A Life Cycle Analysis of ResinDek® Panels and Concrete Decking in the Construction of a Commercial Mezzanine

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1 Introduction

1.1 Project Background

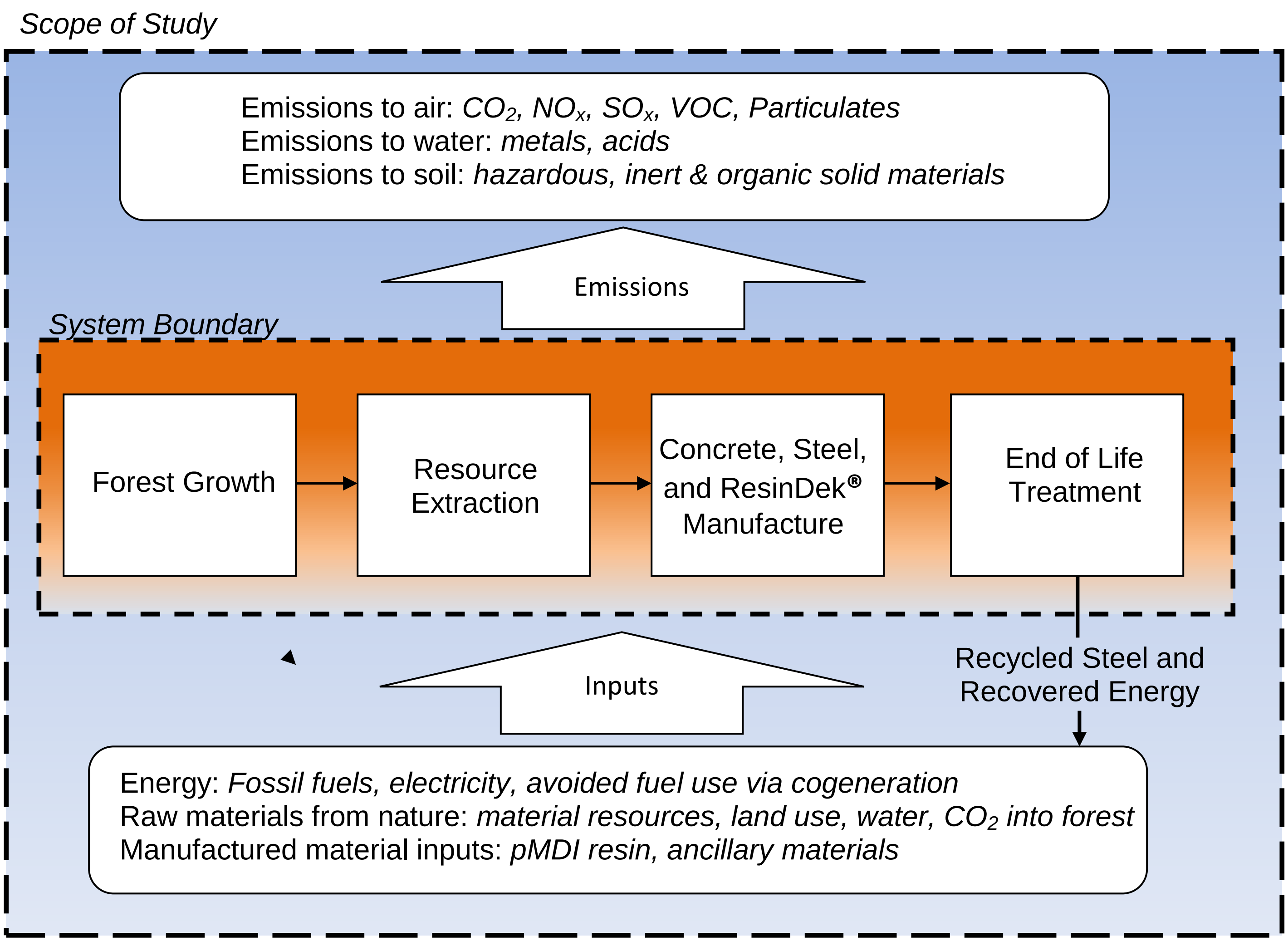
Cornerstone Specialty Wood Products LLC. commissioned Coldstream Consulting to compare and contrast the life cycle environmental impacts of ResinDek® and concrete in the construction of a 50,000 square foot mezzanine system. To this end, Coldstream has conducted a life cycle assessment of the two systems described in this report.

Life cycle assessment (LCA) for construction products is a systematic approach to quantify the environmental impacts associated with a product through its entire life – from initial extraction of the raw materials to manufacturing, use, and eventual disposal or recycling. The key component within the process of LCA is a life cycle inventory (LCI). An LCI tracks all the resource and energy flows from the environment as well as the emissions to air, water and solids to the environment for a product over its life. Depending on the goal and scope of the study, these data may be collected first-hand from manufacturing processes (primary data), or they may be based on information drawn from existing LCI databases (secondary data).

This LCA has taken a streamlined approach in that secondary data from the USLCI database was used to model the major components of each system, with specific material composition of ResinDek® incorporated to customize this dataset. The quantity take-offs provided by Cornerstone were incorporated into the LCA software package SimaPro which links primary process data and secondary background processes (e.g., electricity generation and delivery) to generate a complete life cycle inventory. With the inventory complete, the next step in the LCA process was to prepare a life cycle impact assessment (LCIA) of the modeled systems to determine the environmental burden of the various input and output flows throughout the product life cycle (e.g., climate change, ozone depletion, etc).

1.2 Study Scope

The project's comparison basis is the cradle-to-grave life cycle effects of both products. The life cycle includes the extraction of raw materials, the manufacture of steel, concrete, and the fiberboard product ResinDek®, its service life, and its treatment at the end of its service life. The end of life processing includes the recycling of steel and landfilling of the remaining materials. Additionally, the life cycle of ResinDek® includes carbon sequestration as a credit in the LCI of that product.



* All transportation within and between unit processes is inside the system boundary

Figure 1: Scope and System Boundaries of Mezzanine LCA Study

2 Life Cycle Inventory

Cornerstone provided Coldstream with the material takeoff shown in Table 1 for the construction of the two mezzanine systems. There are common elements between the two systems including the concrete used in the footings, the steel scaffolding used to support the decking, and a portion of the decking system that is made from galvanized steel as opposed to concrete or ResinDek®.

Table 1: Material Inputs for Concrete and ResinDek® Mezzanine Systems

COMMON ELEMENTS		
Concrete in Footings	158	yd3
Steel in Structure	320,000	lb
Steel Decking	85,000	lb
RESINDEK® SYSTEM		
MDF in Decking Surface	155,000	lb
CONCRETE SYSTEM		
Additional Steel in Structure	50,000	lb
Additional Concrete in Footings	41	yd3
Concrete in Decking Surface	463	yd3

To highlight the differences between the two systems, the common elements have been excluded from the system boundaries of both product systems. The comparison basis is 50,000 square foot ResinDek® decking surface and the materials required to produce a comparable concrete system. In addition to the concrete in the decking, the concrete decking is heavier than ResinDek® and requires additional steel and concrete in the footings.

2.1 ResinDek® System

The ResinDek® system requires 50,000 sqft of ResinDek® product with a density of 3.1 lb/sqft. The primary data source for modeling ResinDek® manufacture was the CORRIM

Profile for MDF[1] in the USLCI database. The CORRIM process data was modified by the material inputs specific to ResinDek® that included the specific breakdown of wood fiber, pMDI resin, and wax. The pMDI resin was modeled based on the profile for its production published in the USLCI database, modified with feedstock energy use from Plastics Europe[2].

2.2 Concrete System

The concrete decking system requires 50,000 lb of additional steel to support the increased weight of the concrete over the ResinDek® system. This additional steel is modeled as hot rolled wide flange sections based on data from the USLCI database.

The concrete system also requires 41 cubic yards of additional concrete in the footings in addition to the 463 cubic yards required for the decking surface. The construction of the mezzanine typically employs either 3000 PSI (20 MPa) or 4000 PSI (30MPa) strength concrete which is composed of the mix designs in Table 2.

Table 2: Material Inputs for 3000 PSI (20 MPa) and 4000 PSI (30MPa) Concrete

MATERIAL	AMOUNT 3000 PSI (lb/yd^3)	AMOUNT 4000 PSI (lb/yd^3)		TOTAL AMOUNT 3000 PSI ($lb/ 504\ yd^3$)	TOTAL AMOUNT 4000 PSI ($lb/ 504\ yd^3$)
Portland Cement	367	538		184,968	270,994
Fly Ash	37	52		18,648	26,335
Coarse Aggregate	1,701	1838		857,304	926,537
Fine Aggregate	1,559	1217		785,736	613,347
Water	270	270		136,080	135,922
Total	**3,934**	**3,915**		**1,982,736**	**1,973,134**

[1]CORRIM Phase II Final Report 2008: *Medium Density Fiberboard (MDF) - A Life-Cycle Inventory of Manufacturing Panels from Resource through Product*: http://www.corrim.org/pubs/reports/2010/phase2/Module_G.pdf

[2] The USLCI database profile for pMDI resin contains an error in the amount of oil used as feedstock as the mass balance of this profile as published does not balance. For 1 kg production, the value provided is 5.1 liters but should be 0.51 liters and was modified to this value as per the Plastics Europe document on pMDI resin: http://www.isopa.org/isopa/uploads/Documents/documents/eco_midi.pdf

The Portland cement component was modeled based on USLCI data, with aggregates and fly ash modeled based on unpublished research conducted by the ATHENA Institute.

2.3 Installation

The ResinDek® system requires less material to be transported to the construction site, but from a significantly further distance than steel and concrete. Concrete and steel are typically sourced locally, particularly the aggregates that are the primary mass components of that system.

Since no specific location was established for the installation of the mezzanine systems, generic transportation distances were assumed in developing the life cycle inventory. The concrete decking system inputs are typically available locally and were assumed to be sourced from 50 miles from the installation site. The ResinDek® product is assumed to come from 500 miles away. All transportation of materials is assumed as occurring on a diesel tractor trailer.

2.4 Commodity and Energy Background Data

Two secondary data sources were used to model the production of upstream materials and energy sources prior to their delivery and use by the manufacturers. Both databases were uploaded to SimaPro LCA modelling software.

USLCI: This database is the preeminent source of life cycle inventory data currently available in North America. The USLCI database contains energy production and delivery models for heat fuels, electricity generation, and transportation equipment. USLCI data is of recent vintage (within the last 5 years) and is publicly and freely available from www.nrel.gov/lci. This database also contains the latest CORRIM LCI data on US wood products, and specifically MDF production that was adapted in this analysis to model ResinDek®.

Plastics Europe: This resource was cited to confirm the error in the USLCI profile for pMDI resin and to correct the value for oil feedstock

2.5 Biogenic Carbon

Considering the forest as a supply system, with atmospheric carbon and solar energy as resources and trees as products, brings the flow of carbon into the system boundaries. Crediting the product system with the inflow of carbon dioxide means that the carbon released from burning wood co-products is not accounted in global warming impact. This crediting also means that the carbon sequestered in the product is accounted as a negative carbon emission. This convention is consistent with contemporary LCA methodology and internationally accepted standards like the Intergovernmental Panel on Climate Change's (IPCC) fourth assessment report[3] and the PAS 2050 standard[4].

[3] http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1

[4] http://shop.bsigroup.com/en/Browse-by-Sector/Energy--Utilities/PAS-2050/

3 Service Life and End of Life Treatment

Both systems are assumed to provide comparable service lives. Commercial mezzanine systems are constructed to serve specific requirements in a manufacturing facility. This means that their replacement is typically driven by changes in the requirements of a given manufacturer and not the degradation of the product as with many other construction products. Additionally, no specific maintenance is required for either system besides periodic cleaning, which is also driven by the specific requirements of the facility and is the same for the two systems. For these reasons, the service life and maintenance effects are outside the scope of this analysis.

At the end of the service life, several options exist for the treatment of the materials. The remainder of this chapter explores these options and how they affect the life cycle inventory of the two systems.

3.1 Reuse

At the end of the service life, the ResinDek® and much of the additional steel used in the structural portion may potentially be deconstructed and reassembled at a different facility. The reuse of materials requires no additional processing beyond the labor required to deconstruct and reconstruct the structure and the transportation of the materials between the two locations.

In the LCI accounting, this is modeled the same as extending the service life and essentially divides the cradle to gate manufacturing impacts between multiple life cycles; if reused the impacts attributable to each service life would be half of the original. It follows that assuming a shorter service life and/or lower potential for reuse of one assembly would directly increase its impacts relative to the other.

While the life cycle inventory and impacts of either system is directly proportional to the service life and number or service lives, it is uncertain whether reuse is likely in either case and may only serve to improve the relative performance of ResinDek® over concrete as the concrete decking may not be reused after it is set.

3.2 Recycling

The steel, concrete, and ResinDek® may also be recycled into new products after the service life. In the case of steel, the material is simply used as inputs into a new batch of virgin steel and used to manufacture new products. The concrete may be crushed and used to substitute for aggregate in new concrete products. The ResinDek® may be ground and the fibers reconstituted into new product.

In LCA accounting, recycling is modeled as preventing the manufacture of raw materials for which the recycled product substitutes, less any collection and reprocessing energy. While recycling the steel requires a small fraction of the energy as virgin steel, the potentially substituted aggregate and wood fibers requires similar processing energy as if the material came from a natural origin. For this reason, only the steel recycling is considered in the life cycle inventory as concrete and ResinDek® recycling would only serve to reduce resource use which was not accounted for in this LCA.

3.3 Landfill

In current practice, the most likely current fate of the ResinDek® and concrete is to the landfill at the end of their service lives. Both wood products and concrete are relatively inert materials and typically enter the municipal solid waste stream upon demolition. In the landfill, the concrete remains mostly intact while the wood products partially decompose into methane and carbon dioxide, a portion of which is captured and used to produce energy. The specific conversions of wood into landfill gas, its capture, and recovery for heat are provided in Appendix 1.

Similar to recycling being credited as a substitution for virgin material production, the energy recovered from the landfill gas system is assumed to substitute for fossil energy sources used as the marginal fuels in electricity production[5]. The substitution of coal and natural gas was assumed to occur at a ratio of 2:1 coal to natural gas. This ratio was used because coal-fired plants contribute 44.8 percent of the electric power generated in the United States compared to 24.2 percent for natural gas[6].

The landfill that receives the waste material is assumed to be located 25 miles from the installation site.

[5] Coal and natural gas are the marginal fuels in electricity production, meaning any production of electricity causes a net reduction in production from these sources as opposed to fixed assets like nuclear and hydroelectric power plants.

[6] http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html

3.4 Combustion with Energy Recovery

MDF may also be salvaged before entering the waste stream to be burned in an energy producing boiler. The diversion of wood from landfills is currently law in the European Union[7] and is likely to be more common by the time a mezzanine currently under construction reaches the end of its service life.

Diverting wood products from the landfill makes energy available that substitutes for fossil energy that would have otherwise been required to meet demand. This eliminates a one way conversion of fossil carbon to carbon dioxide in favor of a closed loop carbon cycle, in which the wood combustion mimics aerobic conditions of natural forest cycles.

According to the USLCI database, the fuels are assumed to have the following higher heating value (HHV), electricity yield, and subsequent greenhouse gas emissions[8]:

- Coal: 24.76 MJ/kg provides 2.27 kWh/kg and causes 1.08 kg CO2e/kWh.
- Natural gas: 38.74 MJ/m3 provides 3.33 kWh/m3 and causes 0.72 kg CO2e/kWh.
- Wood: 23.6 MJ/kg provides 2.17 kWh/kg and causes 0.89 kg CO2e/kWh.

Considering that the heat recovery is assumed to substitute for fuel use in electricity production, the fuel use per kWh was used to calculate the substitution effect to the LCI.

[7] European Union. Council directive 99/31/EC: http://europa.eu.int/comm/environment/waste/landfill_index.htm

[8] The heating value for wood fuel was not provided in the USLCI database but was established based on their models for electricity production and the relative fuel use required to produce 1 kWh electricity.

4 Life Cycle Impact Assessment

4.1 LCIA Methodology

The life cycle impact assessment utilized published characterization factors for four widely accepted mid-point impact categories[9] as well as primary energy demand. Characterization results are typically compiled using a reference emission flow and multipliers or factors to equate the effect on an equivalent basis to that of the reference emission flow – e.g., all greenhouse gases are reported on a mass basis using carbon dioxide as the equivalence greenhouse gas to arrive at an overall global warming potential effect.

- Global Warming Potential (kg CO_2 eq): The IPCC has made significant strides towards a uniformly accepted categorization of the greenhouse forcing potential of global warming agents. The 2007 version of their factors were incorporated in this impact assessment.

- Acidification Potential (H+ moles eq.): Acid rain causes increases in the alkalinity of soils and freshwater lakes that is measured in terms of the hydrogen ions. The TRACI characterization of acids relates substances to their corresponding contribution of hydrogen ions.

- Smog Potential (kg NO_x eq.): Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog. The TRACI characterization of smog precursors is based on their intensities relative to nitrogen oxides, the most prevalent smog sources.

- Eutrophication Potential (kg N eq.): Eutrophication is the affect of over-fertilization of soil and water ecosystems caused by atmospheric emissions. Algae blooms and fish depletion are symptoms of eutrophication. The TRACI characterization of eutrophication agents are based on their equivalence to nitrogen.

- Cumulative Energy Demand (MJ): Energy accounting is generally conducted to determine the total demand of a system on renewable and non-renewable sources. This convention is maintained here with totals given for each.

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[9] Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) is a midpoint-oriented LCIA methodology developed by the U.S. Environmental Protection Agency. http://www.epa.gov/ORD/NRMRL/std/sab/traci/

4.2 LCIA Results

All material effects were modeled in SimaPro and the results presented in Tables 3a, 3b, 4a, and 4b. A more detailed table of the impact assessment results are provided in Appendix 2.

Table 3a: LCIA Results for ResinDek® System – wood waste to landfill

Impact category	Unit	Total	Forest Sequestration	MDF	Transportation to Site and Landfill	End of Life
Global Warming	tonnes CO2 eq	**-42.10**	-119.87	57.70	5.52	14.55
Acidification	10^3 H+ moles eq	**28.72**		26.64	1.82	0.26
Smog	tonnes NOx eq	**0.22**		0.17	0.04	0.01
Eutrophication	kg N eq	**11.40**		9.65	1.75	0.00
Total Energy	GJ eq	**658.14**		738.44	75.57	-155.87
Non-renewable, fossil	GJ eq	**540.79**		622.19	74.94	-156.34
Non-renewable, nuclear	GJ eq	**1.69**		0.60	0.64	0.45
Total Renewable	GJ eq	**115.67**		115.66	0.00	0.01

Table 3b: LCIA Results for ResinDek® System – wood waste burned with energy recovery

Impact category	Unit	Total	Forest Sequestration	MDF	Transportation to Site and Boiler Site	Handling and Energy Recovery
Global Warming	tonnes CO2 eq	**-89.04**	-119.87	57.70	5.52	-32.39
Acidification	10^3 H+ moles eq	**28.72**		26.64	1.82	0.26
Smog	tonnes NOx eq	**0.22**		0.17	0.04	0.01
Eutrophication	kg N eq	**11.40**		9.65	1.75	0.00
Total Energy	GJ eq	**-714.67**		738.44	75.57	-1528.68
Non-renewable, fossil	GJ eq	**-832.02**		622.19	74.94	-1529.15
Non-renewable, nuclear	GJ eq	**1.69**		0.60	0.64	0.45
Total Renewable	GJ eq	**115.67**		115.66	0.00	0.01

Table 4a: LCIA Results for Concrete System, 3000 PSI Concrete Mix

Impact category	Unit	Total	Concrete Decking	Additional Steel and Concrete	Transportation to Site and Landfill	End of Life
Global Warming	tonnes CO2 eq	**138.86**	109.49	53.37	8.74	-32.75
Acidification	10^3 H+ moles eq	**43.24**	30.02	8.04	2.89	2.29
Smog	tonnes NOx eq	**0.53**	0.31	0.09	0.06	0.06
Eutrophication	kg N eq	**18.33**	13.37	3.96	2.77	-1.77
Total Energy	GJ eq	**968.52**	459.25	560.67	119.65	-171.04
Non-renewable, fossil	GJ eq	**962.15**	459.25	560.67	118.64	-176.41
Non-renewable, nuclear	GJ eq	**6.22**	0.00	0.00	1.01	5.21
Total Renewable	GJ eq	**0.15**	0.00	0.00	0.00	0.15

Table 4b: LCIA Results for Concrete System, 4000 PSI Concrete Mix

Impact category	Unit	Total	Concrete Decking	Additional Steel and Concrete	Transportation to Site and Landfill	End of Life
Global Warming	tonnes CO2 eq	**186.54**	153.29	57.25	8.74	-32.75
Acidification	10^3 H+ moles eq	**56.32**	42.03	9.10	2.89	2.29
Smog	tonnes NOx eq	**0.66**	0.44	0.10	0.06	0.06
Eutrophication	kg N eq	**24.15**	18.72	4.43	2.77	-1.77
Total Energy	GJ eq	**1168.49**	642.96	576.94	119.65	-171.04
Non-renewable, fossil	GJ eq	**1162.12**	642.96	576.94	118.64	-176.41
Non-renewable, nuclear	GJ eq	**6.22**	0.00	0.00	1.01	5.21
Total Renewable	GJ eq	**0.15**	0.00	0.00	0.00	0.15

The ResinDek® system causes less environmental impact in every impact category than the two concrete systems. The greatest benefits are recognized in the scenario in which the wood waste is burned for energy recovery at the end of the service life compared against the 4000 PSI concrete mix system. In addition to these savings, the ResinDek® product is not just carbon neutral, but is a **net carbon sink over its life cycle**. This means that more carbon is sequestered in the product than is emitted over the rest of the life cycle. If ResinDek® is burned for energy at the end of its life it is also a **net energy producer in addition to being a net carbon sink.** This means that the product makes available more energy at the end of its life than is consumed during the rest of the life cycle.

The relative impacts of the four scenarios normalized against the 4000 PSI concrete case are shown in Figure 2. To display the relative impacts for the various categories that employ different units of measurement, the highest contributor to each impact (4000 PSI concrete scenario) was set equal to 100%, with the three other cases shown relative to this value. For instance, the 3000 PSI case produces 74% of the global warming effect as the 4000 PSI, while the two ResinDek® scenarios cause 123% and 148% less respectively.

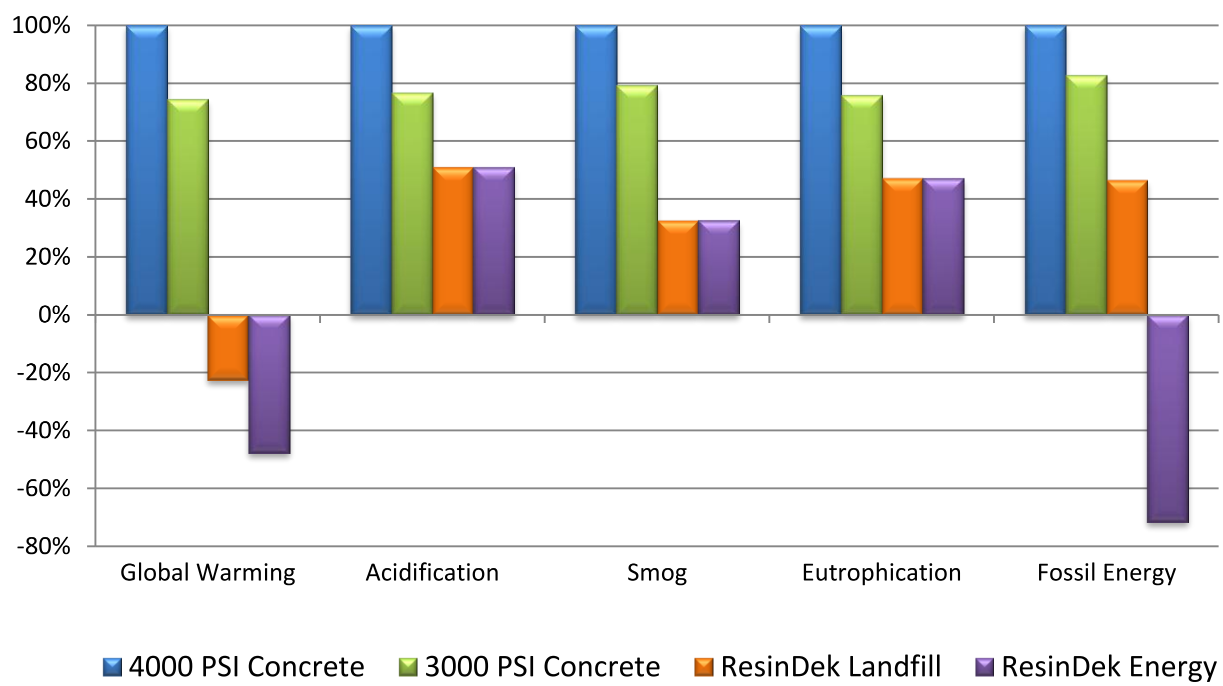

Figure 2: Life Cycle Impact Assessment Results – Normalized Against 4000 PSI Concrete Results

4000 PSI Comparisons: Compared against the 3000 PSI concrete mix system, the ResinDek system with energy recovery results in 276 tons less carbon dioxide equivalent emissions and 1.99 TJ less fossil energy than the concrete life cycle. The landfill results for the ResinDek system results in 229 tons less carbon dioxide equivalent emissions and 0.62 TJ less fossil energy use than concrete. In addition to global warming and fossil energy use reduction, both ResinDek® life cycles causes less acidification (27,594 moles H+ eq.), less smog (446 kg NOx eq.), and less eutrophication (12.75 kg N eq.).

To put these emissions reductions into perspective, let us consider the annual emissions of passenger cars in the United States. In the United States, the average passenger car produces 4.92 tons CO_2e of global warming impact[10]. This means that using ResinDek® over concrete in constructing a 50,000 square foot mezzanine is equivalent to taking **46.5 passenger cars off of the road for one year** if the wood is landfilled at the end of its service life, and **56.0 passenger cars if the wood is burned with energy recovery**.

3000 PSI Comparisons: Compared against the 3000 PSI concrete mix system, the ResinDek system with energy recovery results in 228 tons less carbon dioxide equivalent emissions and 1.68 TJ less fossil energy than the concrete life cycle. The landfill results for the ResinDek system results in 181 tons less carbon dioxide equivalent emissions and 0.42 TJ less fossil energy use than concrete. In addition to global warming and fossil energy use reduction, both ResinDek® life cycles causes less acidification (14,520 moles H+ eq.), less smog (310 kg NOx eq.), and less eutrophication (6.93 kg N eq.).

This means that using ResinDek® over concrete in constructing a 50,000 square foot mezzanine is equivalent to taking **36.7 cars off of the road for one year** if the wood is landfilled at the end of its service life, and **46.3 cars if the wood is burned with energy recovery**.

[10]Calculation methodology for GWP for cars from:
http://www.epa.gov/oms/climate/420f05004.htm
Updated car fuel efficiency data for 2008 from:
http://www.bts.gov/publications/national_transportation_statistics/html/table_04_23.html

Appendix 1: Landfill Dynamics

The following landfill model was developed in the peer reviewed journal article "Prospects for carbon-neutral housing: the influence of greater wood use on the carbon footprint of a single-family residence" authored by James Salazar and Jamie Meil of the ATHENA Institute. References for the numerous assumptions made in this model are provided in this journal article and are not reproduced in this document.

Modern landfills have rapidly adopted methane capture over the past 10 years, up from 15% in 1998 to 50% in 2008. Wood's lignin content and imperfect conditions for anaerobic microbacteria that exist in landfills cause the majority of carbon in wood to remain intact while 24% is converted equally to carbon dioxide and methane. A portion of the methane that is produced, about 10% is oxidized within the landfill before it reaches the surface. Thus, the composition of landfill gas is 55% CO2, 45% CH4 (on a molar basis) when it reaches the surface.

Landfill gas capture systems operate at varying efficiencies. The USEPA estimates that the average landfill gas capture technology results in the capture of about 75% of emitted landfill gas although one empirical study suggests a somewhat lower capture of 35%. Of the 75% that is captured, only 70% is combusted in an industrial turbine to produce electricity. The remaining 30% is flared to eliminate methane but without energy recovery. The LFG that is utilized as fuel has a heating value of 15.8 MJ/kg and reduces demand for equivalent amounts of coal and natural gas that would have otherwise been consumed to produce electricity.

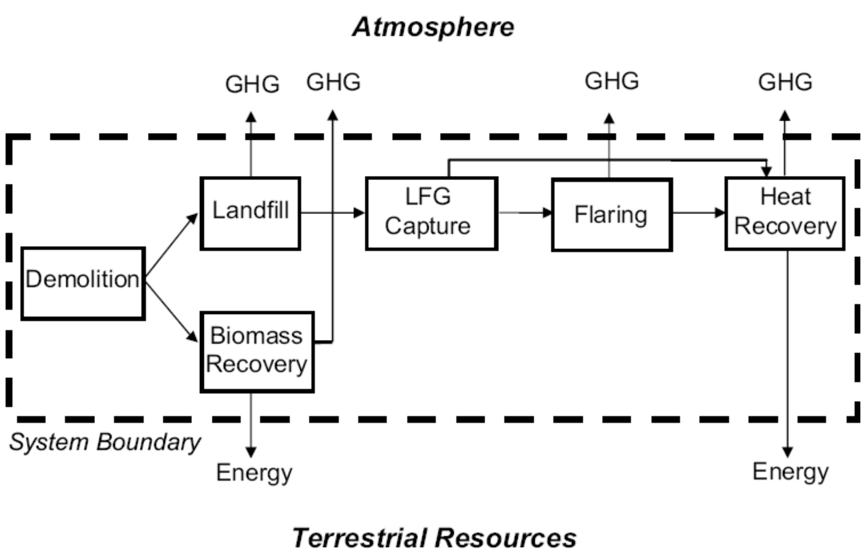

Figure 3: End of Life Treatment Scenarios of Wood Products

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Equation 1: GHG Directly Emitted =

$$W_{kg}\,(C)(C_{CO2})(\,D)(1\text{-}LFG_{C})(44/12) + W_{kg}\,(C)(C_{CH4})(D)(1\text{-}LFG_{C})(\,CH_4GWP\,{*}16/12)$$

$$W_{kg}(C)(D)(1\text{-}LFG_{C})[(44/12)(C_{CO2})+(16/12)(C_{CH4})(CH_4GWP)]$$

Equation 2: GHG Emitted from LFG Energy Recovery =

$$W_{kg}(C)(D)(LFG_{C})(LFG_{R})(44/12)$$

Equation 3: GHG Emitted from LFG Flaring =

$$W_{kg}(C)(D)(LFG_{C})(1\text{-}LFG_{R})(44/12)$$

Equation 4: Energy Offset by LFG Recovery =

$$(LFG_{HHV})(W_{kg})(C)(D)(LFG_{C})(LFG_{R})[(44/12)(C_{CO2})+(16/12)(\,C_{CH4})]$$

W_{kg}: Wood Mass in kg

C: Carbon Content of Wood = .5

D: Decomposition of Wood in Landfill = .24

C_{CO2}: Carbon content of wood converted to CO_2: .55

C_{CH4}: Carbon content of wood converted to CH_4: .45

CH_4GWP: Global Warming Potential of Methane: 25

LFG_C: Landfill Gas Capture Efficiency = .75

LFG_R: Landfill Gas Energy Recovery Efficiency =.7

LFG_{HHV}: Landfill Gas Higher Heating Value = 15.8 MJ/kg

Appendix 2: Detailed Life Cycle Impact Assessment Results

Table 5a: LCIA Results for Concrete System, 3000 PSI Concrete Mix

Impact category	Unit	Total	Additional Steel	Additional Concrete	Concrete Decking	Transportation to Site	Transportation to Landfill	Landfill Processing	Steel Recycling
Global Warming	tonnes CO2 eq	138.86	43.68	9.70	109.49	5.83	2.91	8.46	-41.21
Acidification	10^3 H+ moles eq	43.24	5.38	2.66	30.02	1.93	0.96	4.60	-2.30
Smog	tonnes NOx eq	0.53	0.07	0.03	0.31	0.04	0.02	0.10	-0.04
Eutrophication	kg N eq	18.33	2.77	1.18	13.37	1.84	0.92	0.01	-1.78
Total Energy	GJ eq	968.52	520.00	40.67	459.25	79.76	39.88	192.96	-364.00
Non-renewable, fossil	GJ eq	962.15	520.00	40.67	459.25	79.09	39.55	187.59	-364.00
Non-renewable, nuclear	GJ eq	6.22	0.00	0.00	0.00	0.67	0.34	5.21	0.00
Total Renewable	GJ eq	0.15	0.00	0.00	0.00	0.00	0.00	0.15	0.00

Table 5b: LCIA Results for Concrete System, 4000 PSI Concrete Mix

Impact category	Unit	Total	Additional Steel	Additional Concrete	Concrete Decking	Transport to Site	Transportation to Landfill	Landfill Processing	Steel Recycling
Global Warming	tonnes CO2 eq	186.54	43.68	13.57	153.29	5.83	2.91	8.46	-41.21
Acidification	10^3 H+ moles eq	56.32	5.38	3.72	42.03	1.93	0.96	4.60	-2.30
Smog	tonnes NOx eq	0.66	0.07	0.04	0.44	0.04	0.02	0.10	-0.04
Eutrophication	kg N eq	24.15	2.77	1.66	18.72	1.84	0.92	0.01	-1.78
Total Energy	GJ eq	1168.49	520.00	56.94	642.96	79.76	39.88	192.96	-364.00
Non-renewable, fossil	GJ eq	1162.12	520.00	56.94	642.96	79.09	39.55	187.59	-364.00
Non-renewable, nuclear	GJ eq	6.22	0.00	0.00	0.00	0.67	0.34	5.21	0.00
Total Renewable	GJ eq	0.15	0.00	0.00	0.00	0.00	0.00	0.15	0.00

Table 6a: Detailed LCIA Results for ResinDek® System, wood waste to landfill

Impact category	Unit	Total	Forest Sequestration	MDF	Transportation to Site	Transport to Landfill	Landfill Processing	Landfill Gas and Recovery
Global Warming	tonnes CO2 eq	-42.10	-119.87	57.70	5.26	0.26	0.55	14.01
Acidification	10^3 H+ moles eq	28.72		26.64	1.74	0.09	0.26	
Smog	tonnes NOx eq	0.22		0.17	0.04	0.00	0.01	
Eutrophication	kg N eq	11.40		9.65	1.66	0.08	0.00	
Total Energy	GJ eq	658.14		738.44	71.97	3.60	14.43	-170.31
Non-renewable, fossil	GJ eq	540.78		622.19	71.37	3.57	13.96	-170.31
Non-renewable, nuclear	GJ eq	1.69		0.60	0.61	0.03	0.45	
Total Renewable	GJ eq	115.67		115.66	0.00	0.00	0.01	

Table 6b: Detailed LCIA Results for ResinDek® System, wood waste burned with energy recovery

Impact category	Unit	Total	Forest Sequestration	MDF	Transportation to Site	Transport to Landfill	Waste Processing	Energy Recovery
Global Warming	tonnes CO2 eq	-89.04	-119.87	57.70	5.26	0.26	0.55	-32.94
Acidification	10^3 H+ moles eq	28.72		26.64	1.74	0.09	0.26	
Smog	tonnes NOx eq	0.22		0.17	0.04	0.00	0.01	
Eutrophication	kg N eq	11.40		9.65	1.66	0.08	0.00	
Total Energy	GJ eq	-714.66		738.44	71.97	3.60	14.43	-1543.11
Non-renewable, fossil	GJ eq	-832.02		622.19	71.37	3.57	13.96	-1543.11
Non-renewable, nuclear	GJ eq	1.69		0.60	0.61	0.03	0.45	
Total Renewable	GJ eq	115.67		115.66	0.00	0.00	0.01	