Submission for Verification of Eco-Efficiency Analysis Under NSF Protocol P352, Part B

Residential Insulation, Eco-Efficiency Analysis Final Report - June 2010

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1. Purpose and Intent of this Submission

1.1. The purpose of this submission is to provide a written report of the methods and findings of BASF Corporation's "Residential Insulation, Eco-Efficiency Analysis", with the intent of having it verified under the requirements of NSF Protocol P352, Part B: Verification of Eco-Efficiency Analysis Studies.

1.2. The Residential Insulation, Eco-Efficiency Analysis was performed by BASF according to the methodology validated by NSF International under the requirements of Protocol P352. More information on BASF's methodology and the NSF validation can be obtained at www.nsf.org/info/ecoefficiency.

2. Content of this Submission

2.1. This submission outlines the study goals, procedures, and results for the Residential Insulation, Eco-Efficiency Analysis (EEA) study, which was conducted in accordance with BASF Corporation's EEA (BASF EEA) methodology. This submission will provide a discussion of the basis of the eco-analysis preparation and certification work.

2.2. As required under NSF P352 Part B, along with this document, BASF is submitting the final computerized model programmed in Microsoft® Excel. The computerized model, together with this document, will aid in the final review and ensure that the data and critical review findings have been satisfactorily addressed.

3. BASF's EEA Methodology

3.1. Overview: BASF EEA involves measuring the life cycle environmental impacts and life cycle costs for product alternatives for a defined level of output. At a minimum, BASF EEA evaluates the environmental impact of the production, use, and disposal of a product or process in the areas of energy and resource consumption, emissions, toxicity and risk potential, and land use. The EEA also evaluates the life cycle costs associated with the product or process by calculating the costs related to, at a minimum, materials, labor, manufacturing, waste disposal, and energy.

3.2 Preconditions: The basic preconditions of this eco-efficiency analysis are that all alternatives that are being evaluated are being compared against a common functional unit or customer benefit. This allows for an objective comparison between the various alternatives. The scoping and definition of the customer benefit are aligned with the goals and objectives of the study. Data gathering and constructing the system boundaries are consistent with the functional unit and consider both the environmental and economic impacts of each alternative over their life cycle in order to achieve the specified customer benefit. An overview of the scope of the environmental and economic assessment carried out is defined below.

3.2.1 Environmental Burden Metrics: For BASF, EEA environmental burden is characterized, at a minimum, using eleven categories including: primary energy consumption, raw material consumption, global warming potential (GWP), ozone depletion potential (ODP), acidification potential (AP), photochemical ozone creation potential (POCP), water emissions, solid waste, emissions, toxicity potential, risk potential, and land use. These are shown below. Metrics shown in yellow represent the six main categories of environmental burden that are used to construct the environmental fingerprint, burdens in blue represent all elements of the emissions category, and green show air emissions.

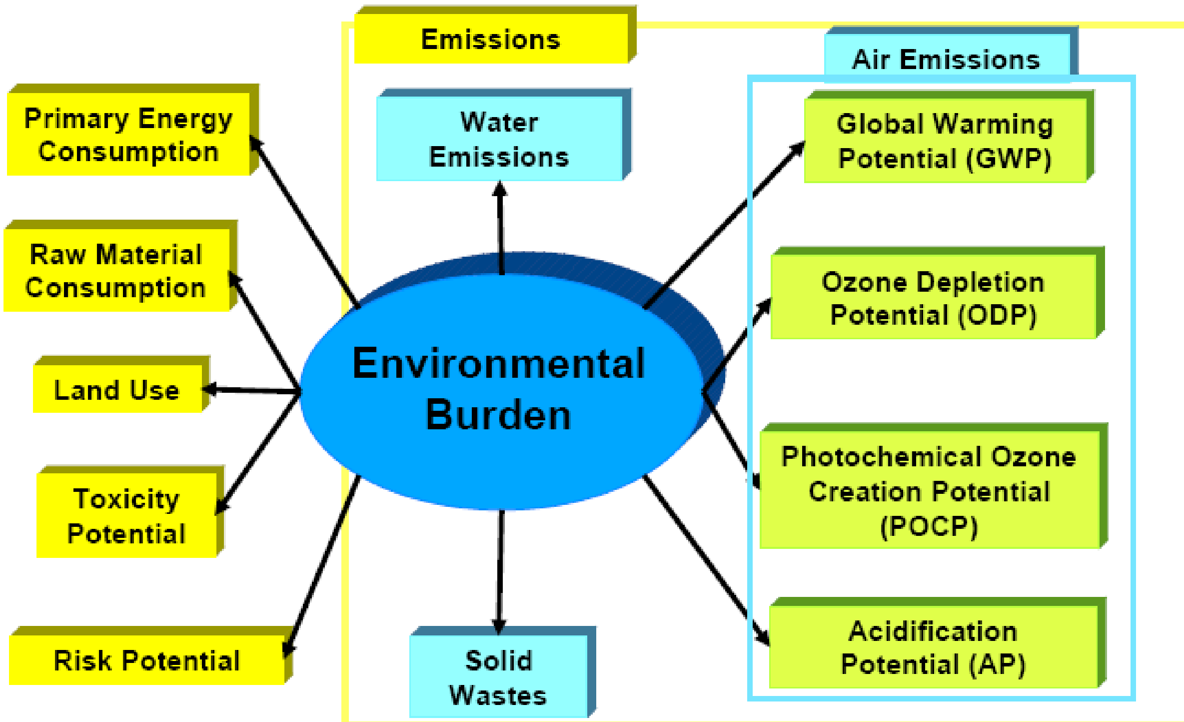

Figure 1: Environmental Impact Categories

3.2.2 Economic Metrics: It is the intent of the BASF EEA methodology to assess the economics of products or processes over their life cycle and to determine an overall total cost of ownership for the customer benefit ($/CB). The approaches for calculating costs vary from study to study. When chemical products of manufacturing are being compared, the sale price paid by the customer is used. When different production methods are compared, the relevant costs include the purchase and installation of capital equipment, depreciation, and operating costs. The costs incurred are summed and combined in appropriate units (e.g. dollar or EURO) without additional weighting of individual financial amounts. The BASF EEA methodology will incorporate:

- the real costs that occur in the process of creating and delivering the product to the consumer;
- the subsequent costs which may occur in the future (due to tax policy changes, for example); and
- costs having an ecological aspect, such as the costs involved to treat wastewater generated during the manufacturing process.

3.3 Work Flow: A representative flowchart of the overall process steps and calculations conducted for this eco-efficiency analysis is summarized in Figure 2 below.

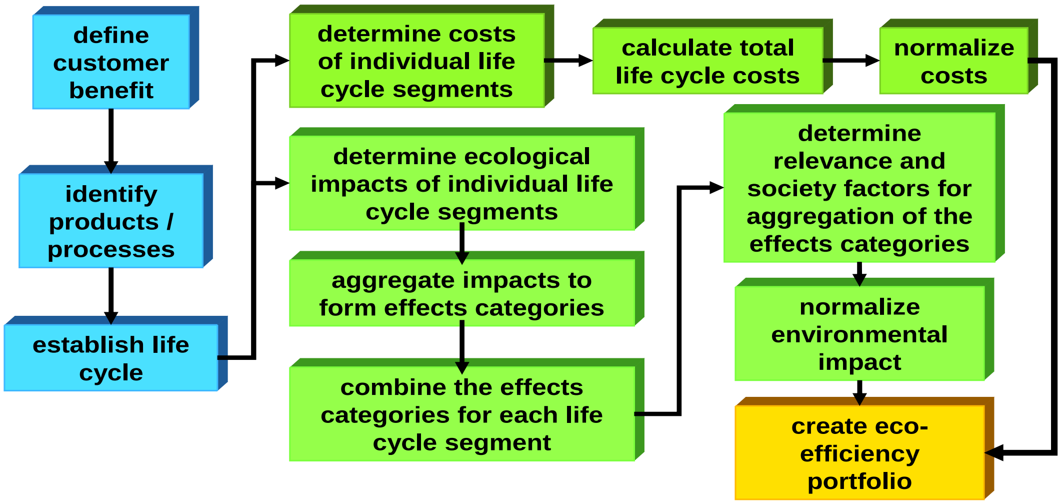

Figure 2: Overall process flow for Residential Insulation EEA study

4. Study Goals, Decision Criteria and Target Audience

4.1. *Study Goals*: The specific goal defined for the Residential Insulation, Eco-Efficiency Analysis was to quantify the differences in life cycle environmental impacts and total life cycle costs of various insulation systems for residential buildings in the United States.

The study specifically compared different insulating systems for a single story residential home in three distinct climate zones in four different locations in the United States (see section 5.4 of this report for specific locations and climate zones). By considering four unique regions, a more comprehensive understanding of the effect regional material and energy costs as well as regional climate conditions can have on the results of the study can be analyzed. Insulation requirements for each region followed the recommended building code requirements specified by the 2006 International Energy Conservation Code for Residential Building Requirements[15].

In order to bring better clarity to the environmental and life cycle cost differences between the alternatives, a differential approach was utilized when comparing the various impacts. Thus, the analysis focused on the unique differences between the alternatives and thus any material or impact which was identical between the alternatives as identified by the customer benefit over the study life cycle was excluded from the analysis. In addition, resistance to weather damage during the use phase is assumed to be the same for all alternatives. The impact of flooding and water damage to the wall unit was considered in the Risk category.

Study results will be used as the basis to guide product development decisions that will result in more sustainable insulation systems as well as provide the necessary information to allow a clear comparison between the life cycle environmental and total cost impacts and benefits of various insulating alternatives.

4.2 Decision Criteria: The context of this EEA study compared the life cycle environmental and cost impacts for Enertite® (open cell spray applied polyurethane foam insulation), Spraytite® 158-LDM, Spraytite® 178-F, Spraytite® 180-F (all closed cell spray applied polyurethane foam insulations), a generic bio-based closed cell spray applied polyurethane foam insulation, cellulose and fiberglass insulations competing in a residential market at a regional level over the course of their life cycle. The study was technology driven and required supplier and customer engagement. The study goals, target audience, and context for decision criteria used in this study are displayed in Figure 3.

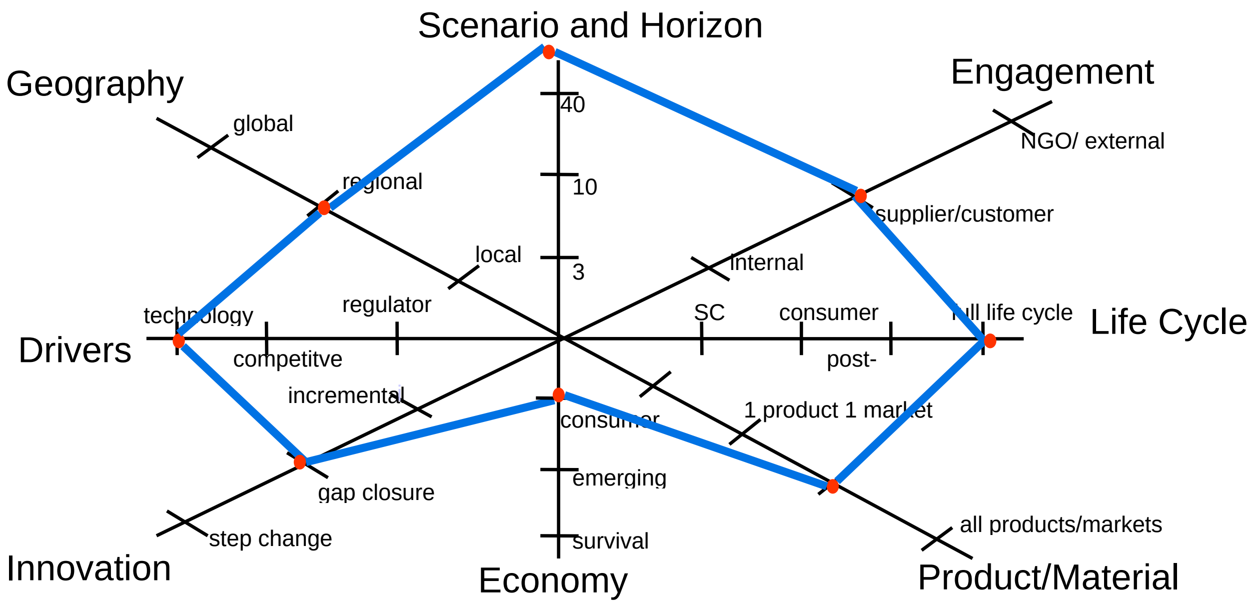

Figure 3. Diagram of study goals, target audience, and context for decision criteria for the Residential Insulation Eco-Efficiency Analysis.

4.3. *Target Audience*: The target audience for the study has been defined as R&D researchers, architects, builders, homeowners and government regulators. It is planned to communicate study results in marketing materials and at trade conferences.

5. Customer Benefit, Alternatives and System Boundaries

5.1. *Customer Benefit*: The Customer Benefit applied to all seven alternatives is the construction, use & disposal of the walls and roof of a single story residential home meeting the 2006 IECC residential building code requirements for insulation over a 60 year time frame.

For the base case analysis, Newark, NJ (climate zone 4; with building requirements for insulation of R-13 (wall) and R-38 (ceiling)) will be considered. The other locations and their respective climate zones are defined in Section 5.4 below and will be handled as scenario analyses.

The justification for this functional unit is that it sufficiently represents stand alone components of a residential home by which the individual alternatives and their required system components can be objectively compared. A time horizon of 60 years was deemed consistent with industry practice for residential modeling and is sufficiently long enough to adequately take into consideration the long-term performance of the individual insulation materials and their system components.

5.2. *Alternatives*: The product alternatives compared under this EEA study are summarized in Table 1, and consisted of Spraytite® 158-LDM, Spraytite® 178-F, Spraytite® 180-F, Enertite® – US, Cellulose, Fiberglass and a generic Biobased closed cell SPF. These alternatives were selected as they represent the most commonly available options for residential insulation, they represent the majority of the market share and reflect the latest technologies (e.g. blowing agents, biobased content in SPF).

Table 1: Summary of study alternatives.

Insulation	Description	Blowing Agent
Spraytite® 158-LDM	Spray Polyurethane Foam (Closed Cell)	Proprietary
Spraytite® 178-F	Spray Polyurethane Foam (Closed Cell)	Proprietary
Spraytite® 180-F	Spray Polyurethane Foam (Closed Cell)	Proprietary
Enertite® - US	Spray Polyurethane Foam (Open Cell)	Water
Cellulose		None
Fiberglass		None
Biobased	Spray Polyurethane Foam (Closed Cell)	Proprietary

5.3. *System Boundaries*: The system boundaries define the specific elements of the production, use, & disposal phases that are considered as part of the analysis. The system boundaries for the seven alternatives evaluated in the base case study are shown in Figure 4. Components of the wall or roof systems as defined by the customer benefit which are identical for each alternative are excluded from this analysis and identified below in the grey boxes.

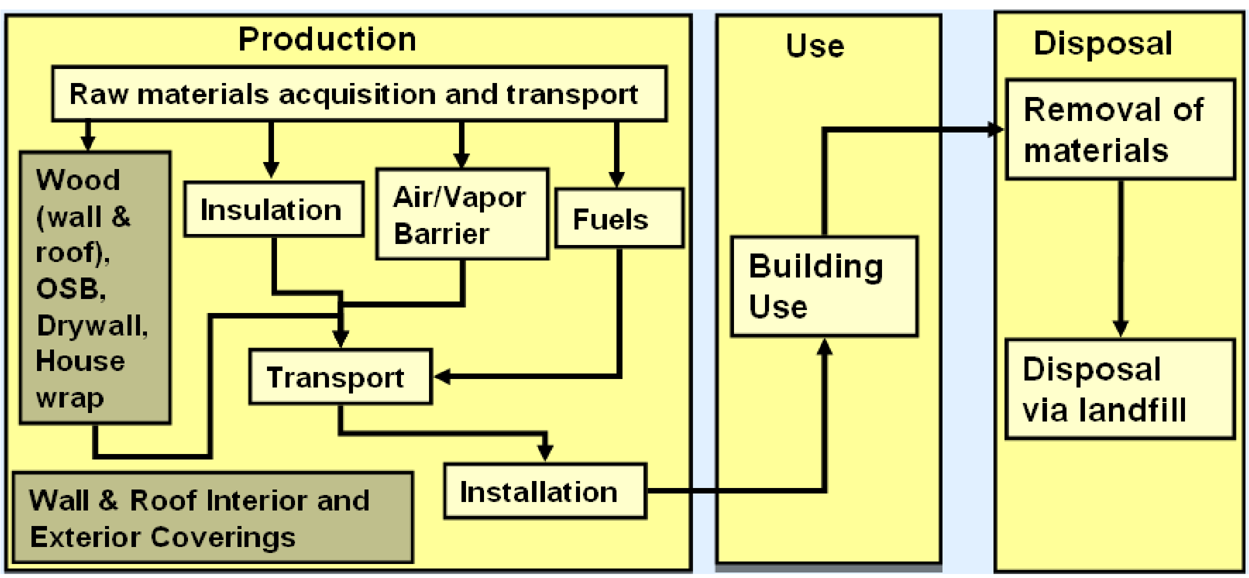

Figure 4. System boundaries

5.4 Scenario Analyses: In addition to the base case analysis which considered the insulation of a residential home in Newark, NJ (Zone 4), three additional locations were considered:

5.4.1 Scenario #1: Tampa, Florida (Zone 2; R-13 (wall) and R-30 (ceiling))

5.4.2 Scenario #2: Phoenix, Arizona (Zone 2; R-13 (wall) and R-30 (ceiling))

5.4.3 Scenario #3: Minneapolis, Minnesota (Zone 6; R-19 (wall) and R-49 (ceiling))

Results from these scenarios will be discussed along with the base case in Section 7, “Eco-efficiency analysis results and discussion.

6. Input Parameters and Assumptions

6.1. *Input Parameters*: A comprehensive list of input parameters were included for this study and considered all relevant material and operational characteristics for the seven alternatives. Consistent with the boundary conditions identified for the analysis, as there was a high degree of similarity in the scope and inputs for each of the alternatives, a differential analysis was performed using relative inputs. In utilizing the relative inputs for each alternative, a higher degree of resolution between the unique differences in the alternatives, specifically the insulation systems which is the focus of this eco-efficiency analysis, can be provided.

6.1.1. *Insulation Parameters:* The insulation materials were parameterized based on representative compositions for each of the seven alternatives. The formulations used for this study are confidential, but full formulations were disclosed to NSF International for the purposes of this verification. Table 2 provides general formulations for the alternatives.

Table 2: General Insulation Formulations for study alternatives.

	Spraytite® 158-LDM	**Spraytite® 178-F**	**Spraytite® 180-F**	**Enertite® (US)**	**Generic Biobased (closed cell)**	**Stabilized Cellulose**	**Fiberglass**
Component	**% wt**	**% wt**	**% wt**	**% wt**	**% wt**	**% wt**	**% wt**
Isocyanate (Part A)	50	51.3	51	53	50		
Resin (includes polyol, flame retardant, and blowing agent)	50	48.7	49	47	50		
Flame Retardant(s)						15	
Recycled Newsprint						85	
Glass Fiber							85
Phenol Formaldehyde Based Binder							15
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**

6.1.2 *Construction Parameters:* A sample residential wall and roof section were defined in order to establish the functional unit of comparison between the alternatives. For this study, the functional unit or customer benefit was defined as the construction, use & disposal of the walls and roof of a single story residential home in Newark, NJ over 60 years. A typical 2”x4” wall schematic is provided below in Figure 5. A 2”x6” wall schematic, applicable to Scenario #3 only, would be analogous to the 2"x4" with similar 16" spacing. The insulation alternative would be applied in the cavity between the studs.

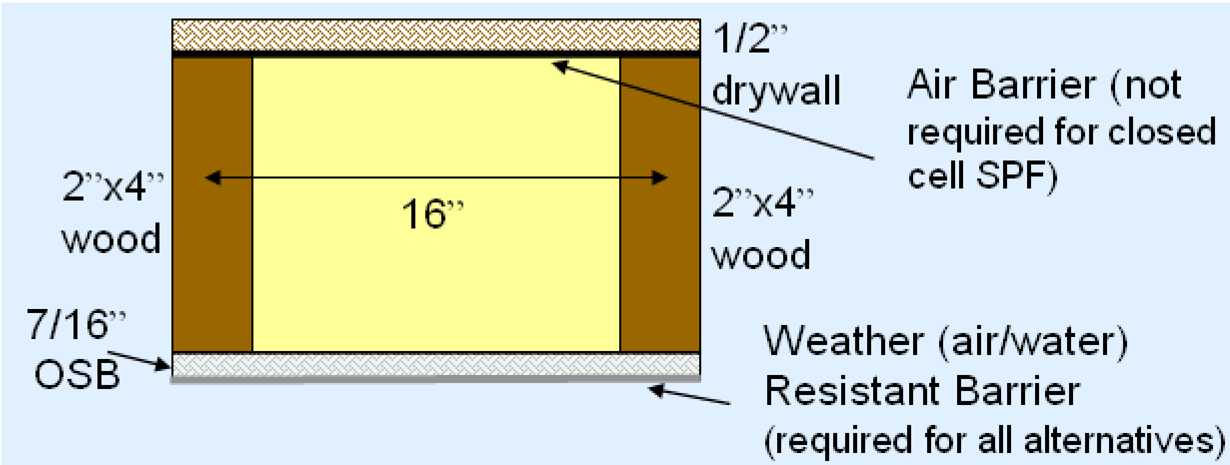

Figure 5. Construction Parameters

Table 3 below shows the material inputs required to make the wall and roof system for each alternative achieve the specified customer benefit. This table represents the material take-offs for the base case analysis (Newark, NJ). Specific amounts for the 3 scenario analyses will be different as they have unique building code requirements for wall and roof insulation.

System Materials		Spraytite 158-LDM	Spraytite 178-F	Spraytite 180-F	Enertite - US	Cellulose	Fiberglass	Biobased
Wall + Roof System								
Total System Materials								
Polyol Resin	kg	274	262	254	122			269
Isocyanate	kg	274	276	265	138			269
Cellulose	kg					792		
Fiberglass	kg						538	
House Wrap (Weather Barrier)	kg	same for all alternatives						
OSB	kg	same for all alternatives						
Wood - wall	kg	0	0	0	0	0	0	0
Wood - roof	kg	same for all alternatives						
Drywall	kg	same for all alternatives						
Air Barrier	kg	0	0	0	18	18	18	0
Total Weight to transport	kg	547	538	519	278	810	556	538
Delta weight transport	kg	270	260	241	0	532	278	260

Table 3: System Material Take-offs

All building systems have the same interior and exterior coverings, and thus these items can be excluded from the analysis. The standard home does not include a basement and has a concrete slab. Specifics related to the home dimensions used for the base case as well as the scenario analyses are shown below in Table 4. A standard truss roof design with insulation applied between ceiling joists was assumed for the base case. For the Minneapolis, Minnesota Scenario #3, an energy truss or raised heel roof was assumed to allow for a better insulated attic.

Table 4: Home Dimensions.

Zone - City	4 - Newark
Stories	1
Floor dimensions ft	27.1 by 40.6
Floor to ceiling height ft	8.0
Floor to top of roof ft	14.6
Floor Area ft2	1100
Surface Area ft2	3283
Wall gross area ft2	1083
Roof gross area ft2	1100
Window gross area ft2	240
wall area un-insulated	20%
Framing factor wall	25%
Framing factor Attic	7%
Time period to consider years	60

Dimensional data were determined as indicative for a standard single story residence. The percentage of the wall not insulated with additional insulation was set at 20% and was based on values of 16% for glazing and 4% for other (e.g. doors). The Energy 10 default U values for windows and doors are 0.47 BTU/hr-ft^2-°F and 0.25 BTU/hr-ft^2-°F, respectively. Framing factors of 25% for the wall and 7% for the attic were based on national averages per ASHRAE[1]. To determine the actual insulation requirements of the wall, the previous values for uninsulated wall area and framing factor were deducted from the wall gross area. To determine the insulation requirements of the roof the attic framing factor was deducted from the roof gross area.

The required building code requirements for insulation were pulled from the 2006 International Energy Conservation Code (IECC)[15]. All locations required a wall insulation of R-13 except for Minneapolis, Minn., which required R-19. The required attic insulation values for the alternatives are as follows:

- Newark, NJ: R38
- Phoenix, Arizona: R30
- Tampa, Florida.: R30
- Minneapolis, Minnesota: R49

6.2 Energy Modeling: To accurately measure a building's overall thermal performance, one needs to consider both the thermal resistance (R-value) of the wall assembly in addition to how well the building assembly seals against air infiltration. According to the Department of Energy[11], air infiltration can account for 30% or more of a home's heating and cooling costs and can contribute to problems with moisture, noise and dust. Reducing air infiltration can improve building durability and create a healthier indoor air quality. Air infiltration can occur in many locations throughout the building envelope. Figure 6 depicts common locations for air infiltration through the building envelope. These include key locations such as the junctions of the ceiling/floor with the external wall, penetrations of the electrical and plumbing installations through the air barrier systems, penetrations of the ventilation ducts through the air barrier systems, leakage around and through electrical sockets and switches, and leakage around and through windows and doors.

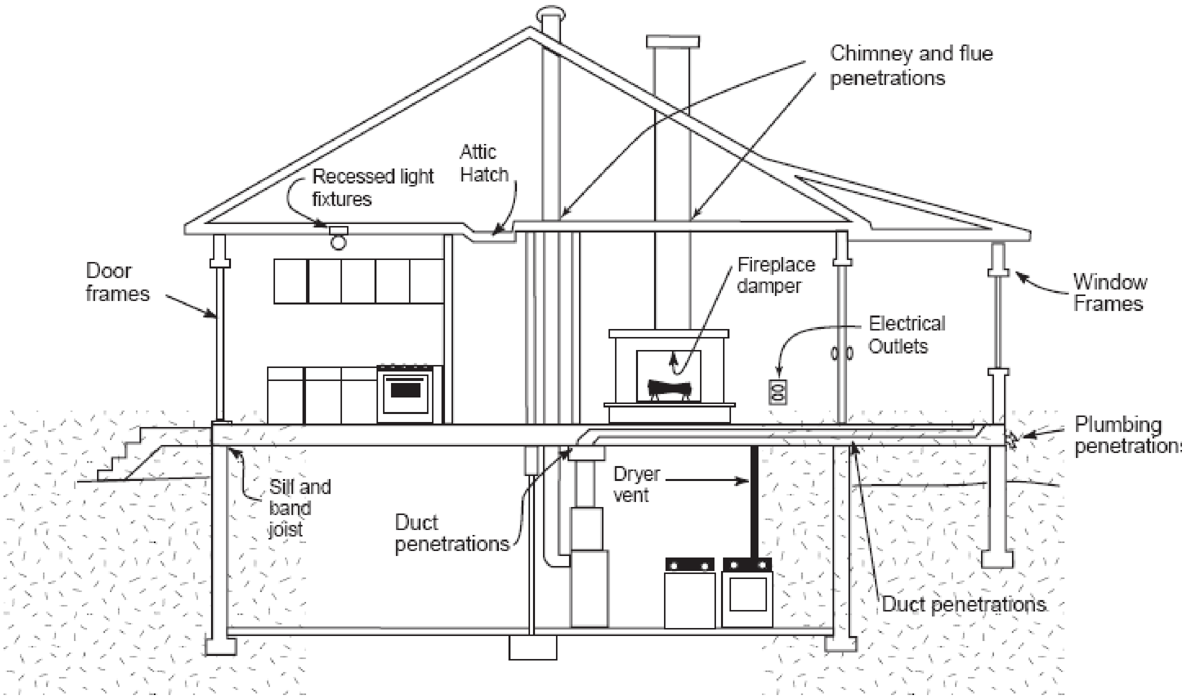

Figure 6. Locations of Common Air Leakage Paths[12]

According to the DOE[11], insulation such as fiberglass, does not stop air leakage while certain types of insulation, such as densely packed cellulose and certain foams can be effective at reducing air flows as well as heat flows. Fibrous insulation materials like cellulose and fiberglass which depend on still air as an insulating material will see its thermal performance significantly degraded through a process called convection looping if outside air is allowed to infiltrate into the wall system. Therefore, in addition to the insulation material, a continuous air barrier system around the building envelope is essential in order to optimize a home's energy efficiency. In order to achieve this continuous air barrier in addition to the installation of an air barrier material/membrane around the exterior of the building, all the cracks, gaps, holes and penetrations through the building envelope need to be sealed properly. Different wall systems are inherently better at providing this sealing than others. Fibrous materials such as fiberglass and cellulose when coupled with a properly installed air barrier system and proper caulking can be effective in reducing air infiltration. However, because of differences in the quality and intricacies of the installation (e.g. tears in the membrane, improper taping, missed gaps/cracks), these wall systems can be more prone to deficiencies in the air barrier and thus allow more opportunities for air infiltration than a spray foam wall system which will expand to fully seal potential areas of air ingress, even in difficult locations, and is fully self adhered to the wall system and thus will not shrink or settle over time. In fact, closed cell spray foam insulation can provide an approved air barrier system when installed at thicknesses greater than 1.0"[13]. A spray foam wall system will in general provide a tighter air barrier and by allowing less air infiltration will provide a more energy efficient home than other insulating wall materials.

As the installed R-value as well as the ability to minimize air infiltration were not the same for the various insulation systems, the overall thermal performance of the alternatives varied. In order to measure the differences in thermal performance over the life cycle considered, energy modeling was required. Energy-10™ software, developed by the SBIC (Sustainable Buildings Industry Council) in collaboration with NREL Center for Building and Thermal Systems, Lawrence Berkeley National Laboratory (LBNL), and the Berkeley Solar Group was utilized. In terms of providing accurate and representative modeling data, the accuracy of Energy-10™ has been demonstrated using the BESTEST (Building Energy Simulation Test) procedure, developed by NREL's Center for Building and Thermal Systems within the International Energy Agency Solar Heating and Cooling Program Task 12, which has been adopted by the U.S. Department of Energy and the international community as the accepted basis for verifying the credibility of computer simulation programs.

Energy-10™ was utilized to calculate the derived R-values for the wall and roof systems as well as conduct the entire energy modeling for the residential home considering both the specific regional climate data as well as the effects of air infiltration. In addition to the input data related to the wall and roof construction and installed insulation thicknesses, assumptions were made related to HVAC system design as well as the air infiltration rates for the various alternatives.

For the HVAC system, a direct compression air conditioning system with natural gas furnace with 90% efficiency was assumed. The SEER (Seasonal Energy Efficiency Ratio) rating for the unit was 13.

With regards to air infiltration, Energy-10™ utilizes the "Sherman–Grimsrud" model to estimate hourly infiltration, based on current wind velocity and the difference between the inside and outside temperature (sometimes referred to as the "stack effect," an analogy to the airflow up a chimney). The model was developed at LBNL by Max Sherman and David Grimsrud.

In Energy-10™, the parameters required to calculate infiltration are the ELA (effective leakage area), given in square inches, the number of stories of the building and the shielding class. ELA is a measure of the total crack area in a building. It is the primary parameter used to determine infiltration. ELA can be estimated based on typical values or measured in a blower-door test. For the home described in Table 4 and considering each wall system's effectiveness in preventing air infiltration, an ELA was developed for each alternative and are shown below in Table 5.

Table 5: ELA (in^2) from Energy-10™

Closed cell	Open cell	Cellulose	Fiberglass
60.6	71.3	105	144

These values were derived by applying information from various literature sources[2], ASTM air permeability test results for open and closed cell foams[3] and recommendations from Energy-10™ to the specific dimensional aspects of the house defined in Table 4. These relative values are consistent with observations and test data that support spray foam wall systems providing a tighter building envelope than fibrous wall systems such as cellulose and fiberglass.

The shielding class was defaulted to a value of 5 (reflecting heavy shielding) as recommended by Energy-10™ and according to the experimental observation that wind has a smaller effect than predicted by the lower shielding classes.

A representative example of an Energy-10™ output results for the base case analysis which considered a residential home in Newark, NJ (climate zone 4) is shown in Figure 7.

Project: PROJ5 **Project Directory:** F:\Energy10 files\PROJ5

Description:	b cc R13 cc R38 final	b cell R13 cell R38 final
Scheme Number:	3 / Saved	4 / Saved
Library Name:	Local Only	Local Only
Simulation status, Thermal/DL	valid/NA	valid/NA
Weather file:	Newark.et1	Newark.et1
Floor Area, ft²	1100.0	1100.0
Surface Area, ft²	3283.2	3283.2
Volume, ft³	8800.0	8800.0
Total Conduction UA, Btu/h-F	346.8	349.5
Average U-value, Btu/hr-ft²-F	0.106	0.106
Wall Construction	cc 158 2x4 r13, R=12.9	b 2 x 4 cell, R=12.5
Roof Construction	b - attic, r-38 cc, R=36.3	b - attic, r-38 cel, R=35.2
Floor type, insulation	Slab on Grade, Reff=9.0	Slab on Grade, Reff=9.0
Window Construction	4060 double, wood, U=0.47	4060 double, wood, U=0.47
Window Shading	None	None
Wall total gross area, ft²	1083	1083
Roof total gross area, ft²	1100	1100
Ground total gross area, ft²	1100	1100
Window total gross area, ft²	240	240
Windows (N/E/S/W:Roof)	3/2/3/2:0	3/2/3/2:0
Glazing name	double, U=0.49	double, U=0.49
Operating parameters for zone 1		
HVAC system	DX Cooling with Gas Furnace	DX Cooling with Gas Furnace
Rated Output (Heat/SCool/TCool),kBtu/h	41/23/31	46/24/32
Rated Air Flow/MOOA,cfm	1147/0	1170/0
Heating thermostat	70.0 °F, no setback	70.0 °F, no setback
Cooling thermostat	78.0 °F, no setup	78.0 °F, no setup
Heat/cool performance	eff=90,EER=11.1	eff=90,EER=11.1
Economizer?/type	no/NA	no/NA
Duct leaks/conduction losses, total %	11/10	11/10
Peak Gains; IL,EL,HW,OT; W/ft²	0.20/0.04/0.66/0.36	0.20/0.04/0.66/0.36
Added mass?	none	none
Daylighting?	no	no
Infiltration, in²	ELA=60.6	ELA=105.0
Results:		
Energy cost	1.440$/Therm,0.151$/kWh,2.470$/kW	1.440$/Therm,0.151$/kWh,2.470$/kW
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec
Energy use, kBtu	79199	88029
Energy cost, $	1819	1949
Saved by daylighting, kWh	-	NA
Total Electric (**), kWh	6078	6095
(** less Sellback, if any)		
Internal/External lights, kWh	864/94	864/94
Heating/Cooling/Fan+Aux, kWh	0/1732/767	0/1725/791
Hot water/Other, kWh	0/2620	0/2620
Peak Electric, kW	3.3	3.4
Fuel, hw/heat/total, kBtu	10760/47697/58458	10760/56472/67232

Figure 7. Sample Energy-10™ Output

A separate file containing a summary of the actual energy modeling results for the base case comparison (Newark, NJ) as well as the scenarios was provided to NSF International as part of the study verification.

LTTR (Long-term thermal resistance) values were used for all insulation alternatives. The R-values used for the Spraytite® alternatives ranged from 6.6 - 6.9/inch while Enertite®, cellulose and fiberglass were 3.7/inch, 3.7/inch and 3.45/inch, respectively. Related to the values for LTTR, the direct effect on air emissions related to the diffusion of the blowing agents from the foams and ultimately into the atmosphere was included in the environmental impact analysis[8].

Specific to the calculation of the derived R-value for the various roofing alternatives, the pitch of the roof and its effect on how much insulation can be installed at the edges of the roof were considered in calculating an average roof insulation value. This average insulation value was used in the derivation of the overall roof R-value which considers both the insulation and the framing. As mentioned previously, an energy truss roof was used for Zone 6 while the other locations used a standard truss roof design.

Table 6: Summary of Wall System Parameters (base case: Newark, NJ).

Wall	**Spraytite® 158-LDM**	**Spraytite® 178-F**	**Spraytite® 180-F**	**Enertite® -US**	**Cellulose**	**Fiberglass**	**Biobased (closed cell)**
R-value used for energy calculations (BTU-in/ft2/h/deg F)	12.9	12.9	12.9	12.5	12.5	12.5	12.9
Insulation density (lb/ft3)	2.0	2.0	2.0	0.6	1.6	1.4	2.0

Table 7: Summary of Roof System Parameters (base case: Newark, NJ).

Roof (Standard Truss R-38)	**Spraytite® 158-LDM**	**Spraytite® 178-F**	**Spraytite® 180-F**	**Enertite® -US**	**Cellulose**	**Fiberglass**	**Biobased (closed cell)**
R-value used for energy calculations (BTU-in/ft2/h/deg F)	36.3	36.3	36.4	35.2	35.2	34.2	36.3
Insulation density (lb/ft3)	2.0	2.0	2.0	0.6	1.6	0.7	2.0

6.3. *Transportation Logistics*: The environmental impacts for transporting the materials to the building site from point of manufacture as well as transporting them to the landfill during the disposal phase of the life cycle were considered. The following distances were assumed for the various construction materials:

- 450 miles for all insulation and air barrier materials
- 150 miles for OSB and Drywall
- 50 miles for wood
- 50 miles from home to landfill

Table 8 below shows the relative impact of transporting to the construction site and disposing to a landfill each of the insulation systems. The table reflects both the weight of material transported (metric tons) as well as the distance transported (km).

Table 8: Transportation Logistics Summary

Transportation (all transport by truck; miles considered (1) delivery to site & (2) removal to landfill)								
Total weight and distance by materi.		**Spraytite 158-LDM**	**Spraytite 178-F**	**Spraytite 180-F**	**Enertite - US**	**Cellulose**	**Fiberglass**	**Biobased**
Polyol Resin	tonne-km	456	437	424	204	0	0	448
Isocyanate	tonne-km	456	460	441	230	0	0	448
Cellulose	tonne-km	0	0	0	0	1320	0	0
Fiberglass	tonne-km	0	0	0	0	0	897	0
House Wrap (Weather Barrier)	tonne-km	0	0	0	0	0	0	0
OSB	tonne-km	0	0	0	0	0	0	0
Wood - wall	tonne-km	0	0	0	0	0	0	0
Wood - roof	tonne-km	0	0	0	0	0	0	0
Drywall	tonne-km	0	0	0	0	0	0	0
Air Barrier	tonne-km	0	0	0	15	15	15	0
TOTAL	tonne-km	912	896	865	448	1335	912	896
delta in transportation	tonne-km	464	448	416	0	887	464	448

6.4 *Costs:* The life cycle cost analysis was consistent with the study approach to consider a differential approach or relative comparison of the cost impacts for each alternative, thus all identical costs related to the construction, use and disposal of the home were excluded as they would have an identical cost impact across each alternative. The life cycle economic analysis for the Residential Insulation EEA considered costs associated with materials and installation, mechanical equipment, energy usage, transportation and waste disposal. Specifically, the initial costs include material, labor and transportation for the insulation and air barrier systems and the initial HVAC system. The reason the HVAC system cost was considered is that the more efficient insulation and air barrier systems can “right size” their HVAC system and thus may install smaller, less expensive systems. This optimization was done automatically within Energy-10™ based on the thermal efficiency of the design. It should be noted, however, that for the HVAC system, only the economic impacts were considered. The differential environmental impact associated with the manufacturing of the various “right sized” HVAC systems was not considered in this analysis as it was deemed overly complicated to accurately model and would have a de minimis impact on the final results. Costs associated with the use of the residential home included natural gas for heating, electricity for cooling, and the periodic replacement of the HVAC system. End of life included costs for transportation and disposal. The final cost comparison also used a differential approach determined by calculating the initial cost for each alternative relative to the lowest cost alternative.

The life cycle cost data was acquired from numerous sources with all costs being calculated in present day dollars. Specifically, utility costs (electricity, natural gas) were obtained from the Energy Information Administration (EIA, US Dept. of Energy). HVAC installation costs and life cycle costs for utilities and HVAC replacement were obtained directly from Energy-10™ ‘s life cycle cost modeling. For future utility costs, representative values for price escalation were used. A discount rate of 6% was assumed to calculate the present value of future fuel, electric and HVAC equipment costs. Material and installation costs for the spray polyurethane foams were provided by spray foam manufacturers. 2008 RS Means Building & Construction Cost Catalog was used for costing the other building materials as well as for adjusting the prices on a regional basis using their city code indexes. Reed Construction data was also used to adjust the construction costs derived from Energy-10™ to January 2009. Finally, fixed prices for transportation fuel and land fill disposal fees were applied across all analyses (base case and scenarios 1 – 3).

6.5 Further Assumptions: Wall maintenance includes replacement of 5% of materials every 30 years for cellulose and fiberglass and every 50 years for Enertite® and Spraytite® systems. Though reasonable, these assumptions will not have significant impact on the environmental or cost analysis for each alternative. Resistance to weather damage during the home use phase is assumed to be the same for all alternatives. The diffusion of blowing agent from the closed cell alternatives was considered in the air emissions impact category. Estimates for these diffusion rates can be found in the literature cited for this study[8].

7. Data Sources

7.1. The environmental impacts for the production, use, and disposal of the seven alternatives were calculated from eco-profiles (a.k.a. life cycle inventories) for the individual components and for fuel usage and material disposal. Life cycle inventory data for these eco-profiles were from several data sources, including BASF specific manufacturing data. Overall, the quality of the data was considered medium-high to high. None of the eco-profile data was considered to be of low data quality. A summary of the eco-profiles is provided in Table 9.

Table 9: Summary of eco-profiles used in this EEA.

Eco-Profile	Source, Year	Comments
Spray Polyurethane Foams		
MDI	BASF, 1993	
Polyol Formations	BASF/Supplier Avg., 2008	Specific for each SPF alternative. Confidential
Proprietary Blowing Agent	Est. US Avg., 2002	
Flame Retardant	SRI Report US, 2002[5,6]	
Wood	US Avg., 2004	Most reliable profile available[7]; Boustead database
Drywall	US Avg., 1996	Most reliable profile available[7]; Boustead database
House Wrap	US Avg., 1996	Most reliable profile available[7]; Boustead database
Air/Vapor Barrier	US, 2008	Henry Bakor Bluekskin® ;Technical data and MSDS
HVAC- Natural Gas	US Avg., 1996	Most reliable profile available[7]; Boustead database
HVAC- Electricity	US Avg., 1996	Most reliable profile available[7]; Boustead database
Diesel Use – US	US Avg., 1996	Most reliable profile available[7]; Boustead database
Material to Landfill	BUWAL 250, 1998[9]	
Biobased Polyol		
Bio-based content	Alberdingk Boley, 2007[4]	
Fiberglass Insulation		
Fiberglass	EMPA Avg., 1996	Covers respective sub-components
Cellulose Insulation		
Cellulose	US Avg., 2008	Covers respective sub-components
BASF data sources are internal data, while the others are external to BASF. Internal data is confidential to BASF; however, full disclosure was provided to NSF International for verification purposes.		

8. Eco-efficiency Analysis Results and Discussion

8.1. *Environmental Impact Results*: The environmental impact results for the Residential Insulation EEA for the base case analysis, Newark, New Jersey are generated as defined in Section 6 of the BASF EEA methodology and reported and discussed below.

8.1.1. *Primary energy consumption*: Energy consumption, measured over the entire life cycle, shows that Spraytite® 180F has the lowest energy consumption, using approximately 47,500 MJ of energy per customer benefit. This is 96% less energy consumption relative to the alternative with the highest level of primary energy consumption, fiberglass, which uses about 1,237,500 MJ of energy per customer benefit. It should be noted for this comparative analysis that a differential approach was applied to the energy consumption related to the heating and cooling of the home over its lifecycle. This means the difference in energy consumption relative to the best performing alternative was utilized for each alternative in order to determine the impacts for both the HVAC natural gas (heating) and electricity (cooling) demands. For the base case scenario and relative to the absolute HVAC loads, the Spraytite® home was about 3% more energy efficient than Enertite®, 11% more efficient than cellulose and 21% more efficient than the fiberglass alternative.

The fiberglass insulation system has the lowest energy efficiency of any of the alternatives, mostly attributed to having the highest air infiltration rate, and thus results in the highest HVAC energy consumption over the lifetime of the home. Each of the four Spraytite® spray polyurethane foam (spf) alternatives has the lowest air infiltration rate thus contributing to the most energy efficient designs. Overall, it can be seen from Figure 8 that the key driver for energy consumption for each alternative is the HVAC energy consumption, specifically natural gas used for heating. For a heating dominated climate (Zone 4) this is not a surprise for Newark, NJ.

Also noted in Figure 8, the energy consumption for heating and cooling the house over its life cycle contributes significantly more to the overall energy impact than the embodied energy of the insulation alternatives. These results highlight the importance of considering life cycle impacts when determining the true environmental impacts of products. Specific to energy consumption, if only the embodied energy of the insulation material was considered, the comparison would be quite different. The approximate primary energy required to produce each type of insulation material for the base case analysis is:

- closed cell spf: 85 MJ/kg & 45,000 – 48,000 MJ/CB
- open cell spf: 70 MJ/kg & 21,000 MJ/CB
- fiberglass: 46 MJ/kg & 24,500 MJ/CB
- cellulose: 4 MJ/kg & 3,100 MJ/CB

Thus the superior insulating and air barrier performance of the spray foams, specifically the closed cell spray foams, far off-sets the higher energy requirements in manufacturing, transportation and installation. Cellulose, which has extremely low embodied energy, does not fair as well in overall energy consumption relative to the spray foams because of its higher air infiltration values.

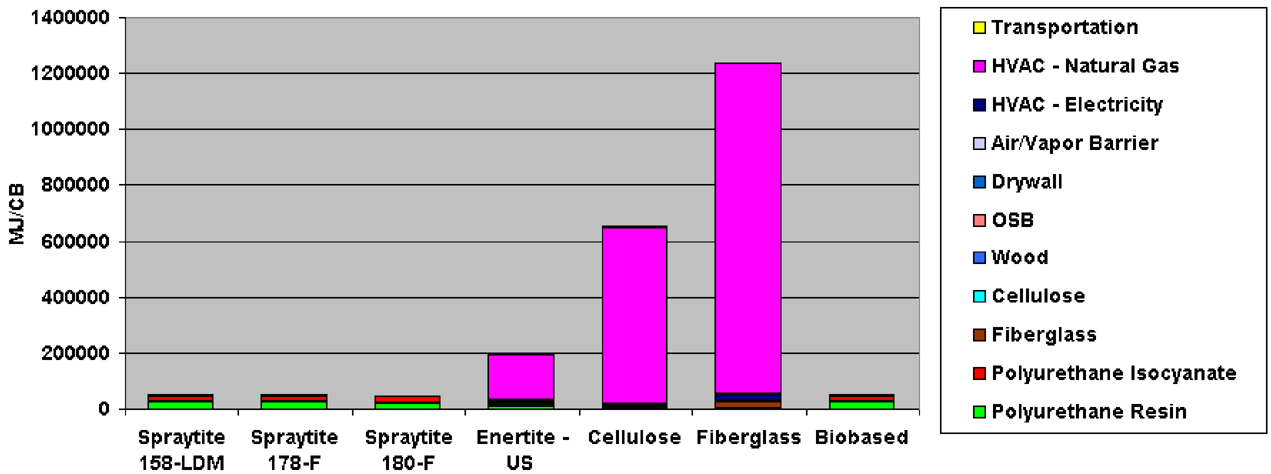

Figure 8. Primary energy consumption.

8.1.2. *Raw material consumption*: Figure 9 shows that the key driver for the raw material consumption is the natural gas used for heating the home. It is clear from Figure 9 that the least energy efficient alternative, fiberglass insulation, consumes the largest amount of natural gas and thus has the largest overall raw material usage. As mentioned previously, this much higher energy/raw material consumption is related to fiberglass having the highest air infiltration rate as well as the lowest overall wall+roof R-value. The cellulose alternative is the next least energy efficient and thus has the 2nd largest raw material consumption. The use of boric acid as a fire retardant in cellulose insulation contributes to the high relative consumption of boron, a relatively scarce raw material, for the cellulose alternative. Boron is weighted more significantly than more readily abundant raw materials considered in this study such as oil and gas and thus contributes significantly to the overall raw material consumption requirements for the cellulose insulation system. Open cell Enertite® uses significantly less resources compared to the fiberglass and cellulose alternatives due to its enhanced air barrier performance and energy efficiency. Each of the four Spraytite® spray polyurethane foam (spf) insulation systems use the least amount of resources due to having the highest overall energy efficiency (high insulating value {R-value} and extremely low air infiltration rate).

Per the BASF EEA Methodology, individual raw materials are weighted according to their available reserves and current consumption profile. These weighting factors are appropriate considering the context of this study. A summary of the key raw material consumption by type for each alternative is shown below in Figure 10.

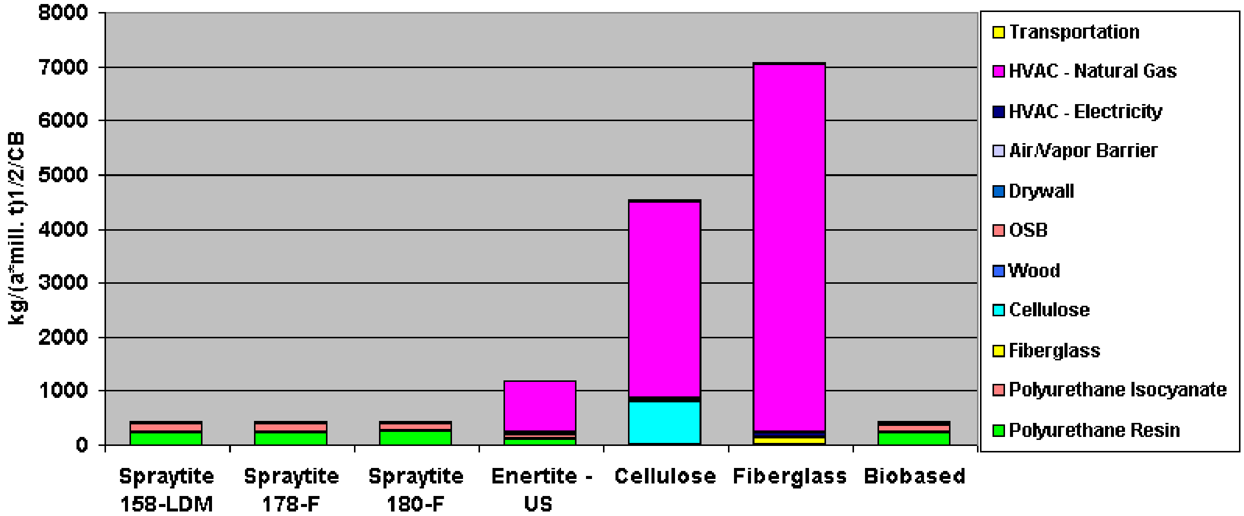

Figure 9. Raw Material consumption by Module.

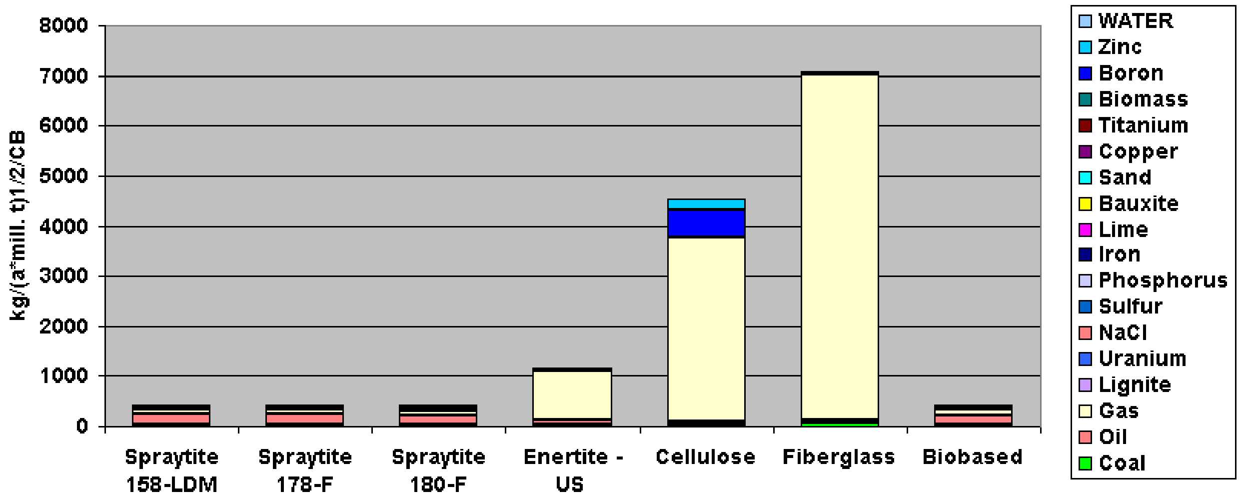

Figure 10. Raw Material consumption by Type.

8.1.3. *Air Emissions*:

8.1.3.1. *Greenhouse Gas Emissions (GHG)*: The global warming potential of the various greenhouse gases (CO_2, CH_4, N_2O, blowing agents) emitted into the atmosphere during the various life cycle stages considered were calculated. Figure 11 shows that the highest carbon footprint occurred in the fiberglass insulation, with a measurement of nearly 86,200 kg of CO_2 equivalents per customer benefit. The lowest carbon footprint, with respect to the other alternatives, is for the Enertite® open cell spray foam insulation, which results in emissions of around 12,800 kg of CO_2 equivalents per customer benefit, 85% less than fiberglass. The four closed cell spray foams averaged around 21,500 kg of CO_2 equivalents, a reduction of 75% relative to fiberglass. The GHG emissions for the closed cell spray foams are mostly attributed to the GWP of the blowing agent. The blowing agent contributes almost 95% to the greenhouse gas emissions for the closed cell spray foams. However, you need to take into consideration that for the base case analysis, only differences in energy consumption during the use phase of the life cycle were considered, thus there were little to no GHG emissions related to the use of the HVAC system for the closed cell spray foams, which where the most efficient insulating system and thus had the lowest energy consumption of all alternatives. When you consider the absolute energy consumption of the residential home over the life cycle considered as shown in Figure 12 below, the blowing agent for the closed cell spray foams only contributes about 3% to the overall carbon footprint or GHG emissions. For the remaining alternatives and as to be expected, the GHG emissions are primarily a result of energy required for heating and cooling the home over its lifetime.

Land use changes related to the bio-based content in the bio-based SPF and its impact on the GHG emissions for this alternative was not considered significant enough to include in this analysis.

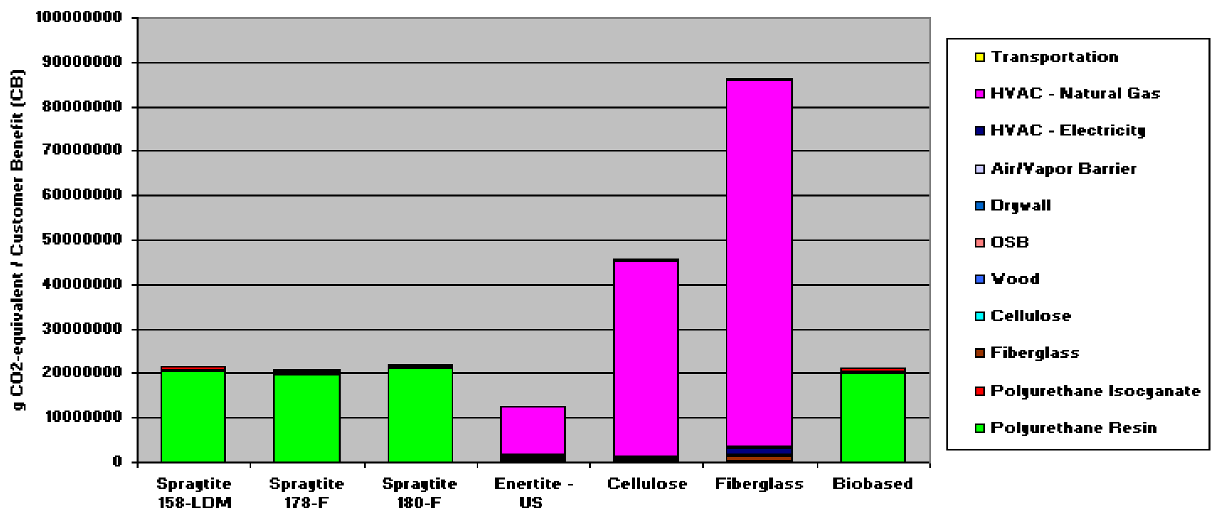

Figure 11. Greenhouse Gas Emissions (relative energy consumption values).

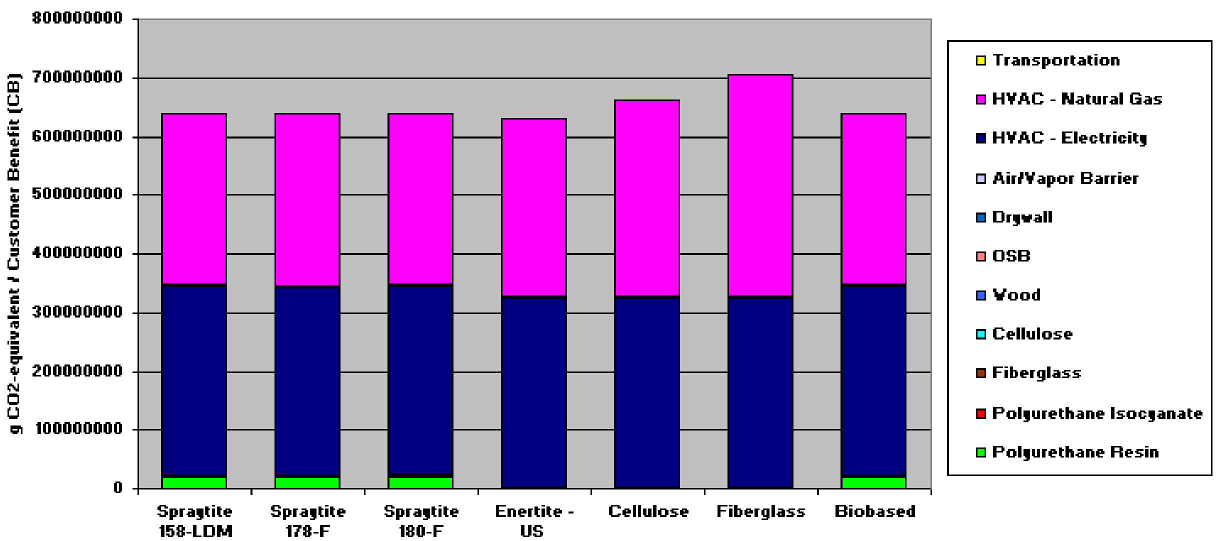

Figure 12. Greenhouse Gas Emissions (absolute energy consumption values).

8.1.3.2. *Photochemical ozone creation potential (smog)*: POCP emissions are generated from both methane and non-methane VOC emissions emitted from the different modules considered. The lowest emissions for ground level ozone creation potential occurs in the Spraytite® 180F alternative, with 1,280 g of ethene equivalents emitted per customer benefit. The largest photochemical ozone creation potential occurs in the fiberglass insulation, with a measurement of 31,900 g of ethene equivalents per customer benefit. Figure 13 indicates that the natural gas energy consumed by the HVAC system over the lifetime of the study has the largest impact on POCP.

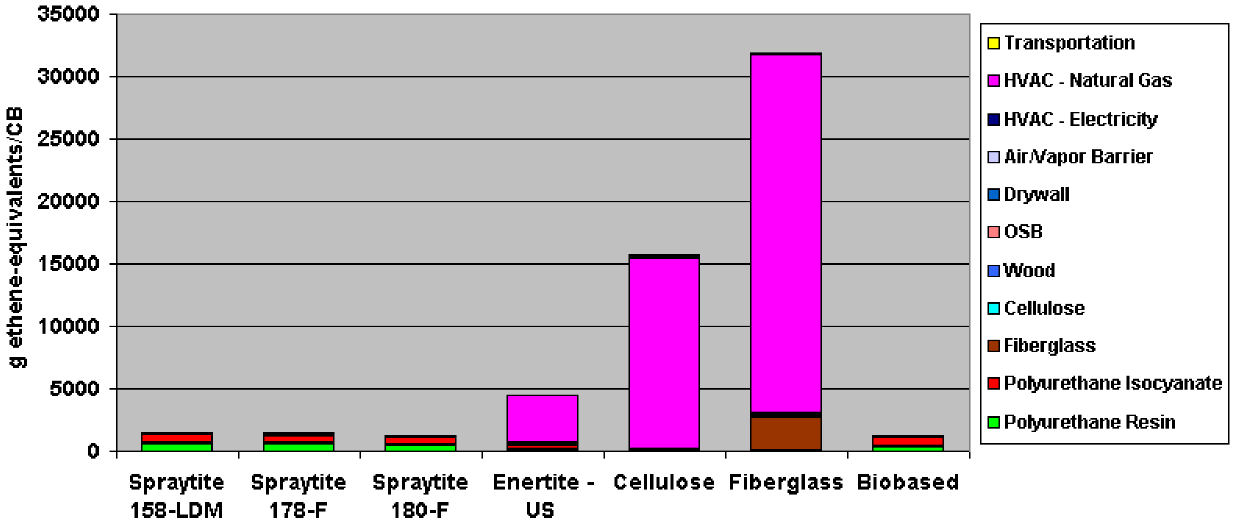

Figure 13. Photochemical ozone creation potential.

8.1.3.3. *Ozone depletion potential (ODP)*: All of the alternatives result in a minimal ozone depletion potential, measured in a range from 0.016 - 2.789 g CFC equivalents per CB. As indicated in Figure 14, ODP mostly comes from the pre-chain chemistries involved in the isocyanate manufacturing process, a main component in both the Enertite® and Spraytite® alternatives. No CFC or HCFC blowing agents were used in any of the alternatives. Overall, all seven of the alternatives result in very minimal ODP. It accounts for less than 2% of the total environmental impact for each of the insulation systems.

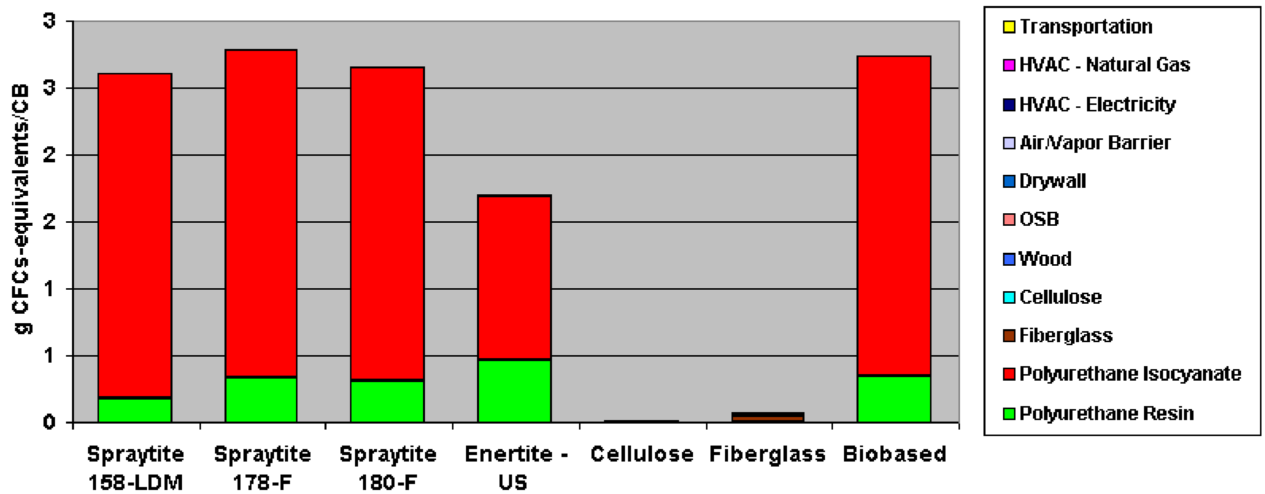

Figure 14. Ozone depletion potential.

8.1.3.4. *Acidification potential (AP)*: It can be seen from Figure 15 that overall, Spraytite® 180F has the lowest acidification potential over the entire life cycle, with emissions of 16,400 g of SO_2 equivalents per customer benefit. Fiberglass has the highest acidification potential, with emissions of 648,000 g of SO_2 equivalent per customer benefit. Since Newark, NJ is primarily a heating dominated zone, AP can mainly be attributed to the NO_x and SO_x generated from the energy required to heat the home over the life cycle.

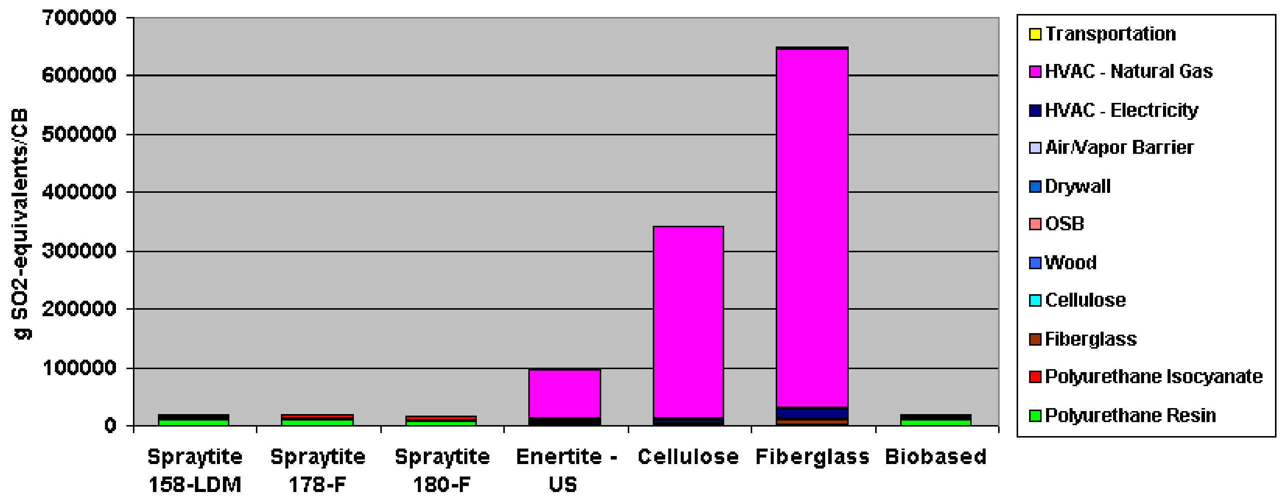

Figure 15. Acidification potential.

8.1.4. *Water emissions*: Figure 16 displays that relative to the other alternatives, the cellulose insulation has the lowest critical waste water volume requirement at 7,858 L/CB. The biobased insulation has the largest critical waste water volume requirement at 641,168 L/CB. Water emissions are high for the spray polyurethane foams due to the BOD and COD emissions from the isocyanate and resin production processes used in the manufacturing of the foams.

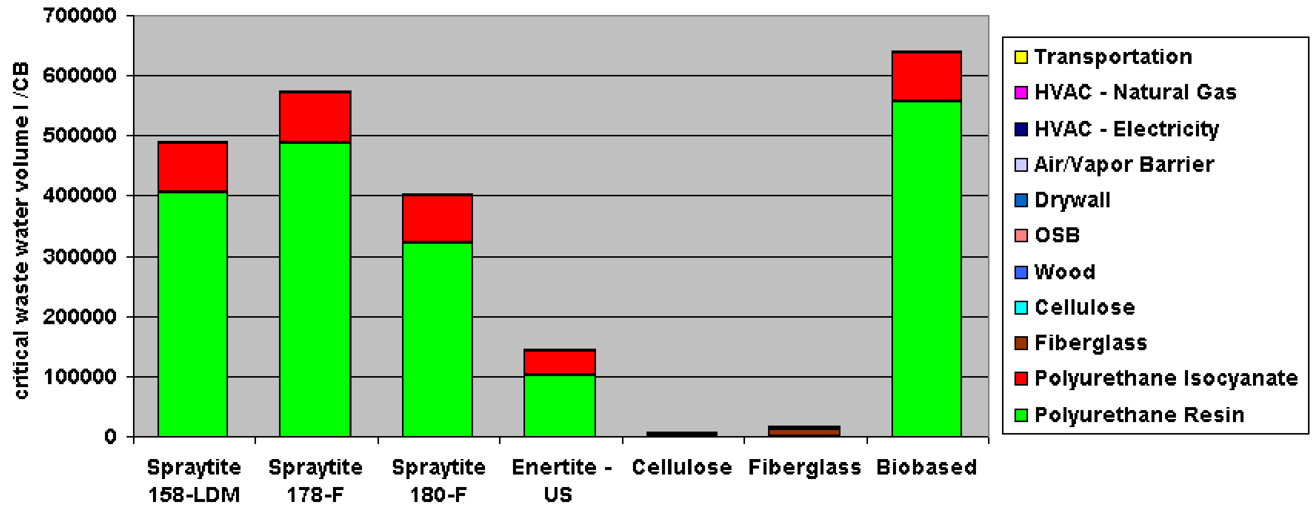

Figure 16. Water emissions.

8.1.5 *Solid waste generation*: Solid waste emissions generated over the life cycle stages of each alternative, including the end of life disposal of each insulation system, is depicted in Figure 17. The Cellulose insulation generates a net reduction in solid waste emissions as it is mostly manufactured from recycled content (newsprint) and thus credited for a reduction in municipal waste generation. Solid waste emissions for the other alternatives are primarily a result of special/hazardous materials sent to landfill during the manufacturing of the insulation materials.

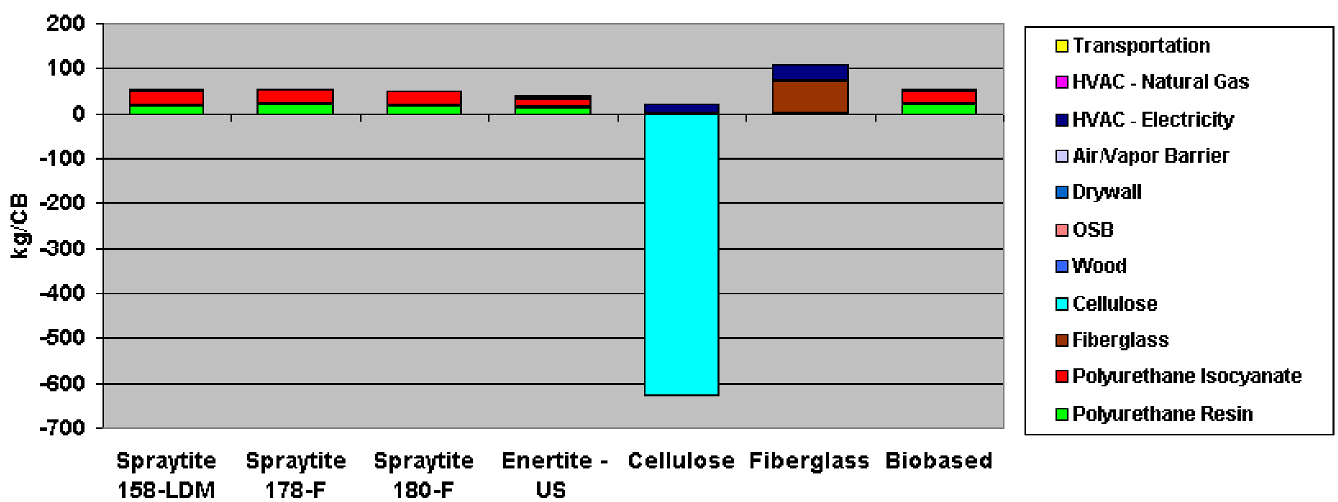

Figure 17. Solid waste generation.

8.1.6 *Land use*: As displayed in 18, the Spraytite® 180F insulation uses 96% less land on a weighted basis than the fiberglass insulation over their respective life cycles. Land impacts of energy generation, distribution and usage for heating the home is the most significant contributor. Land categories specifically impacted by energy generation and usage are developed land and those defined by covered and divided. The differences in land use between each alternative is based more on the differences in energy consumption rather than any unique differences in any of the individual land use categories. The renewable based raw material in the biobased closed cell SPF has an expected high contribution to the land use impact for the urethane resin.

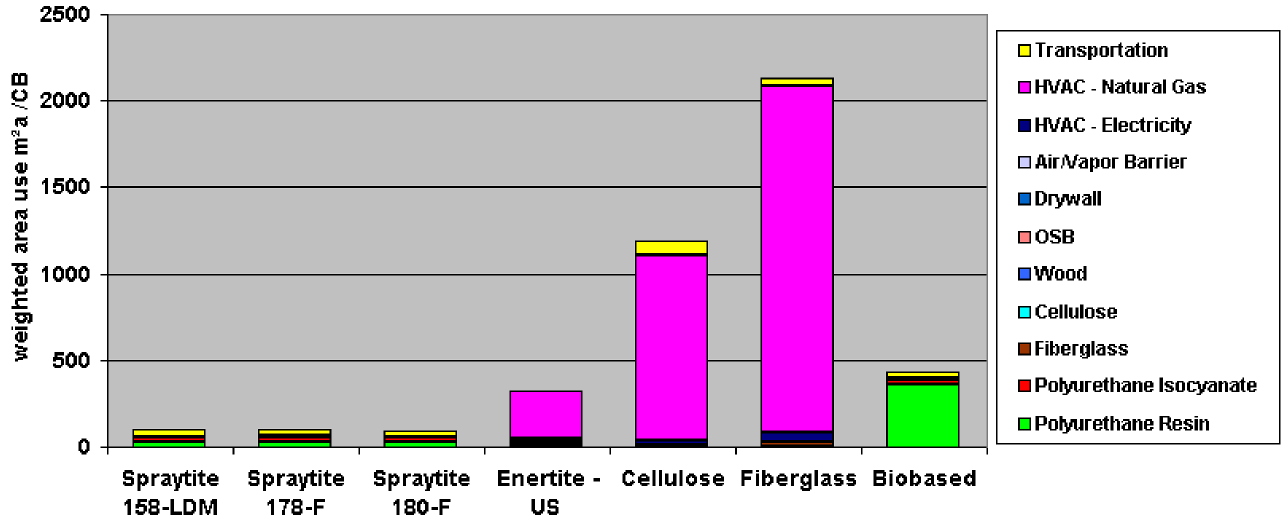

Figure 18. Land use.

8.1.7 *Toxicity potential*: The toxicity potential for the various insulation alternatives was analyzed for the production, use and disposal phases of their respective life cycles. For the production phase, not only were the final products considered but the entire pre-chain of chemicals required to manufacture the products were considered as well. No human health potential exists in the use phase as the only impacts come from the energy consumption during the heating & cooling of the home (zero toxicity potential score for these activities). Toxicity potential in the disposal phase comes from the removal and transport of the materials to a landfill.

Inventories of all relevant materials were quantified for the three life cycle stages. Consistent with our methodology's approach for assessing the human health impact of these materials (ref. Section 6.8 of Part A submittal), a detailed scoring table was developed for each alternative broken down per life cycle stage (Figures 19 and 20). This scoring table with all relevant material quantities considered as well as their R-phrase and pre-chain toxicity potential scores were provided to NSF International as part of the EEA model which was submitted as part of this verification. As displayed in Figure 19 below, the insulation material contributes the largest amount to the toxicity potential during the production phase of the life cycle. Spraytite® 178-F has the highest toxicity potential. The highest toxicity potential in the production phase can be attributed to the pre-chains used to produce the various insulation materials, particularly the resin and isocyanate from the spray polyurethane foams. Fiberglass has the lowest toxicity potential and Enertite® has the lowest toxicity potential of all SPFs due to its low product density. A high safety standard was assumed during the production phase of the raw materials.

Figure 20 shows that transportation of the construction materials after the home is demolished has a significant impact on health effect potential during the disposal phase. Heavier systems use more fuel for transport, resulting in higher health effect potential. In addition, as all insulation materials have relatively the same health effect potential, insulation materials will have a higher impact if more insulation is required to be removed. Cellulose has the heaviest alternative scores the highest while Enertite®, the lightest, has the lowest impact.

No reduction in the scores based on exposure conditions was applied for the disposal phase of the materials as the potential for human contact during removal and disposal of the insulation is high. Finally, the toxicity potential weightings for the individual life cycle phases were production (20%), use (70%) and disposal (10%). These standard values were not modified for this study.

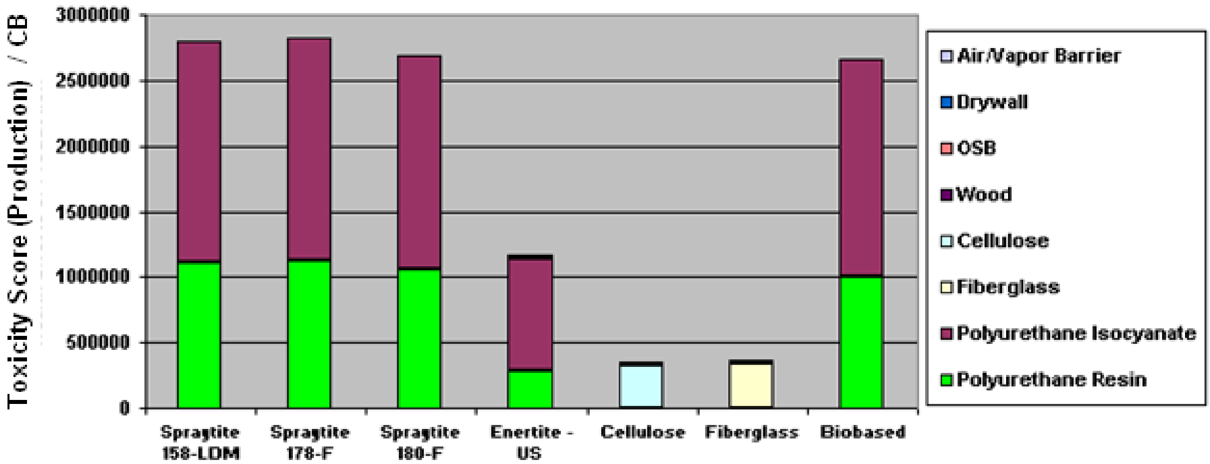

Figure 19. Toxicity potential – Production Phase (Materials)

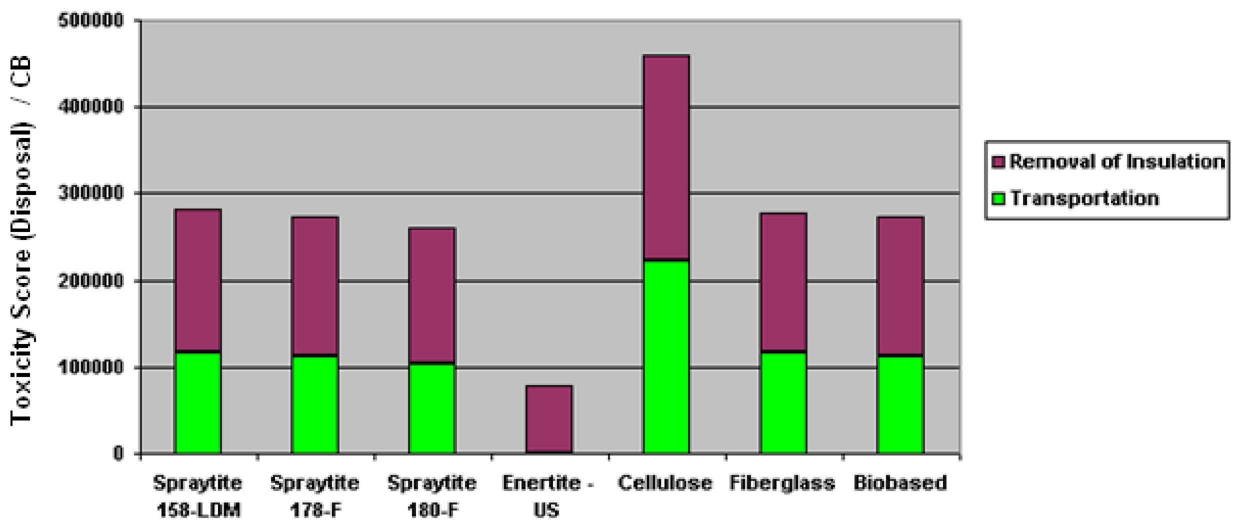

Figure 20. Toxicity potential-Disposal Phase

8.1.8. *Risk (Occupational Illnesses and Accidents potential)*:
All the materials and activities accounted for in the various life cycle stages were assigned specific NACE codes. NACE (Nomenclature des Activities Economiques)

is a European nomenclature which is very similar to the NAICS codes in North America. The NACE codes are utilized in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the business economy and is broken down by specific industries. Specific to this impact category, the NACE codes track, among other metrics, the number of working accidents, fatalities and illnesses and diseases associated with certain industries (e.g. chemical manufacturing, agriculture, etc.) per defined unit of output. By applying these incident rates to the amount of materials required for each alternative, a quantitative assessment of risk is achieved.

In Figure 21, the greatest occupational illnesses and accident potential occurs for the fiberglass system, which arises directly from the production and use of the natural gas and electricity for the HVAC systems. In addition, there is a high risk potential attributed to the manufacturing of the insulation material. The cellulose insulation has the lowest occupational illnesses and accident potential specific to the insulation material. Enertite®, which has the lowest overall occupational illnesses and accident potential, benefits from its low product density and good energy efficiency. The closed cell Spraytite® and biobased alternatives are similar in their occupational illnesses and accident potential and slightly higher in risk than the Enertite®. This is driven primarily by the higher insulation density and thus higher material requirements. Figure 22 shows occupational illnesses and disease contributes the largest to the overall risk category. The closed cell SPFs are the only alternatives that are classified by FEMA (Federal Energy Management Agency) as being highly resistant to flood water damage and thus performed better than the other alternatives in this risk category. This study put a 10% weighting on this additional risk category (Flood/Water Damage/Mold) which was at the midpoint of the range (0-20%) that additional risk categories can have. Resistance to storms and weather damage during the use phase of the home was assumed to be the same for all alternatives. Though not considered, when properly installed, closed cell spray polyurethane foams can offer improved structural strength and wind resistance when compared to conventional insulation alternatives.

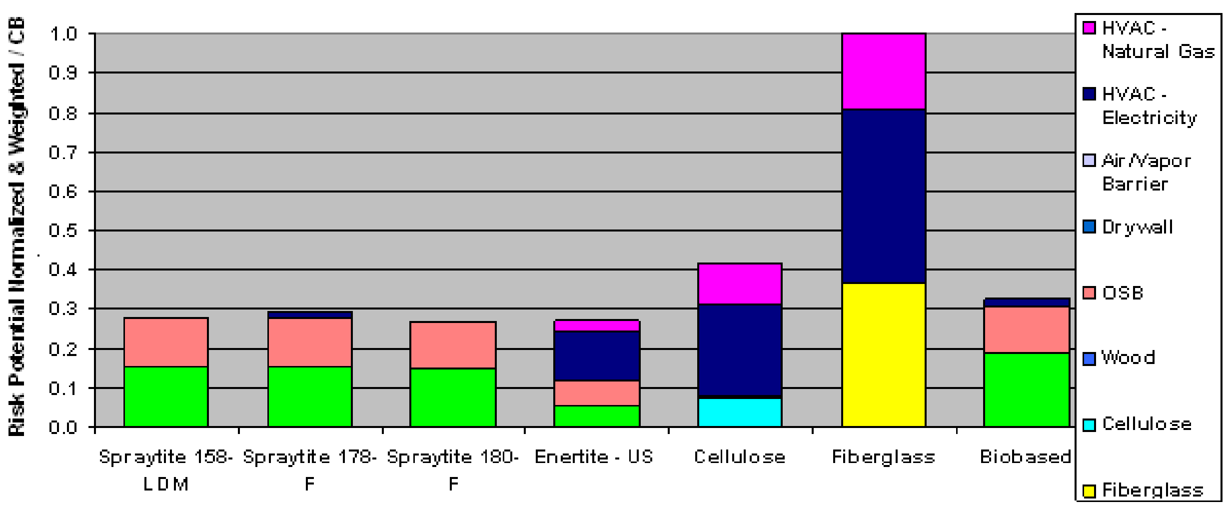

Figure 21. Risk Potential (module)

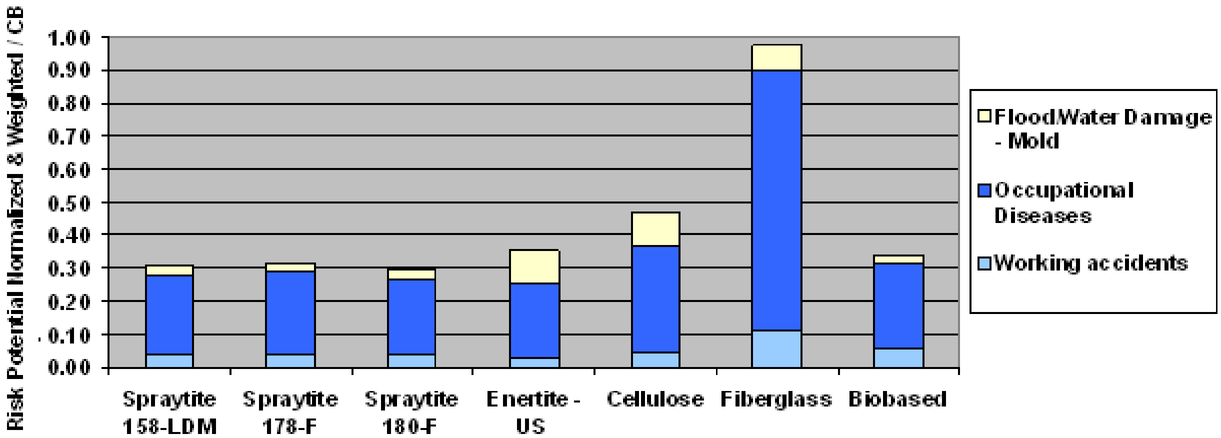

Figure 22. Risk Potential (risk factor)

8.1.9. *Environmental fingerprint*: Following normalization, or normalization and weighting with regards to emissions, the relative impact for all six of the environmental categories each alternative is shown in the environmental fingerprint (Figure 23). Fiberglass insulation system has the highest environmental impact in all categories except for toxicity potential, where it has the lowest impact. Though fiberglass has a whole wall R value that is similar to the other alternatives, the higher air infiltration rate contributes to a significantly higher consumption of fuel and electricity for heating and cooling over the lifetime of the home. Regarding Risk (occupational illnesses and accident) potential, fiberglass is the highest due to its high utility consumption. Cellulose insulation also has high environmental impact in all categories except for toxicity potential. Though better than fiberglass, the higher air infiltration rate relative to the SPF alternatives plays a significant role in higher fuel and electricity consumption. Each of the three closed cell Spraytite® spray polyurethane foam (spf) alternatives have the lowest overall environmental impact in energy use, resource consumption and land use and scores well in risk potential and emissions. They have the lowest air infiltration rates, which lead to the Spraytite® spray polyurethane foam (spf) insulation being the most energy efficient alternatives. The isocyanate content contributes to these alternatives having the highest toxicity potential. The biobased alternative performs similar to the other Spraytite® alternatives in all aspects except for land use, in which it performs worse; this is due to the land requirements for its renewable content. The open cell Enertite® has the lowest environmental impact in risk potential and emissions and scores well in toxicity potential and energy and resource consumption. Its low air leakage rate, combined with its high whole wall R-value, leads to low fuel and electricity consumption for HVAC, the main environmental impact for this study. It also has a light system weight resulting in low impact on the production of construction materials.

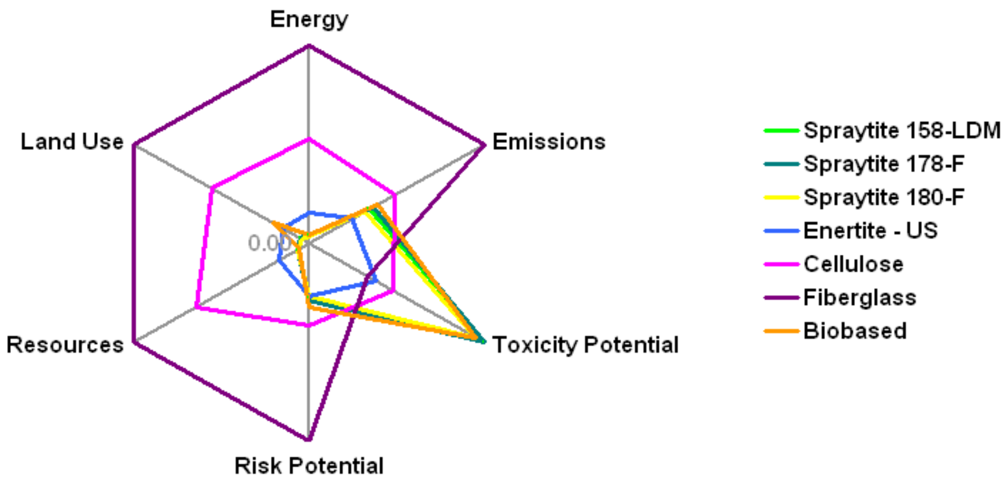

Figure 23. Environmental fingerprint.

8.2. *Economic Cost Results*: The life cycle cost data for the study are generated as defined in Section 7 of the BASF EEA methodology and described in section 6.3 above. The results of the life cycle cost analysis found that the fiberglass alternative has the highest life cycle costs and the alternative with the lowest life cycle cost is Enertite®. Though it has the lowest installed cost, cellulose has a higher life cycle cost than any of the SPF alternatives. From Table 10 and Figure 24, it is clear that the utilities costs are the overwhelming driver of the total cost for each alternative. Life cycle utility costs reflect the absolute costs of the electricity and natural gas consumption over the 60 years of living in the home. It correlates that the alternatives which are less energy efficient (e.g. fiberglass) and have higher energy (e.g. HVAC) requirements over the life cycle of the home (see Figure 8) also have the higher lifetime utility costs.

Table 10: Life cycle costs

Item Costs	Spraytite® 158-LDM	Spraytite® 178-F	Spraytite® 180-F	Enertite® - US	Cellulose	Fiberglass	Biobased (closed cell)
Initial wall framing cost ($/CB)	0	0	0	0	0	0	0
Initial wall insulation cost ($/CB)	1,343	1,322	1,281	932	369	565	1,322
Initial roof insulation cost ($/CB)	6,445	6,330	6,100	4,032	1,903	2,442	6,330
Air / Vapor barrier cost ($/CB)	0	0	0	684	684	684	0
Initial HVAC cost ($/CB)	10,553	10,553	10,552	10,650	10,877	11,154	10,553
HVAC replacement ($/CB)	13,776	13,776	13,776	13,904	14,198	14,562	13,776
Utilities ($/CB)	79,120	79,120	79,120	80,552	84,416	89,114	79,120
Differential Transportation Costs ($/CB)	17	16	15	0	32	17	16
Differential Disposal Costs ($/CB)	28	27	25	0	56	29	27
Total Life Cycle Costs ($/CB)	**111,281**	**111,144**	**110,869**	**110,753**	**112,536**	**118,567**	**111,144**

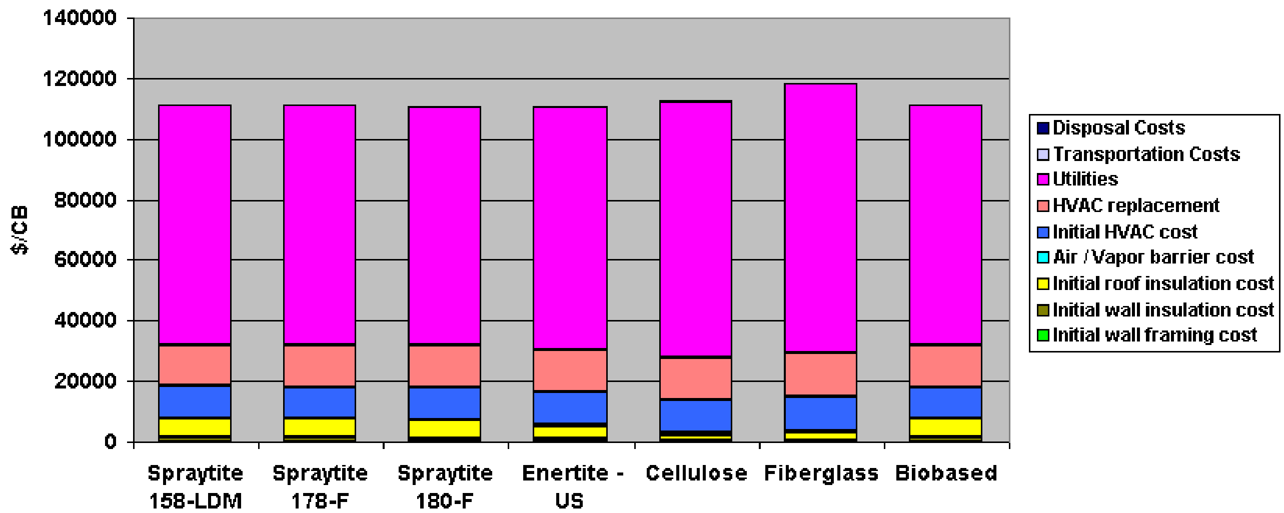

Figure 24. Life cycle costs.

8.3. *Eco-Efficiency Analysis Portfolio*: The eco-efficiency analysis portfolio for the Residential Insulation EEA has been generated as defined in Section 9.5 of the BASF EEA methodology. Utilizing relevance and calculation factors, the relative importance of each of the individual environmental impact categories are used to determine and translate the fingerprint results to the position on the environmental axis for each alternative shown. For a clearer understanding of how weighting and normalization is determined and applied, please reference Section 8 of BASF's Part A submittal to P-352. Specific to this study, the worksheets "Relevance" and "Evaluation" in the EEA model provided to NSF as part of this verification process should be consulted to see the specific values utilized and how they were applied to determine the appropriate calculation factors. Specific to the choice of environmental relevance factors and social weighting factors applied to this study, factors for the USA (national average) were utilized. The environmental relevance values utilized were last reviewed in 2007 and the social weighting factors were recently updated in 2009 by an external, qualified third party[10].

Figure 25 displays the eco-efficiency portfolio, which shows the results when all six individual environmental categories are combined into a single relative environmental impact and combined with the life cycle cost impact. Because environmental impact and cost are equally important, the most eco-efficient alterative is the one with the largest perpendicular distance above the diagonal line and the results from this study find that Enertite® is the most eco-efficient alternative due to its combination of lower environmental burden and having the lowest life cycle cost. The four Spraytite® alternatives are closely related to each other in eco-efficiency and slightly less than Enertite®. The fiberglass alternative is the least eco-efficient followed by the cellulose alternative.

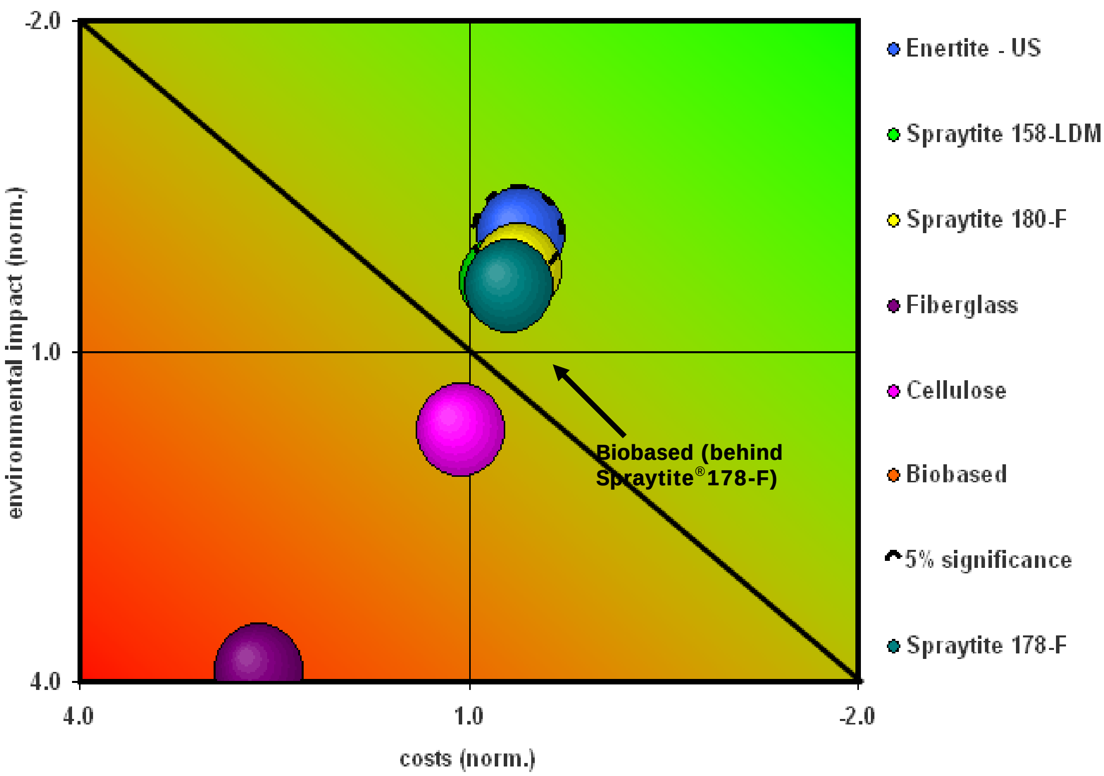

Figure 25. Eco-Efficiency portfolio for Newark, NJ (Base Case).

8.4. *Scenarios:* The locations considered for the different scenarios were Tampa, Florida, Phoenix, Arizona and Minneapolis, Minnesota. The design parameters adjusted for each scenario were the regional utility pricing (electricity and natural gas), regional material and building costs, climate data used for energy modeling, and the building insulation requirements. A brief summary of the scenario analyses with corresponding eco-efficiency portfolio are provided below. More detailed results, similar to what was presented above for the base case analysis, are available in the study Appendix and can be made available by request to NSF International.

8.4.1. *Scenario #1: Tampa, Florida:* Scenario #1 has the lowest overall energy consumption for all locations considered. As shown in Figure 26, Enertite® improves its eco-efficiency relative to the base case (Newark, NJ). Energy consumption switches from a heating dominated zone to a cooling dominated zone. In terms of the relevance and calculation factors relative to base case, there is a lower weighting on air emissions with increases in solid waste and water emissions. There is also a higher weighting on AP and lower on POCP. This is expected due to the increase in electricity consumption for air conditioning. This scenario has the lowest utility and overall life cycle costs. With lower overall utility costs, the initial installation costs have a more significant impact, thus resulting in improved positions for open cell Enertite®, cellulose, and fiberglass relative to the Spraytite® alternatives. The Spraytite® alternatives and the cellulose alternative are of equivalent eco-efficiencies. Cellulose has a lower life cycle cost while the Spraytite® alternatives have the lower environmental burden, relative to cellulose.

For this scenario and relative to the absolute HVAC loads, the Spraytite® home was about 2% more energy efficient than Enertite®, 3% more efficient than cellulose and 6% more efficient than the fiberglass alternative.

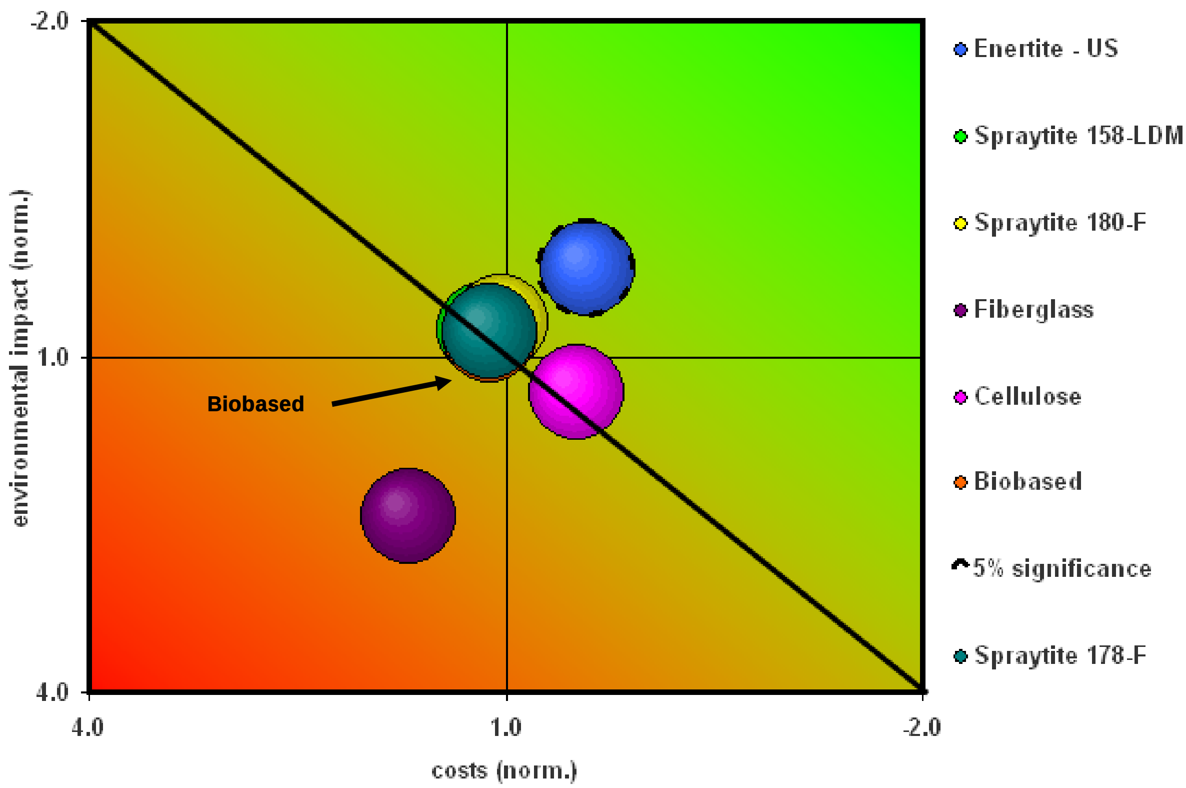

Figure 26. Eco-efficiency Portfolio for Tampa, Florida

8.4.2. S*cenario #2: Phoenix, Arizona:* Though not as significant an impact as in Scenario #1, this scenario has a lower utility and overall energy consumption requirement than the base case. Energy consumption switches from heating dominated to cooling dominated in this zone. The city cost index is significantly lower than Newark, NJ thus lowering the initial installation costs for the insulation systems. Figure 27 shows that the open cell Enertite® is less eco-efficient relative to the base case with specific improvements to the Spraytite® alternatives, which have the lowest overall life cycle costs. The Spraytite® 180-F alternative is now as eco-efficient as Enertite®.

For this scenario and relative to the absolute HVAC loads, the Spraytite® home was about 1% more energy efficient than Enertite®, 4% more efficient than cellulose and 7% more efficient than the fiberglass alternative.

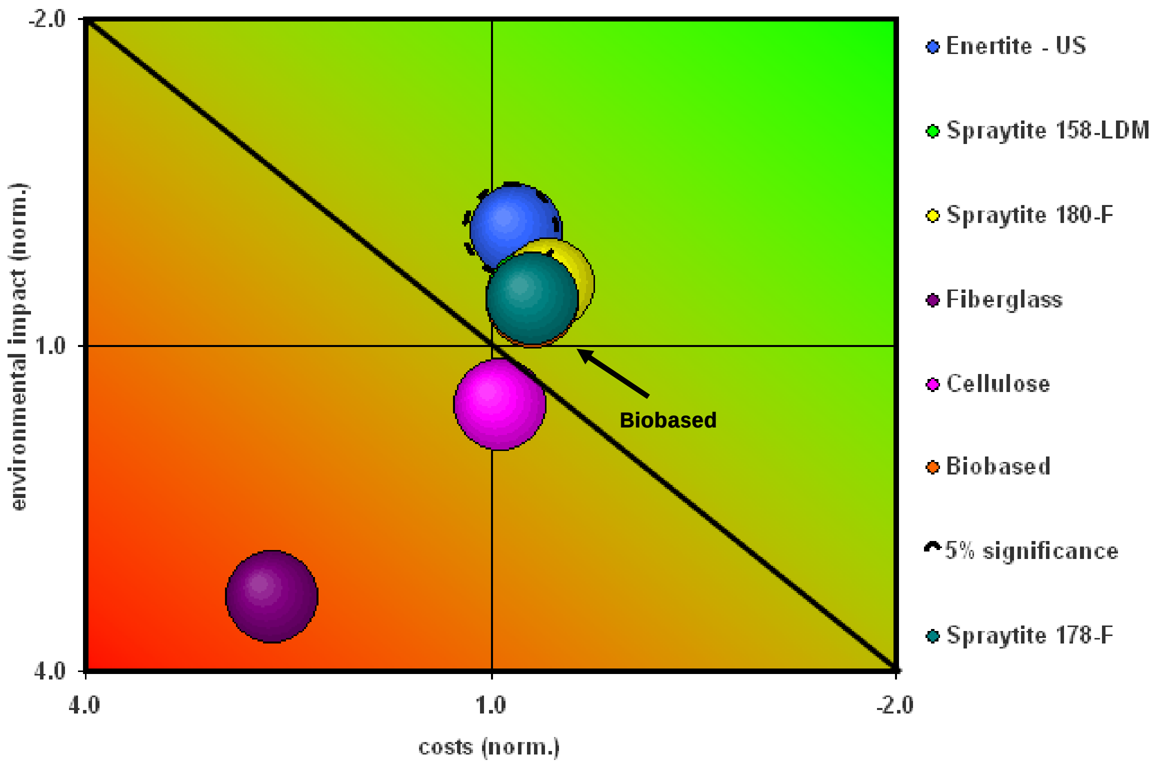

Figure 27: Eco-efficiency Portfolio for Phoenix, Arizona

8.4.3. *Scenario #3: Minneapolis, Minnesota:* This scenario has the largest utility consumption of all the locations analyzed. Figure 28 shows that all the spray foam alternatives (open and closed) have similar eco-efficiencies. Cellulose and the fiberglass alternatives are still less eco-efficient that the spray foams. The Spraytite® formulation is the only alternative that can achieve the R-19 building code in 2x4 construction. The Spraytite® insulation benefits from cost and material savings in installing 2"x4" vs. 2"x6" framing. The relevance and calculation factors are similar to that of the base case. This scenario has a higher overall and energy life cycle costs.

For this scenario and relative to the absolute HVAC loads, the Spraytite® home was about 2% more energy efficient than Enertite®, 12% more efficient than cellulose and 26% more efficient than the fiberglass alternative.

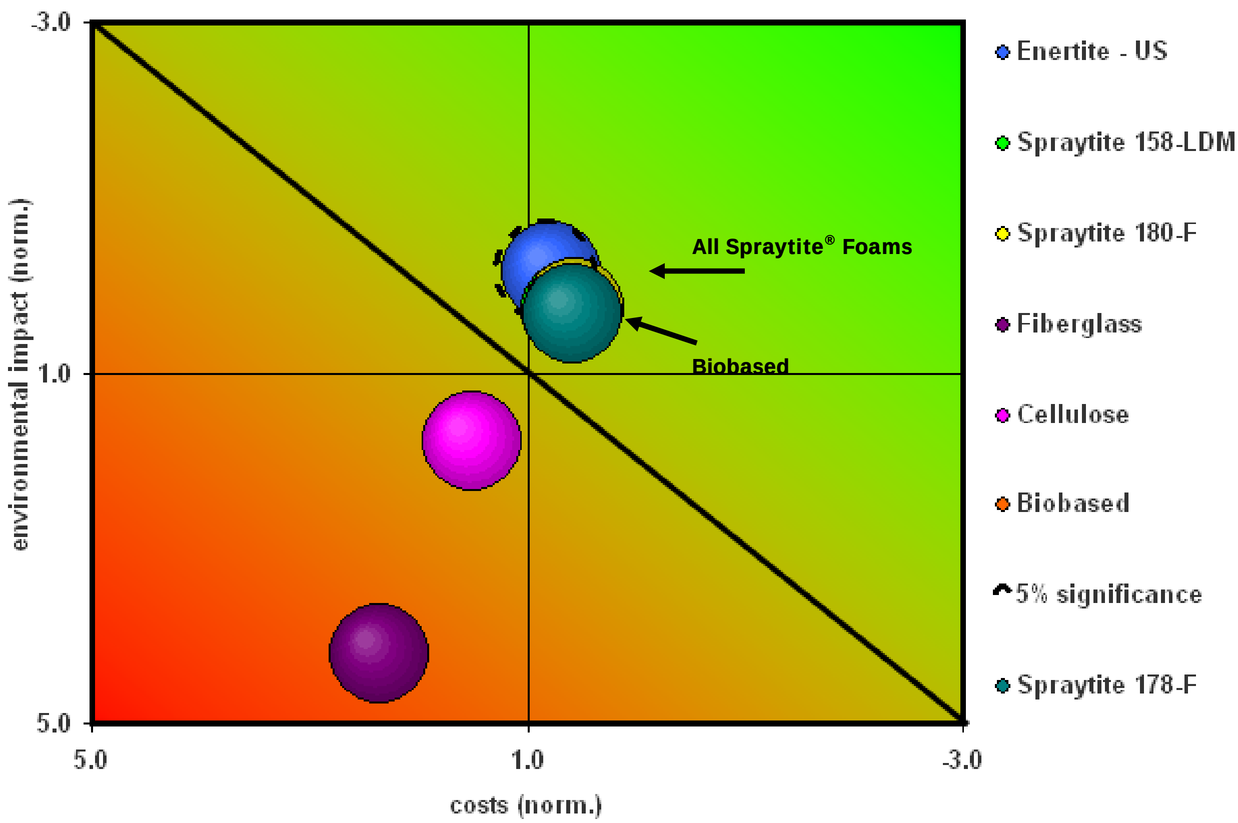

Figure 28: Eco-efficiency Portfolio for Minneapolis, Minnesota

9. Data Quality Assessment

11.1. *Data Quality Statement*: The data used for parameterization of the EEA was sufficient with most parameters of high data quality. Moderate data is where industry average values or assumptions pre-dominate the value. No critical uncertainties or significant data gaps were identified within the parameters and assumptions that could have a significant effect on the results and conclusions. The Eco-profiles utilized were deemed of sufficient quality and appropriateness. Table 11 provides a summary of the data quality for the EEA.

Table 11: Data quality evaluation for EEA parameters.

Parameter	Quality Statement	Comments
Insulation Parameters		
Spraytite® SPF Formulation	High	Known formulation. Many eco-profiles were developed specifically for this study and are based on current technologies and company data.
Enertite® Insulation Formulations	High	Known formulation. Many eco-profiles were developed specifically for this study and are based on current technologies and company data.
Alternate Insulation Formulations	Moderate-High	Average. Industry data and specific product technical data sheets ad MSDSs. Assumed values are reasonable given study context and goals.
Additives Formulations	Moderate-High	Assumed values are reasonable given study context and goals
R-Values	High	Measured or supplier provided data
Assembly Design and Components	High	Standard components per industry/building code requirements.
Air Barrier System Materials	High	Supplier information
Waste Parameters		
Disposal method	High	Assumed method and values are reasonable given study context and goals.
Transportation Distances		Assumed values are reasonable given study context and goals.
Distance and fuel consumption	Moderate	Assumed values are reasonable given study context and goals.
Utility Consumption	High	Energy-10™ Modeling
Costs		
Insulation and Membrane Material and Installation	High	Current prices for region of study. Obtained from BASF and third party suppliers
Utilities	High	Current price for region of study; Government data
Fuel	High	Current price for region of study
Material Disposal	Moderate-High	RS Means. Building and construction cost data

10. Sensitivity and Uncertainty Analysis

11.1. *Sensitivity and Uncertainty Considerations:*

A sensitivity analysis of the final results indicates that the environmental impacts were more influential or relevant in determining the final relative eco-efficiency positions of the alternatives. This conclusion is supported by reviewing the BIP relevance (or GDP-relevance) factor calculated for the study. The BIP Relevance indicates for each individual study whether the environmental impacts or the economic impacts were more influential in determining the final results of the study. For this study, the BIP relevance indicated that the environmental impacts were significantly more influential in impacting the results than the economic impacts (reference the “Evaluation” worksheet in the Excel model for the BIP Relevance calculation). The main assumptions and data related to environmental impacts were:

- R-values and Air Infiltration Data
- Energy Modeling
- Material take-offs

As the data quality related to these main contributors was of high quality, this strengthened our confidence in the final conclusions indicated by the study. A closer look at the analysis and depicted in Figure 28 indicates that the impact with the highest environmental relevance was energy followed by emissions, resource consumption, and toxicity potential. This is to be expected, as the energy consumption defined by our customer benefit drives the overall study results. Air emissions are by far the most important in the emissions category. More specifically, GWP and AP are considered the two most important factors. The calculation factors shown in Figure 30 which considers both the social weighting factors (Figure 29) and the environmental relevance factors, indicate which environmental impact categories were having the largest effect on the outcome as reflected in the portfolio. The impacts with the highest calculation factors were the same as those with the highest environmental relevance factors, which is often the case. The input parameters that were related to these impact categories have sufficient data quality to support a conclusion that this study has a low uncertainty.

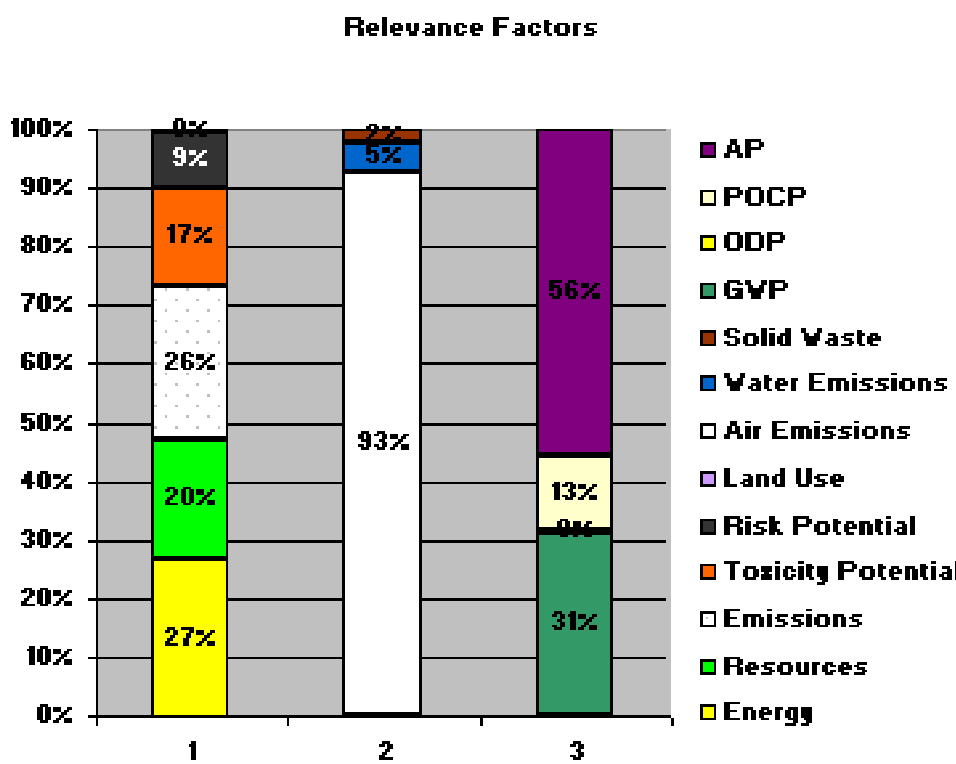

Figure 28. Environmental Relevance Factors used in the sensitivity and uncertainty analyses.

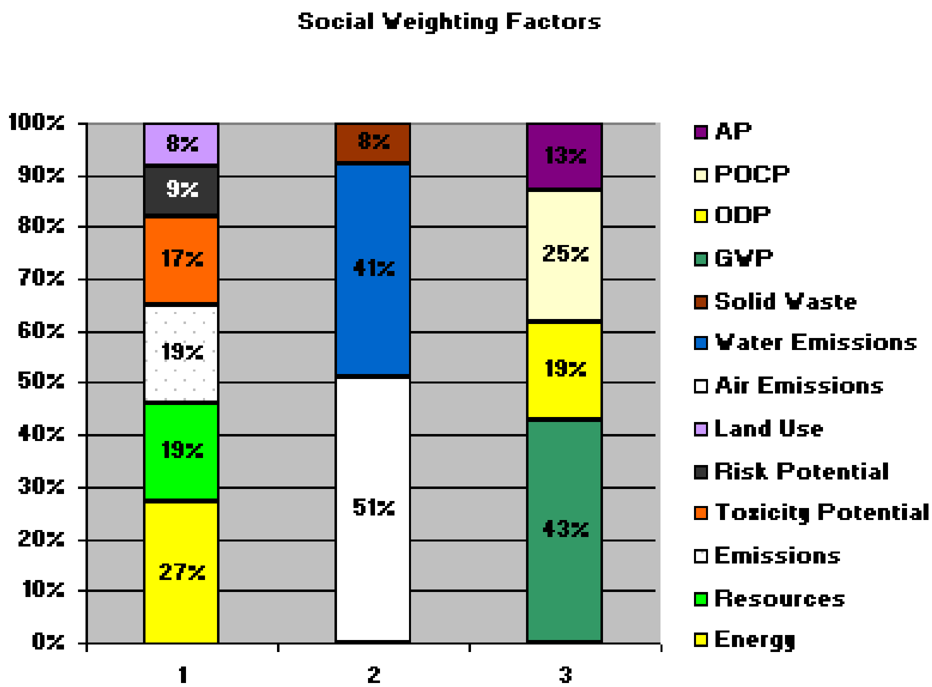

Figure 29. Social Weighting Factors.

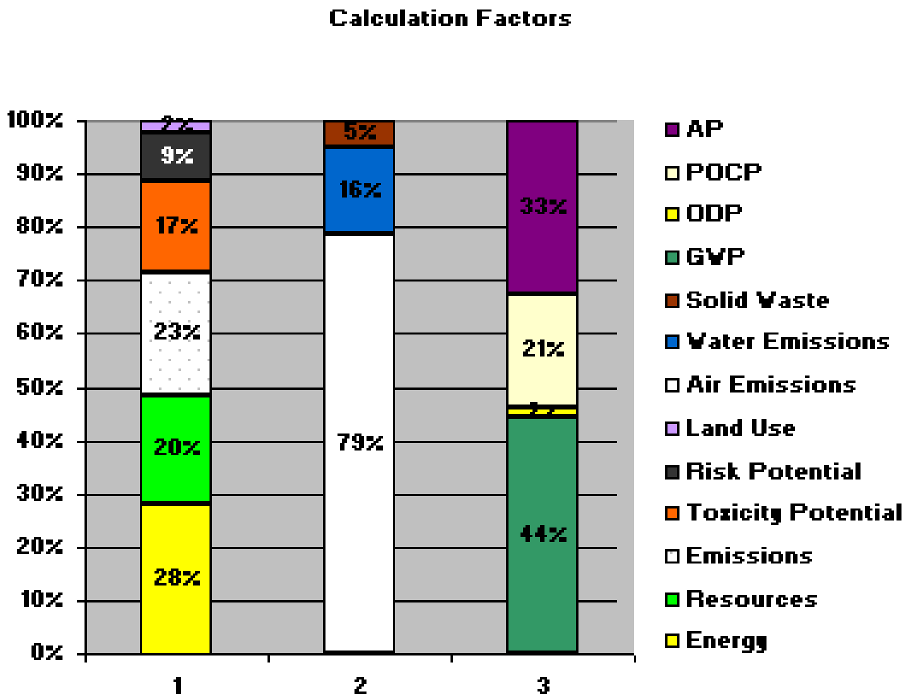

Figure 30. Calculation Factors used in the sensitivity and uncertainty analyses.

11.2. *Critical Uncertainties:* There were no significant critical uncertainties or data gaps from this study that would limit the findings or interpretations of this study. The data quality, relevance and sensitivity of the study support the use of the input parameters and assumptions as appropriate and justified.

11. Limitations of EEA Study Results

11.1. *Limitations*: These eco-efficiency analysis results and its conclusions are based on the specific comparison of the production, use, and disposal, for the described customer benefit, alternatives and system boundaries. Transfer of these results and conclusions to other production methods or products is expressly prohibited. In particular, partial results may not be communicated so as to alter the meaning, nor may arbitrary generalizations be made regarding the results and conclusions.

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