

ENVIRONMENTAL PRODUCT DECLARATION

IN ACCORDANCE WITH ISO 14025:2006 AND ISO 21930:2017

SmartEPD-2026-155-1066-01

Expanded Shale, Clay, and Slate (ESCS) Lightweight Aggregates



Date of Issue:	Expiration:	Last updated:
Sep 23, 2026	Sep 23, 2031	Sep 23, 2026

Refer to the EPD Library at www.smartepd.com for the latest EPD listing information



General Information

Expanded Shale, Clay and Slate Institute

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🌐 [escsi.org](https://www.escsi.org)



Product Name:	Expanded Shale, Clay, and Slate (ESCS) Lightweight Aggregates
Declared Unit:	1 m3 of manufactured ESCS lightweight aggregate equivalent to 1.308 cubic yards
Declaration Number:	SmartEPD-2026-155-1066-01
Date of Issue:	September 23, 2026
Expiration:	September 23, 2031
Last updated:	September 23, 2026
EPD Scope:	Cradle to gate A1 - A3
Market(s) of Applicability:	North America, Global

General Organization Information

Expanded Shale, Clay and Slate Institute

The Expanded Shale, Clay and Slate Institute (ESCSI), founded in 1952, is the international trade association for manufacturers of ESCS lightweight aggregate.

Further information can be found at: <https://www.escsi.org/>

Limitations, Liability and Ownership

The trade association ESCSI that lead the development of industry-average EPDs may need to collect confidential business information from individual members. This data can include proprietary chemical formulations and processes or other confidential information. In this case, a designated third-party entity such as an LCA practitioner shall be identified as the "industry agent". The industry agent shall be responsible for activities including collection, secure storage and analysis of such data needed for the EPD development and will preserve the privacy of individual company information while executing these duties.

Per ISO 21930 Section 5.4, the manufacturer, or group of manufacturers, of the construction product is the sole owner of the EPD and is responsible for developing the EPD of the construction product according to the PCR. Only the manufacturer or group of manufacturers is authorized to declare the environmental performance of the construction product using an EPD.

The group of manufacturers responsible for developing an industry-average EPD shall be responsible for, including but not limited to, ensuring industry-average EPD updates are made based on the most recent LCA modelling software version and impact assessment version available.

Environmental declarations from different programs (ISO 14025) may not be comparable.

Comparison of the environmental performance of ESCS products using EPD information shall be based on the product's use and impacts at the construction works level, and therefore EPDs may not be used for comparability purposes when not considering the whole life cycle as instructed under this PCR.

For EPDs reporting a declared unit, the following language shall be included: "The environmental impact results of products in this document are based on a declared unit and therefore do not provide sufficient information to establish comparisons. The results shall not be used for comparisons without knowledge

of how the physical properties of the product impact the precise function at the construction level. The environmental impact results shall be converted to a functional unit basis before any comparison is attempted. See Section 3.8 for additional EPD comparability guidelines.”

Reference Standards

Standard(s):	ISO 14025:2006 and ISO 21930:2017
Core PCR:	UL Part A PCR for Building-Related Products and Services v.4 Date of issue: March 01, 2022
Sub-category PCR:	UL Part B: Expanded Shale, Clay, Slate, and Lightweight Aggregate v.1 Date of issue: January 25, 2022 Valid until: January 25, 2027
Sub-category PCR review panel:	 Contact Smart EPD for more information.
General Program Instructions:	 Smart EPD General Program Instructions v.2.0, March 2025

Verification Information

LCA Author/Creator:	 Fariborz M. Tehrani  Expanded Shale, Clay and Slate Institute  ftehrani@escsi.org
EPD Program Operator:	 Smart EPD  info@smartepd.com  www.smartepd.com  585 Grove St., Ste. 145, Herndon, VA 20170, USA
Verification:	Independent critical review of the LCA and data, according to ISO 14044 and ISO 14071:  Sarah Curpen  curpen1996@gmail.com Independent external verification of EPD, according to ISO 14025 and reference PCR(s):  Sarah Curpen  curpen1996@gmail.com

External

External

Product Information

Declared Unit:	1 m3 of manufactured ESCS lightweight aggregate equivalent to 1.308 cubic yards
Mass:	770 kg
Reference Service Life:	100 Years
Product Specificity:	 Product Average  Product Specific
Variation in GWP Result (Facilities):	+71% to +688%



Functional unit / declared unit

The declared unit is one cubic meter of ESCS product as manufactured and prepared for shipment, equivalent to 1.308 cubic yards, which might be reported as an optional unit in addition to the required cubic meter unit..]

Product Description

ESCS is a ceramic material produced by expanding and vitrifying select shale, clay, or slate minerals in a rotary kiln at temperatures over 1000°C (1830°F). The production and raw material selection processes are strictly controlled to ensure a uniform, high-quality, lightweight aggregate. The process produces a high-quality ceramic aggregate containing a uniformly distributed system of pores with a size range of approximately 5 to 300µm (0.2 to 12 mil), developed in a continuous, relatively crack-free, high-strength vitreous phase. The ceramic nature of the aggregate ensures that the product is inert, non-toxic, and highly resistant to degradation. Interior pores are essentially non-interconnected; a small fraction remains unfilled after years of immersion. The pores system is responsible for the low density, insulative, and absorptive characteristics of ESCS. ESCS lightweight aggregate is a type of coarse and fine aggregate that is used in the production of lightweight concrete products such as concrete, masonry, backfill, pavement, soil amendments, and filter materials.

Further information can be found at: <https://www.escsi.org/escs-lwa/>

Product Specifications

Product Classification Codes:	UNCPC - 3799 Non-metallic mineral products not elsewhere classified (including mineral wool, expanded mineral materials, worked mica, articles of mica, non-electrical articles of graphite, or other carbon and articles of peat)
	EC3 - Aggregates
Loose Bulk Density:	770 kg/m3
Grading:	0-25 mm
Equilibrium Moisture Content:	5-8 %

Product Composition Diagram



Material Composition

Material/Component Category	Origin	% Mass
Expanded Shale, Clay and Slate	Plants in Northern America	100

Biogenic Carbon Content	kg C per m3 of manufactured ESCS lightweight aggregate
Biogenic carbon content in product	0
Biogenic carbon content in accompanying packaging	0



Hazardous Materials

No regulated hazardous or dangerous substances are included in this product.

EPD Data Specificity

- Primary Data Year:2025
- Manufacturing Specificity:

✓

 Industry Average

✗

 Manufacturer Average

✗

 Facility Specific

Averaging:
This EPD represents an **industry-average product** based on data collected from multiple manufacturing facilities. Averaging was applied in accordance with the PCR and ISO 21930 requirements. The averaging procedure is summarized as follows:

- **Data Collection:** Primary (foreground) data were collected from participating facilities for a consistent 12-month period. All facilities manufacture products that meet the same product definition and performance characteristics.
- **Facility-Level Modeling:** Each facility’s life cycle inventory (LCI) and life cycle impact assessment (LCIA) were modeled separately using identical system boundaries, allocation procedures, LCIA methods, cut-off rules, and data quality requirements.
- **Averaging Approach:** Facility-specific LCIA results for each impact category were combined using **production-weighted averaging**, where each facility’s contribution is weighted according to annual production volume of the declared product(s). This ensures the aggregated results are representative of the industry’s actual output.
- **Data Completeness and Representativeness:** Facilities included in the averaging process collectively represent a significant share of industry production. Facilities not included in the dataset are assumed to have similar technology, fuel use, and manufacturing practices.
- **Background Datasets:** All background data use the same LCI database versions, electricity grid mixes, fuels, and upstream process models to ensure methodological consistency across sites.
- **Uncertainty:** Because facility processes, regional electricity mixes, and operational conditions vary, averaged results represent typical industry performance and do not necessarily reflect any single facility.

This industry-average EPD shall not be used to make claims about any individual facility’s environmental performance.
Some facility-specific data were replaced with proxy values to complete the dataset. These substitutions are not expected to materially affect the production-weighted average results.

System Boundary

Production	A1	Raw material supply	✓
	A2	Transport	✓
	A3	Manufacturing	✓
Construction	A4	Transport to site	ND
	A5	Assembly / Install	ND



Use	B1	Use	ND
	B2	Maintenance	ND
	B3	Repair	ND
	B4	Replacement	ND
	B5	Refurbishment	ND
	B6	Operational Energy Use	ND
	B7	Operational Water Use	ND
End of Life	C1	Deconstruction	ND
	C2	Transport	ND
	C3	Waste Processing	ND
	C4	Disposal	ND
Benefits & Loads Beyond System Boundary	D	Recycling, Reuse Recovery Potential	ND

Note:
ND = Module not declared

Product Composition Diagram

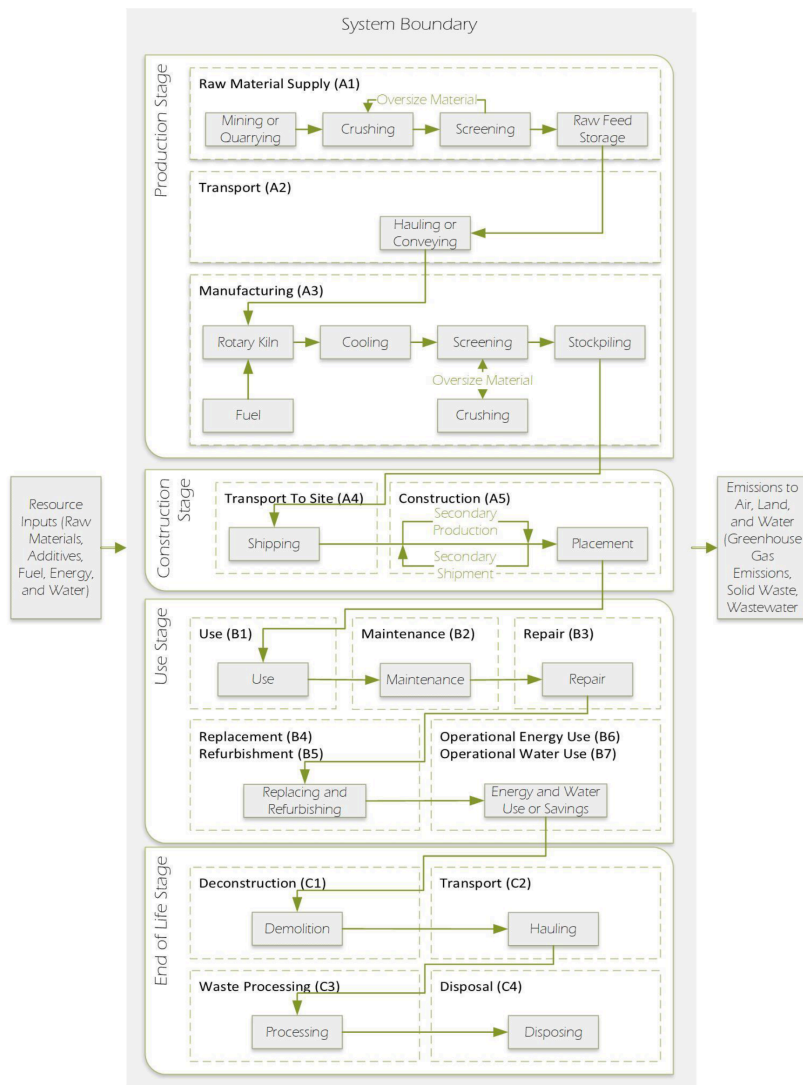
EPD Type	Production			Construction		Use							End of Life				Benefits & Loads Beyond System Boundary	
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	
	Raw Material Supply	Transport	Manufacturing	Transport to Site	Assembly/Install	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	Deconstruction	Transport	Waste Processing	Disposal	Reuse, Recovery, Recycling Potential	
	Reference Service Life																	
Cradle to gate w/ EOL	Required			Excluded								Required, Depending on UL 100.10-37 PCR, Part A, Section 2.8.4.5 ^b				Optional ^a		Optional
Cradle to gate with options	Required			Optional ^d		Optional ^c						Required, Depending on UL 100.10-37 PCR, Part A, Section 2.8.4.5 ^b				Optional ^a		Optional
Cradle to grave	Required															Optional ^a		Required
Declared Modules	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Participating Manufacturers

- Amrize Utelite
- Coalville, UT
- Arcosa Lightweight
- Frazier Park, CA
- Streetman, TX
- Livingston, AL
- Brooks, KY
- Carolina Stalite
- Aquadale, NC

- Gold Hill, NC
- Martin Maretta Buildex
- Dearborn, MO

Product Flow Diagram



Declared modules include A (production)

a) Cradle to gate (modules A1-A3)

Other modules, A (construction), B (use), C (end of life), and D (benefits and loads beyond system boundary) require additional information about specific application scenarios:

b) Cradle to gate with options (modules A1-A3, optional modules A4-A5, B1-B7, C1-C4, and D)

c) Cradle to grave (modules A1-A3, A4-A5, B1-B7, C1-C4, and optional module D)

Reporting optional module D makes reporting modules C1 to C4 required. Module D differs from modules A1 to C4, which involves supplementary environmental information beyond the product system boundary.

The product system boundary excludes capital goods and infrastructure. These items include production, processing, and transport equipment and machinery; administrative buildings and facilities; and other components whose wear and tear fall below the cut-off rule.

Primary inputs are raw materials, additives, fuel, energy, and water. Outputs beyond the main ESCS product include air, land, and water emissions, greenhouse gas emissions, solid waste, and wastewater.

Software And Database

LCA Software:

☰ In-house LCA calculation tool v. N/A

LCI Foreground Database(s):

☰ Collected directly from the ESCS manufacturing facility using in-house software v. N/A

📍 North America | 📄 No allocation is required

LCI Background Database(s):

☰ Generic data or EPD / LCI / LCA of upstream processes using in-house software v. N/A

📍 North America | 📄 Standard cut-off allocation from EPDs

A foreground LCI database is the database used to model the primary, site-specific data collected for this EPD. A background LCI database is the database used to model generic or non-specific data.

Data Quality

The data used in this EPD consist of a combination of primary (foreground) and secondary (background) datasets that meet the data quality requirements of ISO 14044, ISO 21930, and the applicable PCR.

Temporal Representativeness

- Primary data represent 12 consecutive months of measured production data from the declared manufacturing facility, collected within the last five years.
- Background datasets (energy, raw materials, transport, waste) originate from published EPDs and were updated within the last ten years, satisfying ISO temporal requirements.

Geographic Representativeness

- Foreground data reflect the actual geographic location of production in North America.
- Electricity mixes are modeled using national EIA, .
- Background datasets are chosen to reflect U.S. or globally average conditions appropriate for the supply chains modeled.

Technological Representativeness

- Primary data originate from real, current facility operations using the actual technologies and processes employed to manufacture the declared ESCS product.
- Background datasets reflect contemporary industrial processes and upstream technologies.

Accuracy and Precision

- Energy, water, and material consumption data are based on metered or recorded values where available.
- Emissions and waste data are based on measured values or reputable secondary datasets.
- Internal checks (mass and energy balances, outlier screening, cross-verification with historical records) confirm that the data are reliable and sufficiently precise for EPD purposes.

Completeness

- Foreground data achieve >99% completeness for mass and energy flows.
- No environmentally significant flows are omitted.
- Secondary datasets cover all required upstream and downstream processes defined in the system boundary.

Overall Data Quality

Based on temporal currency, geographic and technological relevance, completeness, and accuracy, the overall data quality for both primary and background data is considered high and appropriate for use in this EPD.

Life Cycle Module Description

Declared modules include A (production and construction): Cradle to gate (modules A1-A3)

The product system boundary excludes capital goods and infrastructure. These items include production, processing, and transport equipment and machinery; administrative buildings and facilities; and other components whose wear and tear fall below the cut-off rule.

Primary inputs are raw materials, additives, fuel, energy, and water. Outputs beyond the main ESCS product include air, land, and water emissions, greenhouse gas emissions, solid waste, and wastewater.

Module A1 covers acquiring raw materials from shale, clay, and slate quarries transported to the manufacturing plant (Module A2). For plants using subcontractors for mining and quarrying and lacking detailed information for raw material supply, calculations used an average data collection from the industry. The manufacturing process (Module A3) involves expanding raw materials in the rotary kiln and using fuel to generate heat. Kiln production flows through post-processing using energy supplied by fuels or electricity before shipment and transport. The manufacturing line recycles process wastes and products for re-processing or repurposing to minimize manufacturing waste.

LCA Discussion

Allocation Procedure

This industry-wide EPD includes data from multiple ESCS production facilities. Each facility manufactures only one product type, and therefore no co-product allocation is required. All material, energy, and emission flows at each facility are fully attributed to ESCS production.

None of the facilities use packaging for the declared unit. ESCS is shipped in bulk, so no packaging materials or packaging-related processes require allocation.

Closed-loop internal recycling of off-spec material and fines occurs within each facility's manufacturing system. Because the recycled material retains the same inherent properties and does not enter external markets, it is treated as closed-loop recycling, with all associated impacts allocated to Modules A1-A3.

No Module D credit is assigned for internal recycling.

Energy, water, ancillary materials, and operating supplies are dedicated to ESCS production and are not shared across multiple product systems. Therefore, no economic, mass-based, or system-expansion allocation procedures are required.

At end-of-life, recycling or reuse of ESCS is modeled using substitution in Module D, consistent with ISO 21930. Substitution credits do not represent allocation across product systems and are applied only to net output flows that displace primary material production.

Cut-off Procedure

Cut-off criteria were applied in accordance with ISO 14044, ISO 21930, and the applicable PCR. All known material and energy inputs with potential environmental relevance were included. Inputs and outputs were assessed using mass, energy, and environmental significance criteria. The LCA includes all flows that collectively represent more than 99% of total mass and more than 99% of total primary energy demand for the declared product. Small ancillary flows (e.g., minor maintenance supplies) that represent less than 1% of mass or energy and do not materially influence environmental impacts were excluded. No hazardous substances, fuels, emissions, or end-of-life processes were omitted. No exclusions are expected to influence the results or conclusions. Full cut-off analysis and supporting documentation are provided in the LCA project report.

Renewable Electricity

Energy Attribute Certificates (EACs) such as ☒ No
Renewable Energy Certificates (RECs) or Power
Purchase Agreements (PPAs) are included in the
baseline reported results:

Results

Environmental Impact Assessment Results

EF 3.1, EF3.1

per 1 m3 of manufactured ESCS lightweight aggregate of product equivalent to 1.308 cubic yards.

LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

ESCS Industry Average EPD

Impact Category	Unit	Method	A1	A2	A3	A1 - A3
GWP-fossil	kg CO2 eq	EF 3.1	2.30e-2	4.72e-1	1.73e+2	1.73e+2
GWP-biogenic	kg CO2 eq	EF 3.1	5.39e-5	0	0	5.39e-5
GWP-luluc	kg CO2 eq	EF 3.1	9.98e-5	0	0	9.98e-5
GWP-total	kg CO2 eq	EF 3.1	2.21e-2	4.72e-1	1.73e+2	1.73e+2
ODP	kg CFC11 eq	EF3.1	1.90e-11	7.90e-11	1.87e-9	1.97e-9
AP	mol H+ eq	EF3.1	1.64e-2	1.38e-2	8.38e+1	8.38e+1
EP	kg PO4 eq	EF 3.1	4.51e-7	0	0	4.51e-7
EP-fw	kg P eq	EF3.1	6.05e-8	0	0	6.05e-8
EP-marine	kg N eq	EF3.1	2.36e-5	1.44e-6	3.46e-1	3.46e-1
EP-terrestrial	mol N eq	EF3.1	7.41e-4	2.02e-5	3.90e+0	3.90e+0
POCP	kg NMVOC eq	EF3.1	1.44e-4	5.23e-3	1.11e+0	1.12e+0
ADP-minerals&metals	kg Sb eq	EF3.1	3.46e-10	0	0	3.46e-10
ADP-fossil	MJ, net calorific value	EF3.1	2.43e-1	3.23e+0	2.13e+3	2.13e+3
WDP	m3 world eq	EF 3.1	2.57e-3	0	2.93e+1	2.93e+1
GWP-GHG	kg CO2 eq	EF 3.1	2.31e-2	4.72e-1	1.73e+2	1.73e+2
PM	disease incidence	EF3.1	1.10e-10	3.45e-8	2.30e-7	2.65e-7
IRP	kBq U235 eq	EF 3.1	1.42e-3	0	0	1.42e-3
ETP-fwio	CTUe	EF3.1	9.11e-2	0	4.56e-3	9.57e-2
HTP-c	CTUh	EF 3.1	3.78e-12	0	0	3.78e-12
HTP-nc	CTUh	EF 3.1	1.29e-10	0	0	1.29e-10
SQP	dimensionless	EF 3.1	1.33e+0	0	0	1.33e+0

Note:

Not all abbreviated indicators listed below may be present in the results above. The inclusion of indicators varies based on PCR requirements.

Abbreviations:

GWP = Global Warming Potential, 100 years (may also be denoted as GWP-total, GWP-fossil (fossil fuels), GWP-biogenic (biogenic sources), GWP-luluc (land use and land use change)), ODP = Ozone Depletion Potential, AP = Acidification Potential, EP = Eutrophication Potential, SFP = Smog Formation Potential, POCP = Photochemical oxidant creation potential, ADP-Fossil = Abiotic depletion potential for fossil resources, ADP-Minerals&Metals = Abiotic depletion potential for non-fossil resources, WDP = Water deprivation potential, PM = Particular Matter Emissions, IRP = Ionizing radiation, human health, ETP-fw = Eco-toxicity (freshwater), HTP-c = Human toxicity (cancer), HTP-nc = Human toxicity (non-cancer), SQP = Soil quality index.

Comparison of EPD results between non-competitive products may be conducted per the requirements in Part A, Section 9 of the ESCSI PCR (UL 2022). Here, non-competitive means a product comparison with an industry average or comparison between two products manufactured by the same producer. Comparisons cannot be made between product-specific or industry-average EPDs at the design stage of a project before a construction product has been specified and product performance has been determined.

Comparisons may be made between product-specific or industry-average EPDs at the time of product purchase when product performance and specifications have been established and serve as a functional unit for comparison.

Environmental impact results based on a declared unit of an ESCS product do not provide sufficient information to establish comparisons. The results shall not be used for comparisons without knowledge of how the physical properties of the ESCS product impact the precise function at the construction level. The environmental impact results shall be converted to a functional unit basis based on the same scenario before attempting any comparison.

Emerging LCA impact categories and inventory items are still under development and can have high levels of uncertainty that preclude international acceptance pending further development. Use caution when interpreting data in these categories.

Resource Use Indicator

per 1 m3 of manufactured ESCS lightweight aggregate of product equivalent to 1.308 cubic yards.

ESCS Industry Average EPD

Indicator	Unit	A1	A2	A3	A1 - A3
PERE	MJ	2.48e-2	0	2.44e+1	2.44e+1
PERM	MJ	0	0	0	0
PERT	MJ	2.48e-2	0	2.44e+1	2.44e+1
PENRE	MJ	3.17e-1	4.74e+0	2.16e+3	2.17e+3
PENRM	MJ	0	0	0	0
PENRT	MJ	3.17e-1	4.74e+0	2.16e+3	2.17e+3
SM	kg	1.46e-6	0	0	1.46e-6
RSF	MJ	2.35e-4	0	0	2.35e-4
NRSF	MJ	1.41e-2	0	5.68e+0	5.69e+0
FW	m3	6.80e-5	0	8.20e-1	8.20e-1

Note:

Not all abbreviated indicators listed below may be present in the results above. The inclusion of indicators varies based on PCR requirements.

Abbreviations:

RPRE or PERE = Renewable primary resources used as energy carrier (fuel), RPRM or PERM = Renewable primary resources with energy content used as material, RPRT or PERT = Total use of renewable primary resources with energy content, NRPRE or PENRE = Non-renewable primary resources used as an energy carrier (fuel), NRPRM or PENRM = Non-renewable primary resources with energy content used as material, NRPRRT or PENRT = Total non-renewable primary resources with energy content, SM = Secondary materials, RSF = Renewable secondary fuels, NRSF = Non-renewable secondary fuels, RE = Recovered energy, ADPF = Abiotic depletion potential, FW = Use of net freshwater resources, VOCs = Volatile Organic Compounds.

Comparison of EPD results between non-competitive products may be conducted per the requirements in Part A, Section 9 of the ESCSI PCR (UL 2022).

Here, non-competitive means a product comparison with an industry average or comparison between two products manufactured by the same producer.

Comparisons cannot be made between product-specific or industry-average EPDs at the design stage of a project before a construction product has been specified and product performance has been determined.

Comparisons may be made between product-specific or industry-average EPDs at the time of product purchase when product performance and specifications have been established and serve as a functional unit for comparison.

Environmental impact results based on a declared unit of an ESCS product do not provide sufficient information to establish comparisons. The results shall not be used for comparisons without knowledge of how the physical properties of the ESCS product impact the precise function at the construction level. The environmental impact results shall be converted to a functional unit basis based on the same scenario before attempting any comparison.

Waste and Output Flow Indicators

per 1 m3 of manufactured ESCS lightweight aggregate of product equivalent to 1.308 cubic yards.

ESCS Industry Average EPD

Indicator	Unit	A1	A2	A3	A1 - A3
HWD	kg	2.81e-6	0	2.81e-1	2.81e-1
NHWD	kg	1.40e-3	0	1.16e+1	1.16e+1
RWD	kg	2.08e-6	0	0	2.08e-6
CRU	kg	0	0	0	0
MFR	kg	1.38e-6	0	3.12e+1	3.12e+1
MER	kg	0	0	0	0
EEE	MJ	0	0	0	0
EET	MJ	0	0	0	0

Note:

Not all abbreviated indicators listed below may be present in the results above. The inclusion of indicators varies based on PCR requirements.

Abbreviations:

HWD = Hazardous waste disposed, NHWD = Non-hazardous waste disposed, RWD = Radioactive waste disposed, HLRW = High-level radioactive waste, ILLRW = Intermediate- and low-level radioactive waste, CRU = Components for re-use, MFR or MR = Materials for recycling, MER = Materials for energy recovery, MNER = Materials for incineration, no energy recovery, EE or EEE = Recovered energy exported from the product system, EET = Exported thermal energy.

Comparison of EPD results between non-competitive products may be conducted per the requirements in Part A, Section 9 of the ESCSI PCR (UL 2022).

Here, non-competitive means a product comparison with an industry average or comparison between two products manufactured by the same producer. Comparisons cannot be made between product-specific or industry-average EPDs at the design stage of a project before a construction product has been specified and product performance has been determined.

Comparisons may be made between product-specific or industry-average EPDs at the time of product purchase when product performance and specifications have been established and serve as a functional unit for comparison.

Environmental impact results based on a declared unit of an ESCS product do not provide sufficient information to establish comparisons. The results shall not be used for comparisons without knowledge of how the physical properties of the ESCS product impact the precise function at the construction level. The environmental impact results shall be converted to a functional unit basis based on the same scenario before attempting any comparison.

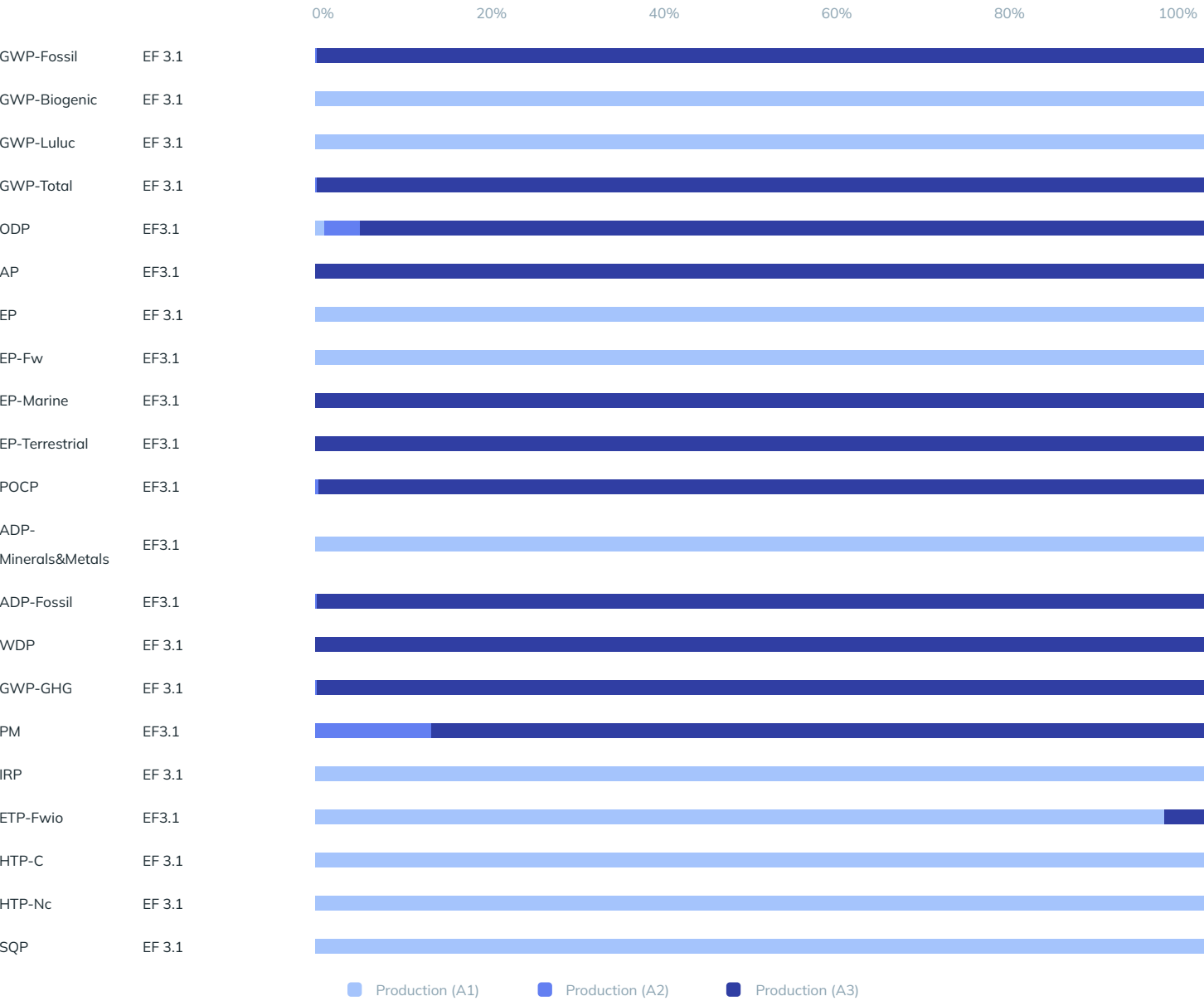
Interpretation

The A1-A3 results for the ESCS product show that the production stage A3 is the dominant contributor to most environmental impact categories. This is primarily due to fuel combustion for the high-temperature rotary kiln process, and electricity use for drying, crushing, screening, and material handling. Transport to the construction site (A4) contributes a smaller share of impacts, mainly driven by diesel fuel use in heavy-duty trucks.

Potential benefits beyond the system boundary (Module D) may occur when ESCS-containing materials are recovered and used to replace virgin aggregate in future applications.

The results should be interpreted with consideration of the underlying assumptions, including scenario-based transport distances, regionally specific electricity mixes, typical end-of-life pathways, and closed-loop internal recycling during manufacturing. Primary data quality for A1-A3 is high, and secondary datasets are temporally, geographically, and technologically representative for North American conditions. No data gaps are expected to materially influence the results.

The indicators presented are relative expressions of potential environmental impacts and do not represent actual environmental performance, risk, or exceedance of thresholds. Environmental improvements are most effectively achieved through optimizing kiln fuel use, improving energy efficiency, and increasing recovery and reuse of ESCS at end-of-life.



Further Information

Additional environmental information

Additional environmental information

Environmental performance indicators include the six pre-defined applications representing 22 scenarios. (Delivered Separately)

Additional social and economic information

There has been no other report on the environmental aspects of the ESCS production.

Information related to Sector EPD

Assessed data represents the production within specified geographical limits.

The LCA and EPD incorporate primary industry average data from all five members of the Expanded Shale, Clay and Slate Institute, the North American trade organization, with all participating plants producing expanded shale, clay, and slate.

The LCA and EPD cover average values for the entire product category within the ESCSI membership.

References

- A. C. Miller Concrete Products, Inc., 2021. Precast Concrete Products. Environmental Product Declaration. Ann Arbor, MI: NSF Certification LLC.
- AASHTO M 95, 2011. Standard Specification for Lightweight Aggregates for Structural Concrete. Washington, DC: AASHTO (American Association of State Highway and Transportation Officials).
- AISC (American Institute of Steel Construction), 2020. Fabricated hot-rolled structural steel sections. Environmental Product Declaration. Chicago, IL: AISC.
- American Galvanizers Association, 2021. Hot-Dip Galvanized Steel After Fabrication. Environmental Product Declaration, Northbrook, IL: UL Environment.
- Angelus, 2021. Angelus Block Concrete Masonry Units. Environmental Product Declaration. Newton, MA: Industrial Ecology Consultants.
- ArcelorMittal, 2016. Hot-Rolled Steel Sheet Piling. Environmental Product Declaration. Berlin, Germany: IBU – Institute Bauen und Umwelt e.V.
- ARMA (Asphalt Roofing Manufacturers Association), 2016. Built-Up Asphalt Roofing Membrane. Environmental Product Declaration. Northbrook, IL: UL Environment.
- Asphalt Institute, 2019. Life Cycle Assessment of Asphalt Binder. Stuttgart, Germany: Thinkstep.
- ASTM C125-21a, 2021. Standard Terminology Relating to Concrete and Concrete Aggregates. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/C0125-21A
- ASTM C144-18, 2018. Standard Specification for Aggregate for Masonry Mortar. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/C0144-18
- ASTM C1761/C1761M-23, 2023. Standard Specification for Lightweight Aggregate for Internal Curing of Concrete. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/C1761_C1761M-23
- ASTM C330/C330M-23, 2023. Standard Specification for Lightweight Aggregates for Structural Concrete. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/C0330_C0330M-23
- ASTM C331/C331M-23, 2023. Standard Specification for Lightweight Aggregates for Concrete Masonry Units. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/C0331_C0331M-23
- ASTM C332-23, 2023. Standard Specification for Lightweight Aggregates for Insulating Concrete. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/C0332-23
- ASTM C35-01(2019), 2019. Standard Specification for Inorganic Aggregates for Use in Gypsum Plaster. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/C0035-01R19
- ASTM C404-18, 2018. Standard Specification for Aggregates for Masonry Grout. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/C0404-18
- ASTM C897-15(2020), 2020. Standard Specification for Aggregate for Job-Mixed Portland Cement-Based Plasters. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/C0897-15R20
- ASTM D1073-16(2022), 2022. Standard Specification for Fine Aggregate for Asphalt Paving Mixtures. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/D1073-16R22
- ASTM D1073-16(2022), 2022. Standard Specification for Fine Aggregate for Asphalt Paving Mixtures. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/D1073-16R22
- ASTM D1139/D1139M-22, 2022. Standard Specification for Aggregate for Single or Multiple Bituminous Surface Treatments. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/D1139_D1139M-22
- ASTM D692/D692M-20, 2020. Standard Specification for Coarse Aggregate for Bituminous Paving Mixtures. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/D0692_D0692M-20

ASTM D698-12(2021), 2021. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ (600 kN-m/m³)). West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/D0698-12R21

ASTM E2788/E2788M-18, 2018. Use of Expanded Shale, Clay and Slate (ESCS) as a Mineral Component in the Growing Media and the Drainage Layer for Vegetative (Green) Roof Systems. West Conshohocken, PA: ASTM International (American Society for Testing and Materials). DOI: 10.1520/E2788_E2788M-18

AWC (American Wood Council), and CWC (Canadian Wood Council), 2020. North American Softwood Plywood. Environmental Product Declaration. Northbrook, IL: UL Environment.

Azarijafari, H., Guo, F., Gregory, J. and Kirchain, R., 2021. Carbon uptake of concrete in the US pavement network. *Resources, Conservation and Recycling*, 167, p.105397. DOI: 10.1016/j.resconrec.2021.105397

Basalite Concrete Products, 2016. ASTM C90 Load Bearing Concrete Masonry Units. Environmental Product Declaration. Vashon, WA: EarthSure.

Bouchelil, L., Ghantous, R.M., Clark, G., Goodwin, M.N., Weiss, W.J. and Moradillo, M.K., 2022. Quantifying Impact of Internally Cured Concrete on Duration of External Curing. *ACI Materials Journal*, 119(5), pp.269-280. DOI:10.14359/51735980

Bowles, J.E., 1988. *Foundation Analysis and Design*. Maidenhead, Berkshire, England: McGraw-Hill.

Caltrans, 2019. *Highway Design Manual (HDM)*. Sacramento, CA: State of California Department of Transportation. <https://dot.ca.gov/programs/design/manual-highway-design-manual-hdm>

Clark Dietrich, 2021. Cold-Formed Steel Framing Systems. Environmental Product Declaration. Northbrook, IL: UL Environment.

Coduto, D.P., Kitch, W., and Yeung, M.C., 2015. *Foundation Design: Principles and Practices*. Upper Saddle River, NJ: Prentice Hall.

CRSI (Concrete Reinforcing Steel Institute), 2017. Fabricated Steel Reinforcement. Environmental Product Declaration. West Conshohocken, PA: ASTM International.

CSI (Construction Specification Institute), 2020. *MasterFormat*. Alexandria, VA: CSI.

Dastan Diznab, M.A., and Tehrani, F.M., 2022. Mapping Standards and Rating Measures of Structural Greenroofs for Socio-Environmental Life Cycle Assessments Using Envision. In *Leveraging Sustainable Infrastructure for Resilient Communities* (pp. 82-90). DOI: 10.1061/9780784483879.008

Davodijam, F., Dastan Diznab, M.A., and Tehrani, F.M., 2022. Sustainability Rating of Internally Cured Concrete in Marine Environments Using Service Life Prediction Models. In *Leveraging Sustainable Infrastructure for Resilient Communities* (pp. 141-151). DOI:10.1061/9780784483879.013

EIA (Energy Information Administration), 2023a. Energy conversion calculators. Washington, DC: U.S. EIA. <https://www.eia.gov/energyexplained/units-and-calculators/energy-conversion-calculators.php>

EIA (Energy Information Administration), 2023b. Monthly Energy Review. Washington, DC: U.S. EIA. <https://www.eia.gov/totalenergy/data/monthly/>

EMCON, 2019. Concrete Pavers and Kerbstone. Environmental Product Declaration. West Conshohocken, PA: ASTM International.

EN 13055:2016, 2016. Lightweight Aggregates. European Committee for Standardization (CEN).

EN 15732:2012, 2012. Light weight fill and thermal insulation products for civil engineering applications (CEA) - Expanded clay lightweight aggregate products (LWA). European Committee for Standardization (CEN).

EN 15804+A2, 2019. Sustainability of construction works — Environmental Product Declarations — Core rules for the product category of construction product. European Committee for Standardization (CEN).

Environment and Climate Change Canada (ECCC), 2021. National Pollutant Release Inventory (NPRI). Gatineau, QC: ECCC. <http://www.ec.gc.ca/inrp-npri/>

EPA (Environmental Protection Agency), 1981. Emission Test Report: Arkansas Lightweight Aggregate Corporation, West Memphis, Arkansas. EMB Report 80-LWA-2. May 1981. Research Triangle Park, NC: U.S. Environmental Protection Agency.

EPA (Environmental Protection Agency), 1982. Emission Test Report: Galite Corporation, Rockmart, Georgia. EMB Report 80-LWA-6. February 1982. Research Triangle Park, NC: U.S. Environmental Protection Agency.

EPA (Environmental Protection Agency), 1982. Emission Test Report: Vulcan Materials Company, Bessemer, Alabama. EMB Report 80-LWA-4. March 1982. Research Triangle Park, NC: U.S. Environmental Protection Agency.

EPA (Environmental Protection Agency), 1985. Calciners And Dryers In Mineral Industries-Background Information For Proposed Standards. EPA-450/3-85-025a. October 1985. Research Triangle Park, NC: U.S. Environmental Protection Agency.

EPA (Environmental Protection Agency), 1985. Emission Test Report: Plant K6, from Calciners And Dryers In Mineral Industries - Background Information Standards. EPA-450/3-85-025a. October 1985. Research Triangle Park, NC: U.S. Environmental Protection Agency.

EPA (Environmental Protection Agency), 1993. AP-42: Compilation of Air Emissions Factors, Chapter 11, Mineral Products Industry, Section 11.20, Lightweight Aggregate Manufacturing. Research Triangle Park, NC: Office of Air Quality Planning and Standards, EPA. <https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors>

EPA (Environmental Protection Agency), 2012. Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI). EPA/600/R-12/554. Cincinnati, OH: Sustainable Technology Division, National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. <https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci>

EPA (Environmental Protection Agency), 2017. Toxic Release Inventory (TRI) Reporting. EPCRA 313. Washington, DC: U.S. Environmental Protection Agency. <https://www.epa.gov/toxics-release-inventory-tri-program>

ESCSI (Expanded Shale, Clay and Slate Institute), 2000. Life Cycle Energy Cost Analysis Shows That SmartWall Systems® Provides Significant Savings in All Climates. Information Sheet 3530. Chicago, IL: ESCSI. <https://www.escsi.org/wp-content/uploads/2017/10/3530.0-Life-Cycle-Energy-Cost-Analysis.pdf>

ESCSI (Expanded Shale, Clay and Slate Institute), 2015. Embodied Energy to Manufacture Expanded Shale, Clay and Slate (ESCS) Lightweight Aggregate. Information Sheet 9153. Chicago, IL: ESCSI. <https://www.escsi.org/wp-content/uploads/2017/10/9153-ESCS-Embodied-Energy-REV-1-15-1.pdf>

ESCSI (Expanded Shale, Clay and Slate Institute), 2015. Expanded Shale, Clay, and Slate Lightweight Aggregate. Product Category Rule. West Conshohocken, PA: ASTM International.

ESCSI (Expanded Shale, Clay and Slate Institute), 2019. Solving Geotechnical Challenges with Structural Lightweight Aggregate Fill. ESCSI 6600.5. Chicago, IL: ESCSI. <https://www.escsi.org/wp-content/uploads/2019/10/6600.5-Solving-Geotech-Challenges-10-19.pdf>

ESCSI (Expanded Shale, Clay and Slate Institute), 2022. Product Category Rule (PCR) Guidance for Building-Related Products and Services, Part B: Expanded Shale, Clay, and Slate Lightweight Aggregate EPD Requirements. UL Environment Standard, Standard 10010-37, Edition 2. Northbrook, IL: UL Environment. https://www.shopulstandards.com/ProductDetail.aspx?productid=ULE10010-37_2_S_20220125

ESCSI (Expanded Shale, Clay and Slate Institute), 2022. SmartWall Systems. ESCSI 3651. Chicago, IL: ESCSI. https://www.escsi.org/wp-content/uploads/2022/07/ESCSI_SmartWall-Systems_FINAL.pdf

EXIBA (European Extruded Polystyrene Insulation Board Association), 2019. Extruded Polystyrene (XPS) Foam Insulation with halogen free blowing agent. Berlin, Germany: Institut Bauen und Umwelt e.V.

Ferinagro Biotech, 2023. Microquel Amin Cuaje. Environmental Product Declaration. Stockholm, Sweden: EPD International AB.

FHWA (Federal Highway Administration), 2009. Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes, FHWA-NHI-10-024, FHWA GEC 011 Volumes I and II. Washington, D.C.: FHWA. <https://www.fhwa.dot.gov/engineering/geotech/pubs/nhi10024/>

FHWA (Federal Highway Administration), 2015. Load and Resistance Factor Design (LRFD) for highway bridge superstructures. FHWA-NHI-15-047. Arlington, VA: FHWA. <https://rosap.nrl.bts.gov/view/dot/43721>

FHWA (Federal Highway Administration), 2016. Synthesis and evaluation of the service limit state of engineered fills for bridge support. FHWA-HRT-15-080. McLean, VA: FHWA. <https://www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/15080/index.cfm>

Green Vision Recycling, 2022. Recycled Crushed Concrete Aggregates. Environmental Product Declaration. Nelson, New Zealand: EPD Australasia Limited.

Hammond, G., Jones, C., Lowrie, E.F. and Tse, P., 2011. Embodied carbon. The inventory of carbon and energy (ICE). Version (2.0). Bath, UK: University of Bath, UK. <https://circularecology.com/embodied-carbon-footprint-database.html>

Holm, T. A., and Reis, J., 2007. *Reference Manual for the Properties and Applications of Expanded Shale, Clay and Slate Lightweight Aggregate*. Chicago, IL: Expanded Shale, Clay and Slate Institute (ESCSI). <https://www.escsi.org/reference-manual/>

Icopal AS (2013). Icopal RMB 400 radon membrane. Environmental Product Declaration. Oslo, Norway: Næringslivets Stiftelse for Miljødeklarasjoner.

IEA, 1992. Emission Test Results For No. 2 Aggregate Kiln, Solite Corporation, Hubers Plant, Brooks, Kentucky. August 8, 1992. Research Triangle Park, NC: IEA.

IEA, 1992. Emission Test Results For No. 2 And No. 4 Aggregate Kilns, Solite Corporation, Leaksville Plant, Cascade, Virginia. August 8, 1992. Research Triangle Park, NC: IEA.

IEA, 1992. Emission Test Results For No. 7 And No. 8 Aggregate Kilns, Solite Corporation, A. F. Old Plant, Arvon, Virginia. August 8, 1992. Research Triangle Park, NC: IEA.

Ingwersen, W., Subramanian, V., Scarinci, C., Mlsna, A., Koffler, C., Assefa Wondimagegnehu, G., Imbeault-tetreault, H., Mahalle, L., Sertich, M., Costello, M., Firth, P., Fallaha, S., and Owen, T. 2013. Guidance for Product Category Rule Development, Version 1.0. Product Category Rule Guidance Development Initiative, Cincinnati, OH: U.S. Environmental Protection Agency.

Iowa State University, 2020. SUDAS: Iowa Statewide Urban Design and Specifications Design Manual. Ames, IA: Iowa State University. <https://iowasudas.org/manuals/design-manual/>

ISCC (Iranian Syndicate of Construction Companies). 2004. Applied Cost Analysis of Construction Activities. Tehran, Iran: ISCC.

ISO 14001:2015, 2015. Environmental management systems — Requirements with guidance for use. Geneva, Switzerland: International Organization for Standards (IS).

- ISO 14025:2006, 2006. Environmental labels and declarations — Type III environmental declarations — Principles and procedures. Geneva, Switzerland: International Organization for Standards (IS).
- ISO 14040:2006, 2006. Environmental management – Life cycle assessment – Principles and framework. Geneva, Switzerland: International Organization for Standards (IS).
- ISO 14044:2006, 2006. Environmental management – Life cycle assessment – Requirements and guidelines. Geneva, Switzerland: International Organization for Standards (IS).
- ISO 14046:2014, 2014. Environmental management — Water footprint — Principles, requirements and guidelines. Geneva, Switzerland: International Organization for Standards (IS).
- ISO 21930:2017, 2017. Sustainability in buildings and civil engineering works—Core rules for environmental product declarations of construction products and services. Geneva, Switzerland: International Organization for Standards (IS).
- ISO/TR 14047:2012, 2013. Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to impact assessment situations. Geneva, Switzerland: International Organization for Standards (IS).
- Kalantari, S., Diznab, M.A.D., Tehrani, F.M. 2021. Sustainability of Internally-Cured Concrete for Mitigating Shrinkage Cracking Using Service Life Prediction Models. In: Kanavaris, F., Benboudjema, F., Azenha, M. (eds) *International RILEM Conference on Early-Age and Long-Term Cracking in RC Structures*. CRC 2021. RILEM Bookseries, vol 31. Cham: Springer. DOI: 10.1007/978-3-030-72921-9_23
- Laterlite S.p.A., 2018. Lightweight Expanded Clay Structural Aggregate. Environmental Product Declaration. Milano, Italy: EPDIItaly.
- Leca International, 2020. Leca Letkilnker 10-20;Hinge. Environmental Product Declaration. Oslo, Norway: The Norwegian EP D Foundation.
- Life-365, 2020. Life-365™ service life prediction model™. Life-365™ Consortium III. www.life-365.org.
- MD DOT, 1985. Stack Test Report No. 85-1, Lehigh Lightweight Aggregate Plant, Dryer-Kiln No. 2, Woodsboro, Maryland, February 1, 1985. Baltimore, MD: Division Of Stationary Source Enforcement, Maryland Department Of Health And Mental Hygiene.
- MD DOT, 1985. Stack Test Report No. 85-7, Lehigh Lightweight Aggregate Plant, Dryer-Kiln No. 1, Woodsboro, Maryland, May 1985. Baltimore, MD: Division Of Stationary Source Enforcement, Maryland Department Of Health And Mental Hygiene.
- Myrans, K., 2009. Comparative energy and carbon assessment of three green technologies for a Toronto roof. M.Sc. Thesis. Toronto, ON: University of Toronto.
- NCMA (National Concrete Masonry Association), 2004. Maintenance of Concrete Masonry Walls. TEK 08-01A. Herndon, VA: NCMA.
- NCMA (National Concrete Masonry Association), 2007. Section Properties of Concrete Masonry Walls. TEK 14-01B. Herndon, VA: NCMA.
- NCMA (National Concrete Masonry Association), 2013. R-Values and U-Factors of Single Wythe Concrete Masonry Walls. TEK 06-02C. Herndon, VA: NCMA.
- NCMA (National Concrete Masonry Association), 2017. Typical Sizes and Shapes of Concrete Masonry Walls. TEK 02-01B. Herndon, VA: NCMA.
- Nisbet, M., and VanGeem, M.G. VanGeem, 2000. CRL Project No. 181009. The Life Cycle Inventory of the Lightweight Aggregate Manufacturing Process. Salt Lake City, UT: ESCSI.
- NRMCA (National Ready Mixed Concrete Association). 2020. NRMCA member industry average EPD for ready mixed concrete. Environmental Product Declaration. Ann Arbor, MI: NSF Certification, LLC.
- Pallet Foundation and National Wooden Pallet & Container Association, 2020. Wooden Pallets. Environmental Product Declaration. Northbrook, IL: UL Environment.
- PBO (Planning and Budget Organization), 2021. Cost Analysis for Roads, Rails, and Airports. Tehran, Iran: MPORG.
- PCA (Portland Cement Association), 2020. Portland Cements (per ASTM C150, ASTM C1157, AASHTO M 85 or CSA A3001). Environmental Product Declaration. West Conshohocken, PA: ASTM International.
- Peurifoy, R.L., Schexnayder, C.J., Schmitt, R.L., and Shapira, A., 2018. *Construction Planning, Equipment, and Methods*. New York, NY: McGraw-Hill Education.
- Protopapas, A., Kruse, C. J., & Olson, L. E. (2013). Modal Comparison of Domestic Freight Transportation Effects on the General Public. *Transportation Research Record*, 2330(1), 55–62. DOI: 10.3141/2330-08
- Rashedi, M. R., Ehsani, R., Kalantari, S., Tehrani, F.M. 2023. Lifecycle analysis approach to the impact of greenroofs on the structural and thermal performances of buildings. *eng*.
- Resource Consultants, 1981. Particulate Emission Source Test Conducted On No. 1 Kiln Wet Scrubber At Tombigbee Lightweight Aggregate Corporation, Livingston, Alabama, November 12, 1981. Brentwood, TN: Resource Consultants.
- Resource Consultants, 1981. Particulate Emission Source Test Conducted On No. 2 Kiln Wet Scrubber At Tombigbee Lightweight Aggregate Corporation, Livingston, Alabama, November 12, 1981. Brentwood, TN: Resource Consultants.
- Roesler, J. R., Hiller, J. E., and Brand, A. S., 2016. Continuously reinforced concrete pavement manual: Guidelines for design, construction, maintenance, and rehabilitation. FHWA-HIF-16-026. McLean, VA: Federal Highway Administration.

Rosnagel & Associates, 1980. Report Of Simultaneous Efficiency Tests Conducted On The Orange Kiln And Baghouse At Carolina Stalite, Gold Hill, N.C., May 9, 1980. Charlotte, NC: Rosnagel & Associates.

RSMeans (R. S. Means Company, Inc.). 2009. *Estimating Handbook*. Third Edition. Kingston, MA: RSMeans.

Schierhorn, C., 1995. Estimating Production. In *Masonry Construction*. ESCSI 3700.4. <https://www.escsi.org/wp-content/uploads/2017/10/3700.4-Estimating-Production-3-95.pdf>

Schwartz, C.W., Elkins, G.E., Li, R., Visintine, B.A., Forman, B., Rada, G.R., Groeger, J.L., 2015. Evaluation of long-term pavement performance (LTPP) climatic data for use in mechanistic-empirical pavement design guide (MEPDG) calibration and other pavement analysis. FHWA-HRT-15-019. McLean, VA: Office of Infrastructure Research and Development Federal Highway Administration.

SDI (Steel Deck Institute), 2015. Steel deck. Environmental Product Declaration. Northbrook, IL: UL Environment.

SETAC (Society of Environmental Toxicology and Chemistry), 1993. Guidelines for Life-Cycle Assessment: A "Code of Practice". Edition 1. Pensacola, FL: SETAC. https://cdn.ymaws.com/www.setac.org/resource/resmgr/books/lca_archive/guidelines_for_life_cycle.pdf

Sholtes & Koogler Environmental Consultants, 1981. Summary Of Particulate Matter Emission Measurements, No. 5 Kiln Outlet, Florida Solite Corporation, Green Cove Springs, Florida, June 19, 1981. Gainesville, FL: Sholtes and Koogler Environmental Consultants.

Sholtes & Koogler Environmental Consultants, 1982. Summary Of Particulate Matter Emission Measurements, No. 5 Kiln Outlet, Florida Solite Corporation, Green Cove Springs, Florida, September 3, 1982. Gainesville, FL: Sholtes and Koogler Environmental Consultants.

Sholtes & Koogler Environmental Consultants, 1983. Summary Of Emission Measurements On No. 5 Kiln, Carolina Solite Corporation, Aquadale, North Carolina, April 1983. Gainesville, FL: Sholtes & Koogler Environmental Consultants, Inc.

Sholtes & Koogler Environmental Consultants, 1991. Sulfur Dioxide Emission Measurements, Lightweight Aggregate Kiln No. 5 (Inlet), Carolina Solite Corporation, Aquadale, North Carolina, May 1991. Gainesville, FL: Sholtes & Koogler Environmental Consultants, Inc.

Sholtes & Koogler Environmental Consultants, 1991. Sulfur Dioxide Emission Measurements, Lightweight Aggregate Kiln No. 5 (Outlet), Carolina Solite Corporation, Aquadale, North Carolina, May 1991. Gainesville, FL: Sholtes & Koogler Environmental Consultants, Inc.

Sika. Sealing and Bonding Sikaflex®-1a. Environmental Product Declaration. West Conshohocken, PA: ASTM International.

Spratt, B.H., 1974. *The structural use of lightweight aggregate concrete*. United Kingdom: Cement And Concrete Association.

TCNA (Tile Council of North America), 2023. Cement Mortar for Tile Installation. Environmental Product Declaration. Northbrook, IL: UL Environment.

Tehrani, F.M., 2020. Service life prediction of structural lightweight concrete using transport properties. ESCSI Report 4363. Expanded Shale, Clay and Slate Institute, Chicago, IL.

Tehrani, F.M., 2021. Service Life Prediction of Internally Cured Concrete Pavements Using Transport Properties. In *Airfield and Highway Pavements 2021* (pp. 82-91). DOI:10.1061/9780784483503.008

Tehrani, F.M., 2023. Application of Environmental Product Declarations in Sustainability of Geotechnical Structures. In *Geo-Congress 2023* (pp. 661-670). DOI:10.1061/9780784484661.069

Tehrani, F.M., Alexandrou, A., Adhikari, D., Mahoney, M. and Maestas, R., 2014. Energy inputs and carbon dioxide emissions during construction of a golf course. *International Journal of Engineering Research & Innovation*, 6(2), pp.78-86. [www.ijeri.org/issues/fall2014/Z_IJERI%20fall%202014%20v6%20n2%20\(PDW-4\).pdf#page=80](http://www.ijeri.org/issues/fall2014/Z_IJERI%20fall%202014%20v6%20n2%20(PDW-4).pdf#page=80)

Tensar International Limited, 2017. Geogrid TriAx TX 150. Nürnberg, Deutschland/Germany: Kiwa BCS Öko-Garantie GmbH.

Testa, D.M. and Hossain, M., 2014. Kansas Department of Transportation 2014 chip seal manual (No. K-TRAN: KSU-09-8). Kansas. Dept. of Transportation. Bureau of Materials & Research. https://rosap.nhtl.bts.gov/view/dot/27232/dot_27232_DS1.pdf

UNCPC (United Nations Central Product Classification), 2015. Central Product Classification, Version 2.1. New York, NY: Department of Economic and Social Affairs, Statistics Division, UN. <https://unstats.un.org/unsd/classifications/unsdclassifications/cpcv21.pdf>

Vinyl Siding Industry, 2022. Polypropylene Siding. Environmental Product Declaration. West Conshohocken, PA: ASTM International.

Vosoughi, P., Tritsch, S., Ceylan, H., and Taylor, P., 2017. Lifecycle cost analysis of internally cured jointed plain concrete pavement. Part of IHRB Project TR-676. Ames, IA: Iowa Highway Research Board. <https://www.trb.org/Pavements/Blurbs/177081.aspx>

Vulcan Materials Company, 2016. Environmental Product Declaration. Glendale, CA: Vulcan Materials Company, Western Division.

Walter P Moore, 2012. Embodied Energy Study Lightweight Concrete in Steel Framed Buildings. Austin, TX: Walter P Moore and Associates Inc. <https://www.escsi.org/wp-content/uploads/2017/10/Embodied-Energy-Study-Report-FINAL-Letter-1.pdf>

Wu, J.P. and Herrington, P.R., 2021. The reuse of end-of-life tyres to enhance the performance of chipseal binders (No. 679). Wellington, New Zealand: Waka Kotahi NZ Transport Agency.