Modules to Introduce Sustainability and Life Cycle Assessment (LCA) to Undergraduate Students

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ABSTRACT

Sustainability has gained a lot of importance in the past couple of decades. Sustainable development has become an important aspect in any new product, process, or service, and it has an effect even for existing products, processes, and services. This trend is one of the main reasons why almost every engineering and sciences curricula being offered at colleges and universities across the globe has a sustainability component. In a technical program, in addition to the classical introductory material, it is important to expose the students to objective measurements of the environmental aspects of the proposed development. One such tool is Life Cycle Assessment (LCA), a technique that helps to introduce sustainability into the engineering design process. This paper presents classroom examples of LCA utilizing resources available in a CAD software, and online. This are introductory material that students use as basis for some exploration.

Keywords: LCA, Life Cycle Assessment, Curricula, Sustainability

1. INTRODUCTION

With sustainability becoming a growing concern in today's society, young professionals entering the engineering and design field today are in a unique and important position to shape the future of our planet's environment. The materials and methods used to construct the products, systems, and services used in today's society can have enormous, long term impacts on the physical environment. This leads to engineers having a technical, ethical and moral obligation to move toward products, systems and services that have a limited impact on the environment [Sabah, 2003]. These demands of new engineers are not purely moral or ethical, however, as a more ecologically conscious consumer base is now taking concerns of the environment more seriously, the issue is becoming just as much about marketing and sales as it is about the environment.

Academia is also beginning to shift into more sustainably themed curricula. While familiarity in the areas of thermodynamics, fluid mechanics, and structure will still play a role in the development of young engineers, other areas such as power generation, chemical engineering, and energy systems will like take a larger role [Beder, 1997]. Traditional engineering still focuses heavily on fossil fuel based systems and lacks insight on how to treat wastes as they are generated on the outbound end of a system. Even the specific field of environmental engineering tends to treat problems not at the source, but as an end-of-pipe issue. Approaching environmental

concerns in the fashion will not likely lead to long term sustainable results, but rather push problems in the present further down the road [Taskforce, 1997].

Design for Manufacturability (DFM) and Design for Assembly (DFA) have been key concepts in engineering for decades; however, a newer focus receiving more attention is Design for Environment (DfE). Design for Environment places the emphasis on the environmental impact of a product, also known as an environmental footprint. To assess and environmental footprint, one tool which can be used is the life cycle assessment (LCA). A life cycle assessment seeks to gather all inputs for a product as well as all possible outputs that come as a result of the product while in use [Guinee, 2005]. These inputs and outputs typically include raw material extraction, processing and manufacture, transportation, use, and end-of-life disposal. The benefits of LCA design principles are not purely intended for the consumer. Companies who engage in thorough LCA analysis of their new and existing products can reap several different benefits. Some of these benefits include increased manufacturing efficiencies, improved customer acceptance, reduced generation of production waste, and cleaner production processes [Christopher, 2012].

A variety of tools are available to help instructors introduce sustainability and DfE concepts into design engineering courses. Two examples of these tools include the Sustainability Xpress add-on for SolidWorks [Solidworks, 2013], and the Economic Input-Output Life Cycle Assessment (EIO-LCA) tool from the University of Carnegie-Melon [EIOLCA, 2013]. Both tools approach LCA from different angles, but provide good insight as to the impact that product and system designs may have on the environment. These tools can be used to help engineers examine the embodied energy and effects different products and systems will have on the environment. Tools such as these will become increasingly important and to integrate into daily classroom activities while also introducing students to concepts of sustainability, an important necessity for both the world of today and tomorrow.

2. STATEMENT AND TOOLS

The availability and level of advanced manufacturing options throughout the world can vary considerably. The environment and levels of manufacturing capability, coupled with the level of environmental regulation in different regions of the world can lead to identical products having dramatically different environmental footprints. The ecological footprint, or otherwise known as environmental footprint of a product can be described as the impact that product has on the environment from raw material extraction and processing to end-of-life disposal. In recent years, the demand for "green" products, or products that have a minimalist environmental footprint, have increased in demand. To help manage environmental waste and impact, ISO 14001, Environmental Management Systems has seen steady growth in certifications issued in major manufacturing regions of the world such as Asia, North America, and Central America. In addition, ISO 50001, Energy Management Systems, is also growing throughout the same regions, but on a different scale [ISO, 2014]. This may be in large part due to the standards very young age.

To assist with the creation of new products, designers, engineers, marketers, and sales professionals are seeking new methods to help showcase their own efforts to produce green products. To aid in the design of products with a minimalist environmental footprint, designers and engineers have tools available to them such as the Sustainability Xpress tool available through Solidworks, and the Economic Input-Output Life Cycle Assessment (EIO-LCA) online tool developed by Carnegie-Melon University.

The Sustainability Xpress tool within Solidworks allows designers and engineers to create products in virtual space and, based on location of use, location of manufacture, materials selection, manufacturing methods, create an environmental impact report for the selected. These environmental impacts are reported as the effect a product has on carbon, energy, air, and water. Designers and engineers can manipulate these values by selecting different modes of transportation, location of manufacture, manufacturing method(s), and materials selection. Manipulating these values can help industry professionals create products and are specifically designed to both maximize their performance, but also minimize their environmental footprint. This tool provides a way to

evaluate a components environmental impact through four different benchmarks. These benchmarks include materials, manufacturing, transportation and use, and end-of-life. Within each of these four broad benchmarks are four additional metrics. These additional metrics include carbon and other greenhouse gas emissions, air acidification, energy consumption, and water eutrophication. Each of the tier two metrics are an embedded portion of a tier one metric. For example, Materials have an embedded impact on carbon, energy, air, and water resources. The SolidWorks Sustainability Xpress tool seeks to help minimize the impact of each of the mention environmental impacts by helping select the material, manufacturing process, and region(s) of manufacture.

The EIO-LCA tool, developed by the Green Design Institute of Carnegie Melon University, approaches the environmental footprint and impact of a product differently. The EIO-LCA estimates the environmental impact of a particular quantity, or value of material. This tool translates the economic activity of an industry process to a wide variety of impacts, such as environmental emissions, energy requires, material impacts, and economic activity. These metrics are further dissected through a list of appropriate sectors for each industry. These sectors detail in depth on how a given economic value in a particular industry process can impact different areas. The concept behind this tools model was developed in the 1970s, and tool now has a user-friendly interface to be used online.

3. METHODOLOGY

There are several approaches that have been utilized to expose undergraduate students to sustainability and LCa concepts, from demos all the away to specialized courses. Our selection was to have tutorials with exercises (modules), similar to a classical technique to expose students to CAD softwares. The tools selected in this case are Sustainability Xpress and EIO-LCA. Although both of them are tools for LCA, they have a significant different requirements, thus making them a good complement, as long as proper information and application is implemented. The implementation for each tools is presented next, based on a cast carbon steel flange (Figure 1).
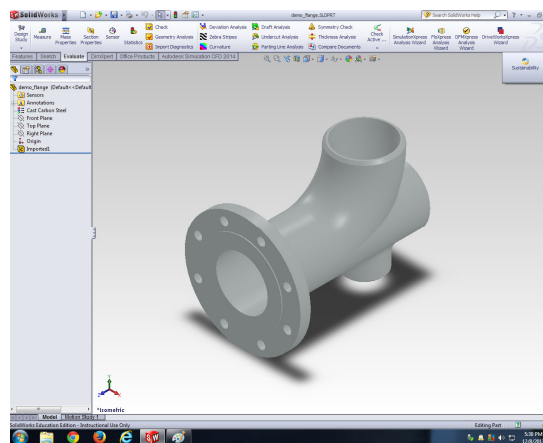

Figure 1. Solid Model of demo part used in exercises.

3.1 Sustainability Xpress

The following steps will provide the sustainability analysis using Sustainability Xpress. It uses the *demo_flange*, and it has different questions at the end of the tutorial. Start by launching Solidworks, and opening the Demo Flange file on your computer, then activate Sustainability Xpress, making sure that it shows all options. The Sustainability Xpress main window will appear in the center of the screen (make sure the "Do not show" was not previously activated). Close the main window when you are ready to start the sustainability analysis.
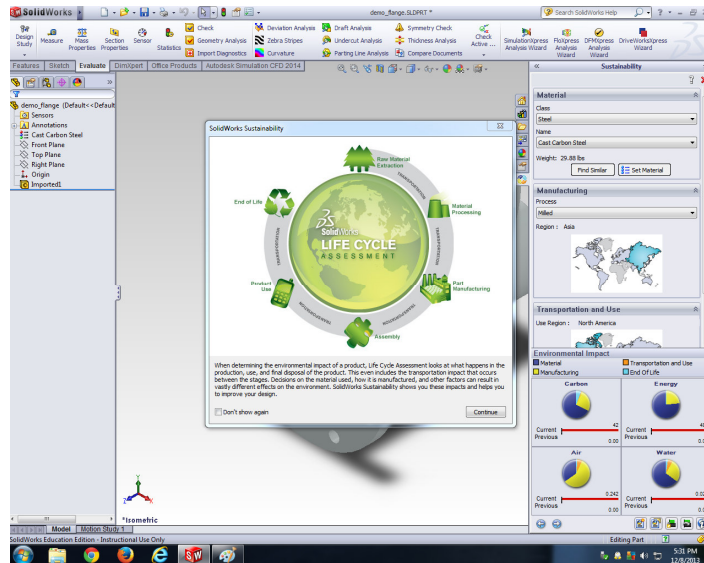
Figure 2 The Sustainability Xpress man window

The Sustainability Xpress ribbon is composed of four different areas:
- material,
- manufacturing,
- transportation and use, and
- environmental impact.

The Material submenu collect the information already provided in the solid model of the component. Collapse the Material section first by clicking on the up arrow on the right side of the Material portion of the ribbon. This allows us to see the Manufacturing section and Transportation and Use section more clearly. In the Manufacturing section, set the Process to Sand Casted. Notice how the default process was "milled." Milling this particular component, while possible, may not be the best option. The Sustainability Xpress tool gives you nearly full control over the settings. It is important to use best practices and common sense when applying various processes, materials, and regional settings. Next, set the Manufacturing, as well as the Transportation and Use "Regions" to North America. This can be done by clicking on the desiring region in the maps shown for both sections.

Below the Manufacturing, and Transportation and Use section is the Environmental Impact Section. Once you changed the default process to Sand Casted, you may have noticed some of the pie chart values change. These changes reflect the impact of the new process selection, indicating that sand casting this component will require more energy and water resources, and will also expel more carbon dioxide and increase air acidification. When the new baseline is set, a thick black bar will replace the light gray bar next to each Current Baseline.

Finally, select the Set Baseline option at the bottom of the Sustainability Xpress ribbon. This will reset the default Environmental Impact settings to the new options selected.
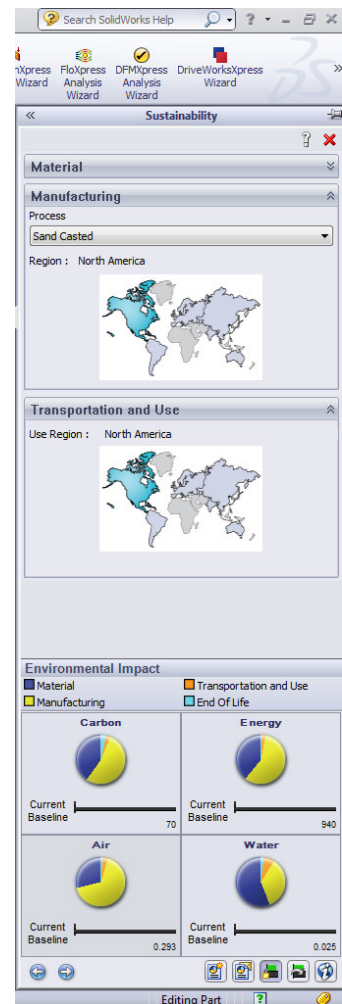
Figure 3. Input submenues for Sustainability Xpress.

Finding Similar Materials. With an established baseline, one option is to find materials that have similar qualities to our current materials, but have a lower level of environmental impact. To bring up the Find Similar Material window, re-expand the Materials section in the Sustainability Xpress ribbon and click the Find Similar button at the bottom of the Materials section.

When the new window appears, you will notice a variety of material properties that are available to change. Altering these properties will help locate and filter new materials that meet the components needs. Before altering these properties, however, first change the Manufacturing Process, located at the lower right portion of the Find Similar Materials window, from Milling to Sand Casted. By altering the Manufacturing Process, the Environmental Impact chart bars at the bottom of the window will change to be identical to your selected baseline. This is due to Sand Casting being the selected option in the primary Manufacturing section when our original baseline was established. Two examples of how to use the material properties will be shown below.

Scenario 1 – Basic Material Class Selection. Set the Material Class to Steel. This will allow the search filter to eliminate everything that is not steel. Select the Find Similar button to continue. Once the Find Similar button is pressed, observe the large list of options available. As steel is a very broad category, the program is showing all of the steels available, as well as their environmental impact. As your move through the options, note how the Environmental Impact meter changes at the bottom of the Find Similar Material window.
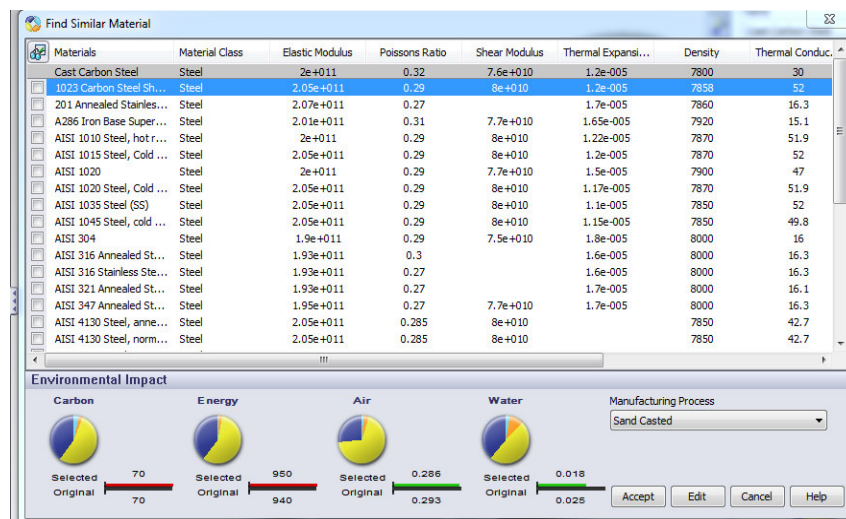

Figure 4. Finding similar materials – Basic Material Option

The selected material is a 1023 Carbon Steel – Sheet. Notice that the carbon and energy ratings for this material are very similar to the original Cast Carbon Steel material. The air acidification and water consumption ratings, however, are shown to have some improvement. Based on environmental impact alone, this material *could* be considered a better choice, however, the material properties selected must *also* be taken into account. Remember, when searching for new materials, the only filtering criteria enabled was "Steel." This means that all steels are shown regardless of their material properties. While this may be a better material based on environmental impact, the properties may not be suitable for the components needs.

Scenario 2 – Refined Filters for Material Class Selection. For the next example, set the Material Class to Steel. In addition, set the Thermal Expansion and Thermal Conductivity to "less than" (<). Again, search for results with a now slightly more refined filter and observe the results.
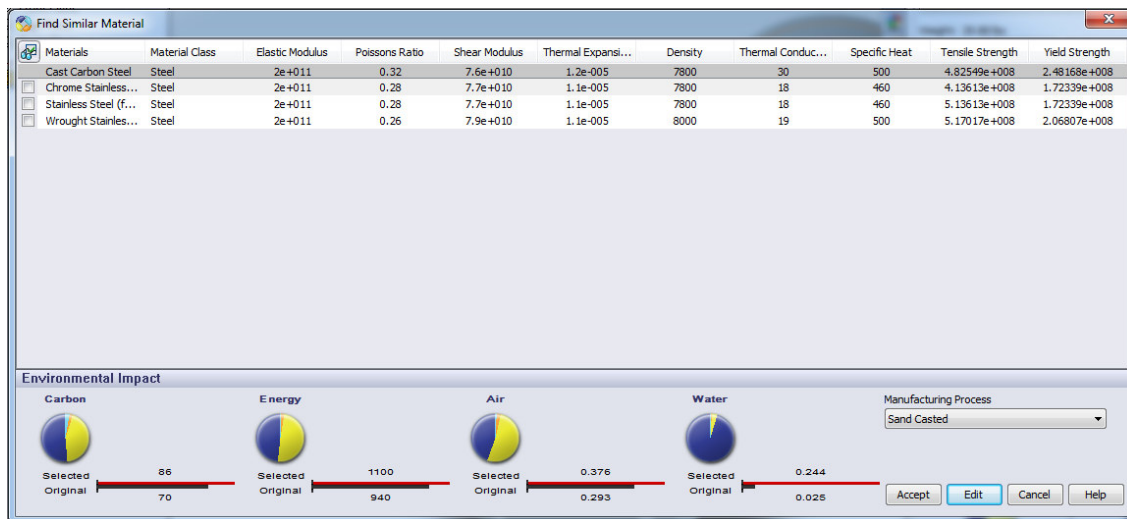
Figure 5. Finding similar materials – Apply Filters option.

The newly presented materials are all a type of Stainless Steel and, as shown in Figure 5, all of the options presented indicate a considerably poorer Environmental Impact. This indicates that Cast Carbon Steel is likely the best material based on our filter criteria and material class requirements. An additional option to searching for some materials involves the use of the "approximate" value option. Instead of searching for materials with a value greater or less than noted, a third option allows you to search for materials with approximately the same value. In some cases this may be a powerful method for finding additional materials with similar properties, however, in this particular case, no materials available are similar enough to quality as a suitable replacement for Cast Carbon Steel.

Generate Report. The Sustainability Xpress tool allows you to create a report with a great deal of the information currently shown in the ribbon listed. The option is found at the bottom of the Sustainability Xpress ribbon and is labeled as Generate Report. Once selected, the feature automatically compiles the session's data and creates a report in Microsoft Word. The report can be printed or sent electronically as needed.

3.2 EIO-LCA
The EIO-LCA tool can be accessed at www.eiolca.net. Once at the homepage, several links are available at the right of the web page. These links include Method, Models, Use the Tool, and Usage and Copyright. The Method, Models, and Usage and Copyright sections all contain information on the EIO-LCA tool, its creation, history, and how to properly credit the website.

Setting the Input. In this case study, the standard model will be used. To access the standard model, click the Use the Tool link on the left side of the EIO-LCA homepage. Once inside the standard model setup screen, you will be presented with options to choose a model, an industry sector, economic activity, display results as, and finally, running the model.

The models available vary considerably. Model options include the US National Producer Price Model, US National Purchaser Price Model, US State Producer Price Model, and International Producer Price Models. Several specific sub-categories for each model are available depending on the specific needs of the project, however, the latest models across all fields are based on information gathered in or prior to 2002. To begin, the US National Producer Price - US 2002 Producer model will be used.

Once the model is selected, an industry and specific sector will also need to be selected. The industry selector focuses on very broad categories such as Mining and Utilities, or Machinery and Engines. The model is the same cast carbon steel flange. From the description alone, two important pieces of information are made available. First, the component is cast, implying the use of a foundry. Second, the component is made from

carbon steel. To select the correct industry, click on the down arrow to the left, under the Select Industry and Sector section. Near the middle of the list you will find the option Ferrous and Non-Ferrous Metal Production. Next is selecting the specific sector from which ferrous and non-ferrous metal production will be operating under. Selecting the drop down arrow to the right, under Select Industry and Sector, brings us to another series of options. Near the bottom, select the option called Ferrous Metal Foundries.

Figure 6. Input Screen for EIO-LCA.

Upon selecting the desired industry and sector, the amount of economic input needs to be entered. The economic input is best entered in millions of dollars. Inputting an economic value of less than one million dollars may produce less accurate data. If the economic activity level is too high, the results can be scaled down once the model runs to levels more desirable. For this example, enter an economic activity value of 1, representing $1 million dollars.

Once information in sections one through four was entered, the model can be run. Before running the model, however, take note of the different sectors described at the bottom of the screen (in the gray box). Of particular interest in this example is the sectors described as Ferrous Metal Foundries, Steel Investment Foundries, and Steel Foundries (except investment). These sector descriptors state in further detail the specific industries taken into account when running the model and generating results. Just before running the model, select the primary category of results to display. These results can be changed at any time after the model runs to view different parses of data. The default setting is Economic Activity and will be left as such.

Reviewing the Output. The output table generated by the model is comprised of rows and columns, with the rows representing different sectors which are contributing toward the industry sector under review, and the columns represent various sub-areas under which portions of each sector fall. The economic activity model creates columns (Figure 7) to measure total economic input, value added, employee compensation, net taxes, profits, direct economic purchases, and % economic investment. The sectors outlined include ferrous metal foundries, company management, trading, iron and steel mills, power generation, pipe and tube manufacturing, monetary authorities, nonferrous foundries, real estate, and transportation. Each of the sectors lists have an input value that corresponds with the columns previously mentioned.

The table indicates that ferrous metal foundries have a total economic impact of 0.978 million dollars, or $978,000 dollars per $1 million invested across the entire supply chain. Again, reviewing ferrous metal

foundries, the total value added (0.47 million or $470,000 – Table 1) is the sum of employee compensation, net taxes, and profits.

Sector #331510: Ferrous metal foundries
Economic Activity: $1 Million Dollars
Displaying: Economic Activity
Number of Sectors: Top 10

Change Inputs (Click here to view greenhouse gases, air pollutants, etc...)

Documentation:
The environmental, energy, and other data used and their sources.
Frequently asked questions about EIO-LCA.

This sector list was contributed by Green Design Institute.

	Sector	Total Economic $mill	Total Value Added $mill	Employee Comp VA $mill	Net Tax VA $mill	Profits VA $mill	Direct Economic $mill	Direct Economic %
	Total for all sectors	1.86	0.926	0.641	0.035	0.249	1.46	78.5
331510	Ferrous metal foundries	0.978	0.470	0.369	0.004	0.097	0.976	99.9
550000	Management of companies and enterprises	0.075	0.047	0.040	0.001	0.006	0.054	71.0
420000	Wholesale trade	0.074	0.051	0.028	0.012	0.011	0.050	67.9
331110	Iron and steel mills	0.061	0.017	0.012	0.000	0.004	0.047	76.6
221100	Power generation and supply	0.046	0.032	0.010	0.006	0.016	0.036	77.0
331200	Iron, steel pipe and tube manufacturing from purchased steel	0.019	0.005	0.004	0.000	0.000	0.014	74.7
52A000	Monetary authorities and depository credit intermediation	0.017	0.012	0.005	0.000	0.007	0.007	41.3
331520	Nonferrous foundries	0.016	0.006	0.005	0.000	0.000	0.015	95.4
531000	Real estate	0.016	0.012	0.001	0.002	0.010	0.002	14.8
484000	Truck transportation	0.016	0.007	0.005	0.000	0.002	0.008	50.0

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Figure 7. Model summary table for ferrous foundries with an economic activity of $1 million dollars

Table 1. Total value of section inputs for ferrous metal foundries

Employee Compensation	$	369,000
Net Taxes	$	4,000
Profits	$	97,000
Total	$	470,000

Different Scenarios. Switching between output charts can be accomplished by selecting the Change Inputs button on the left, directly above the chart. Once pushed, the Change Inputs page appears. Here you may change the displayed mode of activity, such as economic activity, greenhouse gases, energy, hazardous water, and land use. Additionally, you may change the level of economic activity and the top number of sectors displayed in the model results. For this example, change the display to Energy, and the number of sectors from 10 to the top 25. The resulting output is shown in Figure 8.

While the industry and sectors selected have not changed, the sector outputs and column outputs are dramatically different. This is because almost all outputs are energy based. Examining the sectors presented allows us chance to review some other, interesting sectors. Some sectors such as ferrous metal foundries, iron and steel mills, pipeline transportation, and air transportation may seem like reasonable items to have energy based EIO-LCA. However, if you look closer, you'll notice sectors such as paper mills, oil and gas extraction, and pipeline transportation. These sectors may look out of place, but it is important to note that the EIO-LCA encompasses the entire supply chain of a product.

4. CONCLUSIONS AND FUTURE WORK

The concepts of sustainability and Life Cycle Assessment (LCA) can be introduced in the initial courses that students take in a technical curricula. Some of the tools available nowadays will provide a valuable aid to expose students to those concepts. From the two tools presented here, i.e., Solidworks' Sustainability Xpress and Carnegie Mellon's EIO-LCA, the first option is a better fit for students in the first two years of college due to the simpler requirements on information needed. The second option is a very valuable tool for in-depth LCA analysis. Additional tutorials and exercises will be generated, with comparative analysis requirements.

Sector #331510: Ferrous metal foundaries
Economic Activity: $1 Million Dollars
Displaying: Energy
Number of Sectors: Top 25

Documentation:
The environmental, energy, and other data used and their sources.
Frequently asked questions about EIO-LCA.

[Change Inputs] (Click here to view greenhouse gases, air pollutants, etc...)

This sector list was contributed by Green Design Institute.

Sector	Total Energy TJ	Coal TJ	NatGas TJ	Petrol TJ	Bio/Waste TJ	NonFossElec TJ
Total for all sectors	16.6	5.94	5.71	1.23	0.214	3.53
331510 Ferrous metal foundaries	6.78	0.952	3.14	0.079	0	2.61
221100 Power generation and supply	5.04	3.67	1.07	0.178	0	0.118
331110 Iron and steel mills	2.01	1.19	0.547	0.019	0.008	0.242
484000 Truck transportation	0.205	0	0	0.203	0	0.002
482000 Rail transportation	0.151	0	0	0.148	0	0.002
322130 Paperboard Mills	0.147	0.013	0.030	0.006	0.087	0.010
211000 Oil and gas extraction	0.141	0	0.115	0.012	0	0.014
324110 Petroleum refineries	0.136	0.000	0.036	0.088	0.007	0.005
331419 Primary smelting and refining of nonferrous metal (except copper and aluminum)	0.119	0.011	0.047	0.010	0.004	0.047
486000 Pipeline transportation	0.113	0	0.086	0	0	0.027
33131A Alumina refining and primary aluminum production	0.098	0	0.026	0.000	0.002	0.069
331520 Nonferrous foundries	0.084	0.015	0.048	0.001	0	0.019
212210 Iron ore mining	0.078	0.003	0.034	0.009	0	0.032
325190 Other basic organic chemical manufacturing	0.067	0.008	0.026	0.009	0.020	0.004
481000 Air transportation	0.066	0	0	0.066	0	0.000
420000 Wholesale trade	0.065	0.000	0.012	0.037	0	0.015
32712B Clay and non-clay refractory manufacturing	0.060	0.010	0.034	0.007	0.000	0.008
331490 Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying	0.059	0.007	0.028	0.006	0.004	0.013
322120 Paper mills	0.057	0.008	0.012	0.004	0.028	0.006
212100 Coal mining	0.057	0.002	0.022	0.022	0	0.011
230301 Nonresidential maintenance and repair	0.052	0	0.004	0.046	0	0.002
331200 Iron, steel pipe and tube manufacturing from purchased steel	0.051	0	0.032	0	0.001	0.018
212320 Sand, gravel, clay, and refractory mining	0.050	0.004	0.017	0.021	0	0.009
550000 Management of companies and enterprises	0.043	0.000	0.015	0.009	0	0.020
331411 Primary smelting and refining of copper	0.041	0.005	0.019	0.004	0.002	0.010

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Figure 1 Changing and reviewing the chart review type

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