Spray Polyurethane Foam Insulation Products

EPD Background Report

On behalf of Spray Polyurethane Foam Alliance

Client:	**Spray Polyurethane Foam Alliance**
Title:	**Life Cycle Assessment of Spray Polyurethane Foam Insulation**
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On behalf of thinkstep AG and its subsidiaries

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List of Acronyms

2K-LP	2-Component, Low Pressure Spray Foam
ADP	Abiotic Depletion Potential
AP	Acidification Potential
CML	Centre of Environmental Science at Leiden
CPI	Center for the Polyurethanes Industry
EoL	End-of-Life
EP	Eutrophication Potential
FU	Functional Unit
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
ILCD	International Cycle Data System
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-Methane Volatile Organic Compound
ODP	Ozone Depletion Potential
PCR	Product Category Rules
POCP	Photochemical Ozone Creation Potential
SFP	Smog Formation Potential
SPF	Spray Polyurethane Foam
TCPP	Tris(1-chloro-2-propyl) phosphate
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
VOC	Volatile Organic Compound

Glossary

Life cycle

A view of a product system as “consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal” (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

“Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)

“Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle” (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)

“Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product” (ISO 14040:2006, section 3.4)

Life cycle interpretation

“Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations” (ISO 14040:2006, section 3.5)

Functional unit

“Quantified performance of a product system for use as a reference unit” (ISO 14040:2006, section 3.20)

Allocation

“Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems” (ISO 14040:2006, section 3.17)

Closed-loop and open-loop allocation of recycled material

“An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.”

“A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials.”

(ISO 14044:2006, section 4.3.4.3.3)

Foreground system

“Those processes of the system that are specific to it … and/or directly affected by decisions analyzed in the study.” (JRC 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background system

“Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good….” (JRC 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Critical Review

“Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment” (ISO 14044:2006, section 3.45).

1. Goal of the Study

Spray Polyurethane Foam Alliance (SPFA) is recognized as the leading advocate for the spray polyurethane foam industry. In addition to representing companies who manufacture spray polyurethane foam (SPF), SPFA develops tools designed to educate and influence the construction industry with the positive benefits of spray polyurethane foam roofing, insulation, coatings, and specialty installations. Aware of the increasing interest in transparent reporting of products' environmental performance, SPFA seeks to demonstrate their sustainability leadership and leverage business value through evaluating the environmental profiles of member companies' SPF products and communicating the results via industry average Environmental Product Declarations (EPDs).

The goal of the study is to assess the cradle-to-grave environmental impacts of seven SPF formulations produced in North America: three formulations with hydrofluorocarbon (HFC) blowing agents, three formulations with hydrofluoroolefin (HFO) blowing agents, and an open cell formulation with reactive blowing agent. The analyses were conducted according to ULE's Product Category Rule: "Part B: Building Envelope Thermal Insulation EPD Requirements" (UL Environment, 2018). Note that this study is an update to the SPFA's Spray Polyurethane Foam Insulation EPD issued in 2012 (SPFA, 2012).

The intended audience for this report includes the program operator, ASTM International, the reviewer who will be assessing the life cycle assessment (LCA) for conformance to the Product Category Rule (PCR), and SPFA member companies. In addition, thinkstep recommends making this report available upon request to all third parties to whom the EPD is communicated for conformance with ISO 14044, Section 5.2. The resulting EPDs are intended to support business-to-business communication.

Results presented in this document do not constitute comparative assertions. However, these results will be disclosed to the public in EPDs, which architects and builders can potentially use to compare SPFA member companies' products with similar products presented in other EPDs that follow the same PCR. In order to be published by a program operator, the EPD will undergo a verification for conformance to the PCR.

2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

2.1. Product System(s)

SPF products are commonly used in commercial, light commercial, institutional, and residential insulation applications. A two-component mixture composed of isocyanate (side-A) and polyol resin (side-B) is sprayed onto a surface in an equi-volumetric ratio to react to form an expanding foam that has thermally insulating properties. SPF performance characteristics are typically determined by the side-B formulation. Seven specific side-B formulations, which are considered representative of common SPF products manufactured by SPFA member companies, as seen in Table 2-1, will be evaluated in this study.

This declaration covers a range of spray polyurethane foam manufactured at 13 different facilities by participating SPFA members, representing a significant majority of annual production in the US and Canada. Only the following participating companies may claim to be represented by the EPD:

- Accella Polyurethane Systems (2 facilities)
- BASF (1 facility)
- DAP Products Inc. (1 facility)
- Demilec Inc. (1 facility)
- DOW (1 facility)
- Gaco-Western (1 facility)
- General Coatings Manufacturing Corp. (1 facility)
- ICP Adhesives and Sealants (1 facility)
- Icynene-Lapolla (1 facility)
- Johns Manville (1 facility)
- NCFI Polyurethanes (1 facility)
- SES Foam (1 facility)

Table 2-1: SPF products under study

Product	Blowing Agent			Relevant Standards		
	HFC	HFO	Reactive	ASTM	CAN/ULC	ICC
Open cell			X	WK30150 (under development)	S712.1	ICC 1100; ICC-ES AC377
Closed cell	X	X		C1029 Type I and II	S705.1	ICC 1100; ICC-ES AC377
2-component, low pressure (2K-LP)	X	X				ICC-1100; ICC-ES AC377
Roofing	X	X		C1029 Type III and IV; D7245		

ASTM Standards

- C1029-15 Standard Specification for Spray-Applied Rigid Cellular Polyurethane Thermal Insulation
- D7425-13 Standard Specification for Spray Polyurethane Foam Used for Roofing Applications
- WK30150 (under development) Standard Specification for Spray-Applied Open Cellular Polyurethane Thermal Insulation

UL Canada Standards

- S705.1 Standard for Thermal Insulation – Spray Applied Rigid Polyurethane Foam, Medium Density
- S712.1 Standard for Thermal Insulation - Light Density, Open Cell Spray Applied Semi-Rigid Polyurethane Foam
- International Code Council Standards

ICC-ES AC-377 Acceptance Criteria for Spray-Applied Foam Plastic Insulation

- ICC-1100-20xx Standard for Spray-applied Polyurethane Foam Plastic Insulation

2.2. Product Function and Functional Unit

The product function is providing insulation to buildings. Accordingly, the functional unit (FU) for the study, as defined by the UL Environment's Product Category Rule (PCR) for Building Envelope Thermal Insulation, Product Category Rule Number UL 10010-1 (UL Environment, 2018), is: 1 m^2 of installed insulation material with a thickness that gives an average thermal resistance RSI=1m^2·K/W (In imperial units, RSI is known as R = 5.68 h•ft^2•°F/Btu) with a building service life of 75 years (packaging included). Functional units may be expressed as (note that parameter units are expressed in metric units followed by imperial units):

$$FU\ [kg;\ lb] = RSI \cdot \lambda \cdot \rho \cdot A$$

Where,

- RSI = thermal resistance [m^2K/W; ft^2·°F·hr/Btu]
- λ = thermal conductivity [W/mK; Btu-in./hr· ft^2 ·°F]
- ρ = density of insulation product [kg/m^3; lb/ft^3]
- A = Area [m^2; ft^2] (here, 1 m^2; 10.763 ft^3)

Thickness required to satisfy the functional unit may be calculated as follows:

$$thickness\ [m;\ in] = RSI \cdot \lambda = RSI\ /\ R\text{-}value$$

Where,

- R_n = thermal resistance (R-value) of the spray foam per unit thickness [K/Wm; (h•ft^2•°F/Btu)/in]

The mass of foam for each reference flow is calculated using the following formula:

$$Reference\ flow\ (lb) = R\ /\ R_n \cdot 1ft\ /\ 12\ in \cdot A \cdot \rho$$

The products assessed fall under UNSPSC code 301415 Insulation and 301515 Roofing Material, and CSI/CSC code 07 21 19 Foam-in-Place Insulation.

The reference flows for which life cycle inventory (LCI) information will be reported in this study are shown in Table 2-2.

Table 2-2: Reference flows

	Unit	Roofing		2K-LP		Closed cell		Open cell
		HFC	HFO	HFC	HFO	HFC	HFO	
R-Value	(h·ft²·°F/Btu)/in	6.2	6.2	6.2	6.2	6.2	6.2	3.6
Density	lbs/ft³	3.3 [2.7-4.2]	3.3 [2.7-4.2]	2.0 [1.7-2.1]	2.0 [1.7-2.1]	2.5 [2.0-3.1]	2.5 [2.0-3.1]	0.6 [0.6-0.8]
Volume	bd-ft	10.9	10.9	11.3	11.3	11.3	11.3	17.8
Weight	lbs/FU	3.0	3.0	1.9	1.9	2.3	2.3	1.0
	kg/FU	1.4	1.4	0.8	0.8	1.1	1.1	0.4

2.3. System Boundaries

SPF is created by mixing equal volumes of two batches of chemicals, commonly referred to as side-A and side-B. “Side-A” is the industry term for the isocyanate component of foam; in this case methylene diphenyl diisocyanate (MDI).

With SPF, “side-B” is a mixture of polyols, fire retardants, blowing agents, catalysts, and other additives that, when mixed with “side-A,” creates foam used for insulation. The formulations of these side-B mixtures for each company are proprietary. However, the main ingredients do not vary significantly, so seven generic formulations - two from SPFA and five from Center for the Polyurethanes Industry (CPI) - are used to represent the side-B products evaluated in this study. The compositions of each of these generic formulations can be found within the following section in Table 3-1.

Figure 2-1 shows the life cycle stages associated with the study. This LCA study only focuses on the spray foam portion of a building. It excludes all other building materials as well as building use and the effects the spray foam may have on the thermal resistance of the building envelope.

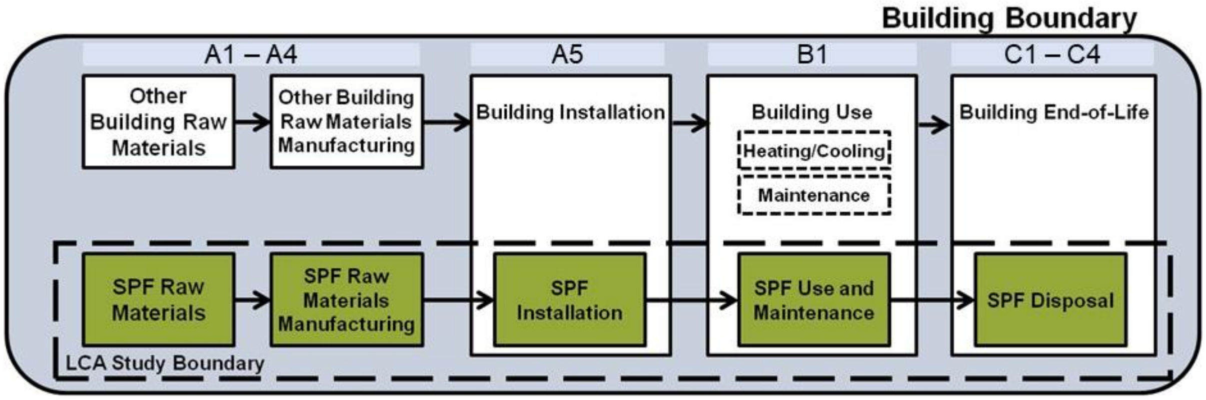

Figure 2-1: Life cycle flow diagram of SPF products

The study includes upstream processing and production of materials and energies needed for the production of SPF, transport of materials (all chemical inputs for production and packaging) to SPF insulation formulation sites, formulation of SPF components, transport of the components to the installation site, installation of insulation, removal and transport of insulation to disposal site, and end-of-life-disposal.

Table 2-3: System boundaries

Included	Excluded
✓ Extraction of raw materials (A1) ✓ Production and manufacturing of raw materials for spray foam and packaging (A2) ✓ Spray foam formulation (A3) ✓ Spray foam installation (A5) ✓ End-of-Life of insulation and packaging (C4) ✓ Transportation between all life cycle stages (A2, A4, C2)	× Construction of capital equipment and infrastructure × Maintenance of support equipment × Human labor and employee commute × Energy savings from product use[1]

2.3.1. Time Coverage

The data are intended to represent spray polyurethane foam production during the 2016 calendar year. As such, each participating SPFA member company provided primary data for 12 consecutive months during the 2016 calendar year. These data were then used to calculate average production values for each company.

2.3.2. Technology Coverage

As mentioned previously in section 2.3, data on material composition were developed by a reformulation group consisting of SPFA and CPI stakeholders to represent the seven products under study. Manufacturing data were collected directly from SPFA members. Waste, emissions, and energy use are calculated from reported annual production during the reference year from SPFA member companies. Section 3.2 gives more detail on the sources for the data used.

2.3.3. Geographical Coverage

This background LCA represents SPFA members' products produced in the United States and Canada. Primary data are representative of these countries, with exceptions noted in Section 3.2.

Regionally specific datasets were used to represent each manufacturing location's energy consumption. Proxy datasets were used as needed for raw material inputs to address lack of data for a specific material or for a specific geographical region. These proxy datasets were chosen for their technological representativeness of the actual materials.

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[1] Energy savings during use are excluded since the effects on the building are excluded. This will be addressed separately by SPFA.

2.4. Allocation

2.4.1. Multi-output Allocation

Multi-output allocation generally follows the requirements of ISO 14044, section 4.3.4.2. When allocation becomes necessary during the data collection phase, the allocation rule most suitable for the respective process step is applied and documented along with the process in Section 3.

Allocation of background data (energy and materials) taken from the GaBi 2018 database is documented online at http://www.gabi-software.com/support/gabi/gabi-database-2018-lci-documentation/.

2.4.2. End-of-Life Allocation

The cut-off allocation approach is adopted in the case of any post-consumer and post-industrial recycled content, which is assumed to enter the system burden-free. Only environmental impacts from the point of recovery and forward (e.g., inbound transports, grinding, processing, etc.) are considered.

Per the UL PCR Part A, the product is modeled as being disposed in a landfill. Plastic and other construction waste is assumed to be inert in landfills so no landfill gas is produced from it. In the case of bio-based packaging installation waste, waste flows are linked to inventories that account for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios; output electricity and thermal energy is assumed to have a benefit beyond the system boundary equivalent to convetional regional methods of producing these respective energy types. These output energy flows are assigned a credit under module D.

2.5. Cut-off Criteria

The cut-off criteria for including or excluding materials, energy and emissions data of the study are as follows:

- Mass – If a flow is less than 1% of the cumulative mass of the model it may be excluded, providing its environmental relevance is not a concern.
- Energy – If a flow is less than 1% of the cumulative energy of the model it may be excluded, providing its environmental relevance is not a concern.
- Environmental relevance – If a flow meets the above criteria for exclusion, yet is thought to potentially have a significant environmental impact, it was included. Material flows which leave the system (emissions) and whose environmental impact is greater than 1% of the whole impact of an impact category that has been considered in the assessment must be covered. This judgment was made based on experience and documented as necessary.

Packaging of incoming raw materials (e.g. pallets, totes, super-sacks) are excluded as they represent less than 1% of the product mass and are not environmentally relevant. Capital goods and infrastructure required to produce and install SPF (e.g. batch mixers, spraying equipment) are presumed to produce millions of units to over the course of their life, so impact of a single functional unit attributed to these equipment is negligible; therefore, capital goods and infrastructure were excluded from this study.

2.6. Selection of LCIA Methodology and Impact Categories

According to the PCR, the following environmental indicators shall be calculated and declared:

Table 2-4: North American LCIA Results

Parameter	Parameter	Unit
GWP	Global warming potential, 100 years, excluding biogenic CO_2	[kg CO_2-eq.]
GWP [IPCC AR5][2]	Global warming potential, 100 years, excluding biogenic CO_2	[kg CO_2-eq.]
ODP	Depletion potential of the stratospheric ozone layer	[kg CFC-11-eq.]
AP	Acidification potential of land and water	[kg SO_2-eq.]
EP	Eutrophication potential	[kg N-eq.]
POCP	Formation potential of tropospheric ozone photochemical oxidants	[kg O_3 -eq.]
ADP_{Fossil}	Abiotic depletion potential for fossil resources	[MJ, LHV]

The North Americans impact assessment results are calculated using characterization factors published by the United States Environmental Protection Agency through its Tool for Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI 2.1). Since the lifetime of material derived from biomass is shorter than the 100-year time horizon of this impact category (GWP100), biogenic carbon was excluded from the global warming potential calculations. Additionally, excluding biogenic carbon from GWP ensures that the reader does not mistakenly infer that overall environmental impact can be reduced by using more material derived from biomass. As such, carbon emissions and removals are not reported, as permitted by Part A.

Table 2-5: LCI Results - Resource Use

Parameter	Parameter	Unit
RPR_E	Renewable primary energy as energy carrier	[MJ, LHV]
RPR_M	Renewable primary energy resources as material utilization	[MJ, LHV]
$NRPR_E$	Non-renewable primary energy as energy carrier	[MJ, LHV]
$NRPR_M$	Non-renewable primary energy as material utilization	[MJ, LHV]
SM	Use of secondary material	[kg]
RSF	Use of renewable secondary fuels	[MJ, LHV]
NRSF	Use of non-renewable secondary fuels	[MJ, LHV]
RE	Recovered Energy	[MJ, LHV]
FW	Use of net fresh water	[m^3]

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[2] IPCC AR5 represents the most up to date GWP factors (IPCC, 2006), whereas TRACI 2.1 refers to the previous version of the IPCC report.

Table 2-6: LCI Results - Output Flows and Waste Categories

Parameter	Parameter	Unit
HWD	Hazardous waste disposed	[kg]
NHWD	Non-hazardous waste disposed	[kg]
HLRW	High-level radioactive waste, conditioned, to final repository	[kg]
ILLRW	Intermediate- and low-level radioactive waste, conditioned, to final repository	[kg]
CRU	Components for re-use	[kg]
MR	Materials for recycling	[kg]
MER	Materials for energy recovery	[kg]
EE	Exported energy	[MJ]

It shall be noted that the above impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emitted molecules would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the reported emissions represent only that fraction of the total environmental load that corresponds to the declared unit.

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

2.7. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modeling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modeling choices, data sources, emission factors, or other artifacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties are able to approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources

- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

An evaluation of the data quality with regard to these requirements is provided in Section 5 of this report.

2.8. Software and Database

The LCA model was created using the GaBi 8.5 Software system for life cycle engineering, developed by thinkstep AG. The GaBi 2018 LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.9. Verification

The background LCA report and EPD must be verified before publication. Report verification was conducted by Thomas Gloria, Ph.D., of Industrial Ecology Consultants, on behalf of ASTM International. This verification was performed against ISO 14040/44 (ISO, 2006a; ISO, 2006b), EN15804 (CEN, 2013), ISO 21930 (ISO, 2017), and the selected PCR for insulation (UL Environment, 2018).

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

All primary data were collected using customized data collection templates, which were sent out by email to the respective data providers in the participating companies. The majority of manufacturers only operate one site, and therefore that site was selected to participate. If data from additional sites was available, it was included. Data providers were asked to provide data for a period of 12 consecutive months of production in 2016. SPFA members provided gate-to-gate data on production volume, product characteristics, packaging materials, energy use, wastes, and emissions, as well as inbound and outbound transportation data. Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, stoichiometry, as well as internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, thinkstep engaged with the data provider to resolve any open issues. Data was combined based on a production-weighted average.

The energy inputs and outputs were modeled according to data provided by each site, while the electricity grid and natural gas mix were chosen based on the locations of each manufacturer’s production facilities.

When possible, energy consumption data on side-B production were collected via sub-metering. However, when not feasible, energy consumption was allocated to the spray polyurethane foam production by mass.

Material inbound transport distances, product outbound distances, packaging details, and installation details, are calculated based on primary data or estimations from participating SPFA companies.

The project was further subjected to a comprehensive quality assurance process at every major milestone in the project to analyze and ensure model integrity, data accounting and consistency with the goal and scope.

3.2. Spray Polyurethane Foam

3.2.1. Overview of Product System

SPF is a chemical product from the reaction of Methylene Diphenyl Diisocyanate (MDI) (side-A) and polyol resin mixture (side-B). SPF expands over thirty-fold its original liquid volume when applied by spraying onto a substrate. As the foam expands, it adheres and contours to the surface, filling in cracks and crevices that can cause air and water infiltration. SPF provides durability, structural strength, water resistance, and thermal insulation.

SPF formulators typically only produce side-B, as side-A is a relatively simple mixture consisting of either purely MDI or MDI with a small fraction of blowing agent. Side-B, a mixture of polyols, fire retardants, blowing agents, catalysts, and other additives, is blended by formulators. The blended side-B is packaged along with side-A to form a “set”. The packaged set is then shipped to a consumer, installed, and used before disposal. The SPF life cycle and system boundaries of this study can be found in section 2 in Table 2-1.

3.2.2. Manufacturing

Generic side-B formulations used in this study were developed by stakeholders from SPFA and CPI. Seven side-B formulations are evaluated in this study, each of which have their own distinctive characteristics, lending themselves to unique applications. The chemical compositions of each formulation are shown in Table 3-1.

The compositions of the 2K-LP, open-cell SPF and HFC-based closed-cell foams are functional formulations used by CPI to develop emissions and air-sampling protocols, and are representative of individual industry formulations. The HFO-based closed-cell formulations were agreed, by sponsor consensus, to use a simple drop-in replacement of the HFC with an HFO. The HFC-based roofing formulation is not a functional foam, but was developed by SPFA in 2012 based on a consensus process with several foam manufacturers. The HFO-based roofing foam is identical to the HFC-based foam, replacing the HFC with HFO.

While some of the ingredients may be classified as hazardous, per the Resource Conservation and Recovery Act (RCRA), Subtitle 3, the product as installed and ultimately disposed of is not classified as a hazardous substance, as hazardous ingredients are rendered chemically inert after installation.

Table 3-1: Side-B Compositions (%)

Chemical (% Composition)		Roofing		2K-LP		Closed cell		Open cell
		HFC	HFO	HFC	HFO	HFC	HFO	
Polyol	Polyester	35	35	23	23	36	36	-
	Polyether	-	-	23	23	34	34	34
	Mannich	45	45	-	-	-	-	-
	Compatibilizer	-	-	-	-	-	-	12
Fire Retardant	TCPP	8	8	30	30	16	16	25
Blowing Agent	Reactive (H_2O)	2	2	-	-	3	3	20
	HFO, aggregate	-	7	-	17	-	7	-
	HFC-245fa	7	-	-	-	7	-	-
	HFC-134a	-	-	17	-	-	-	-
Catalyst	Catalyst, amine	2	-	5	-	4	-	8
	Catalyst, metal	-	1	-	-	-	-	-
	Catalyst, aggregate	-	1	-	5	-	3	-
Surfactant	Silicone	1	1	2	2	1	1	1

A- and B-side material inputs are transported to the producer’s facility by a combination of ship, rail, and container and tanker truck.

Table 3-2 provides a summary of the inbound transportation requirements for the production of SPF products.

Table 3-2: Average transportation distances of SPF materials

Material	Transportation Mode	Distance (miles)	Distance (km)
Inbound Materials			
Polyester polyol	railroad	165	266
	semi truck 12t-30t	12	19
	tanker truck	823	1324
Polyether polyol	railroad	60	97
	semi truck 12t-30t	6	10
	semi truck > 30t	127	204
	tanker truck	474	763
	container ship	323	520
Mannich polyol	semi truck 12t-30t	120	193
	tanker truck	615	990
Compatibilizer polyol	tanker truck	321	517
TCPP	railroad	20	32
	semi truck 12t-30t	11	18
	tanker truck	702	1130
	container ship	6943	11174
HFC-245fa	tanker truck	1981	3188
HFC-134a	semi truck > 30t	105	169
	tanker truck	13	21
	container ship	576	927
HFO, aggregate	semi truck 12t-30t	77	124
	tanker truck	116	187
Catalyst, amine	semi truck 12t-30t	213	343
	semi truck > 30t	161	259
	tanker truck	119	192
Catalyst, metal	semi truck 12t-30t	501	806
	semi truck > 30t	724	1165
Catalyst, aggregate	semi truck 12t-30t	143	230
	semi truck > 30t	388	624
	tanker truck	55	89
	container ship	1304	2099
Silicone	semi truck 12t-30t	294	473
	semi truck > 30t	91	146
	tanker truck	442	711
	container ship	1751	2818
MDI	railroad	30	48
	semi truck 12t-30t	138	222
	semi truck > 30t	263	423
	tanker truck	13	21
Shipping to Customer			
Final Product	semi truck 12t-30t	86	138
	semi truck > 30t	654	1053
	refrigerated truck	113	182

During the side-B production process, materials are blended together in tanks and packaged in containers of varying types, most commonly steel drums and plastic totes. Since each member company utilizes different package types and sizes, packaging data was aggregated by type (i.e. steel or plastic) and function (i.e. side-A or side-B). Finished packaged products are loaded onto pallets, where additional shipping materials, such as strapping, cardboard, and plastic wrap, are applied.

In the case of facilities that have outputs other than the products considered in this study, energy inputs and waste outputs were allocated to the SPF products by mass.

The side-B blending process utilizes internal scrap from its own operations. Additionally, many facilities utilize technology to minimize the release of gaseous material inputs, such as blowing agents, during material transfer and processing. Waste materials are typically reintegrated into the formulation without additional collection, transport, or processing. Packaging materials that are associated with inbound transportation of raw materials have been excluded.

After data were collected from the formulation locations, the values were normalized to a per-pound of side-B formulation, and then a production volume weighted average was calculated to attain the values in Table 3-3.

The values in Table 3-2 and Table 3-3 are used to represent all seven SPF products. Please note that process emissions of R-134a and R-245fa are only present if they are used in those particular formulations.

Table 3-3: Weighted average values of formulation sites

Type	Flow	Unit	Value per 1000 lb side-B	Unit	Value per 1000 kg side-B	Biogenic carbon [kg CO2e/kg material]
Energy	Electricity	kWh	28	kWh	62	
	Natural Gas	BTU	30689	MJ	71.4	
	Propane	BTU	2505	MJ	5.83	
	Diesel	gallon	8.99E-04	kg	0.0075	
Waste	Incineration	lb	2.3	kg	2.3	
	Landfill	lb	2.2	kg	2.2	
	Recycler	lb	6.2	kg	6.2	
Packaging	Steel drums, Side-B	lb	86	kg	86	-
	Steel drums, Side-A	lb	79	kg	79	-
	Plastic totes, Side-B	lb	2.2	kg	2.2	-
	Plastic totes, Side-A	lb	1.9	kg	1.9	-
	Pallets	lb	17	kg	17	1.30
	Plastic wrap	lb	0.044	kg	0.044	-
	Cardboard	lb	0.042	kg	0.042	2.02
Direct process emissions	R-134a	lb	0.066	kg	0.066	
	R-245fa	lb	0.163	kg	0.163	
	VOC	lb	0.041	kg	0.041	
	CO_2	lb	0.550	kg	0.550	

3.2.3. Distribution

Final products are distributed via container truck and refrigerated truck, either directly to customers, or first to warehouse, prior to being sent to customers. Table 3-4, below, details distribution assumptions for finished SPF products.

Table 3-4: Outbound transportation distances

Mode	Distance (miles)	(km)
Semi truck, 12t-30t	195	314
Semi truck, >30t	1320	2124
Refrigerated truck	244	393

3.2.4. Installation

Primary installation data collected from the 2012 study were applied, as no significant changes have occurred in installation technology or methodology over the past five years.

During the installation step, sides A and B are mixed and heated in a one-to-one ratio by volume. During the installation, the applicators use various safety equipment such as goggles, Tyvek® protective suits, and respirator cartridges, as well as other disposable materials such as masking tape and plastic drop cloths. After the foam dries and expands, the excess is cut off and discarded. Discarded from installation also experiences blowing agent release while in landfill. Disposal of packaging materials is modeled in accordance to the assumptions outlined in Part A of the PCR, as seen in Table 3-5. Given that the US represents the majority of production compared to Canada, US assumptions were used. Additionally, they represent more conservative values.

Table 3-5: Packaging disposal assumptions

Material type	Recycling rate (%)	Landfill rate (%)	Incineration rate (%)
Plastics	15	68	17
Metals	57	34	9
Pulp (cardboard, paper)	75	20	5

This study assumes 10% of the installed blowing agent is released to surrounding air during the installation phase.

Within the context of the model, the installation step includes all the energy and materials used, waste out, and transportation to the installation site. All installation materials are assumed to be sent to landfill. Table 3-6 lists these materials required in a representative installation job.

Table 3-6: Weighted Average Values of Installation Contractors

Parameter		Unit	Value per lb SPF applied	Unit	Value per kg SPF applied	Biogenic carbon [kg CO2e/kg material]
Energy	Electricity	kWh	0.0271	kWh	0.0597	-
	Diesel	lb	0.092	kg	0.092	-
Waste	Waste Foam	lb	0.0368	kg	0.0368	-
	Waste Materials	lb	0.00468	kg	0.00468	-
Installation Materials	Chemical Proof Suits	lbs [piece]	0.00153 [0.00055]	kg [piece]	0.00153 [0.00121]	-
	Respirator Cartridges	lbs [piece]	1.24E-05 [0.00209]	kg [piece]	1.24E-05 [0.00461]	
	Goggles	lbs [piece]	4.45E-04 [0.00089]	kg [piece]	4.45E-04 [0.00193]	-
	Duct Tape	lbs [piece]	3.15E-04 [0.00018]	kg [piece]	3.15E-04 [0.000397]	0.0576
	Polyethylene	lbs [piece]	0.0159 [0.00028]	kg [piece]	0.0159 [0.000617]	-
	Chemical Proof Gloves	lbs [piece]	8.75E-05 [0.00165]	kg [piece]	8.75E-05 [0.00364]	-
	Gun Cleaners, Lubricants	lbs	1.00E-05	kg	1.00E-05	
	Masking Tape	lbs [piece]	8.01E-05 [8.00E-05]	kg [piece]	8.01E-05 [0.000617]	2.02
	Cloth Work Gloves	lbs [piece]	5.14E-05 [0.00011]	kg [piece]	5.14E-05 [0.000243]	1.74

3.2.5. Use

As this study only looks at the life cycle of spray foam insulation, and not the building, the use phase only contains the emissions of any chemicals off-gassed from the foam. This study assumes 24%[3] of the original chemical blowing agent is off-gassed over a 75-year lifetime (Honeywell International).

Several SPF manufacturers have certified or tested their insulation products to various VOC standards to measure emissions of volatile or semi-volatile compounds. These standards include:

- UL Environment GREENGUARD® Certification – The GREENGUARD® Certification Program specifies strict certification criteria for VOC's and indoor air quality. This voluntary program helps consumers identify products that have low chemical emissions for improved indoor air quality.
- California Department of Health Services – Also known as Section 01350, this small-chamber emissions test standard is detailed under: Standard Practice for the Testing of Volatile Organic

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[3] It is assumed that 50% of the total blowing agent is emitted eventually (Kjeldsen & Jensen, 2001). 10% is assumed to be released during installation. As global warming potential looks at emissions on a 100-year scale, and as the lifetime of the spray foam is 75 years, it is assumed that of the remaining 40% to be emitted, 60% is emitted over the lifetime of the product, and 40% is emitted at end-of-life. This results in the following life cycle of the blowing agent:

- 10% emitted during installation
- 24% emitted during lifetime in building
- 16% emitted during end-of-life
- 50% remains in product

Emissions from Various Sources Using Small-Scale Environmental Chambers (CA/DHS/EHLB/Standard Method v1.1-2010).

- Canadian ULC – Required for SPF insulation products, this standard provides a similar VOC emissions test protocol specifically for SPF: CAN/ULC S774-09 Standard Laboratory Guide for the Determination of Volatile Organic Compound Emissions from Polyurethane Foam
- Currently, an ASTM workgroup is developing a small-chamber emissions test protocol for chemical compounds specific to SPF that include MDI, blowing agents, flame retardants and catalysts.

3.2.6. End-of-Life

SPF is assumed to endure the entire building RSL of 75 years without any need for replacement. When the building is decommissioned, it is assumed that only manual labor is involved, and no environmental impact is associated with this module (C1). Wastes are then transported 30 miles to disposal (C2). The spray foam is assumed to be collected with mixed construction waste and landfilled at end-of-life, as is typical for construction and demolition waste in the US and Canada. SPF cannot be recycled like other plastics and therefore the 'Other materials' recycling rate for Canada specified in PCR Part A does not apply. No biogenic carbon is removed from the environment as a result of the disposal of the products after use.

This study assumes 16% of the original physical blowing agent is emitted at this stage in the life cycle. It is further assumed the spray foam is inert in the landfill and 50% of the blowing agent remains in the product after disposal.

3.3. Background Data

This section details the GaBi 2018 datasets used in the SPF LCA model. Datasets are grouped by energy, materials, transportation, and disposal. Documentation for all GaBi datasets can be found at http://www.gabi-software.com/deutsch/support/gabi/gabi-database-2018-lci-documentation/.

3.3.1. Energy and fuels

National averages for fuel inputs and electricity grid mixes were obtained from the GaBi 2018 databases. Table 3-7 shows the key life cycle inventory (LCI) datasets used in modeling energy generation and consumption for the product system.

Table 3-7: Energy and fuel datasets

Energy	Geography	Dataset	Data Provider	Reference Year
Crude	US	Crude oil mix	thinkstep	2014
Diesel	US	Diesel mix at refinery	thinkstep	2014
Electricity	CA	Electricity grid mix	thinkstep	2014
Electricity	US	Electricity grid mix	thinkstep	2014
Electricity	US	Electricity grid mix – CAMX	thinkstep	2014
Electricity	US	Electricity grid mix – ERCT	thinkstep	2014
Electricity	US	Electricity grid mix – NWPP	thinkstep	2014

Energy	Geography	Dataset	Data Provider	Reference Year
Electricity	US	Electricity grid mix – RFCW	thinkstep	2014
Electricity	US	Electricity grid mix – SRMW	thinkstep	2014
Electricity	US	Electricity grid mix – SRSO	thinkstep	2014
Electricity	US	Electricity grid mix – SRVC	thinkstep	2014
Heavy fuel oil	US	Heavy fuel oil at refinery (2.5wt.% S)	thinkstep	2014
Light fuel oil	US	Light fuel oil at refinery	thinkstep	2014
LPG	US	Liquefied Petroleum Gas (LPG) (70% propane; 30% butane)	thinkstep	2014
Natural gas	US	Natural gas mix	thinkstep	2014
Thermal energy	US	Thermal energy from heavy fuel oil (HFO)	thinkstep	2014
Thermal energy	US	Thermal energy from natural gas	thinkstep	2014

3.3.2. Raw Materials and Processes

Data for upstream and downstream raw materials and unit processes were obtained from the GaBi 2018 database. Table A-1 in Annex A shows the most relevant material and process datasets used in modeling the product systems.

3.3.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to production and assembly facilities.

The GaBi 2018 database was used to model transportation. Truck transportation within the United States was modeled using the GaBi US truck transportation datasets. The vehicle types, fuel usage, and emissions for these transportation processes were developed using a GaBi model based on the most recent US Census Bureau Vehicle Inventory and Use Survey (2002) and US EPA emissions standards for heavy trucks in 2007. The 2002 VIUS survey is the latest available data source describing truck fleet fuel consumption and utilization ratios in the US based on field data (Langer, 2013), and the 2007 EPA emissions standards are considered to be the appropriate data available for describing current US truck emissions.

Table 3-8: Transportation and road fuel datasets

Mode	Geography	Name	Data Provider	Reference Year
Truck, container, light	US	Truck - Light Heavy-duty Diesel Truck / 6,667 lb payload - 2b	thinkstep	2017
Truck, container, medium	US	Truck - Medium Heavy-duty Diesel Truck / 22,000 lb payload - 7	thinkstep	2017
Truck, container, heavy	US	Truck - Heavy Heavy-duty Diesel Truck / 53,333 lb payload - 8b	thinkstep	2017
Truck, container, heavy	US	Truck - Trailer, basic enclosed / 45,000 lb payload - 8b	thinkstep	2017

Mode	Geography	Name	Data Provider	Reference Year
Truck, refrigerated	US	Truck - Insulated Refrigerated / 47,000 lb payload - 8b	thinkstep	2017
Truck, tanker	US	Truck - Tank, liquid or gas / 50,000 lb payload - 8b	thinkstep	2017
Ship	GLO	Average ship, 1500t payload capacity/ canal	thinkstep	2017
Ship	GLO	Bulk commodity carrier, 20.000 to 20.0000 dwt payload capacity, ocean going	thinkstep	2017
Ship	GLO	Container ship, 27500 dwt payload capacity, ocean going	thinkstep	2017
Rail	GLO	Rail transport cargo - Diesel (Version 2006)	ELCD/PE-GaBi	2017
Rail	GLO	Rail transport cargo - Diesel, average train, gross tonne weight 1000t / 726t payload capacity	thinkstep	2017

3.3.4. End-of-life

The end-of-life stage is modeled primarily using landfill datasets, classified according to the Resource Conservation and Recovery Act (RCRA), Subtitle 3. Recycled material is modeled as leaving the system boundary burden free. Table 3-9 shows datasets used into model the end-of-life stage.

Table 3-9: End-of-life datasets

End-of-life	Geography	Name	Data Provider	Reference Year
Landfill, inert	US	Glass/inert on landfill	thinkstep	2017
Landfill, MSW	US	Municipal solid waste on landfill	thinkstep	2017
Landfill, wood	US	Wood products (OSB, particle board) on landfill, post-consumer	thinkstep	2017
Landfill, plastic	US	Plastic waste on landfill, post-consumer	thinkstep	2017
Landfill, metal	US	Ferro metals on landfill, post-consumer	thinkstep	2017
Landfill, paper	US	Paper waste on landfill, post-consumer	thinkstep	2017
Incineration, plastic	US	Plastics wastes in waste incineration plant	thinkstep	2017
Incineration, metal	US	Ferro metals in waste incineration plant	thinkstep	2017
Incineration, paper	US	Paper waste in waste incineration plant	thinkstep	2017
Incineration	US	Municipal Solid Waste Incineration Plant	thinkstep	2017
Waste water	US	Municipal waste water treatment (mix)	thinkstep	2017

4. Life Cycle Inventory and Impact Assessment

This section presents both inventory and impact assessment results for the declared modules of SPF. Inventory metrics include different forms of resource use as well as environmental impact indicators as shown in Section 2.6. The impact assessment results are calculated using the US EPA's TRACI 2.1 (Tool for Reduction and Assessment of Chemical and Environmental Impacts). Each section shows tabulated results for TRACI 2.1 impact categories, resource use, output flow and waste categories, and carbon emission and removals, followed by relative results for A1-D for each impact category, as required by the PCR.

It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

Please note that results are normalized to the declared unit of SPF that covers 1 m^2 at R_{SI} = 1 over 75 years.

4.1. SPF Results

Life cycle impact assessment and inventory results are summarized in this section. Tabulated results are followed by contribution analyses of the seven SPF products, to provide a sense of which modules are driving environmental burden. Per Part A of the PCR, module D shall be reported separately; totals reported in the subsequent sections only represent the sum of modules A1 through C4.

4.1.1. Roofing, HFC

Figure 4-1 and Table 4-1, below, show life cycle impact assessment results for the Roofing HFC product. The majority of burdens for categories fall within modules A1-A3, with the exception of GWP and SFP, due to the impacts associated with raw material supply and manufacturing. Within GWP, impact is distributed amongst installation (A5), use (B1), and disposal (C4), all of which are driven by the emission of R-245fa. As mentioned in section 3, 50% of blowing agent is assumed to be emitted over the course of the product's life. Most of the emissions take place during use in the building, giving way to the use phase having the highest GWP contribution. Installation includes the off-gassing of discarded waste foam, leading to a noticeable contribution to GWP. Installation of SFP utilizes onsite diesel generators, which contribute greatly to AP, EP, and SFP due to the emissions of VOCs and nitrogen containing compounds.

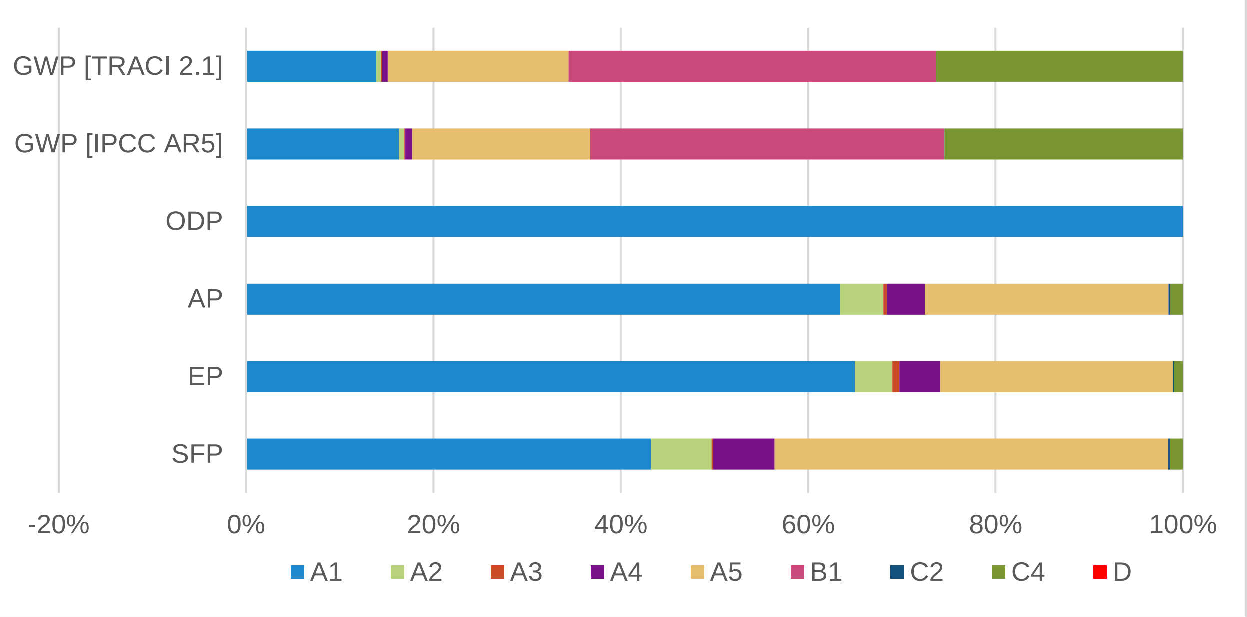

Figure 4-1: A1-D contribution analysis - Roofing, HFC

Table 4-1: Roofing, HFC results

IMPACT ASSESSMENT (TRACI 2.1)								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
GWP [TRACI 2.1]	kg CO_2 eq.	3.83E+00	1.62E-01	5.10E+00	1.04E+01	4.49E-03	6.96E+00	-2.33E-04
GWP [IPCC AR5]	kg CO_2 eq.	3.88E+00	1.62E-01	4.35E+00	8.63E+00	4.50E-03	5.81E+00	-2.33E-04
ODP	kg CFC-11 eq.	8.88E-08	4.65E-15	3.63E-13	-	1.30E-16	9.95E-15	-7.44E-16
AP	kg SO_2 eq.	1.22E-02	7.25E-04	4.64E-03	-	2.02E-05	2.50E-04	-1.36E-06
EP	kg N eq.	9.65E-04	6.01E-05	3.44E-04	-	1.68E-06	1.27E-05	-5.19E-08
SFP	kg O_3 eq.	1.82E-01	2.39E-02	1.53E-01	7.56E-06	6.68E-04	4.97E-03	-6.01E-06
ADPF	Surplus MJ	1.00E+01	3.18E-01	1.11E+00	-	8.89E-03	1.08E-01	2.98E-04
RESOURCE USE								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
RPR$_E$	MJ, LHV	2.36E+00	5.76E-02	2.85E-01	-	1.61E-03	6.12E-02	-1.02E-03
RPR$_M$	MJ, LHV	1.38E-01	-	2.78E-03	-	-	-	-
NRPR$_E$	MJ, LHV	8.39E+01	2.38E+00	8.77E+00	-	6.65E-02	8.67E-01	-3.24E-03
NRPR$_M$	MJ, LHV	3.56E+01	-	9.73E-01	-	-	-	-
SM	kg	-	-	-	-	-	-	-
RSF	MJ, LHV	-	-	-	-	-	-	-
NRSF	MJ, LHV	-	-	-	-	-	-	-
RE	m^3	-	-	-	-	-	-	-
FW	MJ, LHV	1.70E-02	2.84E-04	1.50E-03	-	7.92E-06	1.05E-04	-2.86E-06
OUTPUT FLOWS AND WASTE CATEGORIES								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
HWD	kg	2.06E-06	1.86E-08	4.90E-08	-	5.20E-10	2.98E-09	-2.06E-12
NHWD	kg	1.04E-01	8.60E-05	9.80E-02	-	2.40E-06	1.23E+00	-1.74E-06
HLRW	kg	2.22E-06	5.08E-09	1.18E-07	-	1.42E-10	1.12E-08	-8.26E-10
ILLRW	kg	2.66E-05	1.37E-07	3.24E-06	-	3.82E-09	2.67E-07	-2.28E-08
CRU	kg	-	-	-	-	-	-	-
MR	kg	-	-	6.05E-02	-	-	-	-
MER	kg	-	-	-	-	-	-	-
EE	MJ, LHV	3.77E-04	-	2.65E-03	-	-	-	-

4.1.2. Roofing, HFO

Figure 4-2 and Table 4-2, below, show life cycle impact assessment results for the Roofing HFO product. The majority of burdens for categories fall within modules A1-A3, with the exception of SFP, due to the impacts associated with raw material supply and manufacturing. Note that unlike its HFC counterpart, the GWP impact for the Roofing HFO product is consolidated to primarily raw materials (A1) and is not distributed amongst downstream modules. While released at the same rate over the course of the life of the product as HFCs, HFOs have a substantially lower contribution to GWP due to their GWP characterization factor being less than 1 CO_2-eq., while the GWP characterization factor for HFC-245a is 950-1020 CO_2-eq. Installation of SFP utilizes onsite diesel generators, which contribute greatly to AP, EP, and SFP due to the emissions of VOCs and nitrogen containing compounds.

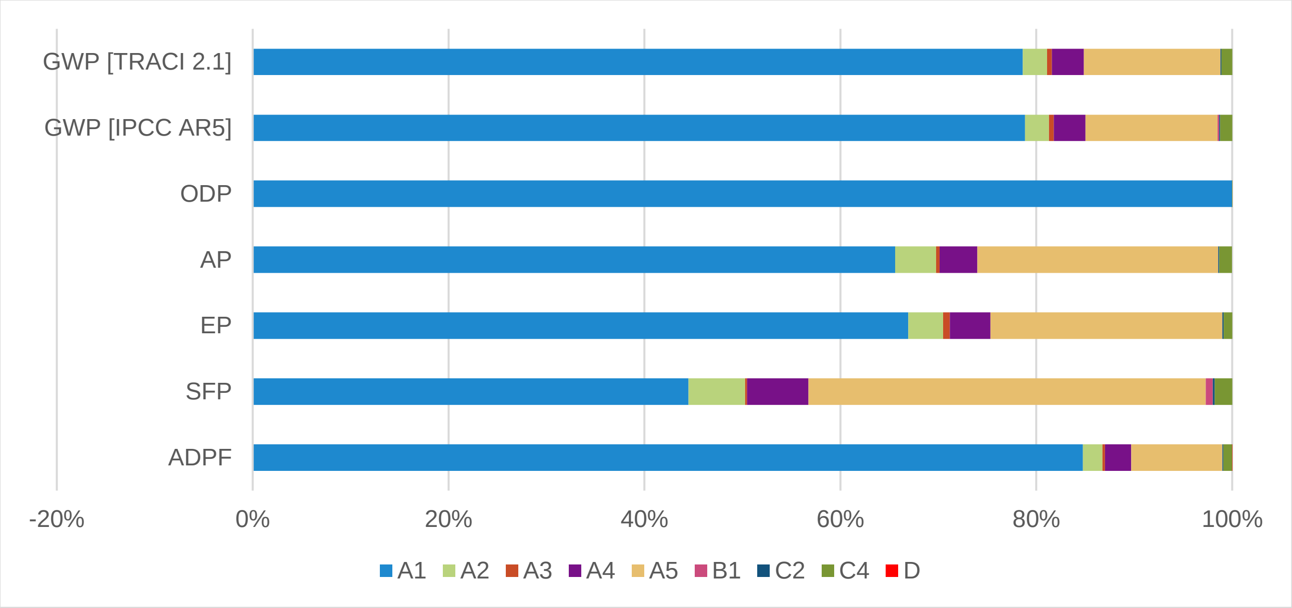

Figure 4-2: A1-D contribution analysis - Roofing, HFO

Table 4-2: Roofing, HFO results

IMPACT ASSESSMENT (TRACI 2.1)								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
GWP [TRACI 2.1]	kg CO$_2$ eq.	4.05E+00	1.62E-01	6.93E-01	-	4.49E-03	5.51E-02	-2.33E-04
GWP [IPCC AR5]	kg CO$_2$ eq.	4.10E+00	1.62E-01	6.76E-01	9.05E-03	4.50E-03	6.17E-02	-2.33E-04
ODP	kg CFC-11 eq.	8.88E-08	4.65E-15	3.63E-13	-	1.30E-16	9.95E-15	-7.44E-16
AP	kg SO$_2$ eq.	1.32E-02	7.25E-04	4.64E-03	-	2.02E-05	2.50E-04	-1.36E-06
EP	kg N eq.	1.03E-03	6.01E-05	3.44E-04	-	1.68E-06	1.27E-05	-5.19E-08
SFP	kg O$_3$ eq.	1.92E-01	2.39E-02	1.54E-01	2.81E-03	6.68E-04	6.83E-03	-6.01E-06
ADPF	Surplus MJ	1.03E+01	3.18E-01	1.11E+00	-	8.89E-03	1.08E-01	2.98E-04
RESOURCE USE								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
RPR$_E$	MJ, LHV	3.40E+00	5.76E-02	2.85E-01	-	1.61E-03	6.12E-02	-1.02E-03
RPR$_M$	MJ, LHV	1.38E-01	-	2.78E-03	-	-	-	-
NRPR$_E$	MJ, LHV	8.77E+01	2.38E+00	8.77E+00	-	6.65E-02	8.67E-01	-3.24E-03
NRPR$_M$	MJ, LHV	3.56E+01	-	9.73E-01	-	-	-	-
SM	kg	-	-	-	-	-	-	-
RSF	MJ, LHV	-	-	-	-	-	-	-
NRSF	MJ, LHV	-	-	-	-	-	-	-
RE	m^3	-	-	-	-	-	-	-
FW	m^3	1.75E-02	2.84E-04	1.50E-03	-	7.92E-06	1.05E-04	-2.86E-06
OUTPUT FLOWS AND WASTE CATEGORIES								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
HWD	kg	2.07E-06	1.86E-08	4.90E-08	-	5.20E-10	2.98E-09	-2.06E-12
NHWD	kg	7.12E-02	8.60E-05	9.80E-02	-	2.40E-06	1.23E+00	-1.74E-06
HLWD	kg	2.48E-06	5.08E-09	1.18E-07	-	1.42E-10	1.12E-08	-8.26E-10
ILLRW	kg	3.22E-05	1.37E-07	3.24E-06	-	3.82E-09	2.67E-07	-2.28E-08
CRU	kg	-	-	-	-	-	-	-
MR	kg	-	-	6.05E-02	-	-	-	-
MER	kg	-	-	-	-	-	-	-
EE	MJ, LHV	3.77E-04	-	2.65E-03	-	-	-	-

4.1.3. 2K-LP, HFC

Figure 4-3 and Table 4-3, below, show life cycle impact assessment results for the 2-Component, Low Pressure, HFC product. The majority of burdens for categories fall within modules A1-A3, with the exception of GWP and SFP, due to the impacts associated with raw material supply and manufacturing. Within GWP, impact is distributed amongst installation (A5), use (B1), and disposal (C4), all of which are driven by the emission of blowing agent. Unlike other HFC formulations, 2-Component, Low Pressure utilizes HFC-134a as its blowing agent, which has a GWP approximately three times higher than HFC-245fa, leading to the highest overall GWP impact of all products assessed. As mentioned in section 3, 50% of blowing agent is assumed to be emitted over the course of the product's life. Most of the emissions take place during use in the building, giving way to the use phase having the highest GWP contribution. Installation includes the off-gassing of discarded waste foam, leading to a noticeable contribution to GWP. Installation of SFP utilizes onsite diesel generators, which contribute greatly to AP, EP, and SFP due to the emissions of VOCs and nitrogen containing compounds.

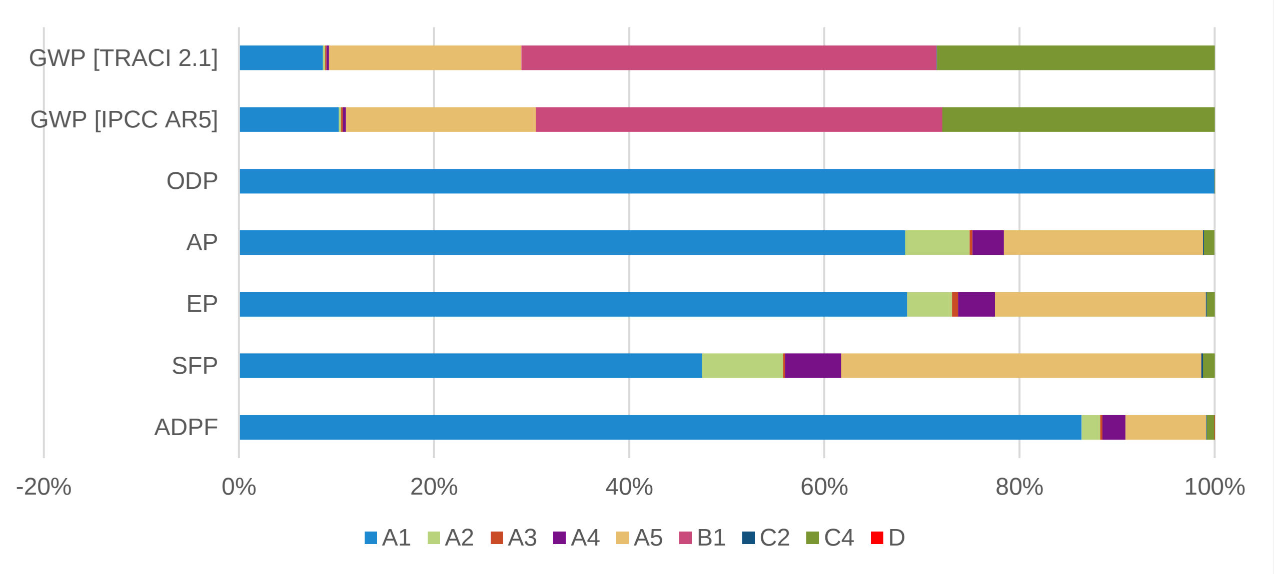

Figure 4-3: A1-D contribution analysis - 2K-LP, HFC

Table 4-3: 2K-LP, HFC results

IMPACT ASSESSMENT (TRACI 2.1)								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
GWP [TRACI 2.1]	kg CO$_2$ eq.	3.21E+00	9.80E-02	7.05E+00	1.52E+01	2.72E-03	1.02E+01	-1.41E-04
GWP [IPCC AR5]	kg CO$_2$ eq.	3.24E+00	9.83E-02	5.93E+00	1.27E+01	2.73E-03	8.50E+00	-1.41E-04
ODP	kg CFC-11 eq.	5.37E-08	2.82E-15	2.20E-13	-	7.87E-17	6.03E-15	-4.51E-16
AP	kg SO$_2$ eq.	1.03E-02	4.40E-04	2.81E-03	-	1.23E-05	1.52E-04	-8.24E-07
EP	kg N eq.	7.11E-04	3.64E-05	2.09E-04	-	1.02E-06	7.68E-06	-3.14E-08
SFP	kg O$_3$ eq.	1.41E-01	1.45E-02	9.29E-02	1.11E-05	4.05E-04	3.01E-03	-3.64E-06
ADPF	Surplus MJ	7.19E+00	1.93E-01	6.71E-01	-	5.39E-03	6.57E-02	1.80E-04
RESOURCE USE								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
RPR$_E$	MJ, LHV	3.72E+00	3.49E-02	1.73E-01	-	9.76E-04	3.71E-02	-6.18E-04
RPR$_M$	MJ, LHV	8.38E-02	-	1.69E-03	-	-	-	-
NRPR$_E$	MJ, LHV	6.36E+01	1.44E+00	5.31E+00	-	4.03E-02	5.25E-01	-1.96E-03
NRPR$_M$	MJ, LHV	1.67E+01	-	5.90E-01	-	-	-	-
SM	kg	-	-	-	-	-	-	-
RSF	MJ, LHV	-	-	-	-	-	-	-
NRSF	MJ, LHV	-	-	-	-	-	-	-
RE	m^3	-	-	-	-	-	-	-
FW	m^3	1.18E-02	1.72E-04	9.10E-04	-	4.80E-06	6.36E-05	-1.73E-06
OUTPUT FLOWS AND WASTE CATEGORIES								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
HWD	kg	2.22E-07	1.13E-08	2.97E-08	-	3.15E-10	1.81E-09	-1.25E-12
NHWD	kg	6.20E-02	5.21E-05	5.94E-02	-	1.46E-06	7.47E-01	-1.06E-06
HLRW	kg	2.10E-06	3.08E-09	7.15E-08	-	8.60E-11	6.81E-09	-5.01E-10
ILLRW	kg	3.38E-05	8.28E-08	1.96E-06	-	2.31E-09	1.62E-07	-1.38E-08
CRU	kg	-	-	-	-	-	-	-
MR	kg	-	-	3.66E-02	-	-	-	-
MER	kg	-	-	-	-	-	-	-
EE	MJ, LHV	2.28E-04	-	1.61E-03	-	-	-	-

4.1.4. 2K-LP, HFO

Figure 4-4 and Table 4-4, below, show life cycle impact assessment results for the 2K-LP, HFO product. The majority of burdens for categories fall within modules A1-A3, with the exception of SFP, due to the impacts associated with raw material supply and manufacturing. Note that unlike its HFC counterpart, the GWP impact for the 2K-LP, HFO product is consolidated to primarily raw materials (A1) and is not distributed amongst downstream modules. While released at the same rate over the course of the life of the product as HFCs, HFOs account for a substantially lower contribution to GWP due to their GWP characterization factor being close to 3000 times less than that of HFC-134a. Installation of SFP utilizes onsite diesel generators, which contribute greatly to AP, EP, and SFP due to the emissions of VOCs and nitrogen containing compounds.

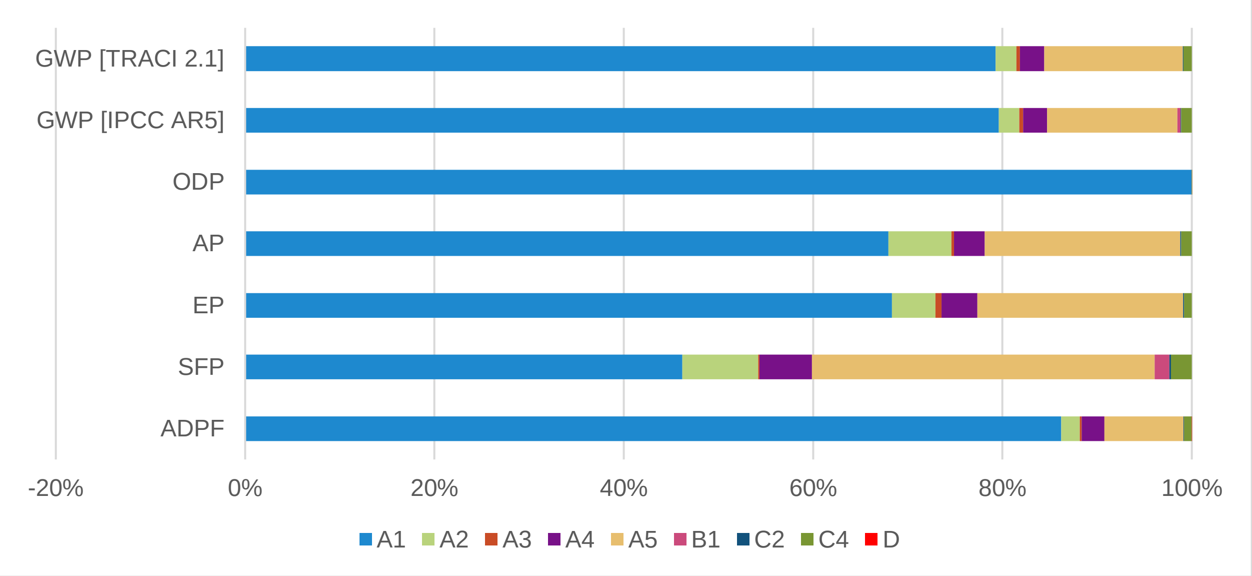

Figure 4-4: A1-D contribution analysis - 2K-LP, HFO

Table 4-4: 2K-LP, HFO results

IMPACT ASSESSMENT (TRACI 2.1)								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
GWP [TRACI 2.1]	kg CO_2 eq.	3.12E+00	9.80E-02	5.58E-01	-	2.72E-03	3.34E-02	-1.41E-04
GWP [IPCC AR5]	kg CO_2 eq.	3.16E+00	9.83E-02	5.28E-01	1.33E-02	2.73E-03	4.26E-02	-1.41E-04
ODP	kg CFC-11 eq.	5.40E-08	2.82E-15	2.20E-13	-	7.87E-17	6.03E-15	-4.51E-16
AP	kg SO_2 eq.	1.02E-02	4.40E-04	2.81E-03	-	1.23E-05	1.52E-04	-8.24E-07
EP	kg N eq.	7.07E-04	3.64E-05	2.09E-04	-	1.02E-06	7.68E-06	-3.14E-08
SFP	kg O_3 eq.	1.42E-01	1.45E-02	9.46E-02	4.13E-03	4.05E-04	5.76E-03	-3.64E-06
ADPF	Surplus MJ	7.11E+00	1.93E-01	6.71E-01	-	5.39E-03	6.57E-02	1.80E-04
RESOURCE USE								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
RPR_E	MJ, LHV	3.54E+00	3.49E-02	1.73E-01	-	9.76E-04	3.71E-02	-6.18E-04
RPR_M	MJ, LHV	8.38E-02	-	1.69E-03	-	-	-	-
$NRPR_E$	MJ, LHV	6.27E+01	1.44E+00	5.31E+00	-	4.03E-02	5.25E-01	-1.96E-03
$NRPR_M$	MJ, LHV	1.67E+01	-	5.90E-01	-	-	-	-
SM	kg	-	-	-	-	-	-	-
RSF	MJ, LHV	-	-	-	-	-	-	-
NRSF	MJ, LHV	-	-	-	-	-	-	-
RE	m^3	-	-	-	-	-	-	-
FW	m^3	1.13E-02	1.72E-04	9.10E-04	-	4.80E-06	6.36E-05	-1.73E-06
OUTPUT FLOWS AND WASTE CATEGORIES								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
HWD	kg	2.39E-06	1.13E-08	2.97E-08	-	3.15E-10	1.81E-09	-1.25E-12
NHWD	kg	6.11E-02	5.21E-05	5.94E-02	-	1.46E-06	7.47E-01	-1.06E-06
HLRW	kg	2.05E-06	3.08E-09	7.15E-08	-	8.60E-11	6.81E-09	-5.01E-10
ILLRW	kg	3.25E-05	8.28E-08	1.96E-06	-	2.31E-09	1.62E-07	-1.38E-08
CRU	kg	-	-	-	-	-	-	-
MR	kg	-	-	3.66E-02	-	-	-	-
MER	kg	-	-	-	-	-	-	-
EE	MJ, LHV	2.28E-04	-	1.61E-03	-	-	-	-

4.1.5. Closed cell, HFC

Figure 4-5 and Table 4-5, below, show life cycle impact assessment results for the closed cell, HFC product. The majority of burdens for categories fall within modules A1-A3, with the exception of GWP and SFP, due to the impacts associated with raw material supply and manufacturing. Within GWP, impact is distributed amongst installation (A5), use (B1), and disposal (C4), all of which are driven by the emission of R-245fa. As mentioned in section 3, 50% of blowing agent is assumed to be emitted over the course of the product’s life. Most of the emissions take place during use in the building, giving way to the use phase having the highest GWP contribution. Installation includes the off-gassing of discarded waste foam, leading to a noticeable contribution to GWP. Installation of SFP utilizes onsite diesel generators, which contribute greatly to AP, EP, and SFP due to the emissions of VOCs and nitrogen containing compounds.

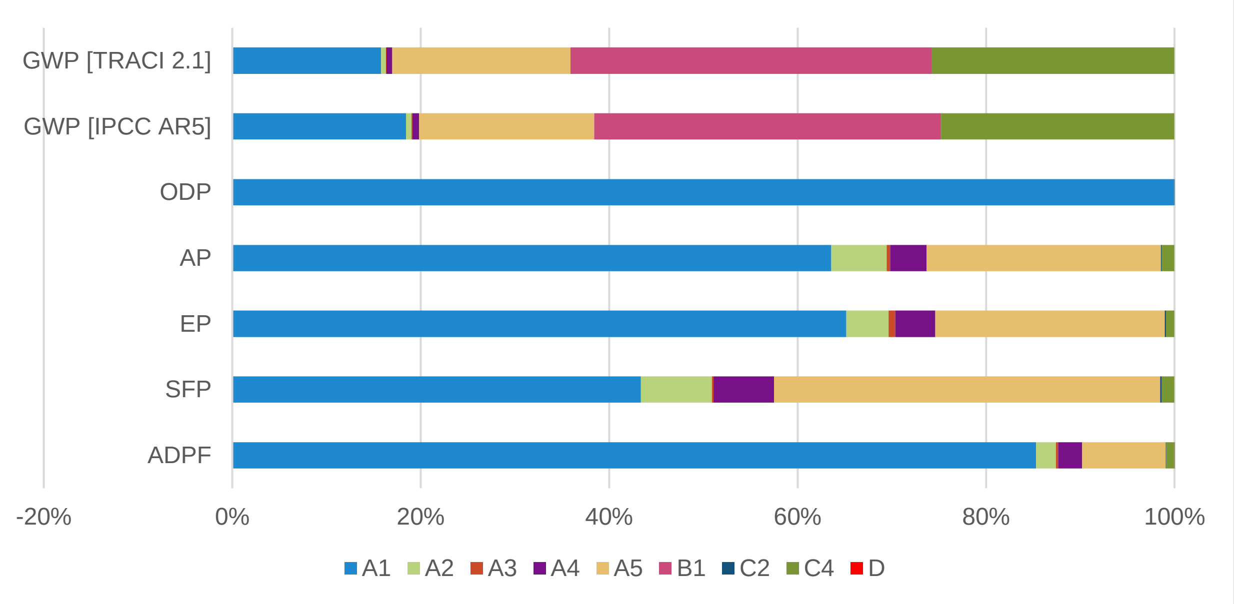

Figure 4-5: A1-D contribution analysis – closed cell, HFC

Table 4-5: Closed cell, HFC results

IMPACT ASSESSMENT (TRACI 2.1)								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
GWP [TRACI 2.1]	kg CO_2 eq.	3.31E+00	1.22E-01	3.82E+00	7.73E+00	3.40E-03	5.20E+00	-1.77E-04
GWP [IPCC AR5]	kg CO_2 eq.	3.35E+00	1.23E-01	3.25E+00	6.44E+00	3.41E-03	4.34E+00	-1.77E-04
ODP	kg CFC-11 eq.	6.71E-08	3.52E-15	2.75E-13	-	9.84E-17	7.54E-15	-5.63E-16
AP	kg SO_2 eq.	9.87E-03	5.50E-04	3.51E-03	-	1.53E-05	1.89E-04	-1.03E-06
EP	kg N eq.	7.53E-04	4.55E-05	2.61E-04	-	1.27E-06	9.60E-06	-3.93E-08
SFP	kg O_3 eq.	1.45E-01	1.81E-02	1.16E-01	5.65E-06	5.06E-04	3.76E-03	-4.55E-06
ADPF	Surplus MJ	8.30E+00	2.41E-01	8.39E-01	-	6.74E-03	8.21E-02	2.26E-04
RESOURCE USE								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
RPR$_E$	MJ, LHV	2.09E+00	4.37E-02	2.16E-01	-	1.22E-03	4.63E-02	-7.73E-04
RPR$_M$	MJ, LHV	1.05E-01	-	2.11E-03	-	-	-	-
NRPR$_E$	MJ, LHV	6.95E+01	1.80E+00	6.64E+00	-	5.04E-02	6.56E-01	-2.46E-03
NRPR$_M$	MJ, LHV	2.46E+01	-	7.37E-01	-	-	-	-
SM	kg	-	-	-	-	-	-	-
RSF	MJ, LHV	-	-	-	-	-	-	-
NRSF	MJ, LHV	-	-	-	-	-	-	-
RE	m^3	-	-	-	-	-	-	-
FW	m^3	1.37E-02	2.15E-04	1.14E-03	-	6.00E-06	7.95E-05	-2.16E-06
OUTPUT FLOWS AND WASTE CATEGORIES								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
HWD	kg	2.65E-07	1.41E-08	3.71E-08	-	3.94E-10	2.26E-09	-1.56E-12
NHWD	kg	7.90E-02	6.52E-05	7.42E-02	-	1.82E-06	9.34E-01	-1.32E-06
HLRW	kg	1.90E-06	3.85E-09	8.94E-08	-	1.08E-10	8.51E-09	-6.26E-10
ILLRW	kg	2.57E-05	1.04E-07	2.45E-06	-	2.89E-09	2.03E-07	-1.73E-08
CRU	kg	-	-	-	-	-	-	-
MR	kg	-	-	4.58E-02	-	-	-	-
MER	kg	-	-	-	-	-	-	-
EE	MJ, LHV	2.86E-04	-	2.01E-03	-	-	-	-

4.1.6. Closed cell, HFO

Figure 4-6 and Table 4-6, below, show life cycle impact assessment results for the closed cell, HFO product. The majority of burdens for categories fall within modules A1-A3, with the exception of SFP, due to the impacts associated with raw material supply and manufacturing. Note that unlike its HFC counterpart, the GWP impact for the closed cell, HFO product is consolidated to primarily raw materials (A1) and is not distributed amongst downstream modules. While released at the same rate over the course of the life of the product as HFCs, HFOs account for a substantially lower GWP due to their GWP characterization factor being close to 1000 times less than that of HFC-245a. Installation of SFP utilizes onsite diesel generators, which contribute greatly to AP, EP, and SFP due to the emissions of VOCs and nitrogen containing compounds.

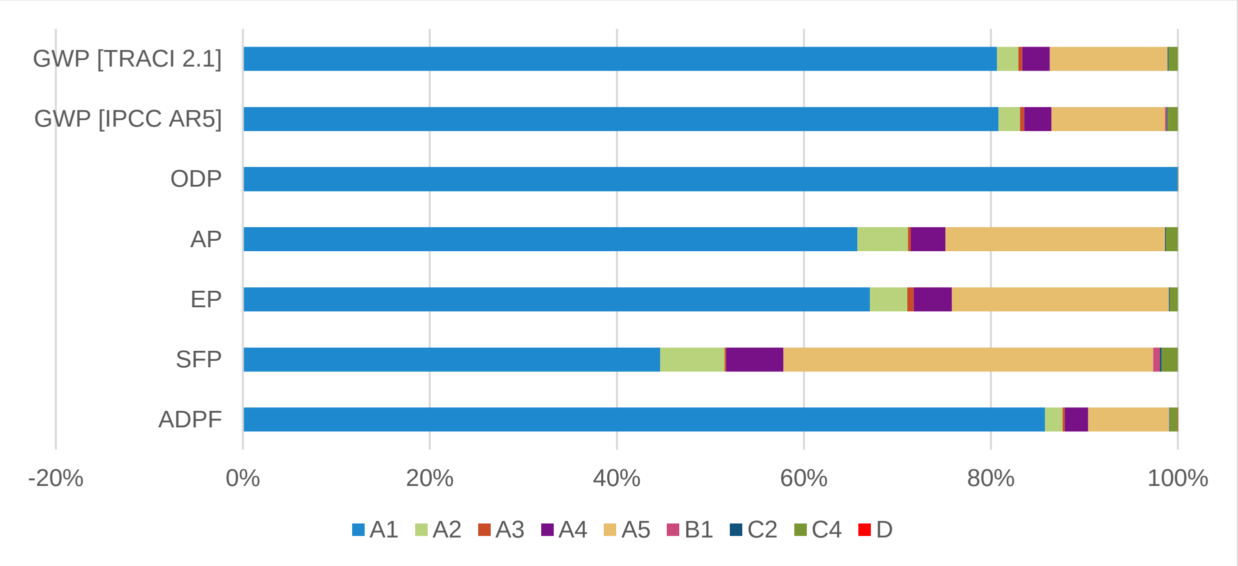

Figure 4-6: A1-D contribution analysis – closed cell, HFO

Table 4-6: Closed cell, HFO results

IMPACT ASSESSMENT (TRACI 2.1)								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
GWP [TRACI 2.1]	kg CO_2 eq.	3.47E+00	1.22E-01	5.25E-01	-	3.40E-03	4.17E-02	-1.77E-04
GWP [IPCC AR5]	kg CO_2 eq.	3.52E+00	1.23E-01	5.12E-01	6.85E-03	3.41E-03	4.67E-02	-1.77E-04
ODP	kg CFC-11 eq.	6.74E-08	3.52E-15	2.75E-13	-	9.84E-17	7.54E-15	-5.63E-16
AP	kg SO_2 eq.	1.07E-02	5.50E-04	3.51E-03	-	1.53E-05	1.89E-04	-1.03E-06
EP	kg N eq.	8.06E-04	4.55E-05	2.61E-04	-	1.27E-06	9.60E-06	-3.93E-08
SFP	kg O_3 eq.	1.53E-01	1.81E-02	1.17E-01	2.13E-03	5.06E-04	5.18E-03	-4.55E-06
ADPF	Surplus MJ	8.49E+00	2.41E-01	8.39E-01	-	6.74E-03	8.21E-02	2.26E-04
RESOURCE USE								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
RPR_E	MJ, LHV	2.90E+00	4.37E-02	2.16E-01	-	1.22E-03	4.63E-02	-7.73E-04
RPR_M	MJ, LHV	1.05E-01	-	2.11E-03	-	-	-	-
$NRPR_E$	MJ, LHV	7.23E+01	1.80E+00	6.64E+00	-	5.04E-02	6.56E-01	-2.46E-03
$NRPR_M$	MJ, LHV	2.47E+01	-	7.37E-01	-	-	-	-
SM	kg	-	-	-	-	-	-	-
RSF	MJ, LHV	-	-	-	-	-	-	-
NRSF	MJ, LHV	-	-	-	-	-	-	-
RE	m^3	-	-	-	-	-	-	-
FW	m^3	1.40E-02	2.15E-04	1.14E-03	-	6.00E-06	7.95E-05	-2.16E-06
OUTPUT FLOWS AND WASTE CATEGORIES								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
HWD	kg	1.89E-06	1.41E-08	3.71E-08	-	3.94E-10	2.26E-09	-1.56E-12
NHWD	kg	5.51E-02	6.52E-05	7.42E-02	-	1.82E-06	9.34E-01	-1.32E-06
HLRW	kg	2.10E-06	3.85E-09	8.94E-08	-	1.08E-10	8.51E-09	-6.26E-10
ILLRW	kg	3.01E-05	1.04E-07	2.45E-06	-	2.89E-09	2.03E-07	-1.73E-08
CRU	kg	-	-	-	-	-	-	-
MR	kg	-	-	4.58E-02	-	-	-	-
MER	kg	-	-	-	-	-	-	-
EE	MJ, LHV	2.86E-04	-	2.01E-03	-	-	-	-

4.1.7. Open cell

Figure 4-7 and Table 4-7, below, show life cycle impact assessment results for the open cell product. The majority of burdens for categories fall within modules A1-A3, with the exception of SFP, due to the impacts associated with raw material supply and manufacturing. Note that unlike all other products evaluated, open cell SFP only utilizes reactive blowing agent (water) and does not contain any physical blowing agent. While released at the same rate over the course of the life of the product as HFCs and HFOs, reactive blowing agent has no GWP. Installation of SPF utilizes onsite diesel generators, which contribute greatly to AP, EP, and SFP due to the emissions of VOCs and nitrogen containing compounds.

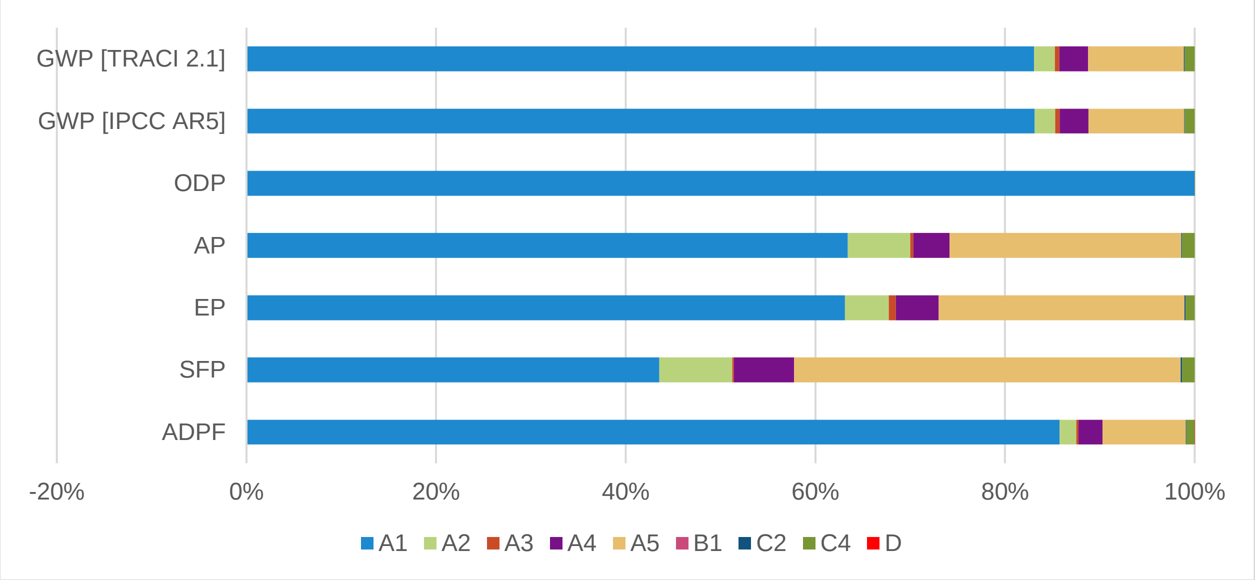

Figure 4-7: A1-D contribution analysis – open cell

Table 4-7: Open cell results

IMPACT ASSESSMENT								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
GWP [TRACI 2.1]	kg CO$_2$ eq.	1.42E+00	5.06E-02	1.67E-01	-	1.41E-03	1.72E-02	-7.30E-05
GWP [IPCC AR5]	kg CO$_2$ eq.	1.44E+00	5.08E-02	1.69E-01	-	1.41E-03	1.74E-02	-7.30E-05
ODP	kg CFC-11 eq.	2.77E-08	1.46E-15	1.14E-13	-	4.07E-17	3.12E-15	-2.33E-16
AP	kg SO$_2$ eq.	4.18E-03	2.27E-04	1.45E-03	-	6.34E-06	7.83E-05	-4.26E-07
EP	kg N eq.	2.85E-04	1.88E-05	1.08E-04	-	5.25E-07	3.97E-06	-1.62E-08
SFP	kg O$_3$ eq.	6.05E-02	7.50E-03	4.79E-02	-	2.09E-04	1.55E-03	-1.88E-06
ADPF	Surplus MJ	3.46E+00	9.97E-02	3.47E-01	-	2.78E-03	3.39E-02	9.33E-05
RESOURCE USE								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
RPR$_E$	MJ, LHV	9.42E-01	1.80E-02	8.93E-02	-	5.04E-04	1.91E-02	-3.20E-04
RPR$_M$	MJ, LHV	4.33E-02	-	8.72E-04	-	-	-	-
NRPR$_E$	MJ, LHV	2.92E+01	7.46E-01	2.74E+00	-	2.08E-02	2.71E-01	-1.01E-03
NRPR$_M$	MJ, LHV	9.14E+00	-	3.05E-01	-	-	-	-
SM	kg	-	-	-	-	-	-	-
RSF	MJ, LHV	-	-	-	-	-	-	-
NRSF	MJ, LHV	-	-	-	-	-	-	-
RE	m^3	-	-	-	-	-	-	-
FW	m^3	4.82E-03	8.88E-05	4.70E-04	-	2.48E-06	3.28E-05	-8.94E-07
OUTPUT FLOWS AND WASTE CATEGORIES								
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B1**	**C2**	**C4**	**D**
HWD	kg	1.09E-07	5.83E-09	1.53E-08	-	1.63E-10	9.34E-10	-6.46E-13
NHWD	kg	2.46E-02	2.69E-05	3.07E-02	-	7.53E-07	3.86E-01	-5.45E-07
HLRW	kg	8.15E-07	1.59E-09	3.69E-08	-	4.45E-11	3.52E-09	-2.59E-10
ILLRW	kg	1.13E-05	4.28E-08	1.01E-06	-	1.20E-09	8.37E-08	-7.14E-09
CRU	kg	-	-	-	-	-	-	-
MR	kg	-	-	1.89E-02	-	-	-	-
MER	kg	-	-	-	-	-	-	-
EE	MJ, LHV	1.18E-04	-	8.30E-04	-	-	-	-

4.2. LCIA Results Summary

To better understand the differences between the products discussed previously, the total life cycle results are presented in Figure 4-8, Figure 4-9, Figure 4-10, Figure 4-11, and Figure 4-12 for GWP [TRACI 2.1], GWP [IPCC AR5], AP, EP, and SFP impact categories, respectively.

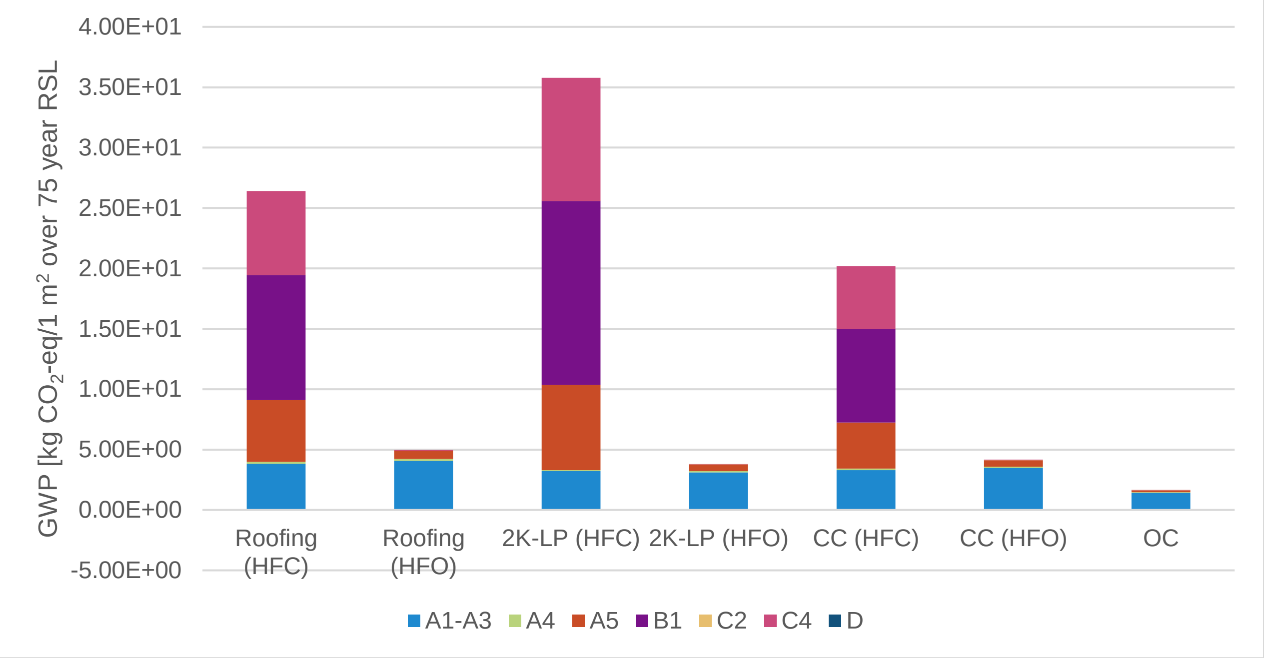

Figure 4-8: Total life cycle GWP [TRACI 2.1] results for all scenarios

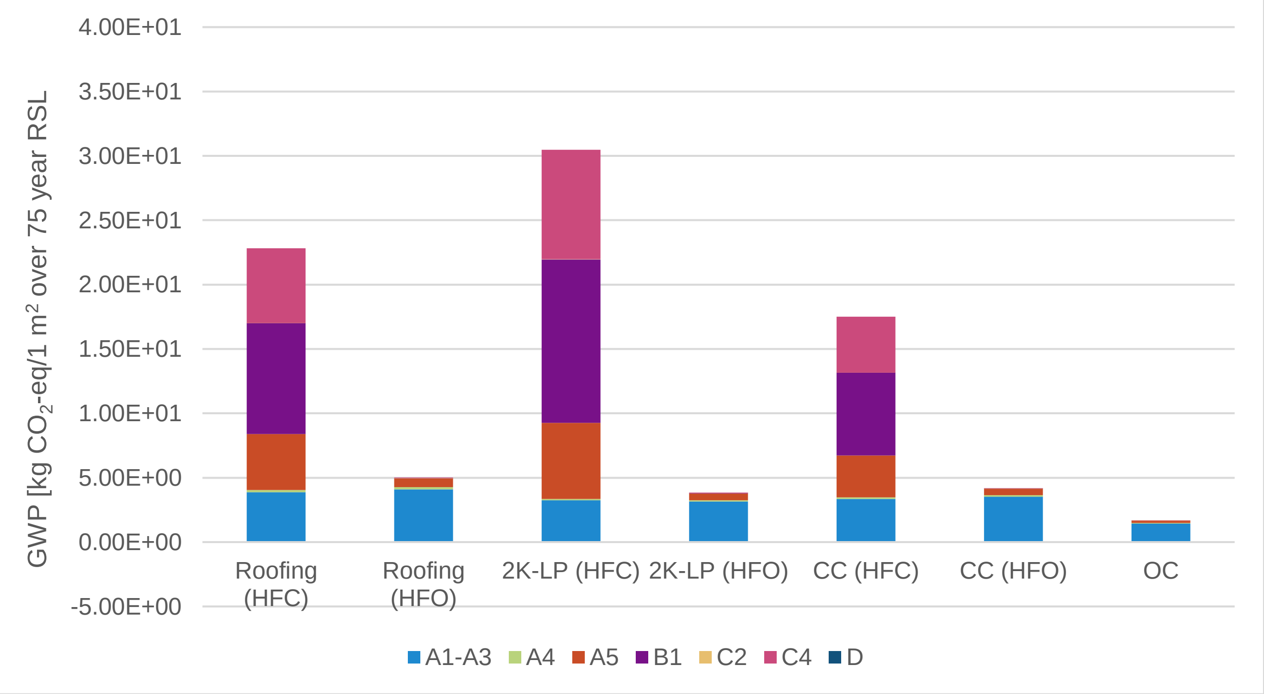

Figure 4-9: Total life cycle GWP [IPCC AR5] results for all scenarios

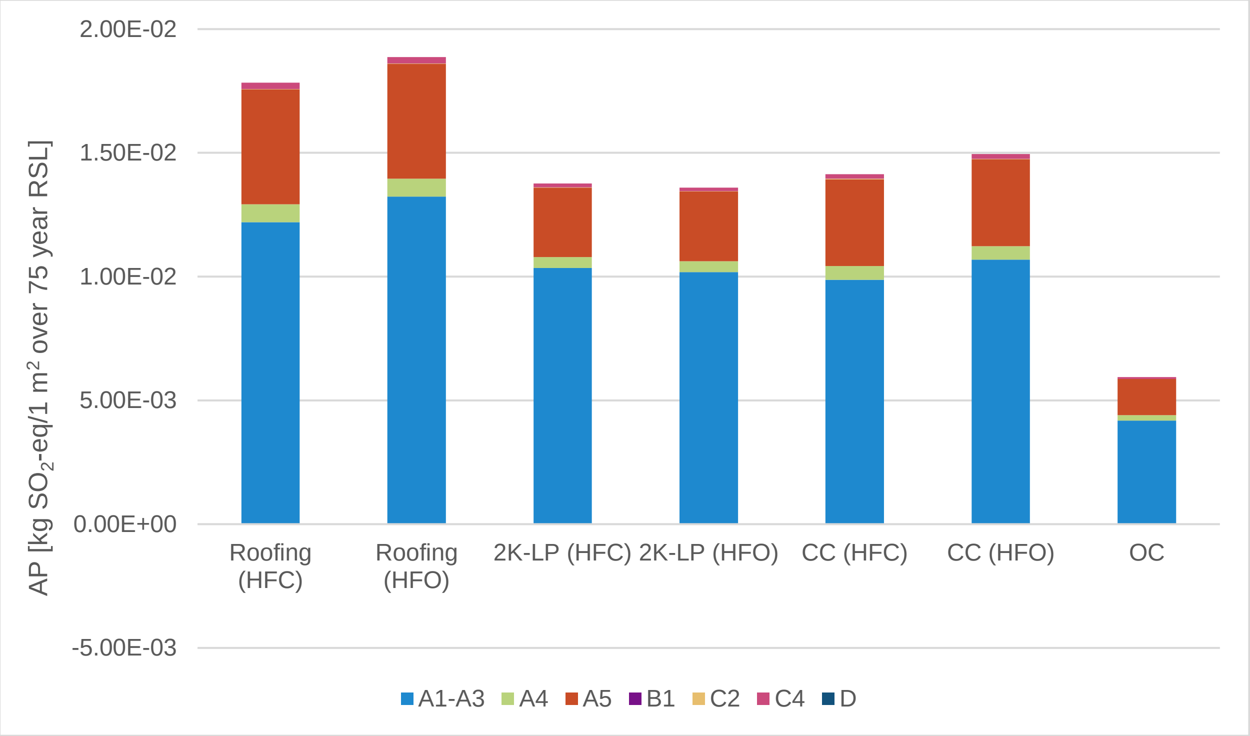

Figure 4-10: Total life cycle AP results for all scenarios

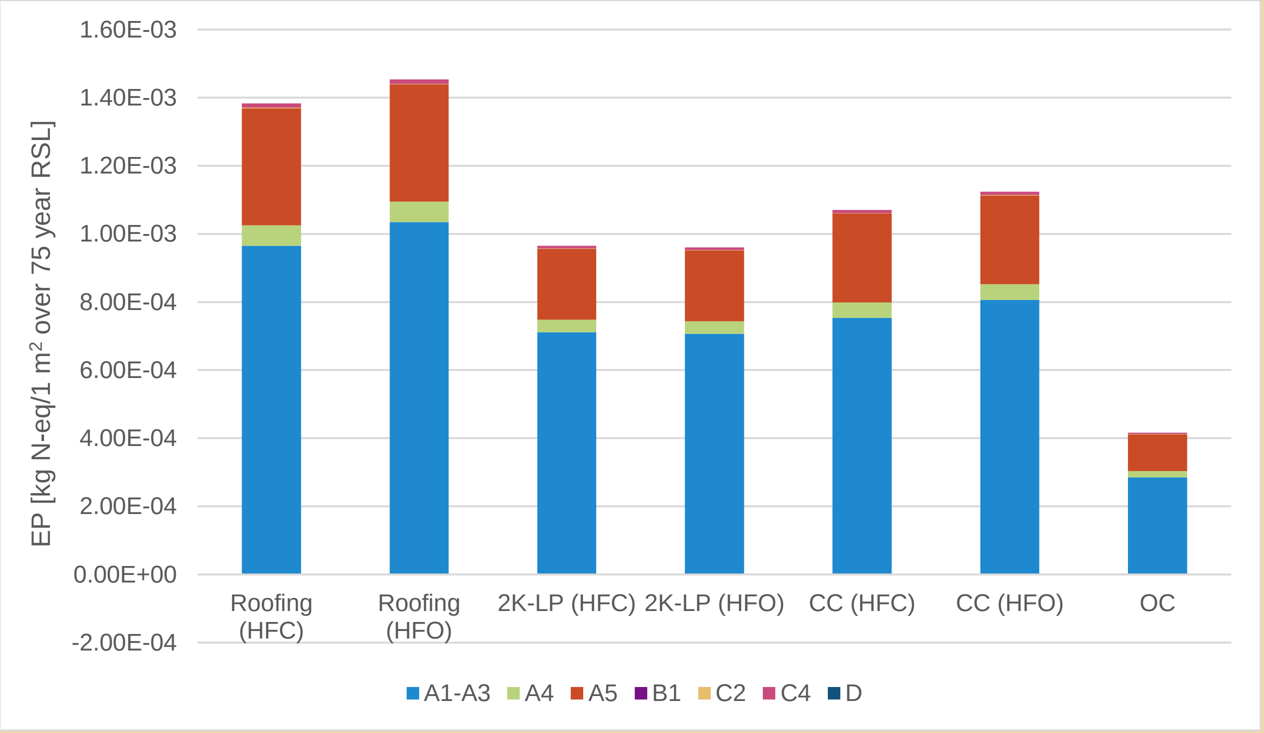

Figure 4-11: Total life cycle EP results for all scenarios

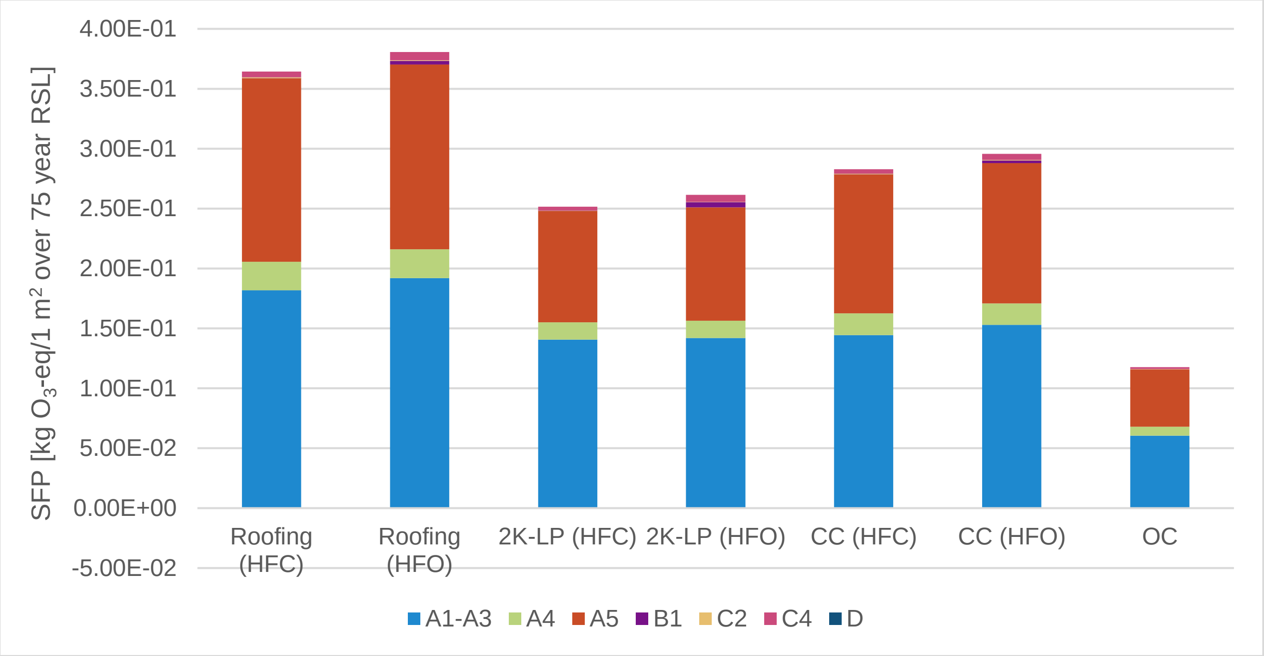

Figure 4-12: Total life cycle SFP results for all scenarios

5. Interpretation

5.1. Identification of Relevant Findings

The results in section 4 represent the cradle-to-grave environmental performance of 1 m^2 of installed SPF at R_{SI}=1 over a 75-year RSL. These results are consistent with SPF blowing agent characteristics. SPF formulations using HFCs correspond to higher environmental impact, formulations with HFOs correspond to lower environmental impact, and the open cell SPF product has the lowest impact due to the use of water as the blowing agent.

This study assumes 50% of blowing agent consumed in the production of the formulation is eventually emitted, with 10% released during installation, 24% released during lifetime in building, and 16% released during end-of-life. For HFC containing products, installation (A5), use (B1), and disposal (C4) are the greatest contributors to the GWP category due the emissions of HFCs over the course of its lifecycle. HFO formulations and open cell do not have pronounced GWP impacts across the life cycle due to lower blowing agent GWP characterization factors.

In nearly all other impact categories, SPF environmental performance is driven primarily by raw materials (A1), in particular polyols and TCPP due to their high mass contribution to the product. Installation tends to be the second highest driver of impact due to the use of on-site diesel generator, as well as waste foam disposal.

Though some raw materials are transported vast distances, the inbound transportation module (A2) has a modest contribution to overall impact. Other transportation modules representing transport to site (A4) and transport to end-of-life (C2), have negligible impact to impact categories.

5.2. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the GaBi 2018 database were used. The LCI datasets from the GaBi 2018 database are widely distributed and used with the GaBi 8 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.2.1. Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data are measured data or calculated based on primary information sources of the owner of the technology, precision is considered to be high. Although generic formulations were used instead of actual formulation from each manufacturer, results should still be precise. Seasonal variations were balanced out by using yearly averages. All background data are sourced from GaBi databases with the documented precision.

- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. This study omits the use of raw materials packaging, as it represents less than 1% of overall inputs to the product system and is not environmentally relevant. Capital goods and infrastructure were also excluded, as they produce millions of units over the course of their life and the impacts attributed to each functional unit of SPF is negligible. No other data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from GaBi databases with the documented completeness.

5.2.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases.
- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modeling approaches.

5.2.3. Representativeness

- ✓ **Temporal:** All of the primary data is taken from 12 months of continuous operation in the 2016 calendar year. All secondary data were obtained from the GaBi 2018 databases and published EPDs. Data are representative of the years 2012 to 2017.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used. Participating members represent a significant majority of annual production for the region under study. Geographical representativeness is considered to be high.
- ✓ **Technological:** All primary and secondary data were modeled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Participating members represent a significant majority of annual production for the region under study. Technological representativeness is considered to be high.

5.3. Model Completeness and Consistency

5.3.1. Completeness

All relevant process steps for each product system were considered and modeled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regard to the goal and scope of this study.

5.3.2. Consistency

All assumptions, methods and data are consistent with each other and with the study’s goal and scope. Differences in background data quality were minimized by exclusively using LCI data from the GaBi 2018 databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.4. Conclusions, Limitations, and Recommendations

5.4.1. Conclusions

The goal of this study was to conduct a cradle-to-grave LCA of spray polyurethane foam in order to develop two industry-average EPDs—one for SPF products containing HFC blowing agents and one for products containing HFO blowing agents. The creation of these EPDs will allow consumers or architects in the building and construction industry to make better-informed decisions about the environmental impacts associated with the products they choose. This study found that GWP of HFC-containing SPF products is driven by the emission of blowing agent over the course of the product's lifetime (installation, use, and disposal), while HFO-containing and open cell products do not experience the same GWP impacts from blowing agent release. Additionally, the study found that other impact categories are driven primarily by raw materials production, with the majority of impact from raw materials due to the production of polyols and TCPP. Installation also has a sizeable contribution to many categories due to the disposal of waste foam, as well as the use of diesel generators

5.4.2. Assumptions and Limitations

This study has been carried out for SPFA with the goal of quantifying the environmental performance of the seven side-B formulations. This will, in turn, enable them to communicate results via EPDs, as well as to gain understanding and identify opportunities for improvement. The intent of this study was not to conduct a comparative assessment of SPFA member company products. Additionally, the results from this analysis are specifically for the aforementioned SPF formulations and are not intended to be applied to other adjacent insulation products on the market.

This study was based on primary data collected at SPFA member company facilities. As such, datasets selected to represent the production of raw materials by upstream suppliers are based on regional or global averages rather than on primary data collected directly from member company supply chains. When selecting these datasets, a conservative approach is applied in that datasets associated with higher impacts are used when there are multiple possible options.

Global warming potential for HFC products is overwhelmingly being driven by the emission of HFCs. Based on literature research and discussions with industry experts, this study assumes that 50% of HFCs are emitted over the course of its life. However, actual blowing agent release may vary, thus affecting global warming potential impacts

Lastly, this study was conducted in accordance with a PCR. While this guidance document has been developed by industry experts to best represent this product system, real life environmental impacts of SPF may extend beyond those defined in this document.

5.4.3. Recommendations

Given that HFC emissions from foam production are a key driver of global warming potential, SPFA may wish to investigate technology that allows for the capture of R-134a emissions during installation or evaluate alternatives to R-134a in order to reduce its environmental impact. Since additional releases occur at end-of-life, it may be possible to recommend that the foam be shredded in a unit capable of capturing refrigerant emissions instead of being sent directly to landfill. SPFA should also encourage spray foam installers to limit the amount of on-site energy consumed, particularly the use of diesel generators. Otherwise, most impact assessment categories are driven by raw material production (A1) – SPFA should seek to limit high impact raw materials such as polyols and TCPP.

5.4.4. Retroactive Participation

Per the PCR, certain information is required to be declared for facilities to measure against to gain retroactive participation in this industry average EPD. However, as the manufacturing data supplied by manufacturers (A3) has an insignificant contribution to the total results, and an average formulation was used for each product (A1), eligibility should not be based on company-specific manufacturing details. Rather, it should be based on whether or not the company produces a product that falls within the product descriptions supplied in this report.

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Annex A: Manufacturing Datasets

Table A-1: Material and process datasets

Geography	Name	Source	Date
EU-28	Activated carbon	thinkstep	2017
US	Ammonia (NH3)	thinkstep	2017
GLO	Compressed air 7 bar (low power consumption)	thinkstep	2017
US	Corrugated product	thinkstep/AF&PA	2012
US	Cotton - fabric (based on US cotton yarn, conventional)	thinkstep	2017
GLO	Diesel combustion in construction machine	thinkstep	2017
US	Diethanolamine (DEA)	thinkstep	2017
US	Diethylene glycol by product ethylene glycol from ethene and oxygen via EO	thinkstep	2017
DE	Dimethyl terephthalate (DMT)	thinkstep	2017
GLO	Equalizing agent (on basis alcohol ethoxylate)	thinkstep	2017
US	Ethanol (96%) (hydrogenation with nitric acid)	thinkstep	2017
US	Ethylene oxide (EO) via air	thinkstep	2017
US	Ethylene oxide (EO) via O2/methane	thinkstep	2017
US	Fluorspar (extraction and processing)	thinkstep	2017
US	Formaldehyde (HCHO; 100%)	thinkstep	2017
US	Isobutane (from n-butane)	thinkstep	2017
US	Limestone (CaCO3; washed)	thinkstep	2017
US	Lubricants at refinery	thinkstep	2017
US	Mannich Polyol	thinkstep (created from combination of Dow[4] and Huntsman[5] patents)	2017 (background data)
US	Methane	thinkstep	2017
US	Methanol from natural gas (combined reforming)	thinkstep	2017
US	Methylamine (by product di-, trimethylamine)	thinkstep	2017
US	Methylene Diphenyl Diisocyanate (MDI)	ACC	2011
US	Nitrogen (gaseous)	thinkstep	2017

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[4] United States Patent US 6,281,393 B1, Aug. 28, 2001. http://www.google.com/patents?id=xBMIAAAAEBAJ&printsec=abstract&zoom=4&source=gbs_overview_r&cad=0#v=onepage&q&f=false

[5] United States Patent US 6,495,722 B1, Dec. 17, 2002. http://www.freepatentsonline.com/6495722.pdf

Geography	Name	Source	Date
GLO	Non-ionic surfactant (fatty acid derivate)	thinkstep	2017
DE	o-Xylene	thinkstep	2017
US	Pentane (estimation)	thinkstep	2017
US	Phenol (from cumene)	thinkstep	2017
US	Phosphate mining and processing	thinkstep	2017
US	Phthalic anhydride (PSA) via oxidation	thinkstep	2017
DE	Plastic injection moulding part (unspecific)	thinkstep	2017
US	Polycarbonate Granulate (PC)	thinkstep	2017
EU-28	Polyester (PET) fabric	thinkstep	2017
US	Polyether Polyol (from PO+EO)	thinkstep	2017
US	Polyester Polyol	thinkstep (foreground data from PIMA study[6])	2011 (background data 2017)
DE	Polyethylene (HDPE/PE-HD) blow moulding	thinkstep	2017
US	Polyethylene film (LDPE/PE-LD)	thinkstep	2017
US	Polyethylene glycol	thinkstep	2017
US	Polyethylene High Density Granulate (HDPE/PE-HD)	thinkstep	2017
US	Polyethylene terephthalate (PET) (biobased) in waste incineration plant	thinkstep	2017
DE	Polyethylene terephthalate granulate (PET via DMT)	thinkstep	2017
US	Polystyrene Granulate (PS) (estimation)	thinkstep	2017
US	Polyvinyl chloride granulate (Suspension, S-PVC)	thinkstep	2017
US	Process steam from natural gas 95%	thinkstep	2017
US	Propylene Oxide (Chlorohydrin Process with Cell Liquor)	thinkstep	2017
US	Purified terephthalic acid (PTA)	thinkstep	2017
DE	R-1234yf production (estimation)	thinkstep	2017
DE	Siloxane (cyclic) (from organosilanes)	thinkstep	2017
US	Sodium chloride (rock salt)	thinkstep	2017
US	Soybean oil, conditioned (economic allocation)	thinkstep	2017
GLO	Steel cold rolled coil	thinkstep	2014
US	Sulphur (elemental) at refinery	thinkstep	2017
US	Tap water from groundwater	thinkstep	2017
DE	Tetrafluoroethane (R134a)	thinkstep	2017

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[6] Life Cycle Assessment of Polyiso Insulation for the Polyisocyanurate Insulation Manufacturers Association (PIMA) – Phelan, Pavlovich, Jewell, 2011.

Geography	Name	Source	Date
GLO	Tin	thinkstep	2017
US	Tris(2-chloroisopropyl)phosphate (TCPP)	thinkstep	2017
US	Water deionized	thinkstep	2017
US	Water deionized (reverse-osmosis/electro-deionization)	thinkstep	2017
EU-28	Wooden pallets (EURO, 40% moisture)	thinkstep	2017