building general contractors, design builders, engineer-constructors, joint-venture contractors, and turnkey contractors.

Examples of activities in this sector:
* Administration building construction
* Amusement building construction
* Animal shelter/clinic construction
* Auditorium construction
* Bank building construction
* Barrack construction
* Building alterations, nonresidential, commercial and institutional buildings, general constructi
* Casino construction
* Church, synagogue, mosque, temple, and related building construction
* Cinema construction
* Civic center construction
* Clinic construction

* Commercial and institutional building construction management firms
* Commercial building construction
* Commercial warehouse construction, general construction contractors
* Construction management firms, commercial and institutional building firms
* Designing and erecting combined, commercial, general construction contractors
* Dome construction
* Dormitory construction
* Farm building construction
* Fire station construction
* Garage, commercial or institutional, construction contractors
* Hangar (i.e., aircraft storage buildings) construction
* Health or athletic club construction
* Hospital construction
* Hotel construction
* Institutional and commercial building construction management firms
* Institutional building construction
* Laboratory, commercial and educational, construction
* Library construction
* Mausoleum construction
* Motel construction
* Municipal building construction
* Museum construction
* Office building construction
* Operative builders of commercial and institutional buildings
* Parking structure construction
* Passenger and freight terminal building construction
* Post office construction
* Prefabricated nonresidential building (except industrial) erection
* Prison construction
* Public warehouse construction
* Recreational building construction
* Remodeling nonresidential (except industrial) buildings
* Renovating nonresidential (except industrial) buildings
* Repairing nonresidential (except industrial) buildings
* Restaurant construction
* Salon construction
* School building construction
* Service station construction
* Shop construction
* Shopping center or mall construction
* Silo construction

- Stadium and arena construction
- Store construction
- Studio construction

234 Heavy Construction

Industries in the Heavy Construction subsector group establishments that engage in the construction of heavy engineering and industrial projects (except buildings), for example, highways, power plants, and pipelines. The construction work performed may include new work, reconstruction, or repairs. Establishments identified as heavy construction management firms are also included. Establishments in this subsector usually assume responsibility for entire nonbuilding projects but may subcontract some or all of the actual construction work. Special trade contractors are included in this group if they are engaged in activities primarily related to heavy construction, for example, grading for highways. Kinds of establishments include heavy construction general contractors, design builders, engineer-constructors, and joint-venture contractors.

2341 Highway, Street, Bridge, and Tunnel Construction

23411 Highway and Street Construction

234110 Highway and Street Construction

This industry comprises: (1) establishments primarily responsible for the entire construction (i.e., new work, reconstruction, or repairs) of highways (except elevated), streets, roads, or airport runways; (2) establishments identified as highway and street construction management firms; and (3) establishments identified as special trade contractors engaged in performing subcontract work primarily related to highway and street construction (e.g., grading for highways, installing guardrails, public sidewalk construction). Establishments in this industry may subcontract some or all of the actual construction work. Kinds of establishments include highway and street general contractors, design builders, engineer-constructors, and joint-venture contractors.

Examples of activities in this sector:

- Airport runway construction
- Alley construction
- Asphalt paving (e.g., public sidewalks, roads, streets) contractors
- Concrete (e.g., roads, highways, public sidewalks, streets) construction contractors

* Construction management firms, highway and street
* Curbs and street gutter construction
* Grading construction contractors for highway and street construction
* Guardrail construction
* Gutters, concrete, street and highway construction
* Highway and street construction management firms
* Highway construction (except elevated)
* Highway guardrail construction contractors
* Parkway construction
* Paving construction contractors
* Resurfacing streets and highways
* Road (except elevated) construction
* Sidewalk construction, public
* Sign erection (i.e., highway, street) contractors
* Street and highway construction management firms
* Street construction
* Street maintenance or repair
* Street paving

23412 Bridge and Tunnel Construction

234120 Bridge and Tunnel Construction

This industry comprises: (1) establishments primarily responsible for the entire construction (i.e., new work, reconstruction, or repairs) of bridges, viaducts, elevated highways, and tunnels; (2) establishments identified as bridge and tunnel construction management firms; and (3) establishments identified as special trade contractors primarily engaged in performing subcontract work related to bridge and tunnel construction. Establishments in this industry may subcontract some or all of the actual construction work. Kinds of establishments include bridge and tunnel general contractors, design builders, engineer-constructors, and joint-venture contractors.

Examples of activities in this sector:

* Abutment construction
* Bridge and tunnel construction management firms
* Bridge construction
* Bridge decking construction
* Causeway construction
* Construction management firms, bridge and tunnel
* Highway construction, elevated
* Overpass construction
* Road elevated (e.g., bridges) construction

* Trestle construction
* Tunnel and bridge construction management firms
* Tunnel construction
* Underpass construction contractors
* Viaduct construction

2349 Other Heavy Construction

This industry group comprises establishments primarily engaged in heavy nonbuilding construction (except highway, street, bridge, and tunnel construction).

23491 Water, Sewer, and Pipeline Construction

234910 Water, Sewer, and Pipeline Construction

This industry comprises: (1) establishments primarily responsible for the entire construction (i.e., new work, reconstruction, rehabilitation, or repairs) of water mains, sewers, drains, gas mains, natural gas pumping stations, and gas and oil pipelines; (2) establishments identified as water, sewer, and pipeline construction management firms; and (3) establishments identified as special trade contractors engaged in activities primarily related to water, sewer, and pipeline construction. Establishments in this industry may subcontract some or all of the actual construction work. Kinds of establishments include water, sewer, and pipeline general contractors, design builders, engineer-constructors, and joint-venture contractors.

Examples of activities in this sector:

* Aqueduct construction
* Construction management firms, water, sewer and pipeline
* Culvert construction
* Distribution line construction, oil and gas fields
* Gas main construction
* Interceptor construction
* Natural gas compressing station construction
* Pipeline (e.g., gas, oil, sewer, water) construction
* Pipeline (e.g., gas, oil, water, sewer) construction management
* Pipeline rehabilitation construction contractors
* Pipeline wrapping construction contractors
* Pumping station construction
* Sewage collection and disposal line construction
* Sewer construction
* Sewer, water and pipeline construction management firms
* Water main and line construction

* Water, sewer, and pipeline construction management firms

23492 Power and Communication Transmission Line Construction

234920 Power and Communication Transmission Line Construction

This industry comprises: (1) establishments primarily responsible for the entire construction (i.e., new work, reconstruction, or repairs) of electric power and communication transmission lines and towers, radio and television transmitting/receiving towers, cable laying, and cable television lines; (2) establishments identified as power and communication transmission line construction management firms; and (3) establishments identified as special trade contractors engaged in activities primarily related to power and communication transmission line construction. Establishments in this industry may subcontract some or all of the actual construction work. Kinds of establishments include power and communication transmission line general contractors, design builders, engineer-constructors, and joint-venture contractors.

Examples of activities in this sector:
* Cable laying
* Cable television line construction
* Communication transmission and power line construction management firms
* Conduit construction
* Construction management firms, power and communication transmission line
* Electric power transmission line and tower construction
* Manhole construction contractors
* Pipelaying construction contractors
* Pole line construction contractors
* Power and communication transmission line construction management services
* Power line construction
* Telecommunications line (e.g., telephone, telegraph) construction
* Telephone line construction
* Television transmitting tower construction
* Tower construction, radio and television transmitting/receiving
* Transmission and distribution line construction

23493 Industrial Nonbuilding Structure Construction

234930 Industrial Nonbuilding Structure Construction

This industry comprises: (1) establishments primarily responsible for the entire construction (i.e., new work, reconstruction, or repairs) of heavy industrial nonbuilding structures, such as chemical complexes or facilities, cement plants, petroleum refineries, industrial incinerators, ovens, kilns, power plants (except hydroelectric plants), and nuclear reactor containment structures; (2) establishments identified as industrial nonbuilding construction management firms; and (3) establishments identified as special trade contractors engaged in activities primarily related to industrial nonbuilding construction. Establishments in this industry may subcontract some or all of the actual construction work. Kinds of establishments include industrial nonbuilding general contractors, design builders, engineer-constructors, and joint-venture contractors.

Examples of activities in this sector:
* Cement plant construction
* Chemical complexes or facility construction
* Co-generation plant construction
* Construction management firms, industrial nonbuilding
* Furnace for industrial plant construction
* Industrial incinerator construction contractors
* Industrial nonbuilding construction management firms
* Industrial plant appurtenance construction
* Industrial structures, construction (except building)
* Kiln construction
* Mine loading and discharging station construction
* Mining appurtenance construction contractors
* Nonbuilding structures, industrial construction
* Nuclear reactor containment structure construction
* Oil refinery construction
* Ovens construction, industrial
* Ovens, baker's, construction
* Ovens, coke, construction
* Petrochemical plant construction
* Petroleum refinery construction
* Power plant (except hydroelectric) construction
* Tipple construction
* Washery, mining, construction

23499 All Other Heavy Construction

234990 All Other Heavy Construction

This industry comprises: (1) establishments primarily responsible for the entire construction (i.e., new work, reconstruction, or repairs) of heavy nonbuilding construction projects (except highway, street, bridge, tunnel, water lines, sewer lines, pipelines, power and communication transmission lines, and industrial nonbuilding structures); (2) establishments identified as all other heavy construction management firms; (3) establishments primarily engaged in construction equipment rental with an operator; and (4) establishments identified as special trade contractors engaged in activities related primarily to all other heavy construction. Typical projects constructed by establishments in this industry include athletic fields, dams, dikes, docks, drainage projects, golf courses, harbors, parks, reservoirs, canals, sewage treatment plants, water treatment plants, hydroelectric plants, subways, and other mass transit projects. Establishments in this industry may subcontract some or all of the actual construction work. Kinds of establishments include heavy construction general contractors, design builders, engineer-constructors, and joint-venture contractors.

Examples of activities in this sector:
* Athletic field construction
* Blasting (except building demolition)
* Breakwater construction
* Bridle path construction
* Brush clearing or cutting
* Caisson drilling
* Canal construction
* Channel construction
* Channel cutoff construction, general construction contractors
* Cofferdam construction
* Conservation and development construction
* Construction management firms, nonbuilding (except industrial)
* Cutting right-of-way
* Dam, dike, and dock construction
* Drainage project construction
* Dredging, general construction contractors
* Earth moving not connected with building construction
* Flood control project construction
* Golf course construction
* Harbor construction
* Harbor dredging construction contractors
* Heavy construction equipment rental with operator
* Hydroelectric plant construction
* Irrigation project construction
* Jetty construction
* Land clearing
* Land drainage construction contractors
* Land leveling, irrigation, construction contractors

* Land reclamation
* Levee construction
* Loading station construction, mine, general construction contractor
* Locks and waterway construction
* Marine construction
* Mass transit construction
* Missile facility construction
* Nonbuilding structures (except industrial) contractor
* Park construction
* Pier construction
* Pond construction
* Power plant, hydroelectric, construction
* Railroad construction
* Railway roadbed construction
* Reclamation projects construction
* Reservoir construction
* Revetment construction
* Rock removal, underwater, construction
* Sewage treatment plant construction
* Ski tow construction
* Soil compacting service
* Sound barrier construction, highways
* Streetcar line construction
* Subway construction
* Tennis court construction
* Timber removal, underwater
* Trail building
* Trailer camp construction
* Trenching
* Underwater rock removal
* Waste disposal plant construction
* Water power project construction
* Water treatment plant construction
* Waterway construction
* Wharf construction

235 Special Trade Contractors

Industries in the Special Trade Contractors subsector engage in specialized construction activities, such as plumbing, painting, and electrical work. Those establishments that engage in activities primarily related to heavy construction, such as grading for highways, are classified in Subsector 234, Heavy Construction. The activities of this subsector may be subcontracted from builders or general contractors or it may be performed directly for project owners. The construction work performed may include new work, additions, alterations, or maintenance and repairs. Special trade contractors usually perform most of their work at the job site, although they may have shops where they perform prefabrication and other work.

2351 Plumbing, Heating, and Air-Conditioning Contractors

23511 Plumbing, Heating, and Air-Conditioning Contractors

235110 Plumbing, Heating, and Air-Conditioning Contractors

This industry comprises establishments primarily engaged in one or more of the following: (1) installing plumbing, heating, and air-conditioning equipment; (2) servicing plumbing, heating, and air-conditioning equipment; and (3) the combined activity of selling and installing plumbing, heating, and air-conditioning equipment. The plumbing, heating, and air-conditioning work performed includes new work, additions, alterations, and maintenance and repairs. The activities performed by these establishments range from duct fabrication and installation at the site to installation of refrigeration equipment, installation of sprinkler systems, and installation of environmental controls.

Examples of activities in this sector:
* Air system balancing and testing contractors
* Air-conditioning installation contractors
* Boiler chipping, scaling, cleaning
* Boiler cleaning
* Boiler contractors
* Drainage system installation (e.g., cesspool, septic tank) construction contractors
* Dry well construction contractors
* Environmental control construction contractors
* Fuel oil burner construction contractors
* Furnace construction contractors
* Gas line hookup construction contractors
* Heat pump construction contractors
* Heating construction contractors
* Mechanical construction contractors
* Plumbing construction contractors
* Refrigeration and freezer installation contractors
* Septic system construction contractors
* Sewer hookup construction contractors
* Solar heating construction contractors
* Sprinkler system construction contractors

- Steam fitting construction contractors
- Sump pump construction contractors
- Ventilating construction contractors
- Water pump construction contractors
- Water system balancing and testing construction contractors

2352 Painting and Wall Covering Contractors

23521 Painting and Wall Covering Contractors

235210 Painting and Wall Covering Contractors

This industry comprises establishments primarily engaged in interior or exterior painting and interior wall covering. The painting and wall covering work performed includes new work, additions, alterations, and maintenance and repairs. Activities performed by these establishments range from bridge, ship, and traffic lane painting to paint and wall covering removal.

Examples of activities in this sector:

- Bridge painting construction contractors
- Electrostatic painting construction contractors
- Highway line painting construction contractors
- House painting construction contractors
- Painting, exterior (except roof) and interior, construction contractors
- Paper hanging or removal construction contractors
- Ship painting construction contractors
- Traffic lane painting construction contractors
- Wall covering or removal construction contractors
- Whitewashing construction contractors

2353 Electrical Contractors

23531 Electrical Contractors

235310 Electrical Contractors

This industry comprises establishments primarily engaged in one or more of the following: (1) performing electrical work at the site (e.g., installing wiring); (2) servicing electrical equipment at the site; and (3) the combined activity of selling and installing electrical equipment. The electrical work performed includes new work, additions, alterations, and maintenance and repairs.

Examples of activities in this sector:
* Cable splicing, electrical, construction contractors
* Cable television hookup construction contractors
* Communication equipment construction contractors
* Computer cable construction contractors
* Electrical construction contractors
* Electrical repair construction contractors
* Electronic control system construction contractors
* Fiber optic cable construction contractors
* Highway lighting and electrical signal construction contractors
* Home automation system construction contractors
* Lighting system construction contractors
* Sound equipment construction contractors
* Telecommunications wiring installation contractors

2354 Masonry, Drywall, Insulation, and Tile Contractors

23541 Masonry and Stone Contractors

235410 Masonry and Stone Contractors

This industry comprises establishments primarily engaged in masonry work, stone setting, and other stone work. The masonry work, stone setting, and other stone work performed includes new work, additions, alterations, and maintenance and repairs. Activities performed by establishments in this industry range from the construction of foundations made of block, stone, or brick to glass block laying; exterior marble, granite and slate work; and tuck pointing.

Examples of activities in this sector:
* Bricklaying construction contractors
* Chimney construction contractors
* Concrete block laying construction contractors
* Foundation (e.g., block, brick, stone) construction contractors
* Glass block laying construction contractors
* Granite (i.e., exterior stonework) construction contractors
* Marble, granite, and slatework (i.e., exterior) construction contractors
* Masonry construction contractors
* Refractory brick construction contractors
* Retaining wall, masonary (i.e., brick, stone), construction contractors
* Slate (i.e., exterior) construction contractors
* Stone setting construction contractors

* Stonework construction contractors
* Tuck pointing construction contractors

23542 Drywall, Plastering, Acoustical, and Insulation Contractors

235420 Drywall, Plastering, Acoustical, and Insulation Contractors

This industry comprises establishments primarily engaged in drywall, plaster work, acoustical, and building insulation work. The drywall, plaster work, acoustical, and insulation work performed includes new work, additions, alterations, and maintenance and repairs. Plaster work includes applying plain or ornamental plaster, including installation of lathing to receive plaster.

Examples of activities in this sector:
* Acoustical paneling construction contractors
* Ceiling construction contractors
* Drywall construction contractors
* Exterior insulation finishing system construction contractors
* Fresco construction contractors
* Insulation construction contractors
* Lathing construction contractors
* Plastering (i.e., ornamental, plain) construction contractors
* Sound proofing construction contractors
* Stucco construction contractors
* Taping and finishing drywall construction contractors

23543 Tile, Marble, Terrazzo, and Mosaic Contractors

235430 Tile, Marble, Terrazzo, and Mosaic Contractors

This industry comprises establishments primarily engaged in (1) setting and installing ceramic tile, marble (interior only), terrazzo, and mosaic and/or (2) mixing marble particles and cement to make terrazzo at the job site. The tile, marble, terrazzo, and mosaic work performed includes new work, additions, alterations, and maintenance and repairs.

Examples of activities in this sector:
* Mantel construction contractors
* Marble, granite, and slate work (interior) construction contractors
* Mosaic construction contractors (except fresco)
* Terrazzo construction contractors
* Tile construction contractors

2355 Carpentry and Floor Contractors

23551 Carpentry Contractors

235510 Carpentry Contractors

This industry comprises establishments primarily engaged in framing, carpentry, and finishing work. The carpentry work performed includes new work, additions, alterations, and maintenance and repairs. Activities performed by establishments in this industry range from the installation of doors and windows to paneling, steel framing work, and ship joinery.

Examples of activities in this sector:
* Cabinet work on site construction contractors
* Carpentry (rough and framing) construction contractors
* Carpentry (trim and finish) construction contractors
* Door and window construction contractors
* Garage door construction contractors
* Paneling construction contractors
* Post frame construction contractors
* Ship joinery construction contractors
* Steel framing construction contractors
* Store fixture construction contractors (i.e., built-in, on site)
* Window and door construction contractors

23552 Floor Laying and Other Floor Contractors

235520 Floor Laying and Other Floor Contractors

This industry comprises establishments primarily engaged in the installation of resilient floor tile, carpeting, linoleum, and wood or resilient flooring. The floor laying and other floor work performed includes new work, additions, alterations, and maintenance and repairs.

Examples of activities in this sector:
* Asphalt tile construction contractors
* Carpet laying or removal construction contractors
* Floor laying, finishing, or refinishing construction contractors
* Linoleum construction contractors
* Resilient flooring construction contractors
* Vinyl flooring construction contractors
* Wood flooring construction contractors

2356 Roofing, Siding, and Sheet Metal Contractors

23561 Roofing, Siding, and Sheet Metal Contractors

235610 Roofing, Siding, and Sheet Metal Contractors

This industry comprises establishments primarily engaged in the installation of roofing, siding, sheet metal work, and roof drainage-related work, such as downspouts and gutters. Activities performed by these establishments also include treating roofs (i.e., by spraying, painting, or coating), copper smithing, tin smithing, installing skylights, installing metal ceilings, flashing, duct work, and capping. The roofing, siding, and sheet metal work performed includes new work, additions, alterations, and maintenance and repairs.

Examples of activities in this sector:

* Architectural sheet metal construction contractors
* Ceiling metal construction contractors
* Copper smithing contractors, in connection with construction work
* Downspout construction contractors
* Duct work, sheet metal, construction contractors
* Flashing construction contractors
* Gutter and down spout construction contractors
* Metal ceiling construction contractors
* Painting, roof, construction contractors
* Roof spraying, painting or coating, construction contractors
* Roofing construction contractors
* Sheet metal work (except plumbing, heating, air-conditioning) construction contractors
* Siding construction contractors
* Skylight construction contractors
* Tin smithing contractors, in connection with construction work

2357 Concrete Contractors

23571 Concrete Contractors

235710 Concrete Contractors

This industry comprises establishments primarily engaged in the use of concrete and asphalt to produce parking areas, building foundations, structures, and retaining walls, and in the use of all materials to produce patios, private driveways, and private walks. Activities performed by these establishments include grout and shotcrete work. The concrete work performed includes new work, additions, alterations, and maintenance and repairs.

Examples of activities in this sector:
* Asphalt seal coating construction contractors
* Asphalting of private driveways and parking areas construction contractors
* Blacktop, private driveways and parking areas, construction contractors
* Concrete construction contractors (i.e., parking areas, private driveways, sidewalks)
* Concrete finishing construction contractors
* Concrete pumping construction contractors
* Culvert construction contractors
* Curb construction contractors
* Driveway construction contractors
* Foundations of buildings, poured concrete, construction contractors
* Gravel walk and driveway construction contractors
* Grout constuction contractors
* Parking lot construction contractors
* Patio construction contractors
* Retaining wall, concrete, construction contractors
* Shotcrete construction contractors
* Sidewalk, private, construction contractors

2358 Water Well Drilling Contractors

23581 Water Well Drilling Contractors

235810 Water Well Drilling Contractors

This industry comprises establishments primarily engaged in drilling, tapping, and capping of water wells, and geothermal drilling. The water well drilling work performed includes new work, servicing, and maintenance and repairs.

Examples of activities in this sector:
* Capping of water wells construction contractors
* Drilling water wells construction contractors
* Geothermal drilling construction contractors
* Ground source heat pump construction contractors

* Water well drilling (except oil or gas field water intake) construction contractors

2359 Other Special Trade Contractors

This industry group comprises establishments primarily engaged in specialized construction activities (except plumbing, painting, electrical, masonry, drywall, insulation, tile, carpentry, flooring work, roofing, siding, sheet metal, concrete, and water well drilling).

23591 Structural Steel Erection Contractors

235910 Structural Steel Erection Contractors

This industry comprises establishments primarily engaged in one or more of the following: (1) erecting metal, structural steel, and similar products of prestressed or precast concrete to produce structural elements, building exteriors, and elevator fronts; (2) setting rods, bars, rebar, mesh, and cages, to reinforce poured-in-place concrete; and (3) erecting cooling towers and metal storage tanks. The structural steel erection work performed includes new work, additions, alterations, reconstruction, and maintenance and repairs.

Examples of activities in this sector:
* Building front metal, construction contractors
* Concrete products (e.g., structural precast or prestressed), placement, construction contractors
* Concrete reinforcement placement, construction contractors
* Cooling tower construction contractors
* Curtain wall construction contractors
* Iron work structural, construction contractors
* Metal furring contractors
* Precast concrete product placement construction contractors
* Rebar construction contractors
* Steel work structural, construction contractors
* Storage tanks, metal, construction contractors
* Store front metal, installation, construction contractors
* Structural steel construction contractors

23592 Glass and Glazing Contractors

235920 Glass and Glazing Contractors

This industry comprises establishments primarily engaged in installing glass (i.e., glazing work) and/or tinting glass. The glass work performed includes new work, additions, alterations, and maintenance and repairs.

Examples of activities in this sector:

* Glass installation (except automotive) construction contractors
* Glass tinting (except automotive) construction contractors
* Glass work (except automotive) construction contractors
* Glazing construction contractors

23593 Excavation Contractors

235930 Excavation Contractors

This industry comprises establishments primarily engaged in preparing land for building construction. Activities performed by these establishments are drilling shafts, foundation digging, foundation drilling, and grading. The excavation work performed includes new work, additions, alterations, and repairs.

Examples of activities in this sector:

* Boring contractors, building construction
* Caisson contractors, building construction
* Drilled pier construction contractors
* Drilled shaft construction contractors
* Excavation construction contractors
* Foundation digging (i.e., excavation) construction contractors
* Foundation drilling construction contractors
* Grading for buildings, construction contractors
* Piling (i.e., bored, cast-in-place, drilled) construction contractors

23594 Wrecking and Demolition Contractors

235940 Wrecking and Demolition Contractors

This industry comprises establishments primarily engaged in the wrecking and demolition of buildings and other structures, including underground tank removal and the dismantling of steel oil tanks, except those for hazardous materials. The establishments engaged in wrecking and demolition work may or may not sell materials derived from demolishing operations.

Examples of activities in this sector:

* Concrete breaking and cutting construction contractors
* Demolition of buildings or other structures construction contractors
* Dismantling steel oil tanks (except oil field work) construction contractors
* Underground tank removal construction contractors
* Wrecking, buildings or other structures, construction contractors

23595 Building Equipment and Other Machinery Installation Contractors

235950 Building Equipment and Other Machinery Installation Contractors

This industry comprises establishments primarily engaged in one or more of the following: (1) the installation or dismantling of building equipment, machinery or other industrial equipment (except plumbing, heating, air conditioning or electrical equipment); (2) machine rigging; and (3) millwriting. Types of equipment installed include automated and revolving doors, conveyor systems, dumbwaiters, dust collecting equipment, elevators, small incinerators, pneumatic tubes systems, and built-in vacuum cleaning systems. The building equipment and other machinery installation work performed includes new work, additions, alterations, and maintenance and repairs.

Examples of activities in this sector:

* Automated and revolving door construction contractors
* Conveyor system construction contractors
* Dismantling of machinery and other industrial equipment construction contractors
* Dumbwaiter construction contractors
* Dust collecting equipment construction contractors
* Elevator installation contractors
* Escalator installation contractors
* Incinerators, small, construction contractors
* Installation of machinery and other industrial equipment construction contractors
* Machine rigging construction contractors
* Millwrights
* Pneumatic tube system constuction contractors
* Power generating equipment construction contractors
* Revolving door construction contractors
* Vacuum cleaning systems, built-in, construction contractors

23599 All Other Special Trade Contractors

235990 All Other Special Trade Contractors

This industry comprises establishments primarily engaged in specialized construction work, (except plumbing, painting, electrical, masonry, drywall, insulation, tile, carpentry, flooring, roofing, siding, sheet metal work, concrete work, glass and glazing, structural steel erection, excavation, wrecking and demolition, and building equipment installation work). Activities undertaken by these establishments include constructing swimming pools and fences, house moving, waterproofing, dewatering, dampproofing, fireproofing, and sandblasting; installing antennas, artificial turf, awnings, countertops, fire escapes, forms for poured concrete, gasoline pumps, lightning conductors, ornamental metal, shoring systems, and signs (on buildings); and specialized activities, such as bathtub refinishing, coating and glazing of concrete surfaces, gas leakage detection, insulation of pipes and boilers, mobile home site setup and tie-down, posthole digging, radon remediation, scaffolding work, and on-site welding. The other special trade work performed includes new work, additions, alterations, and maintenance and repairs.

Examples of activities in this sector:

* Anchored earth retention construction contractors
* Antenna installation construction contractors
* Artificial turf construction contractors
* Awning construction contractors
* Bathtub refinishing construction contractors
* Bowling alley installation and service construction contractors
* Cleaning building exteriors construction contractors
* Cleaning new buildings after construction contractors
* Coating and glazing of concrete surfaces construction contractors
* Coating of concrete structures with plastics, construction contractors
* Concrete form construction contractors
* Counter top construction contractors
* Dampproofing, building, construction contractors
* Dewatering construction contractors
* Fence construction contractors
* Fire escape construction contractors
* Fireproofing buildings construction contractors
* Forms for poured concrete construction contractors
* Gas leakage detection contractors
* Gasoline pump construction contractors
* Glazing concrete surfaces, construction contractors
* House moving construction contractors
* Insulating pipes and boilers construction contractors
* Insulation of pipes and boilers construction contractors

* Lead burning construction contractors
* Lightning conductor construction contractors
* Mobile home site setup and tie down construction contractors
* Ornamental metalwork construction contractors
* Posthole digging construction contractors
* Radon remediation construction contractors
* Sandblasting of building exteriors construction contractors
* Scaffolding construction contractors
* Shoring and underpinning construction contractors
* Sign contractors, installation (on buildings)
* Spectator seating construction contractors
* Steeplejacks
* Swimming pool construction contractors
* Waterproofing construction contractors
* Welding, on site, construction contractors
* Window shade installation construction contractors

Appendix V

Converted Paper Product Manufacturing

This sector is comprised of one or more NAICS sectors, as described below:

322299 All Other Converted Paper Product Manufacturing

This U.S. industry comprises establishments primarily engaged in converting paper or paperboard into products (except containers, bags, coated and treated paper, stationery products, and sanitary paper products) or converting pulp into pulp products, such as egg cartons, food trays, and other food containers from molded pulp.

Examples of activities in this sector:

* Cards, die-cut (except office supply) made from purchased paper or paperboard
* Cartons, egg, molded pulp manufacturing
* Cigarette paper made from purchased paper
* Cigarette paper, book, made from purchased paper
* Coffee filters made from purchased paper
* Confetti made from purchased paper
* Crepe paper made from purchased paper
* Cups, molded pulp, manufacturing
* Die-cut paper products (except for office use) made from purchased paper or paperboard
* Doilies, paper, made from purchased paper
* Filters, paper, made from purchased paper
* Food containers made from molded pulp
* Food trays, molded pulp, manufacturing
* Glassine wrapping paper made from purchased paper
* Hats made from purchased paper
* Insulating batts, fills, or blankets made from purchased paper
* Molded pulp products (e.g., egg cartons, food containers, food trays) manufacturing
* Paper dishes (e.g., cups, plates) made from purchased molded pulp
* Paper novelties made from purchased paper
* Paper products (except office supply), die-cut, made from purchased paper or paperboard
* Photograph folders, mats, and mounts manufacturing
* Plates, molded pulp, manufacturing
* Pulp products, molded, manufacturing
* Trays, food, molded pulp, manufacturing

Appendix W
Use & Maintenance Phase Projections

Use and Maintenance Phase Projections

GFA

Year	Filter	Maintenance Description	Base Cost Maint.	FV 2% Maint.	PV 5% Maint.	FV 2% blower	PV 5% blower	FV 2% filter	PV 5% filter
1	30	YSC	66	66	66			30	30
2	30	YSC	66	68.640	62.256			31.200	27.210
3	30	YSC	66	70.026	60.502			31.830	25.920
4	30	YSC	66	71.412	58.701			32.460	24.660
5	30	YSC	66	72.864	57.12538			33.12	23.52
6	30	YSC	66	74.316	55.43974			33.78	22.38
7	30	YSC	66	75.834	53.91797			34.47	21.33
8	30	YSC	66	77.352	52.3673			35.16	20.31
9	30	YSC	66	78.87	51.58098			35.85	19.62
10	30	YSC	66	74.514	45.7516			33.87	18.42
11	30	YSC	66	82.038	47.99223			37.29	17.55
12	30	YSC	166	210.488	117.2418	285.3	158.9121	38.04	16.71
13	30	YSC	66	85.404	45.26412			38.82	15.9
14	30	YSC	66	87.054	43.96227			39.57	15.15
15	30	YSC	66	88.836	42.73012			40.38	14.43
16	30	YSC	66	90.618	41.50304			41.19	13.74
17	30	YSC	66	92.4	40.2864			42	13.08
18	30	YSC	66	94.248	39.11292			42.84	12.45
19	30	YSC	66	96.162	38.08015			43.71	11.88
20	30	YSC	66	98.076	36.97465			44.58	11.31
GFA life-cycle maintenance costs					1056.79				$375.57

Notes

1. Yearly Service Check (YSC) is typically required by most manufacturers for warranty validation.
2. The equipment quoted is a Trane 80k BTU, 93% with 2-stage gas valve and 2-speed blower. Information about service and long term maintenance obtained from furnace contractor's repair division.
3. Yearly service includes filters, burner clean and adjust, heat exchanger inspection,& 2 visits yearly.
4. The 2007 blower costs are $225 and the installation labor is $100. The labor is added into the base costs maintenance figure.

NATURAL GAS

Average NG Btu usage per home West Census Region	53200000
Covert to cubic feet (CF) /1000	53200
Average NG cost per home for heat	419
Indices for NG UPV factor	13.21
GFA life-cycle NG costs	5534.99

Notes

1. The indices for NG costs is from the Energy Price Indices and Discount Factors for Lice-Cycle Cost Analysis, April 2007. Census region 4 was chosen from Table Ba-4. www.eere.energy.gov/femp/pdfs/ashb07.pdf

Electrical Usage for blower fan estimate

Month	Days with heat
Oct	16
Nov	30
Dec	31
Jan	31
Feb	28
Mar	31
Apr	15
Total Days	182
kWh/day	6
kWh/yr	1092
Cost/kWh	0.08125
GFA life-cycle electric costs	88.725

Note: this cost is used for the NAICS sector EIO-LCA and the BLCC estimate

Appendix X

All Other Misc. Chemical Product and Preparation

This sector is comprised of one or more NAICS sectors, as described below:

325998 All Other Miscellaneous Chemical Product and Preparation Manufacturing

This U.S. industry comprises establishments primarily engaged in manufacturing chemical products (except basic chemicals, resins, synthetic rubber; cellulosic and noncellulosic fiber and filaments; pesticides, fertilizers, and other agricultural chemicals; pharmaceuticals and medicines; paints, coatings and adhesives; soap, cleaning compounds, and toilet preparations; printing inks; explosives; custom compounding of purchased resins; and photographic films, papers, plates, and chemicals).

Examples of activities in this sector:

* Activated carbon or charcoal manufacturing
* Additive preparations for gasoline (e.g., antiknock preparations, detergents, gum inhibitors) ma
* Aerosol can filling on a job order or contract basis
* Aerosol packaging services
* Anise oil manufacturing
* Antifreeze preparations manufacturing
* Antiscaling compounds manufacturing
* Bay oil manufacturing
* Brake fluid, synthetic, manufacturing
* Caps for toy pistols manufacturing
* Capsules, gelatin, empty, manufacturing
* Carbon, activated, manufacturing
* Carburetor cleaners manufacturing
* Cat litter manufacturing
* Cedar oil manufacturing
* Charcoal, activated, manufacturing
* Citronella oil manufacturing
* Clove oil manufacturing
* Concrete additive preparations (e.g., curing, hardening) manufacturing
* Correction fluids (i.e., typewriter) manufacturing
* Crankcase additive preparations manufacturing
* Cutting oils, synthetic, manufacturing
* Defoamers and antifoaming agents manufacturing
* Degreasing preparations for machinery parts manufacturing
* Deicing preparations manufacturing

* Desalination kits manufacturing
* Distilled water manufacturing
* Drawing inks manufacturing
* Drilling mud compounds, conditioners, and additives (except bentonites) manufacturing
* Dye preparations, clothing, household-type, manufacturing
* Embalming fluids manufacturing
* Engine degreasers manufacturing
* Engine starting fluids manufacturing
* Essential oils manufacturing
* Eucalyptus oil manufacturing
* Fire extinguisher chemical preparations manufacturing
* Fire retardant chemical preparations manufacturing
* Fireworks manufacturing
* Flares manufacturing
* Fluxes (e.g., brazing, galvanizing, soldering, welding) manufacturing
* Foundry core oil, wash, and wax manufacturing
* Gelatin capsules, empty, manufacturing
* Grapefruit oil manufacturing
* Greases, synthetic lubricating, manufacturing
* Hydraulic fluids, synthetic, manufacturing
* Incense manufacturing
* Indelible inks manufacturing
* India inks manufacturing
* Industrial salt manufacturing
* Inhibitors (e.g., corrosion, oxidation, polymerization) manufacturing
* Inks, writing, manufacturing
* Insulating oils manufacturing
* Lemon oil manufacturing
* Lighter fluids (e.g., charcoal, cigarette) manufacturing
* Lime oil manufacturing
* Lubricating oils and greases, synthetic, manufacturing
* Matches and match books manufacturing
* Motor oils, synthetic, manufacturing
* Napalm manufacturing
* Oil additive preparations manufacturing
* Oils (e.g., cutting, lubricating), synthetic, manufacturing
* Oils, lubricating, synthetic, manufacturing
* Orange oil manufacturing
* Orris oil manufacturing
* Ossein manufacturing
* Packer's fluids manufacturing
* Penetrating fluids, synthetic, manufacturing
* Peppermint oil manufacturing

* Pyrotechnics (e.g., flares, flashlight bombs, signals) manufacturing
* Radiator additive preparations manufacturing
* Recycling services for degreasing solvents (e.g., engine, machinery) manufacturing
* Retarders (e.g., flameproofing agents, mildewproofing agents) manufacturing
* Rubber processing preparations (e.g., accelerators, stabilizers) manufacturing
* Rust preventive preparations manufacturing
* Salt (except table) manufacturing
* Soil testing kits manufacturing
* Spearmint oil manufacturing
* Stamp pad ink manufacturing
* Sugar substitutes (i.e., synthetic sweeteners blended with other ingredients) made from purchas
* Swimming pool chemical preparations manufacturing
* Tint and dye preparations, household-type (except hair), manufacturing
* Tire inflators, aerosol, manufacturing
* Transmission fluids, synthetic, manufacturing
* Water, distilled, manufacturing
* Wintergreen oil manufacturing
* Writing inks manufacturing

Appendix Y
GFA Disposal

Supporting Calculations for GFA Disposal Phase Activities

Transport est CO_2 emissions

	MILES Commute	Recycle	Dump
Est miles	42.4	18	0
MPG est.	17.6	17.6	17.6
Gas used	2.41	1.02	0.00
CO_2lbs/gal	19.4	19.4	19.4
CO_2lbs produced	46.73636	19.84091	0
short ton	0.023368	0.00992	0
$MTCO_2E$	0.0212	0.009	0

Notes

1. Estimated commute mileage on 10.6 miles one-way is from Highway Statistics 2005.
2. One gallon of gasoline produces 19.4 pounds of CO_2
3. To convert from a short ton to a metric ton, multiply by .9072.

2 & 3 Source: Unit Conversions, Emissions Factors, And Other Reference Data, 2004.

Supporting Calculations for SRS Disposal Phase Activities

Transport est CO_2 emissions

	MILES Commute	 Recycle	 Dump
Est miles	84.8	6	0
MPG est.	30	17.6	17.6
Gas used	2.83	0.34	0.00
CO_2lbs/gal	19.4	19.4	19.4
CO_2lbs produced	54.83733	6.613636	0
short ton	0.027419	0.003307	0
$MTCO_2E$	0.024874	0.003	0

Notes

1. Estimated Commute mileage on 10.6 miles one way is from Highway Statistics 2005.
2. 17.6 MPG estimate is the light duty truck fleet average for 2001.

Source Emission Facts, EPA420-F-05-004, Feb 2005

3. One gallon of gasoline produces 19.4 pounds of CO_2
4. To convert from a short ton to a metric ton multiply by .9072.
5. One gallon of diesel fuel produces 22.25 pounds of CO_2

3, 4, & 5 Source: Unit Conversions, Emissions Factors, And Other Reference Data, 2004.

Appendix Z

BLCC Input Data Listing

NIST BLCC 5.3-07: Input Data Listing
Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information
File Name: C:\Program Files\BLCC5\projects\Diss LCC to use.xml
Date of Study: Tue Sep 11 08:50:51 MDT 2007
Analysis Type: FEMP Analysis, Energy Project
Project Name: Gas Forced Air
Project Location: Colorado
Analyst: Scott Glick
Comment: Use GFA to heat residence in Fort Collins, Colorado
Base Date: June 1, 2007
Service Date: June 1, 2007
Study Period: 20 years 0 months (June 1, 2007 through May 31, 2027)
Discount Rate: 5%
Discounting Convention: End-of-Year
Discount and Escalation Rates are NOMINAL (inclusive of general inflation)

Alternative: Gas Forced Air

Energy: Electricity
Annual Consumption: 1,092.0 kWh
Price per Unit: $0.08125
Demand Charge: $0
Utility Rebate: $0
Location: Colorado
Rate Schedule: Residential
State: Colorado

Usage Indices

From Date	Duration	Usage Index
June 1, 2007	Remaining	100%

Escalation Rates

From Date	Duration	Escalation
April 1, 2007	1 year 0 months	1.75%
April 1, 2008	1 year 0 months	0.59%
April 1, 2009	1 year 0 months	0.21%

April 1, 2010	1 year 0 months	-0.31%
April 1, 2011	1 year 0 months	0.29%
April 1, 2012	1 year 0 months	1.47%
April 1, 2013	1 year 0 months	1.59%
April 1, 2014	1 year 0 months	1.98%
April 1, 2015	1 year 0 months	2.56%
April 1, 2016	1 year 0 months	2.79%
April 1, 2017	1 year 0 months	1.98%
April 1, 2018	1 year 0 months	1.21%
April 1, 2019	1 year 0 months	1.82%
April 1, 2020	1 year 0 months	2.37%
April 1, 2021	1 year 0 months	2.4%
April 1, 2022	1 year 0 months	2.13%
April 1, 2023	1 year 0 months	2.21%
April 1, 2024	1 year 0 months	2.28%
April 1, 2025	1 year 0 months	2.24%
April 1, 2026	1 year 0 months	2.01%
April 1, 2027	1 year 0 months	2.13%
April 1, 2028	1 year 0 months	2.5%
April 1, 2029	1 year 0 months	2.43%
April 1, 2030	1 year 0 months	2.27%
April 1, 2031	1 year 0 months	2.27%
April 1, 2032	1 year 0 months	2.27%
April 1, 2033	1 year 0 months	2.27%
April 1, 2034	1 year 0 months	2.31%
April 1, 2035	1 year 0 months	2.27%
April 1, 2036	1 year 0 months	2.27%
April 1, 2037	Remaining	2.28%

Energy: Natural Gas
Annual Consumption: 53,200.0 CuFt
Price per Unit: $0.00800
Demand Charge: $0
Utility Rebate: $0
End-Use: Residential Furnace
Rate Schedule: Residential
State: Colorado

Usage Indices

From Date	Duration	Usage Index
June 1, 2007	Remaining	100%

Escalation Rates

From Date	Duration	Escalation
April 1, 2007	1 year 0 months	-0.79%

April 1, 2008	1 year 0 months	-0.95%
April 1, 2009	1 year 0 months	-1.32%
April 1, 2010	1 year 0 months	-0.84%
April 1, 2011	1 year 0 months	0.49%
April 1, 2012	1 year 0 months	-0.34%
April 1, 2013	1 year 0 months	1.69%
April 1, 2014	1 year 0 months	1.8%
April 1, 2015	1 year 0 months	2.42%
April 1, 2016	1 year 0 months	3.56%
April 1, 2017	1 year 0 months	0.57%
April 1, 2018	1 year 0 months	-0.17%
April 1, 2019	1 year 0 months	2.53%
April 1, 2020	1 year 0 months	2.74%
April 1, 2021	1 year 0 months	3.05%
April 1, 2022	1 year 0 months	3.86%
April 1, 2023	1 year 0 months	3.11%
April 1, 2024	1 year 0 months	2.6%
April 1, 2025	1 year 0 months	2.4%
April 1, 2026	1 year 0 months	2.69%
April 1, 2027	1 year 0 months	3.17%
April 1, 2028	1 year 0 months	3.35%
April 1, 2029	1 year 0 months	2.95%
April 1, 2030	1 year 0 months	2.66%
April 1, 2031	1 year 0 months	2.65%
April 1, 2032	1 year 0 months	2.64%
April 1, 2033	1 year 0 months	2.73%
April 1, 2034	1 year 0 months	2.63%
April 1, 2035	1 year 0 months	2.63%
April 1, 2036	1 year 0 months	2.71%
April 1, 2037	Remaining	2.67%

Component:

Initial Investment

Initial Cost (base-year $):	$6,200
Annual Rate of Increase:	1.9%
Expected Asset Life:	20 years 0 months
Residual Value Factor:	0%

Cost-Phasing

Cost Adjustment Factor: 1.9%

Years/Months (from Date)	Date	Portion

0 years 0 months	June 1, 2007	100%

Recurring OM&R: Yearly Service Check
Amount: $99
Annual Rate of Increase: 1.9%

Usage Indices

From Date	Duration	Factor
June 1, 2007	Remaining	100%

Non-Recurring OM&R: Replace blower

Years/Months:	12 years 0 months
Amount:	$325
Annual Rate of Increase:	1.9%

Alternative: Solar Radiant System
Comment: Use gas forced air instead of solar radiant system for residence heat source

Energy: Electricity
Annual Consumption: 1,092.0 kWh
Price per Unit: $0.08000
Demand Charge: $0
Utility Rebate: $0
Location: U.S. Average
Rate Schedule: Residential
State: Colorado

Usage Indices

From Date	Duration	Usage Index
June 1, 2007	Remaining	100%

Escalation Rates

From Date	Duration	Escalation
April 1, 2007	1 year 0 months	1.75%
April 1, 2008	1 year 0 months	0.59%
April 1, 2009	1 year 0 months	0.21%
April 1, 2010	1 year 0 months	-0.31%
April 1, 2011	1 year 0 months	0.29%

April 1, 2012	1 year 0 months	1.47%
April 1, 2013	1 year 0 months	1.59%
April 1, 2014	1 year 0 months	1.98%
April 1, 2015	1 year 0 months	2.56%
April 1, 2016	1 year 0 months	2.79%
April 1, 2017	1 year 0 months	1.98%
April 1, 2018	1 year 0 months	1.21%
April 1, 2019	1 year 0 months	1.82%
April 1, 2020	1 year 0 months	2.37%
April 1, 2021	1 year 0 months	2.4%
April 1, 2022	1 year 0 months	2.13%
April 1, 2023	1 year 0 months	2.21%
April 1, 2024	1 year 0 months	2.28%
April 1, 2025	1 year 0 months	2.24%
April 1, 2026	1 year 0 months	2.01%
April 1, 2027	1 year 0 months	2.13%
April 1, 2028	1 year 0 months	2.5%
April 1, 2029	1 year 0 months	2.43%
April 1, 2030	1 year 0 months	2.27%
April 1, 2031	1 year 0 months	2.27%
April 1, 2032	1 year 0 months	2.27%
April 1, 2033	1 year 0 months	2.27%
April 1, 2034	1 year 0 months	2.31%
April 1, 2035	1 year 0 months	2.27%
April 1, 2036	1 year 0 months	2.27%
April 1, 2037	Remaining	2.28%

Component: Solar Radiant System
Comment: Install solar radiant system

Initial Investment
Initial Cost (base-year $): $45,688
Annual Rate of Increase: 1.9%
Expected Asset Life: 20 years 0 months
Residual Value Factor: 25%

Cost-Phasing
Cost Adjustment Factor: 1.9%

Years/Months (from Date)	Date	Portion
0 years 0 months	June 1, 2007	100%

Recurring OM&R: Annual Inspection
Amount: $75
Annual Rate of Increase: 1.9%

Usage Indices

From Date	Duration	Factor
June 1, 2007	Remaining	100%

Non-Recurring OM&R: Antifreeze
Years/Months: 10 years 0 months
Amount: $550
Annual Rate of Increase: 1.9%

Non-Recurring OM&R: Replace Pump
Years/Months: 16 years 0 months
Amount: $145
Annual Rate of Increase: 1.9%

Appendix AA
BLCC Comparative Analysis

NIST BLCC 5.3-07: Comparative Analysis
Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

Base Case: Gas Forced Air
Alternative: Solar Radiant System

General Information
File Name:C:\Program Files\BLCC5\projects\comparative LCC.xml
Date of Study: Tue Sep 11 09:00:34 MDT 2007
Project Name: Gas Forced Air
Project Location: Colorado
Analysis Type: FEMP Analysis, Energy Project
Analyst: Scott Glick
Comment: Use GFA to heat residence in Fort Collins Colorado
Base Date: June 1, 2007
Service Date: June 1, 2007
Study Period:20 years 0 months(June 1, 2007 through May 31, 2027)
Discount Rate:5%
Discounting Convention: End-of-Year

Comparison of Present-Value Costs

PV Life-Cycle Cost

	Base Case	Alternative	Savings from Alt
Initial Investment Costs:			
Capital Requirements as of Base Date	$6,200	$45,688	-$39,488
Future Costs:			
Energy Consumption Costs	$6,894	$1,233	$5,661
Energy Demand Charges	$0	$0	$0
Energy Utility Rebates	$0	$0	$0
Water Costs	$0	$0	$0
Recurring and Non-Recurring OM&R Costs	$1,701	$1,682	$19
Capital Replacements	$0	$0	$0
Residual Value at End of Study Period	$0	-$6,325	$6,325
	------------	------------	------------
Subtotal (for Future Cost Items)	$8,595	$-3,410	$7,771
	------------	------------	------------

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Total PV Life-Cycle Cost                    $14,795        $42,278        -$27,483


Net Savings from Alternative Compared with Base Case
PV of Non-Investment Savings                               $5,680
- Increased Total Investment                               $33,163
                                                           ------------
Net Savings                                               -$27,483

Savings-to-Investment Ratio (SIR)
SIR = 0.17
SIR is lower than 1.0; project alternative is not cost effective.

Adjusted Internal Rate of Return
AIRR = -3.91
AIRR is lower than your discount rate; project alternative is not cost effective.

Payback Period
Estimated Years to Payback (from beginning of Service Period)
Simple Payback never reached during study period.
Discounted Payback never reached during study period.

Energy Savings Summary
Energy Savings Summary (in stated units)
Energy           -----Average      Annual         Consumption-----     Life-Cycle
Type               Base Case     Alternative        Savings              Savings
Electricity      1,092.0 kWh    1,092.0 kWh        0.0 kWh              0.0 kWh
Natural Gas     53,200.0 CuFt      0.0 CuFt     53,200.0 CuFt    1,063,854.3 CuFt

Energy Savings Summary (in MBtu)
Energy           -----Average      Annual         Consumption-----     Life-Cycle
Type               Base Case     Alternative        Savings              Savings
Electricity        3.7 MBtu        3.7 MBtu        0.0 MBtu             0.0 MBtu
Natural Gas       54.8 MBtu        0.0 MBtu       54.8 MBtu         1,096.4 MBtu

Emissions Reduction Summary
Energy           -----Average      Annual          Emissions-----      Life-Cycle
Type               Base Case     Alternative        Reduction           Reduction
Electricity
      CO2       1,033.09 kg       966.63 kg         66.46 kg         1,328.98 kg
      SO2           1.04 kg         2.48 kg         -1.44 kg           -28.78 kg
      NOx           1.79 kg         2.03 kg         -0.24 kg             4.72 kg

Natural Gas
      CO2       2,896.26 kg         0.00 kg      2,896.26 kg        57,917.33 kg
      SO2          23.37 kg         0.00 kg         23.37 kg           467.41 kg
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NOx	2.26 kg	0.00 kg	2.26 kg	45.12 kg
Total:				
CO2	3,929.35 kg	966.63 kg	2,962.72 kg	59,246.31 kg
SO2	24.42 kg	2.48 kg	21.93 kg	438.63 kg
NOx	4.05 kg	2.03 kg	2.02 kg	40.40 kg

Appendix AB

BLCC Summary LCC

NIST BLCC 5.3-07: Summary LCC

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

General Information

File Name:	C:\Program Files\BLCC5\projects\comparative LCC.xml
Date of Study:	Wed Sep 26 08:37:39 MDT 2007
Analysis Type:	FEMP Analysis, Energy Project
Project Name:	Gas Forced Air
Project Location:	Colorado
Analyst:	Scott Glick
Comment:	Use GFA to heat residence in Fort Collins Colorado
Base Date:	June 1, 2007
Service Date:	June 1, 2007
Study Period:	20 years 0 months (June 1, 2007 through May 31, 2027)
Discount Rate:	5%
Discounting Convention:	End-of-Year

Discount and Escalation Rates are NOMINAL (inclusive of general inflation)

Alternative: Gas Forced Air

LCC Summary

	Present Value	Annual Value
Initial Cost	$6,200	$496
Energy Consumption Costs	$6,894	$551
Energy Demand Costs	$0	$0
Energy Utility Rebates	$0	$0
Water Usage Costs	$0	$0
Water Disposal Costs	$0	$0
Annually Recurring OM&R Costs	$1,473	$118
Non-Annually Recurring OM&R Costs	$228	$18
Replacement Costs	$0	$0
Less Remaining Value	$0	$0
	------------	------------
Total Life-Cycle Cost	$14,795	$1,183

Alternative: Solar Radiant System
LCC Summary

	Present Value	Annual Value
Initial Cost	$45,688	$3,653
Energy Consumption Costs	$1,233	$99
Energy Demand Costs	$0	$0
Energy Utility Rebates	$0	$0
Water Usage Costs	$0	$0
Water Disposal Costs	$0	$0
Annually Recurring OM&R Costs	$1,116	$89
Non-Annually Recurring OM&R Costs	$566	$45
Replacement Costs	$0	$0
Less Remaining Value	-$6,325	-$506
	------------	------------
Total Life-Cycle Cost	$42,278	$3,380

Alternative: Hybrid
LCC Summary

	Present Value	Annual Value
Initial Cost	$20,489	$1,638
Energy Consumption Costs	$6,894	$551
Energy Demand Costs	$0	$0
Energy Utility Rebates	$0	$0
Water Usage Costs	$0	$0
Water Disposal Costs	$0	$0
Annually Recurring OM&R Costs	$0	$0
Non-Annually Recurring OM&R Costs	$146	$12
Replacement Costs	$0	$0
Less Remaining Value	-$3,971	-$317
	------------	------------
Total Life-Cycle Cost	$23,559	$1,884