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Life Cycle Greenhouse Gas Emission Comparison of Steel Products with Other Materials

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ABSTRACT

This paper outlines the background of Life-Cycle Inventory/ Life-Cycle Assessment (LCI/LCA) and reviews an undergraduate design project in progress at the University of Missouri – Rolla (UMR) comparing LCI/LCA of steel products with similar products produced from competing materials. GaBi 4 LCI/LCA software is being used to model LCI/LCA with a demonstration of the use of the software for a typical steelmaking operation.[1] Future research utilizing the LCI/LCA methodology is being applied to compare the environmental impact of steel products to other alternative engineering materials. This work involves 13 undergraduate students working in four design teams under a FeMET design grant provided by the American Iron and Steel Institute (AISI) and the Association of Iron and Steel Technology (AIST) Foundation.

BACKGROUND ON LCI/LCA

A new approach for international industries has been environmental stewardship; reducing the economic and environmental footprint of their products and processes. In the late 1960s and early 1970s, the theory of life-cycle analysis and assessment originated as a study to reduce the cost and emissions (i.e. greenhouse gases, carbon dioxide emissions and energy consumption) associated with various production processes. LCA refers to the "cradle to grave" assessment of the energy requirements and environmental impacts of a given product design. All assessments of the total life-cycle of the product are considered, including raw-material extraction from the earth and product manufacture, use, recycling (including design for recycling), and disposal.[2]

Life-cycle assessments and inventories are a part of the International Organization for Standardization (ISO) 14000 family classification. ISO 14000 is primarily focused on the environmental management of corporations with preexisting ISO programs. The ISO 14000 family contains ISO 14040 through 14043, which are specific standards showing studies that have been performed to delineate LCAs and LCIs. The intention of these standards is to give companies a goal to reach by minimizing the overall environmental impact of their products. As illustrated in Figure 1, the ISO 14000 family model gives a comprehensive representation of all environmental aspects of a product.

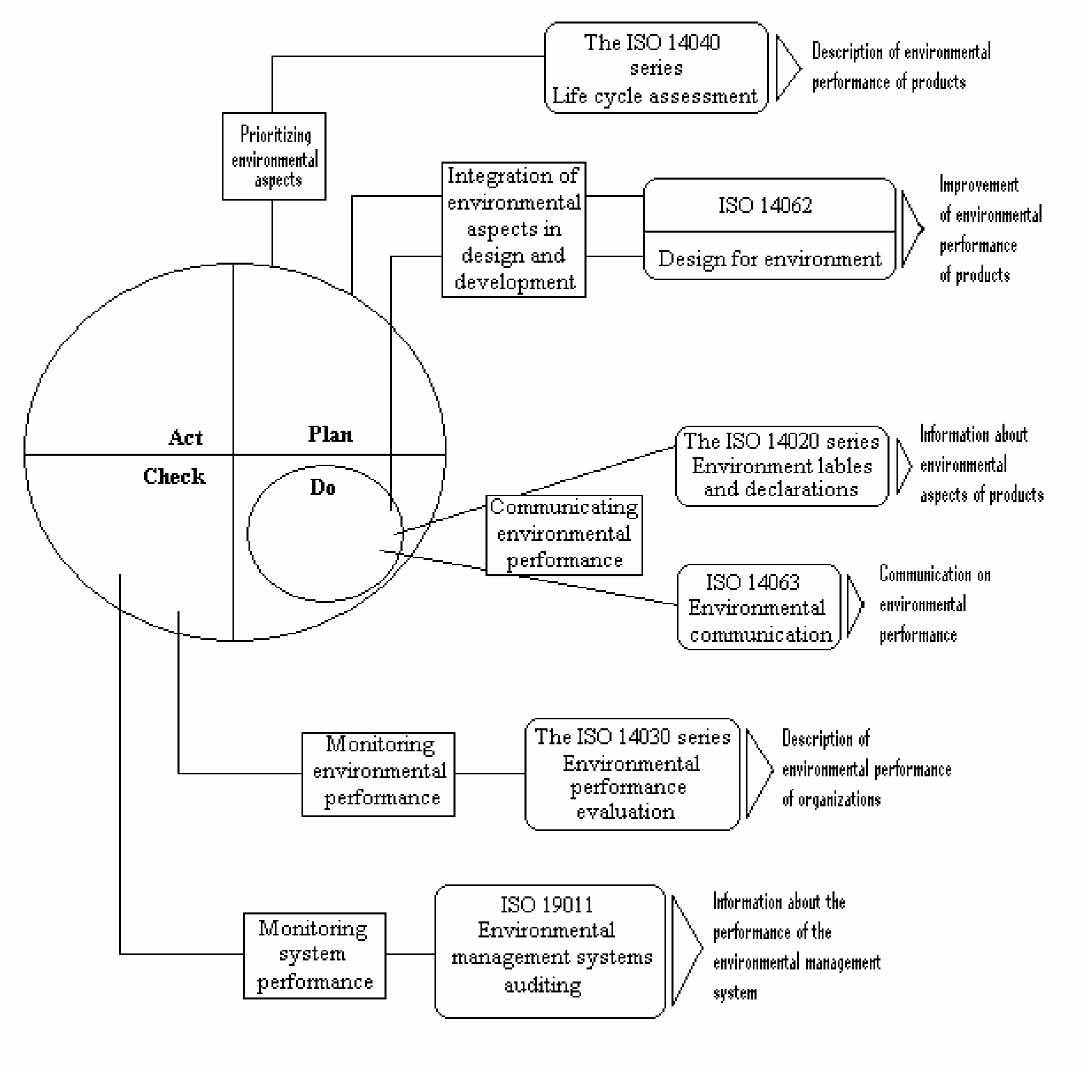


Figure 1: Model of environmental management similar to ISO 14000 model.[3]

The diagram in Figure 1 gives the benefits of the ISO 14000 family of international standards which describes the Environmental Management System (EMS). In an EMS, life-cycle assessment methodological requirements are outlined and then generalized through the ISO 14040 categorization. These outlines give corporations a starting point to conduct their own LCA for their process. Once this starting point is established a company can use current practices relating to their own process from ISO 14062 to attempt to evaluate their environmental impact. After an improvement has been established in companies manufacturing an evaluation will be done in accordance to the ISO 14030 series. Companies are audited by external organizations to ensure their environmental performance is accurate. Consulting firms should be from the ISO 19011 to stay within the required standards to keep their ISO status.

LCA is defined by four main components:

1. The goal definition and scope of the project
2. The life cycle inventory (LCI)
3. The impact analysis
4. The improvement analysis

The goal definition and scope identify the purpose and the expected outcomes. LCI quantifies the various inputs and outputs (i.e. energy, wastes, and resources) required for each phase of the life-cycle as seen in Figure 2.

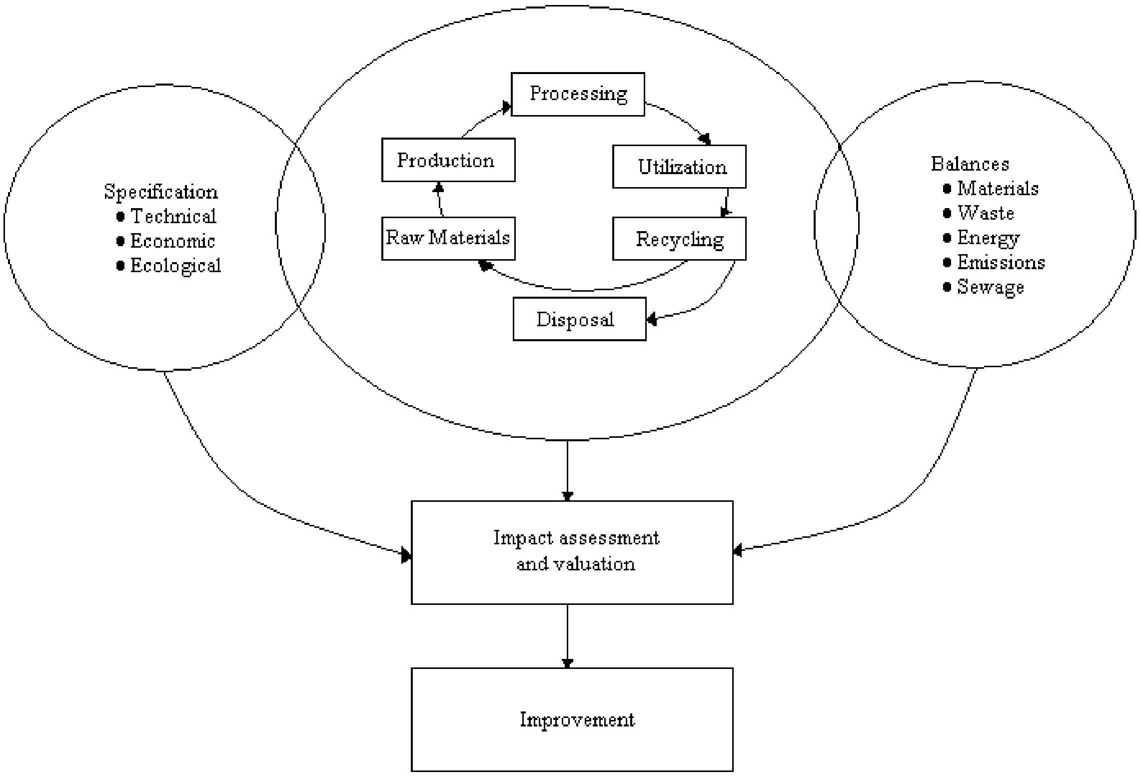


Figure 2: Factors considered in the life-cycle engineering approach.[4]

The impact analysis considers the effects on health and environmental issues along with the inputs and outputs in the LCA. The improvement analysis evaluates reductions, such as minimizing cost and harm to the environment. Using these four main concepts, an entire assessment can be accomplished.

Identifying a purpose, the goal definition and scope defines the “cradle to grave” cycle of manufactured products that will be examined. The ‘cradle’ of a product is the beginning of its life-cycle. For example, the raw materials for a pencil originate in the environment or forest with timber as seen at the top of Figure 3. The ‘grave’, also known as end of life (EOL), is the disposal of the product. For example, the EOL of a pencil is discarded into the environment as seen at the bottom of Figure 3. The remaining components of the LCA will flow smoothly and quickly if the scope is well defined with parameters on the life-cycle of the product.

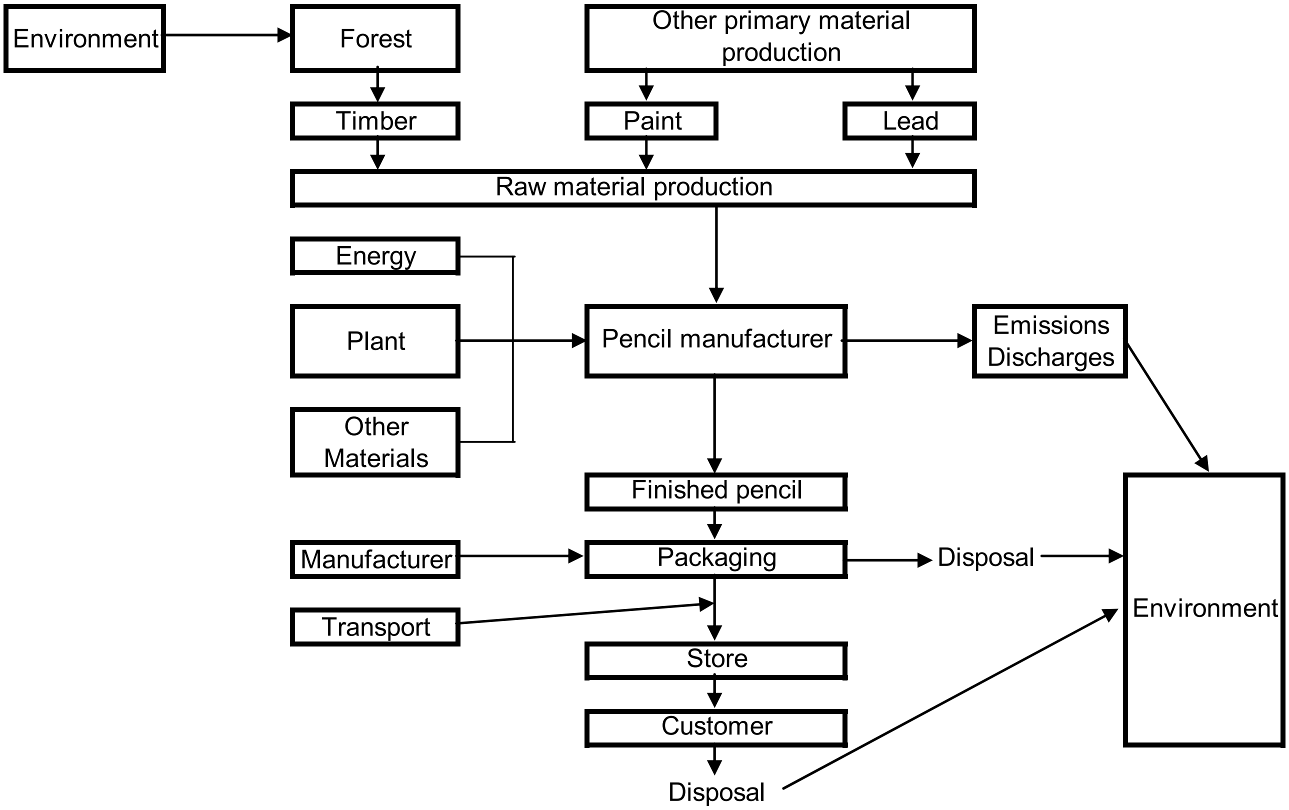


Figure 3: Simplified life-cycle analysis process for a pencil[4]

The LCI is the data collection process of an LCA, and is the least complicated if the boundaries of research are well defined in the goal definition and scope. Complications still occur with products that are recyclable and thus do not have a traditional end of life. The problem is uniquely dealt with based on the individual LCA and the discretion of the researcher.

The last two components of the LCA are important due to health and environmental conclusions that are generated. The impact analysis is strenuous because of the complications inherent in the interpretation of data. Special LCI/LCA software has been developed to complete the complex analysis required for an LCA. In this project, GaBi 4 software was selected to develop LCI/LCA models for each of the products.[1] The model analyzes the health and environmental concerns associated with each product. The final component of the LCA is the improvement analysis, suggested improvements in the manufacturing practices to reduce health and environmental impacts.

In an LCA, proving that one product or process is superior to the other is difficult. The parameters of one process are seldom comparable with another and cannot be simplified to the same extent when using different materials. The most important aspect of an LCA is that it can improve the specific process used by the manufacturer to make the product less detrimental to the environment. An LCA can make the consumer of a product more informed on which manufacturer has a more efficient process, allowing a personal choice on which vendor to employ. Finally, the LCA process has encouraged companies to be more willing to disclose environmental data to their consumers and environmental consulting firms.

DEVELOPMENT OF THE MODEL

The research in this paper uses software and materials databases in GaBi version 4.2 developed by PE Europe GmbH and IKP University of Stuttgart.[1] This product is a commercial LCA modeling program used to tabulate data, produce flow diagrams, and output possible environmental impact statistics. In conjunction with an LCA, this environmental data assists the researcher in greenhouse gas accounting, life-cycle engineering, and environmental design. The LCA process benefits engineers by providing a useful tool to aid in the design of more environmentally friendly products. This software was selected because of its frequent use for modeling manufacturing processes, including those in the steel industry.

One can either use measured inputs or world wide industry averages contained in GaBi 4 databases to model the manufacturing process. Figure 4 is an example of a "cradle to grave" LCA project for steelmaking used to describe the GaBi 4 software program capabilities.[1]

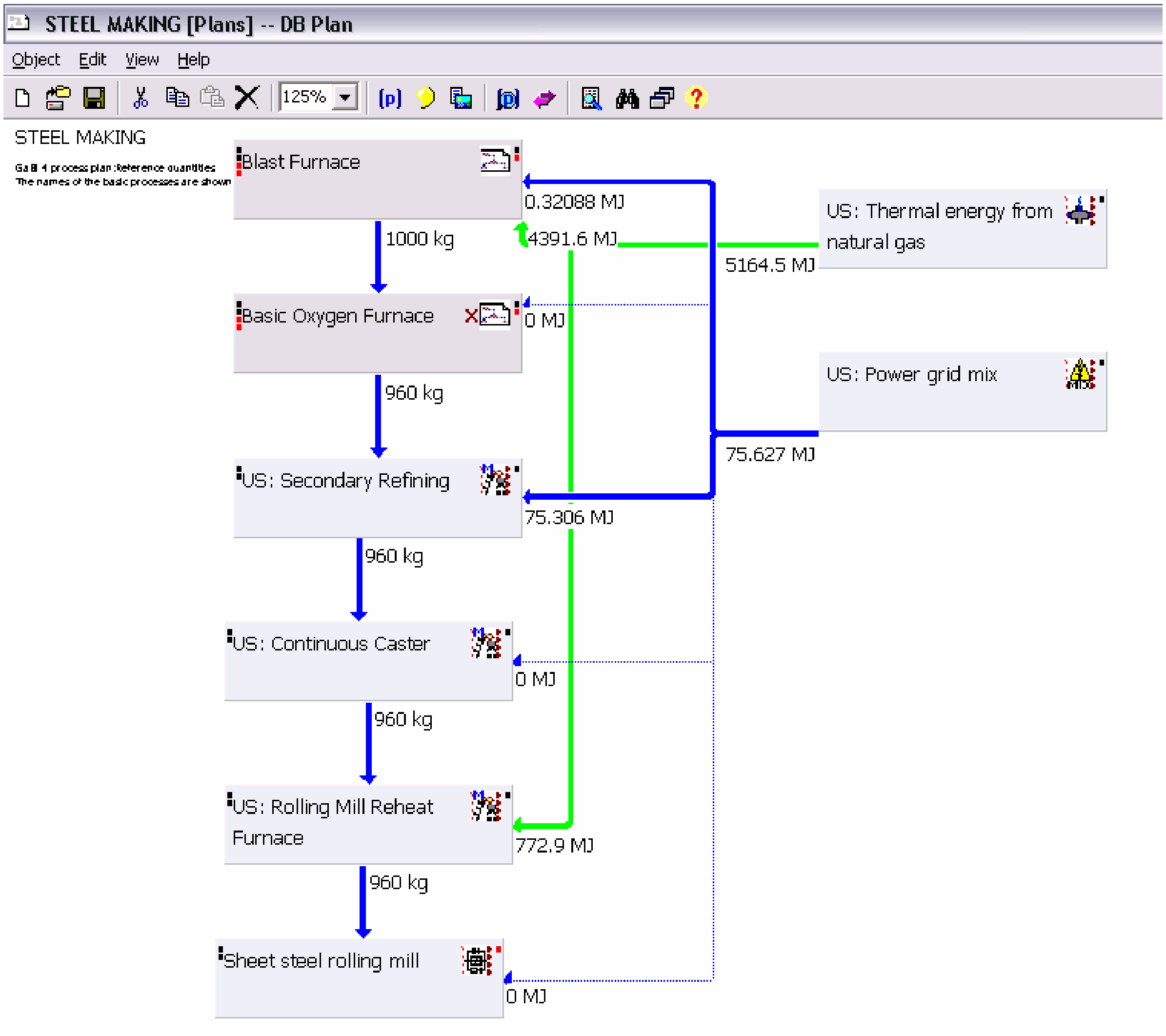
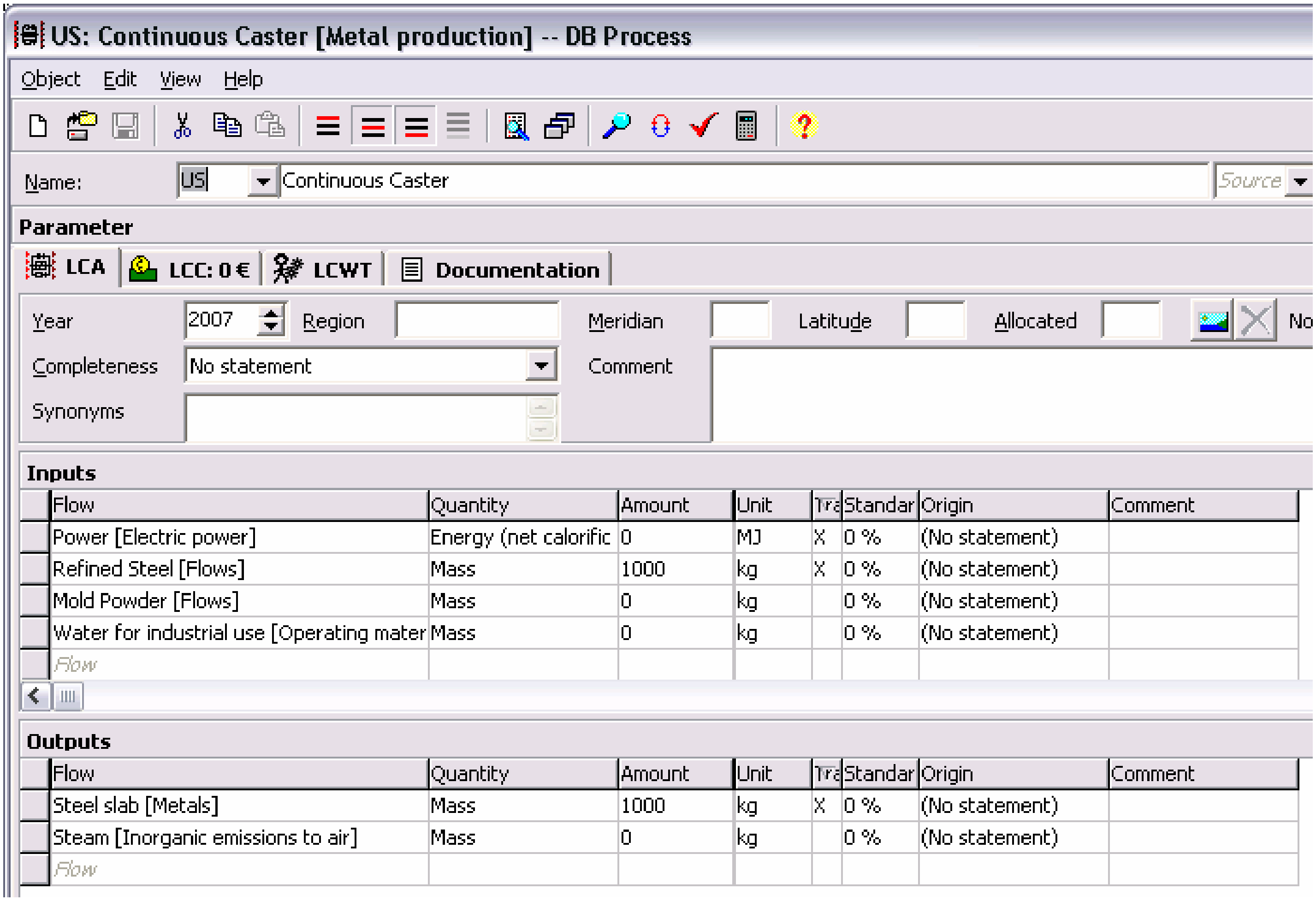


Figure 4: Steelmaking flow process from GaBi 4 model.

This is an example of a flow process made in the GaBi 4 software program and showcases the production model in which there are multiple production units: blast furnace, basic oxygen furnace, secondary refining, continuous caster, rolling mill reheat furnace and sheet steel rolling mill. Within each of these blocks representing a production unit is the acquired LCI data. For example, the continuous caster receives a flow from the secondary steel making process and exports material to the rolling mill reheat furnace. The flow lines show the quantity imported and exported by the numbers beside the lines. The continuous caster detail window, shown in Figure 5, contains a description of materials consumed and emissions produced during production.

The creation of the process models like the one illustrated in Figure 5 can be as simple or complicated as the user desires. These models can be built as simple input/output models like Figure 5, or can be made more complicated with the addition of process parameters. These parameters are particularly useful when accounting for vehicle transportation. The parameter can be modified to reflect changes in fuel consumption as the weight of the vehicle's load increases, along with the distance traveled by the vehicle. There are many possible inputs for each process, including many types of raw materials, electrical power, thermal energy derived from natural gas, coal, and other sources. These inputs, or flows, can be obtained from existing GaBi databases or created by the user. In the figure below, the refined steel and mold powder flows were created by the FeMET groups for use in the steelmaking process tree and the other inputs and outputs already existed in GaBi. The process window allows the user to customize many features of the flows shown in Figure 5. GaBi 4 allows for the modification of the quantity of the material flow, along with the specified units, the origin of the material, and whether the material is tracked by the GaBi 4 program.



US: Continuous Caster [Metal production] -- DB Process

Name: US Continuous Caster

Parameter

Year 2007

Region

Meridian

Latitude

Allocated

Completeness No statement

Comment

Synonyms

Inputs

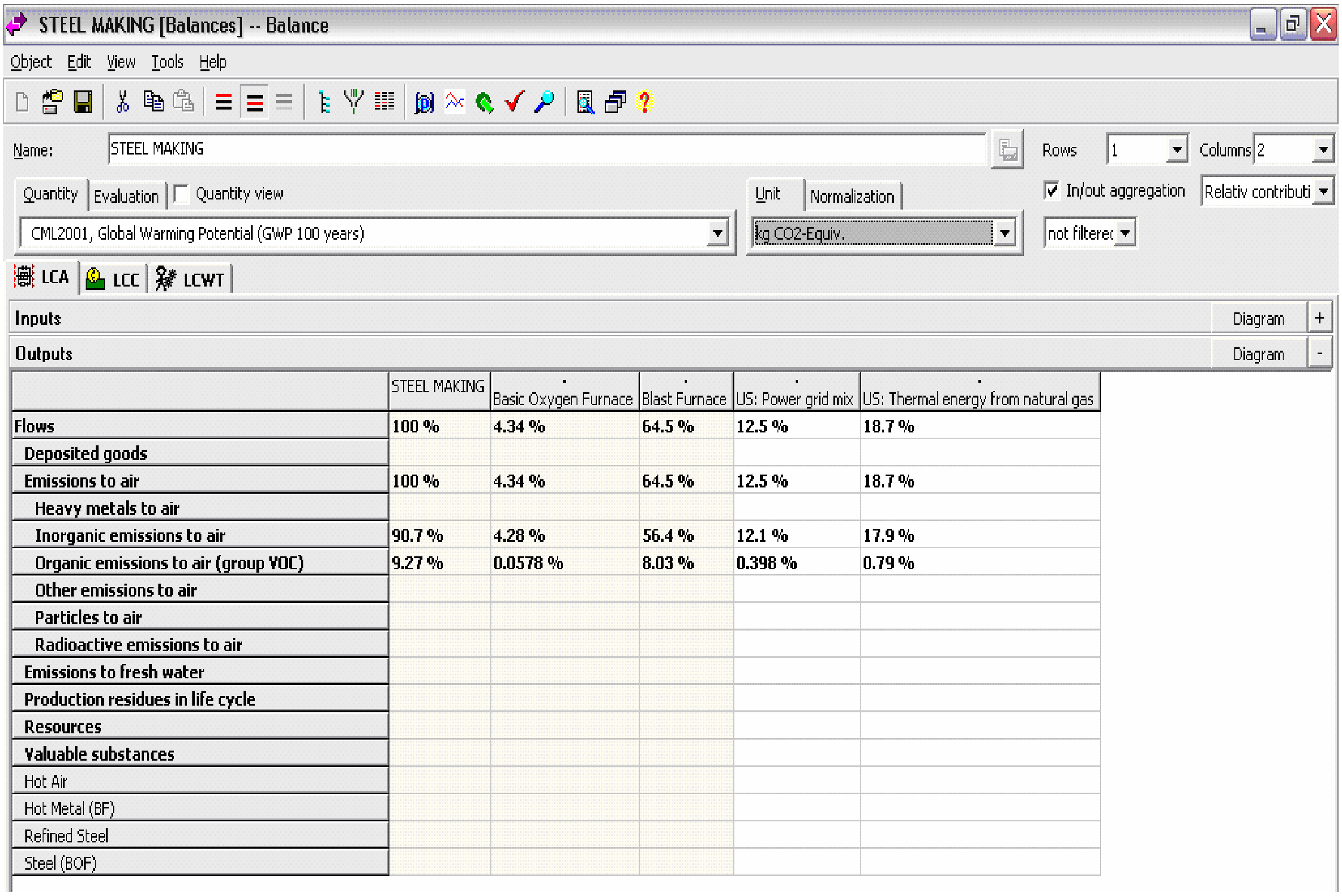
Flow	Quantity	Amount	Unit	Tra	Standar	Origin	Comment
Power [Electric power]	Energy (net calorific	0	MJ	X	0 %	(No statement)	
Refined Steel [Flows]	Mass	1000	kg	X	0 %	(No statement)	
Mold Powder [Flows]	Mass	0	kg		0 %	(No statement)	
Water for industrial use [Operating mater	Mass	0	kg		0 %	(No statement)	
Flow							

Outputs

Flow	Quantity	Amount	Unit	Tra	Standar	Origin	Comment
Steel slab [Metals]	Mass	1000	kg	X	0 %	(No statement)	
Steam [Inorganic emissions to air]	Mass	0	kg		0 %	(No statement)	
Flow							

Figure 5: Detail of continuous caster from GaBi 4 software.

LCA/LCI has become a valuable tool to evaluate the environmental foot print of a particular industry. With the continued focus on sustainability in the steel industry, LCA/LCI shows potential for keeping companies competitive while reducing their overall environmental impact. A software package like GaBi 4 demonstrates this and allows for continued studies to be performed concerning manufacturing processes. These programs generate many reports that help evaluate the environmental impact. For example, Figure 6 illustrates the global warming potential of steelmaking as modeled in the paper. The UMR senior design groups will use GaBi to perform an analysis of different materials as described in the future research section.



Name: STEEL MAKING

Rows 1 Columns 2

☐ Quantity view

☑ In/out aggregation

Relativ contributi

CML2001, Global Warming Potential (GWP 100 years)

kg CO2-Equiv.

not filterec

Inputs

Outputs

	STEEL MAKING	Basic Oxygen Furnace	Blast Furnace	US: Power grid mix	US: Thermal energy from natural gas
Flows	**100 %**	**4.34 %**	**64.5 %**	**12.5 %**	**18.7 %**
Deposited goods					
Emissions to air	**100 %**	**4.34 %**	**64.5 %**	**12.5 %**	**18.7 %**
Heavy metals to air					
Inorganic emissions to air	**90.7 %**	**4.28 %**	**56.4 %**	**12.1 %**	**17.9 %**
Organic emissions to air (group VOC)	**9.27 %**	**0.0578 %**	**8.03 %**	**0.398 %**	**0.79 %**
Other emissions to air					
Particles to air					
Radioactive emissions to air					
Emissions to fresh water					
Production residues in life cycle					
Resources					
Valuable substances					
Hot Air					
Hot Metal (BF)					
Refined Steel					
Steel (BOF)					

Figure 6: Detail report of life-cycle analysis from GaBi 4 software.

FUTURE RESEARCH

The purpose of the FeMET design grant project is to examine the environmental burden associated with the production of products using various materials. The four FeMET design groups are each studying products made from steel and comparing the life cycle environmental impact with similar components made from alternative materials.

Each of the four groups are using GaBi 4 software for their LCA modeling similar to the illustration in the previous section. These studies will look primarily at greenhouse gas production, but will also include a comprehensive waste and energy usage analysis. Modeling and data analysis in GaBi 4 will allow for a comparison of the environmental impact of each of these products. This analysis will help point to areas or processes in which the industries can improve their environmental performance. The following sections outline the project that is in progress. Final results should be available in late 2007.

Steel structural members versus pre-stressed concrete in highway bridges

An examination of the environmental effects of the construction of highway bridges using either structural steel or reinforced structural concrete as the primary load bearing material will be performed. The manufacture of concrete structural shapes will be a focus of research over the next several months. Numerous inputs involved with the production of both materials will be entered into GaBi 4 and analyzed in the LCA similar to the study performed by Guggemos.[6] Both of these production processes consume large amounts of electricity and carbonaceous fuels, thus producing significant amounts of greenhouse gases. These emissions will all be accounted for by GaBi 4 during the analysis phase.

Steering knuckles for automobiles from cast iron, cast aluminum and forged steel

The manufacturing process of three automotive steering knuckles will be compared for the LCA. The three different materials for the steering knuckles are cast aluminum, cast iron, and forged steel. In order to eliminate variables and make the report more concise, the

LCA study of the automotive steering knuckles has set parameters and boundaries. The scope of this report will be "cradle-to-grave" of the steering knuckles. The LCA will begin with a cast part or steel billet assuming the data is available in GaBi 4 software and it will end with the steering knuckles being transported to a secondary process or to a landfill. During the use phase, the environmental impact of the steering knuckles will differ only by the effect of weight differences as the vehicle life will be assumed to be the same for each part and the parts will not fail during their life. The overall goal was to determine the environmental impact of the inputs and emissions, mainly green house gases, due to the production of the three different steering knuckles.

Steel roofing versus standard asphalt shingles in residential construction

Steel shingles versus asphalt shingles in residential construction will be analyzed through an LCA. This research will determine which material produces a lower environmental burden with respect to production, the products' useful life, and recyclability. This analysis will be performed by assuming the steel used is steel sheet electroplated with zinc to a thickness of 0.01 mm on both sides of the sheet and the asphalt is Bitumen, a European alternative for asphalt from GaBi 4. Shingle manufacturers are assisting with data from their process of painting and stamping out the steel shingles and rolling asphalt into shingles.

Steel cans versus plastic frozen food containers

An LCA is being performed to compare greenhouse gas emissions from the production, use, and disposal of steel cans versus plastic bags used for food storage. It is assumed that the plastic bags will go to a landfill after disposal as well as a percentage of steel cans while the remainder of cans will be taken to recycling. There are multiple ways to manufacture steel cans and plastic bags; however, to keep this study concise only one process for each product will be studied. The average energy and fuel consumption for each process will be used in the GaBi 4 software.

SUMMARY

LCA is a viable tool for assessing environmental impacts for a product although many complications frequently arise due to the intricacies of the modeled process. The main components of environmental impacts can be identified by considering the different phases of life for the part. Companies can then proceed to correct any identified issues. Finally, LCAs can be used in comparison studies to evaluate which component is more environmentally friendly, which is one of the main goals of this project. Final results from this study are expected in late 2007 and will be the subject of additional publications.

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REFERENCES

1. PE International. GaBi Software Product Sustainability. 23 October 2006. <http://www.pe-international.com/index.php?id=1159>
2. J.R. Davis, ed. Metals Handbook Desk Edition 2nd Ed. 1997: 137.
3. International Standards Organization. "Environmental Management." 22 August 2006. 28 January 2007 <www.iso.org/iso/en/iso9000-14000/understand/inbrief.html>
4. J.R. Davis, ed. Metals Handbook Desk Edition 2nd Ed. 1997: 1198-1199.
5. Srinivas, Hari. "Life cycle analysis and assessment." The Global Development Research Center. 1 November 2007 <www.gdrc.org/uem/lca/life-cycle.html>
6. Guggemos, A. Comparison of Environmental Effects of Steel- and Concrete-Framed Buildings. Journal of Infrastructure Systems. 2005. 94-101.