COMPARING SUSTAINABILITY OF STEEL AND WOOD STUDS THROUGH LIFE-CYCLE STRESSOR-EFFECTS ASSESSMENT (LCSEA)

Gregory L. Crawford
Steel Recycling Institute

Abstract

Sustainability is the ultimate environmental claim for green marketing, as exemplified by light gauge steel studs and wood studs for residential construction. Comparing sustainability is challenging because it eludes precise definition and these two materials are vastly different in origin, service, and ultimate fate.

Sustainability may be claimed through life cycle inventory (LCI) or life cycle assessment (LCA) of inputs for energy and other resources, and outputs for waste and pollution. This typically ignores the structure's significant usage phase and its disposal or recycling phase. Moreover, it does not provide a framework for evaluating sustainability relative to the effects of material production and construction on our natural environment for future generations.

Now, however, the life-cycle stressor-effects assessment (LCSEA) methodology considers land use effects of material production on habitats and biodiversity (ecosystem disruption) as they impinge on sustainability. This paper discusses the final report of Scientific Certification Systems, Inc., "Analysis of Galvanized Steel Production Suitable for Residential Construction Based on Life-Cycle Stressor-Effects Assessment: A U.S. Case Study".

Among its conclusions: the ecosystem disruption by steel production for residential steel studs is less than one percent of equivalent wood stud production. This demonstrates steel's contribution to sustainable construction for future generations.

1 INTRODUCTION

In today's competitive business world, environmental or "green" marketing claims are routinely made for products ranging from packaging to automobiles to buildings. Mono-dimensional green marketing claims, such as recycled content, are typically defined by established industry practices, subject to verification by government regulation or interested "watchdog" environmental organizations. However, "sustainability" has become arguably the ultimate green marketing claim. As a relatively new, more complex theme, it can have powerful implications for underpinning the future environmental marketing of steel. While its cachet extends beyond the narrow parameters of most other green marketing claims, sustainability requires careful definition and rationale to support its credible and effective use.

Steel is now well positioned to use sustainability for environmental marketing. For example, light gauge steel studs and wood studs for residential construction are two competing construction material products that both may claim sustainability for green marketing. Comparing their relative sustainability is challenging because the term itself eludes precise accepted definition and also these two construction products are vastly different in origin, service, and ultimate fate. With these differences, environmental marketing of steel requires the sustainability concept to be well understood and applied.

The theme of sustainability has been clarified though perspectives of renowned authors but intuitively it can be seen as the human actions of today that affect the natural environment of future generations. As addressed by *Steel in Sustainable Construction*, "Sustainable development strategies are being adopted by governments and forward-thinking companies around the world. Their aim is to ensure that our children have the same opportunities for growth and development that we currently enjoy."

What are the significant environmental benefits of steel that will help sustain "the future opportunities of our children" and how can they be measured? The science and art of environmental measurement have evolved in recent years to help show the way. In the production of basic materials as well as intermediate and final products, we know that life cycle inventory (LCI) and life cycle assessment (LCA) serve to document energy and other system inputs, as well as waste and pollution outputs.

In such studies, there are varied definitions of system boundaries and specific parameters of interest. These "cradle-to-gate" life cycle measurements typically ignore the subsequent "gate-to-grave" phase, that is, usage of materials and products over their service life and their ultimate disposal or recycling. Even using "cradle-to-grave", LCI and LCA still may not address material production and construction effects on the viable growth and development of future generations now expressed as "sustainability".

Indeed, LCI and LCA are missing a vital dimension, namely, the land use effects of material production on habitats and biodiversity (ecosystem disruption) as they impinge on sustainability. Now, life-cycle stressor-effects assessment (LCSEA) methodology by Dr. Stanley Rhodes and other practitioners with Scientific Certification Systems, Inc. provides a basis for such measurement. This heralding paper discusses selected aspects of the SCS report, "Analysis of Galvanized Steel Production Suitable for Residential Construction Based on Life-Cycle Stressor-Effects Assessment: A U.S. Case Study". The findings and perspectives of this study create a highly compelling green marketing imperative to position steel studs as being environmentally superior to wood studs. The marketing implications of this revelation are enormous as steel strategies can be developed with new confidence and authority.

Indeed, this new work now allows steel marketing managers to capture salient environmental lessons and translate them into new value for steel and the construction community. The context of measuring the sustainability of steel studs versus wood studs has been fundamentally redefined in steel's favor over those selected claims made historically by wood. Among the conclusions of this landmark study is that the ecosystem disruption by steel production for residential steel studs is less than one percent of equivalent wood stud production. This profound statistic gives new understanding and support to the reduced environmental impact from steel studs versus wood studs. The SCS study conclusively demonstrates steel's contribution to sustainable construction for future generations and establishes the foundation for highly credible green marketing claims. It is incumbent upon the steel industry to use the supporting definition and rationale of this study to its fullest extent for communicating the long term environmental benefits of steel studs and other steel construction products, to include sustainability.

2 APPLYING LCSEA TO RESIDENTIAL FRAMING

2.1 Background

In recent years, "…Scientific Certification Systems (SCI) has worked closely with the North American steel industry in its efforts to understand and evaluate the science and potential applications of life-cycle assessment (LCA). The steel industry's interest in this methodology has been driven by customer demands, competitive considerations, and by an internal drive for improvement analysis."

Examining these drivers in reverse order, LCA can be a powerful tool for *improvement analysis*, identifying and evaluating the economic and environmental usage of raw materials, including scrap resources. This level of study allows the steel industry to reduce waste and even strive toward "zero waste", a recent environmental imperative that complements sustainability as it gains momentum.

C*ompetitive considerations* can be a double-edged sword. Wood and steel have vastly different physical properties and origins, being organic and inorganic respectively. Wood as an industry is an entrenched competitor in North America for residential framing construction and makes strong green marketing claims. Not altogether facetiously, wood is "green" since it comes from trees, which are green, literally. More rigorously, however, wood purports to be sustainable, being grown from nature, requiring less energy and other resource inputs, as documented through LCA. If these claims were not enough, some wood claims also accent certain features of steel as negatives, like embodied energy and thermal conductance. Wood often promotes itself as "renewable" against a projected steel image of finite, diminishing resources. "Green" claims from the wood industry, positive and negative; require responsible, credible responses from the steel industry that draw upon broader LCA principles.

Whether architect or building owner, the c*ustomer demands* enhanced environmental achievement among selected building materials, including improved energy and other factors of performance within total building systems. These are increasingly driven by internal company goals and external impetus from government and professional organizations, such as the U.S. Green Building Council and the National Association of Home Builders. For example, because of such pressures, more architects and other steel industry customers want to know steel's recycled content. In response to this issue, detailed information is now available on the Steel Recycling Institute web site at www.recycle-steel.org.

However, other environmental questions are sometimes not asked about steel because their anticipated responses have been conditioned over time by wood industry commentary, especially within some of the imposed boundaries of LCI and LCA. These unasked questions surround the very subjects introduced above, namely, embodied energy, thermal conductivity, and finite resources. Thus, traditional LCA has been a constraint for the steel industry since the wood industry has been allowed to selectively define the environmental playing field for its own advantage by focusing on parameters that cast wood in a favourable light.

Negative parameters for wood, such as termites, combustibility, and poor indoor air quality from off-gassing of engineered wood products, never seem to arise. At the same time, the many environmental benefits of steel are cloaked, such as its durability, which uses fewer resources over its long life. The most telling environmental detriment of wood has been its potential for permanent habitat destruction and its effect on eco-diversity. This Achilles' heel of wood may have successfully avoided the arrows of steel in the past, but it has certainly not escaped the attention of the environmental community that has been successful in blocking the harvesting of old-growth timber.

To provide a more balanced and complete view of the relative environmental impact of steel studs versus wood studs, the life-cycle stressor-effects assessment (LCSEA) methodology was selected for this new comprehensive, authoritative study, as developed and practiced by Scientific Certification Systems, Inc. This paper alone cannot provide the reader with an in-depth knowledge of the subject LCSEA study. LCA practitioners are invited to review and confirm the details of the actual study itself. This paper instead attempts to provide an overview of the study, coupled with observations that may assist the steel marketing manager in promoting new, thoughtful environmental marketing of steel.

2.2 Launch and Completion

Scientific Certification Systems, Inc., Oakland, California, USA, was engaged by the Steel Recycling Institute, the American Iron and Steel Institute, and the U.S. Steel Group of USX to conduct the subject study. The primary goal of this five-phase SCS study, launched in September 1996, was a cradle-to-gate LCSEA of the steel produced at the U.S. Steel Mon Valley Works, West Mifflin, Pennsylvania, USA, from raw material extraction to product manufacturing.

This study, less the fifth phase, was completed in January 2000, following field investigation, report preparation, peer review, supplementary investigation, and report completion. Phase 1 was LCI of North American steel, site specific to the Mon Valley Works. Phase 2 was an ecosystem study of Mesabi Range mining, source of iron ore for this mill and other sites. Phase 3 was LCSEA of coke battery operations for this mill. Phase 4 was LCSEA for remaining unit operations of this mill. Phase 5 was completed for steel but wood industry participants declined to provide data that would allow certain quantitative comparisons between wood and steel in residential framing.

2.3 Calculation Methodology

As noted in the SCS study, the "…LCSEA methodology is consistent with the criteria described in ISO-14042, the international standard for life-cycle impact assessment (LCIA), including its provisions for comparative assertions." The methodology converts raw LCI data into environmentally relevant impact factors for an overall LCIA impact profile of products and materials. The key study indicators are extensive, including energy resource depletion, renewable resource depletion, mineral resource depletion, ecosystem disruption due to direct physical disturbance, emission loadings, and residual hazardous wastes. Modelling and other details of the LCSEA framework and protocols are available for the LCA practitioner and interested reader in the body and Appendix A of the complete SCS study.

2.4 Goals, Objectives, and Scope

Succinctly, "…the overall goal of the study was to determine the environmental relevance of the known material inputs and emissions from Mon Valley Works to establish an LCIA impact profile for hot-dipped galvanized steel." It was to support selected internal performance evaluation and decision-making objectives as well as certain external objectives, including communication of "…steel's actual environmental performance to key customers, stakeholders, and policy makers." The scope of the study was "cradle-to-gate", from the extraction of raw materials through the production of hot-dip galvanized sheet steel at the Mon Valley steel mill.

2.5 System Description

Major unit processes of the steel making system for making galvanized sheet steel, suitable for use in the production of residential framing materials, were incorporated into the study. It was assumed that all steel production would be AISI #1006 carbon steel, 22-26 gauge, in 60-inch wide coils. Briefly, the three following broad categories of unit processes are included: raw materials extraction and energy production, coke production, and galvanized steel production. Each category has extensive detail for their subordinate processes and all are interrelated into a total steel production system flow.

2.6 Functional Unit

A suitable common denominator was needed for the study to compare the environmental impact of steel studs and wood studs in a meaningful manner. A ton of steel studs, for example, is not directly comparable to a ton of wood studs. And, since steel studs are stronger than wood, and thus spaced further apart in construction, the total running feet of steel and wood studs respectively is not comparable either. The functional unit devised for comparison relates the number of new houses constructed annually in the United States to the annual production of steel from the Mon Valley mill. Demand for single-family houses is 1.3 million houses per year, which can be constructed with either wood studs or steel studs. For steel, this would require a theoretical 8 million metric tons of steel. The Mon Valley mill produces 2.31 million metric tons per year, or, enough for about 30 percent of 1.3 million houses, which becomes the functional unit. This allows comparison of the environmental inputs and outputs for steel and wood production. Although wood did not participate in the study, the land area eco-system disruption for wood production proved one hundredfold greater than steel for building an equivalent number of single-family homes, thus outweighing many other "green" considerations.

2.7 Allocation Protocols

Allocation protocols were established for certain byproducts of unit processes required to produce the theoretical annual 2.31 million metric tons of hot-dipped galvanized steel, including chemicals, slags, and methane. These protocols helped to scale, for example, coal and coke byproducts, on a percent basis to match the modeled level of Mon Valley steel production. While many byproducts are produced and refined for commercial utilization, slag and methane, as byproducts, proved insignificant and were not allocated. In order to model galvanizing of the entire 2.31 million metric tons of production, the hot-dip process was scaled upward on a linear basis for energy, materials, emissions, and wastes. Wastewater requirements were nonlinear but found to be within existing capacity.

2.8 Inventory Assumptions

Primary and secondary sources of data for inventory input and inventory output were established for the major unit processes in the steel production system, including raw materials extraction and energy production, coke production, and galvanized steel production. The raw materials were burdened with feedstock value and the resources, energy, emissions, and wastes corresponding to their extraction, refining, and transportation. It is noted that in the steel making system, the majority of electricity is self-generated from coke-oven gas and other byproducts. Energy balances were prepared for actual production and modeled production for steel making and galvanizing for these site specific locations.

2.9 Inventory Results

LCI data were calculated and aggregated for key raw material resources for all main unit processes for the theoretical 2.31 million metric tons of galvanized steel production. Designated sites included Clairton for coke, Mon Valley for steel and galvanizing production, Mesabi Range for iron ore, and West Virginia for coal, as well as other fuels and minerals for total system requirements. LCI data were similarly calculated and aggregated for key emissions to air and water and key solid wastes on a site specific basis. It is important to note for the steel making unit operations for this company that "…no *residual* hazardous wastes -- that is, untreatable wastes posing a potential risk -- remain in the system." The minor amounts of hazardous wastes are recycled internally or sold commercially.

2.10 Calculation of Impact Indicator Results

Calculating the results of impact indicators required several steps. Environmental effects known to be associated with steel making were compiled, based upon published literature and government records, selected databases, and designated experts in and outside the steel industry. Collection and analysis of inventory data involved confirmation of any significant activity in the key stressor-effects networks associated with the core unit processes, such as the water depletion stressor-effects network. Allocation protocols were established since emissions are often associated with more than one environmental mechanism.

2.11 Resource Depletion and Emission Characterization Factors

Within LCSEA methodology, "…conversion of inventory results into impact indicators involves the establishment and application of characterization factors that are used to quantitatively relate system stressors to actual environmental impact." For mineral, renewable, and energy resources, these are known as "resource depletion factors". For emissions, "stressor characterization factors" address their relative inherent potency while "environmental characterization factors" address relative thresholds of receiving environments in a given situation. Spreadsheets were prepared for major unit processes to show calculations for each significant impact indicator and the cumulative totals per year. For example, water resource depletion from coal and iron mining was measured, as well as energy resource depletion for fossil fuel resources. The "embodied energy" of the net storage of energy resources within steel was also estimated relative to fuel consumed. Other mineral resource depletion was measured, including zinc, aluminum, and ferro-manganese.

2.11 Ecosystem Disruption for Steel Stud Production

A unique and telling feature of LCSEA methodology is its provision for the meaningful measurement of large-scale habitat change. This may act as a surrogate measure of subsequent changes induced in biodiversity, according to the plant or animal life dependence on that habitat. Field surveys conducted for the study in the Mesabi Range for iron mining, West Virginia for coal mining, and Pennsylvania for coal, steel, and galvanizing production, provided habitat definition baselines for determining changes attributable to these human activities. Pristine and non-mined areas were surveyed for comparison to the abandoned or reclaimed mined areas and manufacturing locations. Detailed surveys included characterizations of natural vegetation, landscape patterns, and regional hydrology, as well as rare, threatened, and endangered species. Manufacturing locations were assumed to be permanent disturbances of habitat, while mining areas were considered one-time disturbances that reverted to natural states after operations ceased. The surveys quantified and organized specific terrestrial and aquatic habitat disruption attributable to the production of 2.31 million metric tons of steel.

2.12 Ecosystem Disruption for Wood Stud Production

The functional unit defined earlier in paragraph 2.6 establishes the common factor for calculating and comparing the ecosystem disruption for wood production equivalent to residential construction with 2.31 million metric tons of steel. The functional unit is 30 percent of 1.3 million single-family houses constructed annually in the United States. This quantity of wood studs translates into 20,000,000 hectares of wood production annually. Given the assumption of highly selective wood harvesting practices depleting only 3% of forest land each year, this massive area represents some 600,000 hectares of depletion. Comparable, measured habitat depletion for steel studs is only 4,707 hectares. LCSEA demonstrates **steel habitat depletion is less than one percent of wood habitat depletion!**

2.13 Air and Water Emissions

Data on air and water emissions were readily available since they are regulated by the Clean Air Act and Clean Water Act, respectively, which require routine collection and reports. Air emissions regulated under national ambient air quality standards include NOX, SOX, CO, ground level ozone, and particulates. The national emission standard for hazardous air pollutants includes soluble organics, benzene, hydrogen sulfide, toluene, and ethylbenzene. Regulated water emissions include particulates, heavy metals, benzene, toluene, cyanides, organics, ions, nutrients, and bacteria. Water emission loadings were accordingly derived from discharge monitoring reports under the National Pollutant Discharge Elimination System.

2.14 Emission Loading Factors

As noted in the study, "The manufacture of steel creates both air and water emissions. These stressors are associated with a variety of potential effects on human health and the environment." Under the LCSEA methodology, emission loading indicator results are calculated by considering inventory data and the respective stressor characterization factor and environmental characterization factor. Air emission loadings included greenhouse gas, acidification, ground level ozone, ozone depleting chemicals, hazardous chemicals (air). Water emission loading included eutrophication chemicals (water) from nitrogen compounds and phosphate, and aquatic toxicity.

2.15 Findings

Prior studies have quantified material input and energy flows as well as emission and waste streams for steel. However, comparing such inventory data for steel directly to aluminum or wood creates confusion on its actual environmental significance. Such worst-case, life-cycle impact assessment models tend to simply aggregate data while ignoring their environmental relevance. This LCSEA study is able to show environmental impact of steel production according to established indicator categories. The functional unit defined under LCSEA using a scale of annual production provides for material comparisons that have much greater environmental relevance. The energy depletion component of this study does not take credit for recycling although it represents a significant energy savings. However, the steel depletion component appropriately credits current recycling and the future recycling that will be afforded by the standing stock of steel products, such as existing office buildings. The study found that the ecosystem disruption of steel was minor with no key species affected. While the study found that the greenhouse gas loading of steel could be reduced, it positively noted that acidification and ground level ozone were 70-75% less than previous studies suggested. The air loadings were found to be within limits, below de minimus risk. The study reports that eutrophication potential exists but its environmental effect is unknown. Significantly, there were no modeled eco-toxicity effluents over standard and no values reported for residual hazardous waste.

3 CONCLUSIONS

LCSEA provides a powerful, credible environmental comparison of steel studs to wood studs. The hundredfold greater land area ecosystem disruption of wood production over steel production for an equivalent number of residential units is a compelling cornerstone for steel's rightful claim to sustainable construction as it provides for the natural environment of future generations.

Although the wood industry has not supported completion of the fifth phase of this study, the baseline is complete for steel and remains available should the wood industry accept the challenge. While these LCSEA results are specific to the U.S. Steel sites and processes, the methodology is applicable for adaptation to other steel manufacturers.

Meanwhile, the LCSEA study by the Scientific Certification Systems, Inc., provides an authoritative and confident basis for steel marketing managers to generate "green" marketing claims for steel studs. Within the steel industry, marketing managers, together with LCA practitioners, must internally educate the sales force on the basic environmental messages found in the report. All concerned need to be armed with facts that overcome negative claims by the wood industry. For example, the oft-lambasted embodied energy of steel should be seen in the context of durability and energy savings through recycling. And, the issue of thermal conductivity should be addressed with steel's contribution to a tighter building envelope together with the technical information for incorporating thermal breaks.

Finally, as environmental leaders and influencers throughout business and government become more knowledgeable of steel's contribution to sustainable construction, their ensuing support will benefit the steel industry, civilization's built environment, and our world's remaining natural environment.

4 REFERENCES

Rhodes, Stanley, *et al*, "Analysis of Galvanized Steel Production Suitable for Residential Construction Based on Life-Cycle Stressor-Effects Assessment: A U.S. Case Study", Scientific Certification Systems, Inc., Oakland, California, USA, January, 2000.