Building Life-Cycle Assessment

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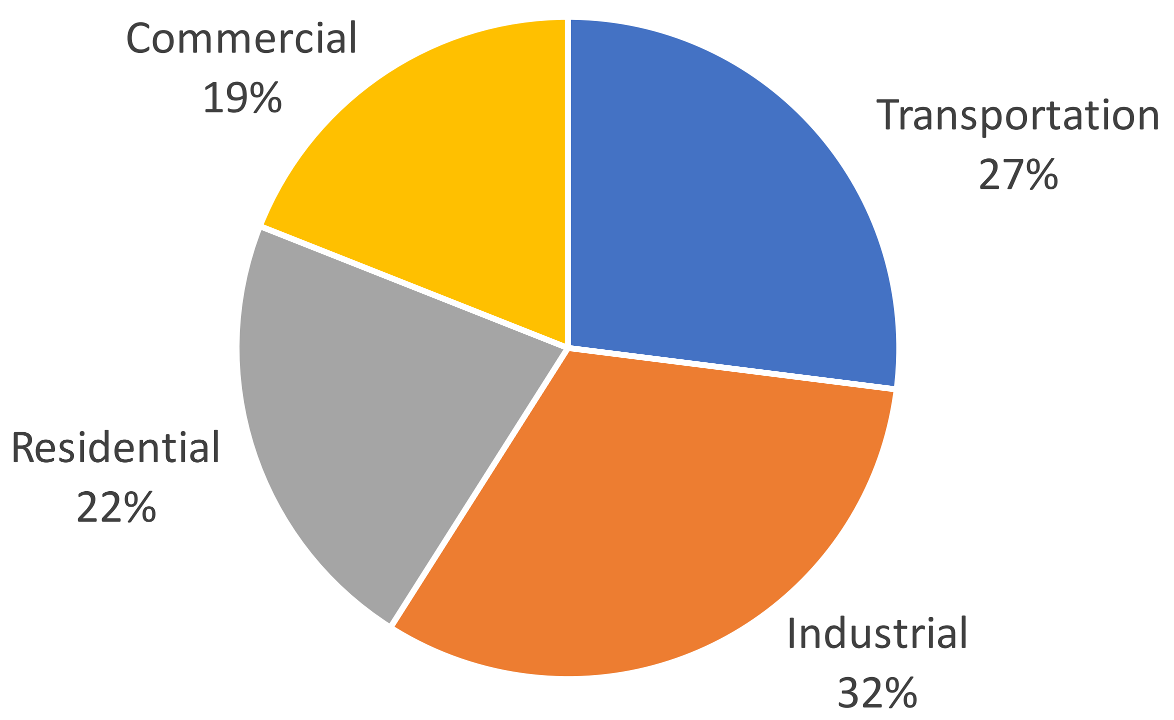
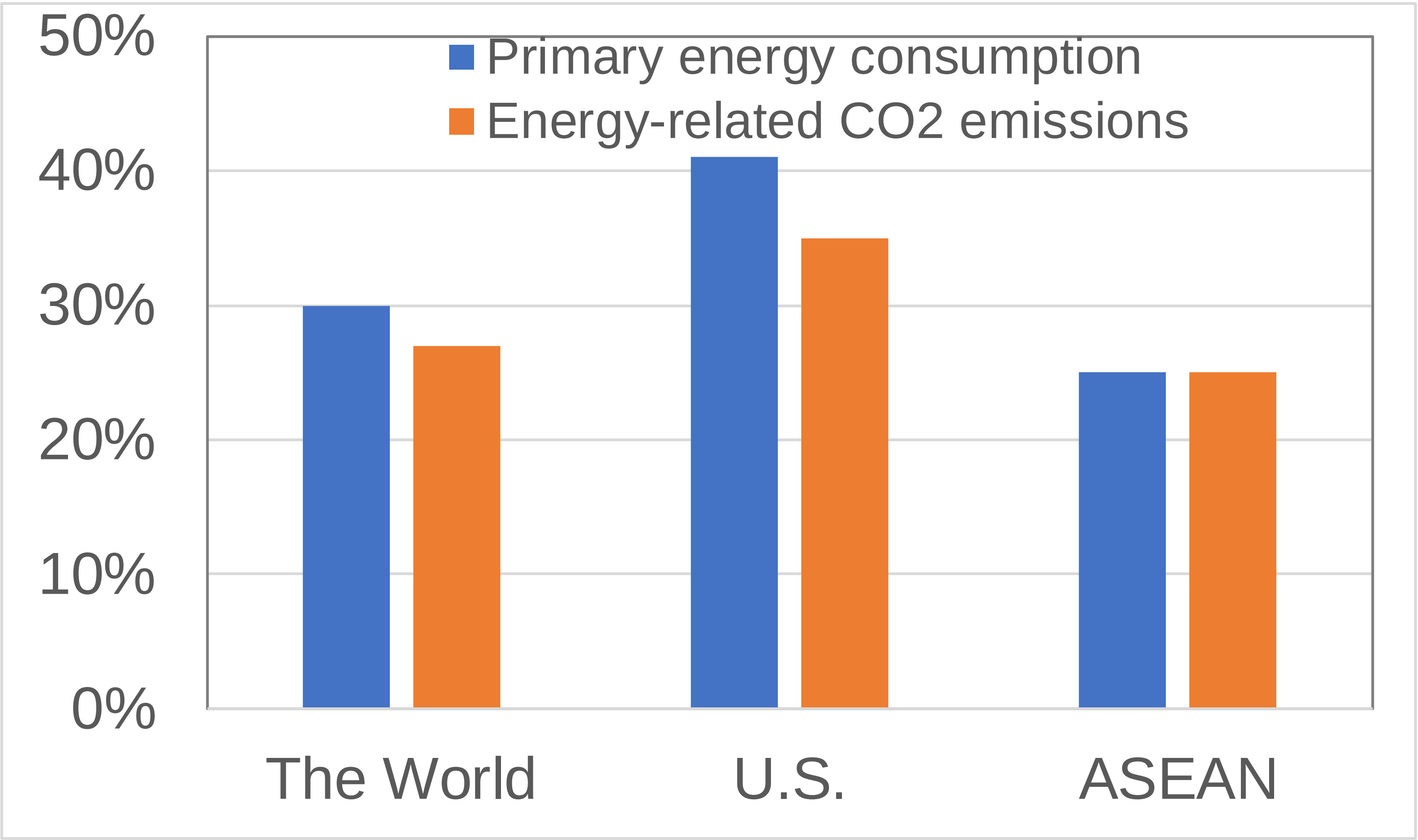
September 5, 2023

Building and Environment





In the U.S., the building sector accounts for

- 41% of total energy consumption
- 35% of energy-related carbon emissions
- 25% - 45% of solid waste by mass

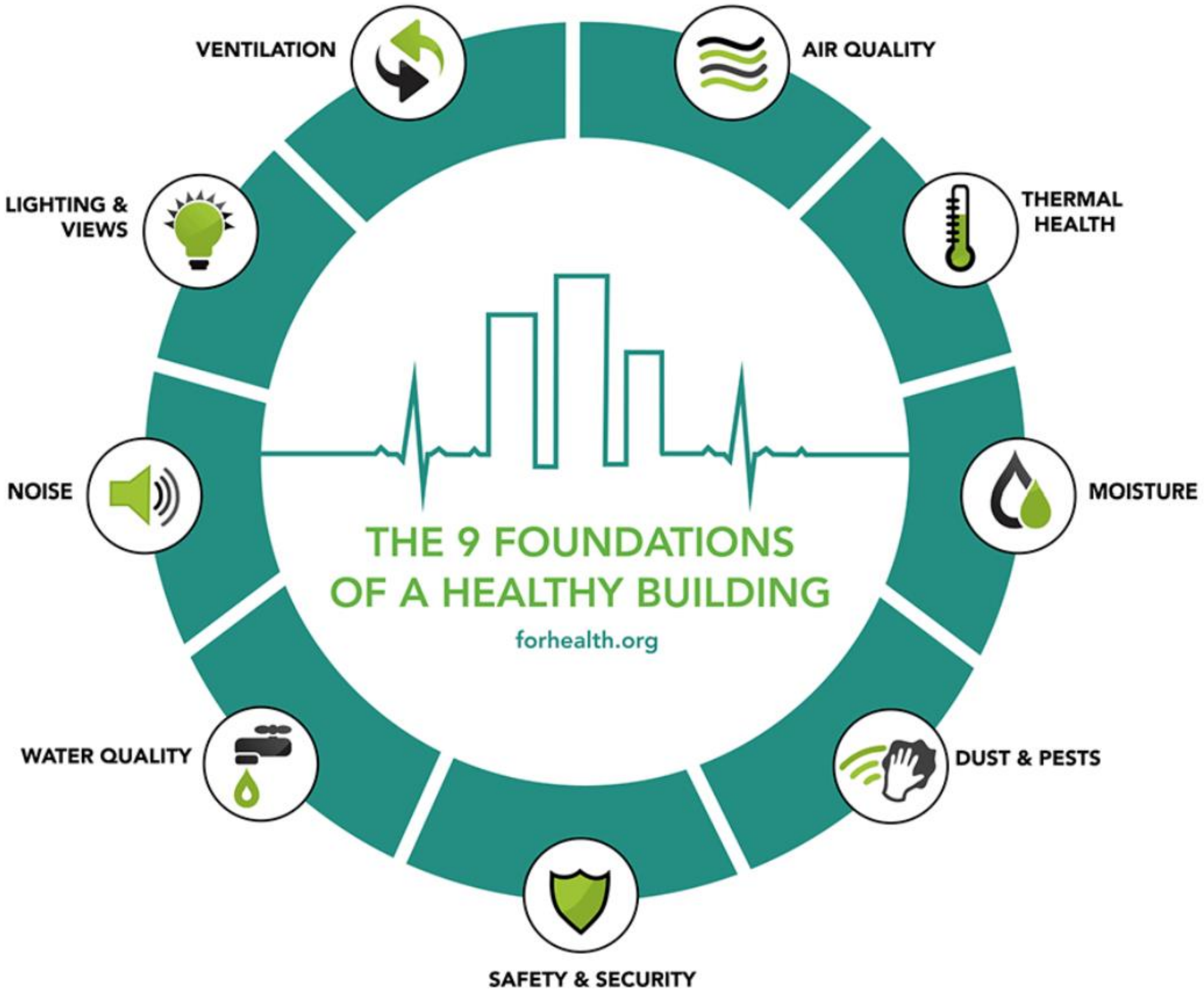
Sources:

- IEA (2022), https://www.iea.org/reports/buildings
- EIA (2022), https://www.eia.gov/energyexplained/use-of-energy/

Building and Environment

On average, people spend 90% of their time in buildings.

- Comfort
- Health
- Productivity



Green Building Innovation Program

Education

- Curricula Development
  - Bioclimatic Design
  - Building Life-Cycle Assessment
  - Selected HVAC Systems
  - Carbon-Neutral Design
  - Sustainable Façade Design
  - Resiliency in the Built Environment
  - Others
- Lectures
- Training Workshops

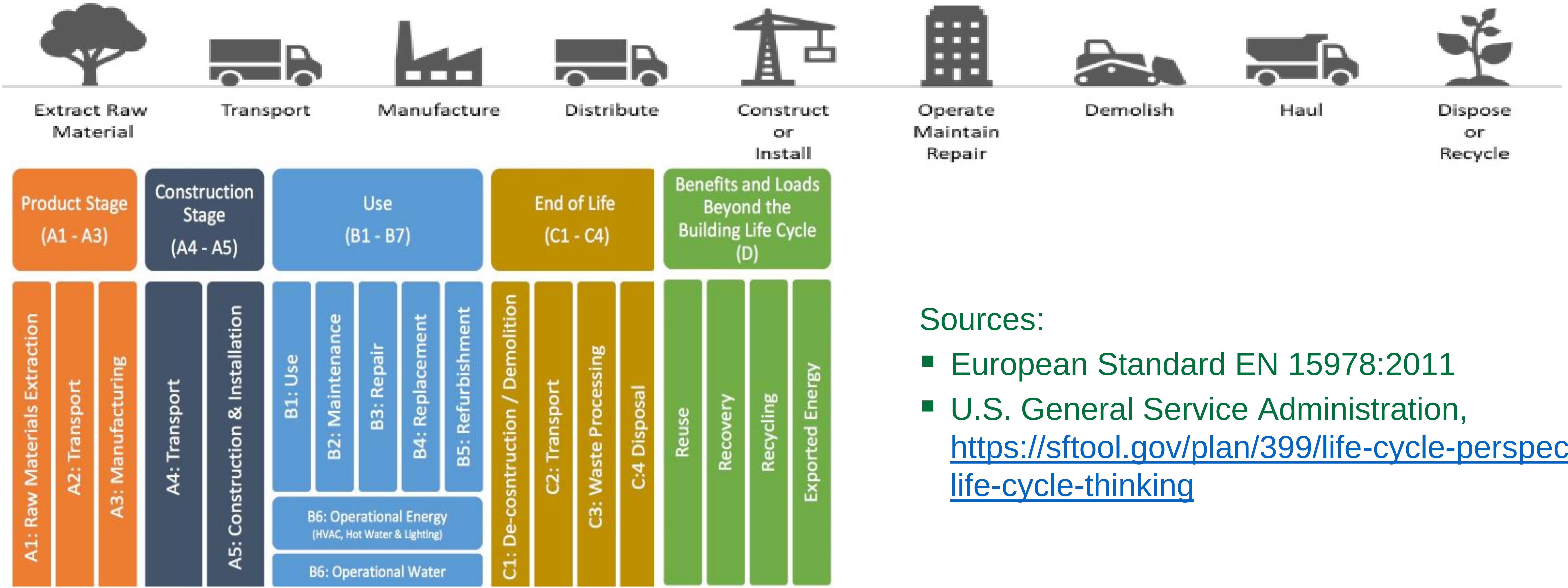
Research

- Co-develop and co-implement research projects with our ASEAN partners
- Co-authorize conference and journal articles
- Develop joint research proposals

Knowledge Sharing

- Project website (greenbuilding.charlotte.edu)
- Publications
- Presentations at conferences and workshops

Building Life Cycle Stages

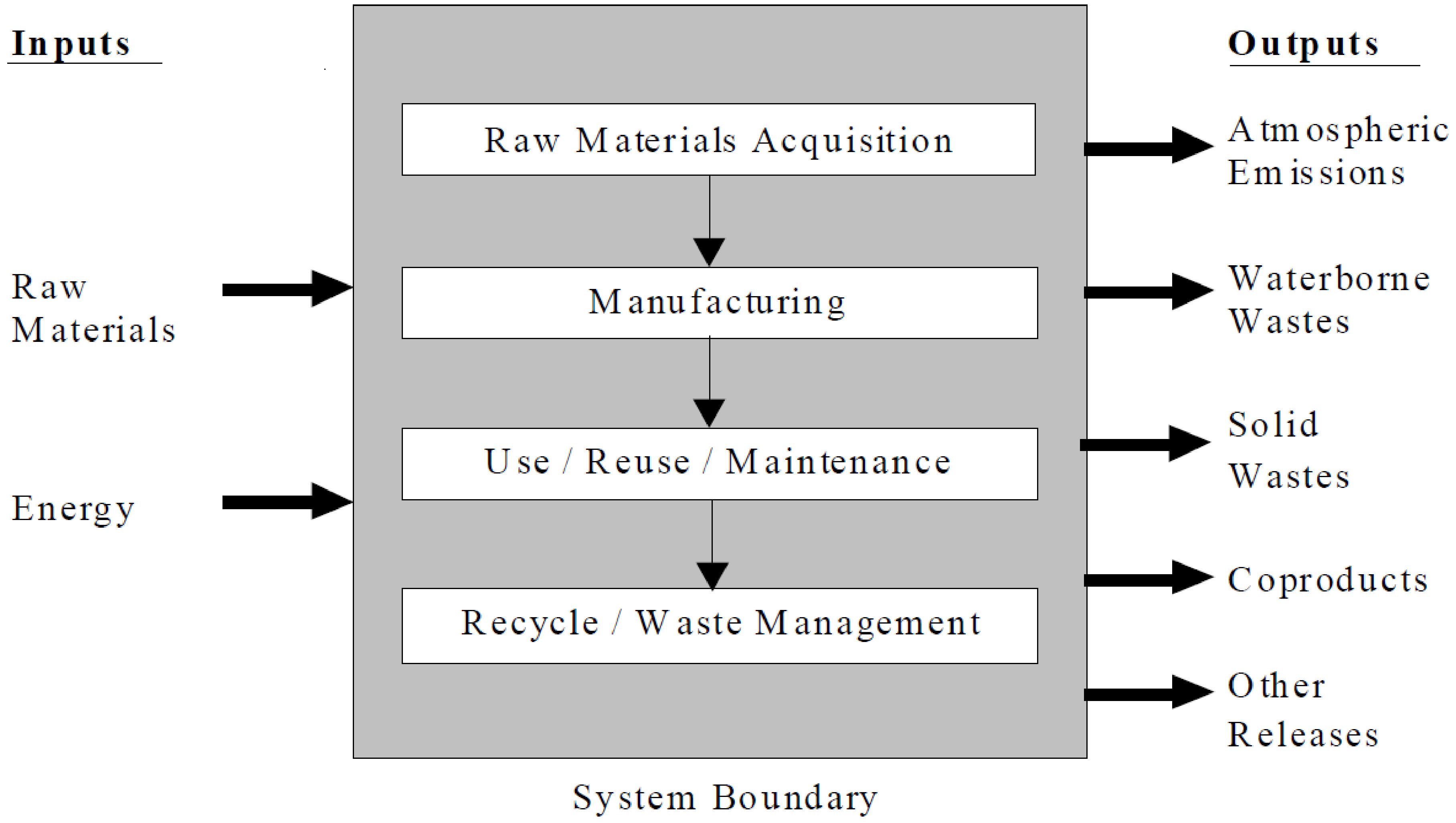


Sources:

- European Standard EN 15978:2011
- U.S. General Service Administration, https://sftool.gov/plan/399/life-cycle-perspective-life-cycle-thinking

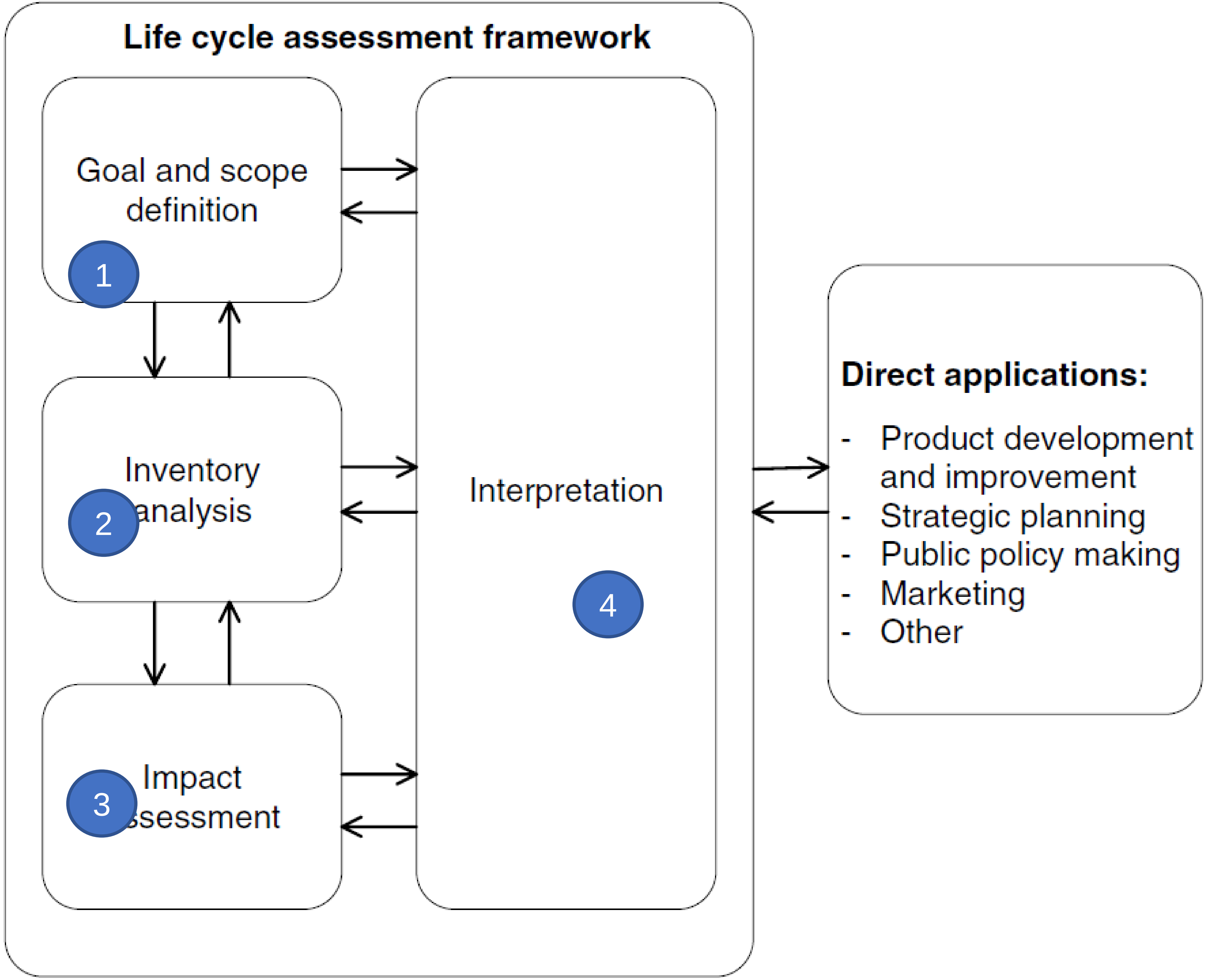
Life-Cycle Assessment (LCA)

- LCA is an approach to compile and evaluate the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.



Source: EPA (2006)

LCA Components



Source: EPA (2006)

1 Goal and Scope Definition

Purpose of Assessment

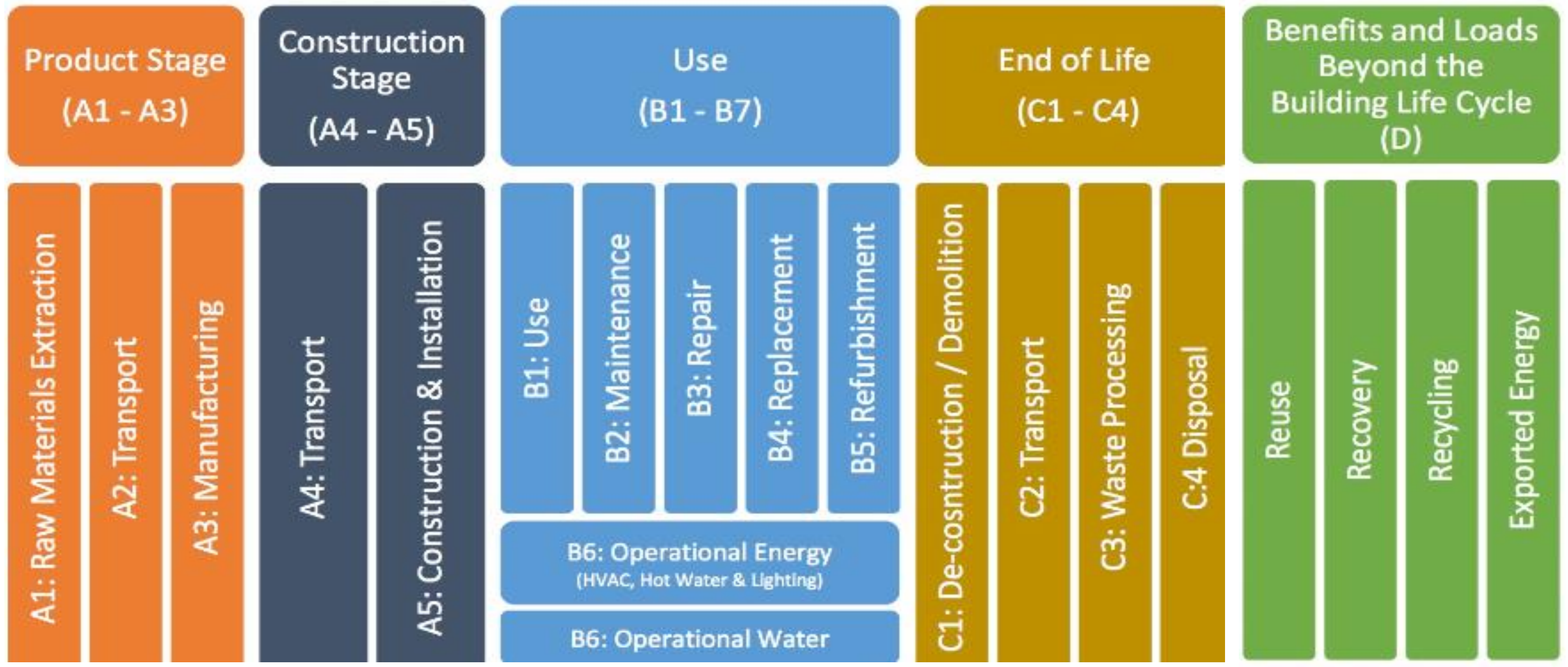
- Design improvement
- Comparison
- Declaration
- Rating and standard compliance (e.g., LEED)

Object of Assessment

- Product
- Assembly
- System
- Whole Building

System Boundary

- Cradle to Gate (A1-A3)
- Cradle to Grave (A1-A5, B1-B7, and C1-C4)
- Cradle to Cradle (A1-A5, B1-B7, C1-C4, and D)



2 Inventory Analysis

- An inventory of all inputs to and outputs from the production system is prepared
  - Inputs: energy, non-energy resources
  - Outputs: emissions to atmosphere, water and soil
- The most resource-intensive process of LCA
- Life-Cycle Inventory (LCI) Databases
  - Usually for unit processes
  - Be specific to countries and regions
  - Specific manufacturer vs. Industry average

U.S. Life-Cycle Inventory Database:
https://www.lcacommons.gov/lca-collaboration

Collaborating Agencies

USDA

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Argonne NATIONAL LABORATORY

U.S. Department of Transportation Federal Highway Administration

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

NIST

3 Impact Assessment

Evaluate the potential human health and environmental impacts of the inputs & outputs identified from the LCI analysis.

- Impact category selection and definition
- Classification
- Characterization
- Normalization (optional)
- Grouping (optional)
- Weighting (optional)

Impact Categories

- Global Warming
- Ozone Depletion
- Acidification
- Eutrophication
- Smog Formation
- Human Health
- Ecotoxicity
- Fossil Fuel Use
- Land Use
- Water Use

Source: EPA TRACI 2.1 (2012)

Classification

- Organize and combine LCI results into impact categories.
- An LCI item may contribute to one or multiple impact categories.
- Example: Global Warming
  - Carbon dioxide (CO_2)
  - Methane (CH_4)
  - Nitrous oxides (N_2O)
  - CFC's
  - HCFC's
  - HFC's
  - Halons
  - Tetrachloromethane (CCl_4)
  - 1,1,1-Trichloroethane (CCl_3CH_3)
  - …

Source: EPA TRACI 2.1 (2012)

Characterization

- Use characterization factors (equivalency factors) to convert and combine LCI results into representative indicators of impact to human and ecological health.
- Make it possible to compare the LCI results within each impact category.
- Example: Global Warming Potential (GWP)
  - GWP measures how much energy the emissions of 1 ton of a greenhouse gas will absorb over a given period of time, relative to the emissions of 1 ton of CO_2. ➔ CO_2 Equivalent

Greenhouse Gas	GWP100
CO_2	1
CH_4	27.9
N_2O	273

Source: IPCC (2021)

EPA's TRACI (Partly Shown)

CAS #	Formatted CAS #	Substance Name	Global Warming Air (kg CO2 eq / kg substance)	Acidification Air (kg SO2 eq / kg substance)	HH Particulate Air (PM2.5 eq / kg substance)	Eutrophication Air (kg N eq / kg substance)	Eutrophication Water (kg N eq / kg substance)
7723140	7723-14-0	PHOSPHORUS	0.00E+00	0.00E+00	0.00E+00	1.12E+00	7.29E+00
x	x	PHOSPHORUS PENTOXIDE	0.00E+00	0.00E+00	0.00E+00	4.90E-01	3.19E+00
14265442	14265-44-2	PHOSPHATE	0.00E+00	0.00E+00	0.00E+00	3.66E-01	2.38E+00
7664382	7664-38-2	PHOSPHORIC ACID	0.00E+00	9.80E-01	0.00E+00	3.55E-01	2.31E+00
17778880	17778-88-0	NITROGEN	0.00E+00	0.00E+00	0.00E+00	1.50E-01	9.86E-01
14798039	14798-03-9	AMMONIUM	0.00E+00	0.00E+00	0.00E+00	1.19E-01	7.79E-01
7664417	7664-41-7	AMMONIA	0.00E+00	1.88E+00	6.67E-02	1.19E-01	7.79E-01
10102439	10102-43-9	NITRIC OXIDE	0.00E+00	1.07E+00	0.00E+00	6.86E-02	4.51E-01
10102440	10102-44-0	NITROGEN DIOXIDE	0.00E+00	7.00E-01	7.22E-03	4.43E-02	2.91E-01
x	x	NITROGEN OXIDES	0.00E+00	7.00E-01	7.22E-03	4.43E-02	2.91E-01
14797558	14797-55-8	NITRATE	0.00E+00	0.00E+00	0.00E+00	3.60E-02	2.37E-01
7697372	7697-37-2	NITRIC ACID	0.00E+00	5.10E-01	0.00E+00	3.45E-02	2.27E-01
x	x	BIOLOGICAL OXYGEN DEMAND	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-02
x	x	CHEMICAL OXYGEN DEMAND	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-02
2551624	2551-62-4	SULFUR HEXAFLUORIDE	2.28E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
x	x	TRIFLUOROMETHYL SULFUR PENTAFLUORIDE	1.77E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
x	x	PROPANE, PERFLUOROCYCLO-	1.73E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7783542	7783-54-2	NITROGEN TRIFLUORIDE	1.72E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3822682	3822-68-2	HFE-125	1.49E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75467	75-46-7	HFC-23	1.48E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75729	75-72-9	CFC-13	1.44E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76164	76-16-4	PFC-116	1.22E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75718	75-71-8	CFC-12	1.09E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00

https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci

4 Interpretation

- Present LCA results in a most informative way
- Analyze results
- Reach conclusions
- Explain limitations
- Provide recommendations

Representative Building LCA Tools

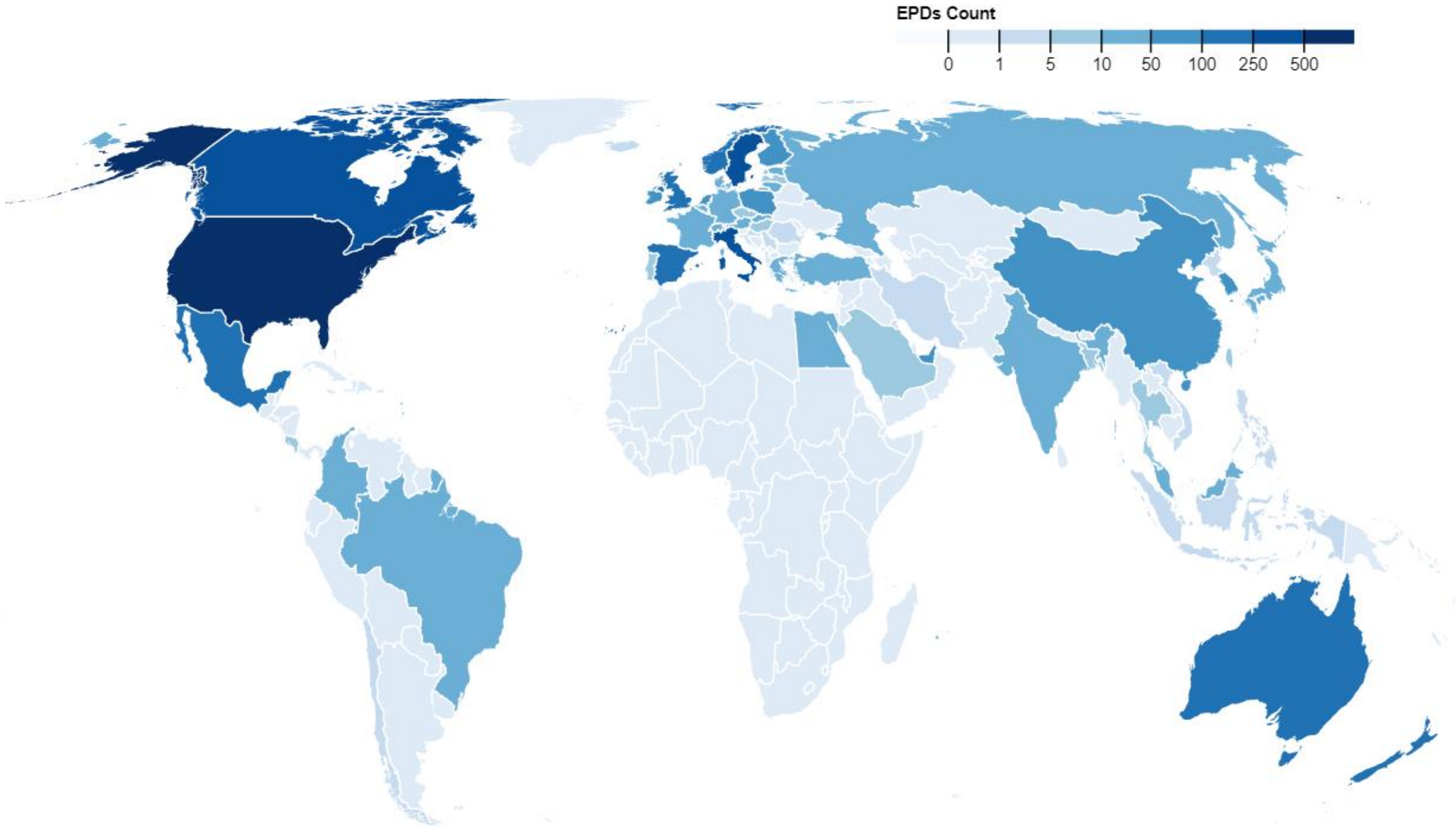
- Embodied Carbon in Construction Calculator (EC3) Tool
  https://buildingtransparency.org/ec3
- BEES Online 2.1 ➔ building products
  https://ws680.nist.gov/Bees2
- ATHENA Impact Estimator ➔ building products, assemblies, and whole building
  https://calculatelca.com/software/impact-estimator/

EC3 Tool

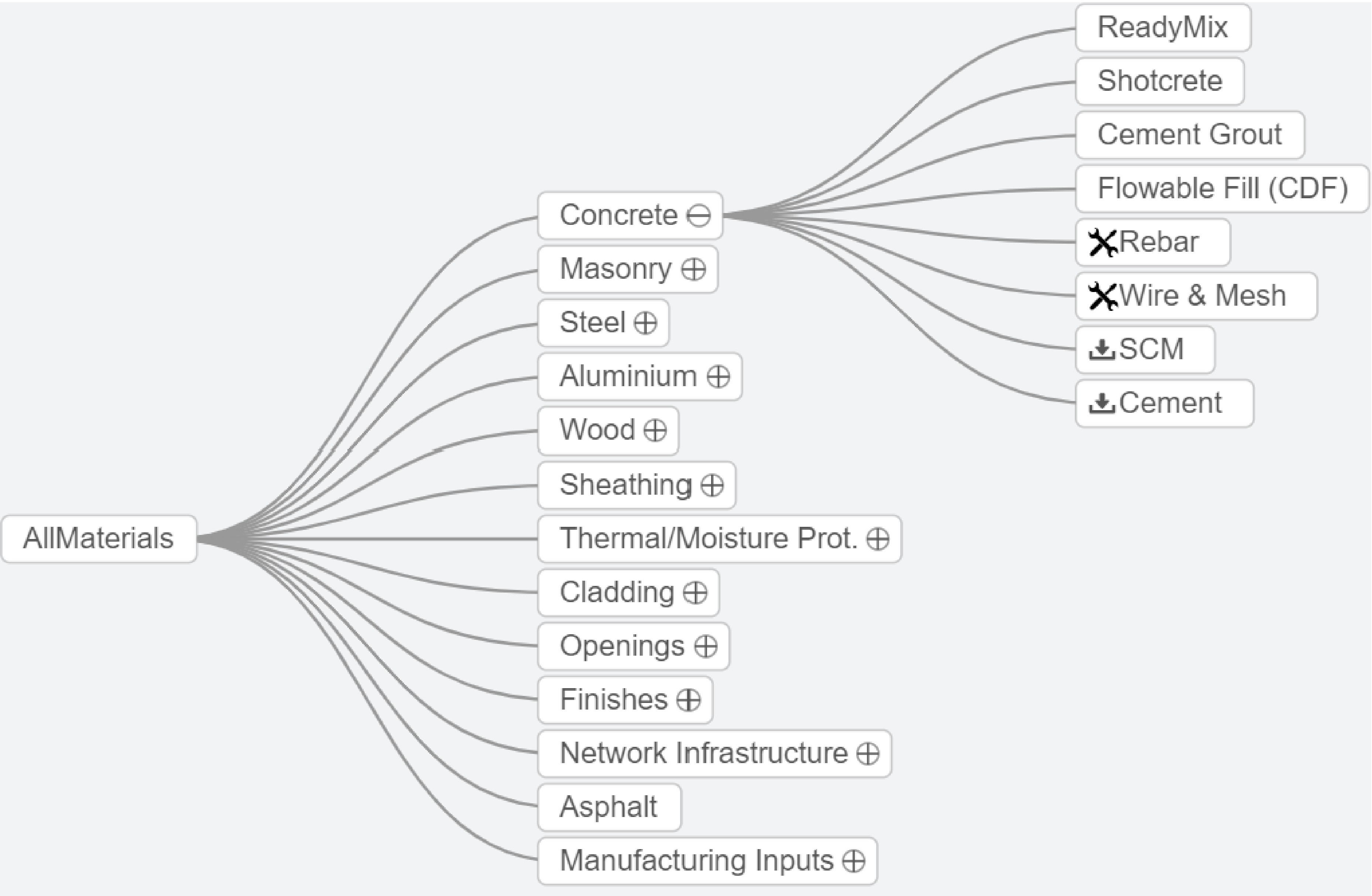
- An EPD (Environmental Product Declaration) is a public, verified report that documents a product's life cycle environment impacts based on LCA.
- Compliance with ISO Standard 14025.
- Adherence to the appropriate industry-standard Product Category Rules (PCRs), specifying how the LCA should be conducted.
- Third party certification of the LCA process.

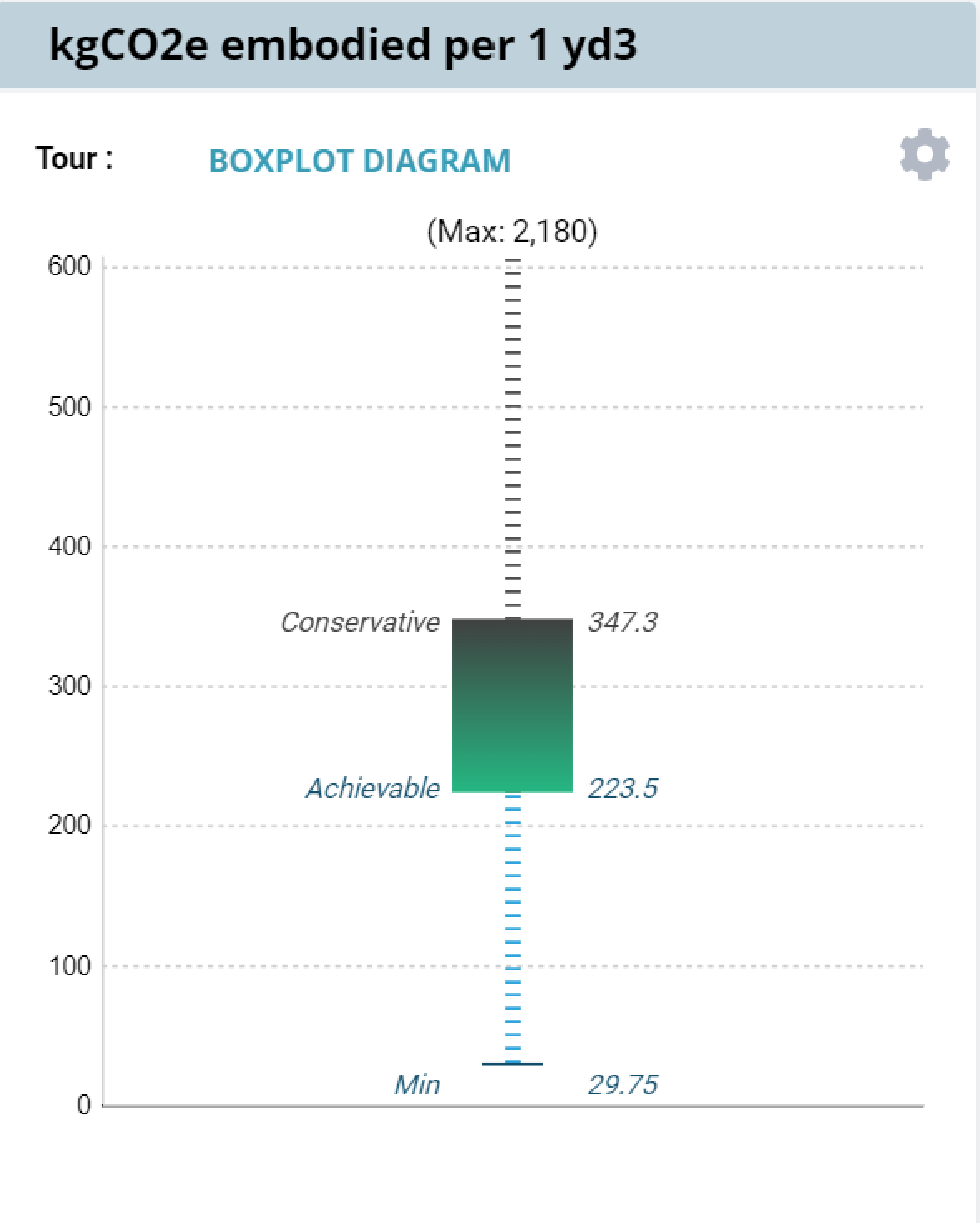
Environmental Facts	
Functional unit: 1 m^2 of Ceramic Tile Floor Covering	
Reference Service Life (RSL): 60 Years	
Life Cycle Inventory Analysis	
Energy Demand	
Primary Renewable (MJ)	10.4
Primary Non-Renewable (MJ)	225
Secondary Renewable (MJ)	0.15
Secondary Non-Renewable (MJ)	1.4
Non-Renewable Material Sources (kg)	51
Waste Output	
Non-Hazardous (kg)	41
Hazardous (kg)	0.0028
60 Year Impact Assessment	
Global Warming Potential (kg CO_2 eq)	15
Acidification Potential (kg SO_2 eq)	0.0565
Ozone Depletion Potential (kg R11 eq)	8.11E-10
Smog Potential (kg Ethene eq)	0.0052
Eutrophication Potential (kg Phosphate eq)	0.00604
Abiotic Depletion Potential - Elemental (kg Sb eq)	1.22E-05
Abiotic Depletion Potential - Fossil (MJ)	219
Boundaries: Cradle to Grave	Clay: 70.3%
Company: North American Tile Manufacturers	Quartz: 4.8%
Product Name: North American-Made Ceramic Tile	Feldspar: 5.3%
Recycled Content: Wide Percentage Range	Scrap: 4.2%
Certification: Some Tiles **Green Squared Certified®**	Kaolin: 3.2%
Other Attributes: Zero VOCs	Granite: 1.3%
	Lime: 1.1%
	Glaze & Stain: 5.4%
	Other Minerals: 4.0%

EC3 Tool



EC3 Tool


AllMaterials
Concrete
Masonry
Steel
Aluminium
Wood
Sheathing
Thermal/Moisture Prot.
Cladding
Openings
Finishes
Network Infrastructure
Asphalt
Manufacturing Inputs
ReadyMix
Shotcrete
Cement Grout
Flowable Fill (CDF)
Rebar
Wire & Mesh
SCM
Cement


kgCO2e embodied per 1 yd3
Tour :
BOXPLOT DIAGRAM
(Max: 2,180)
600
500
400
300
200
100
0
Conservative
347.3
Achievable
223.5
Min
29.75

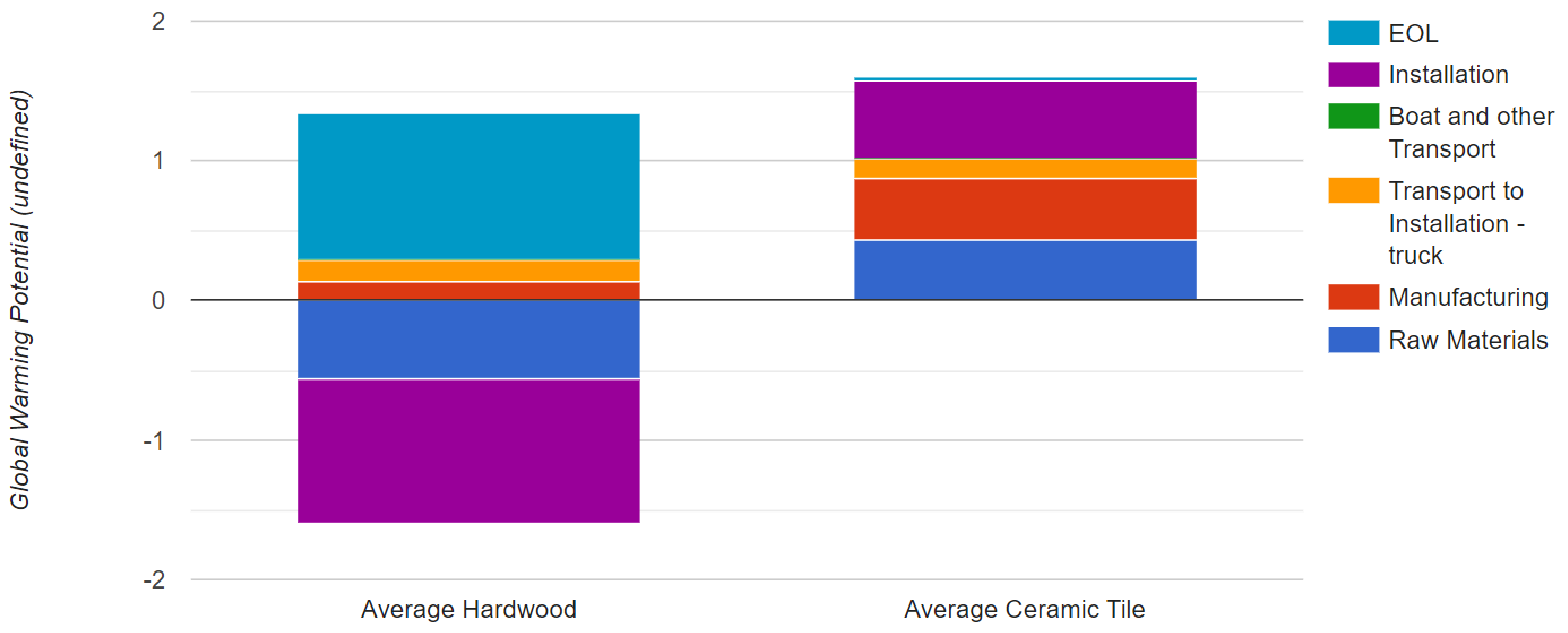
BEES

Major Group Element	Group Element	Individual Element
Building sitework	Site improvements	Parking lot paving
Substructure	Foundations	Slab on grade
	Basement construction	Basement walls
Shell	Superstructure	Beams, columns, roof sheathing, floor decks and slabs
	Roofing	Roof coverings, roof coatings, ceiling insulation
	Exterior Enclosure	Wall insulation, wall sheathing
Interiors	Interior finishes	Floor coverings, wall finishes, ceiling finishes
	Interior construction	Partitions

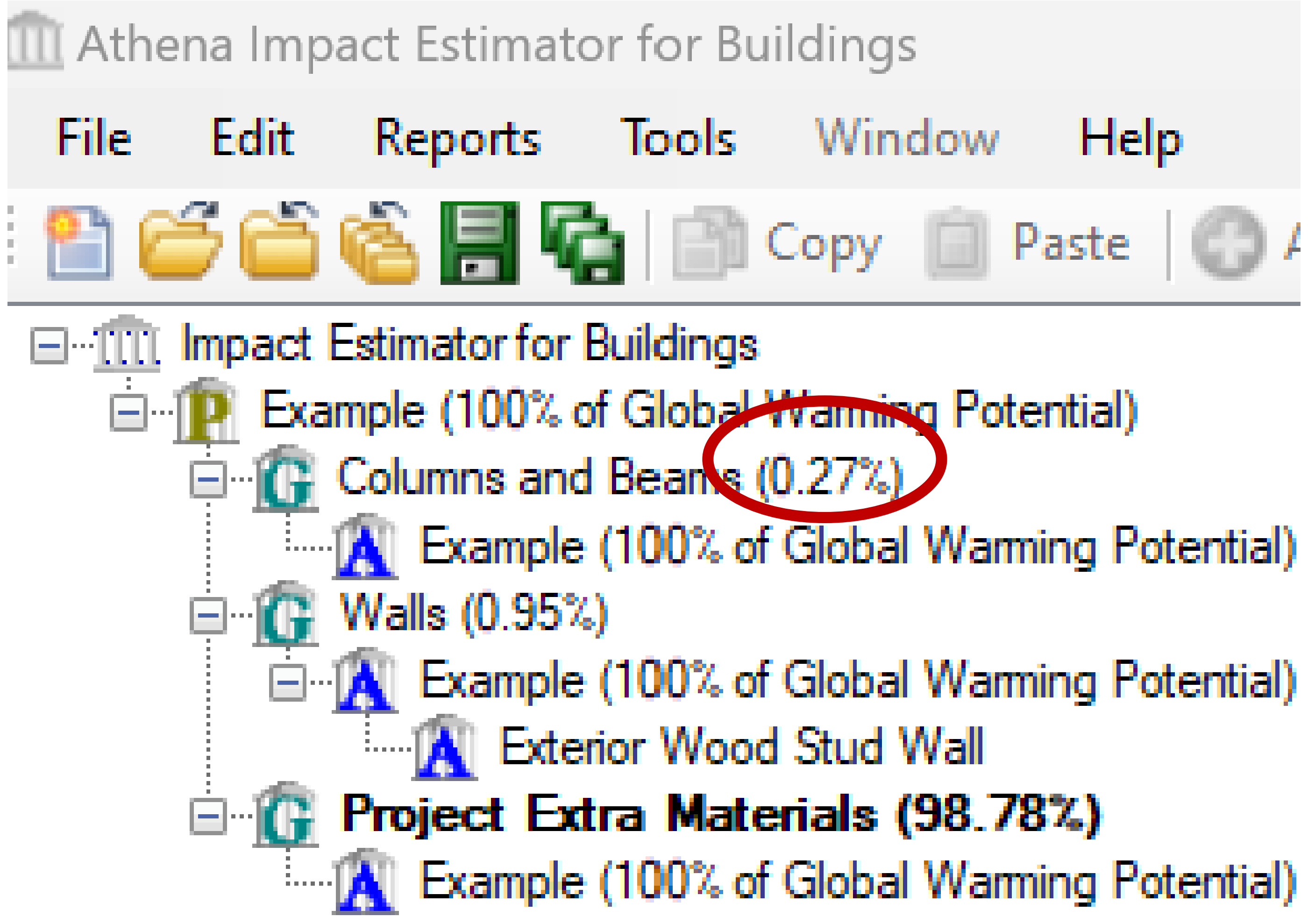
BEES

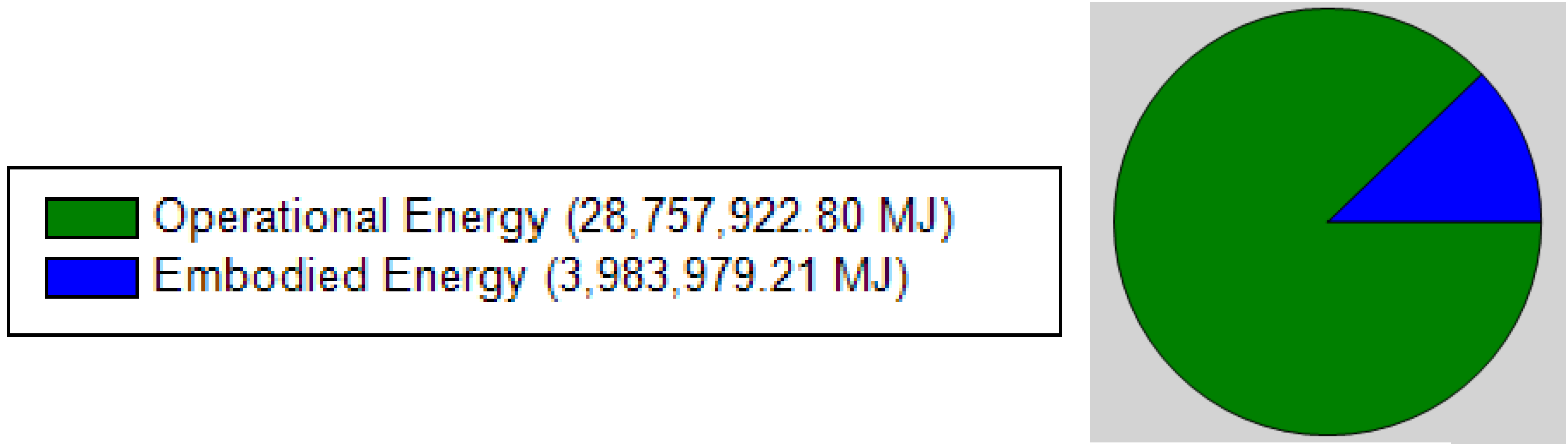
Parameter	Selection Value
Product Category	Floor Coverings
Additional Restriction	Application: residential Type: N/A Sub-Type: N/A Certification: N/A
Analysis Basis	All
Impact Method	TRACI 2
Do Environmental Impact Score	NO
Impact Category Weights	N/A
Product Amount	1.0
Do Enconomic Analysis	YES
Discount Rate	3 %
CO2 Cost ($/Ton)	N/A

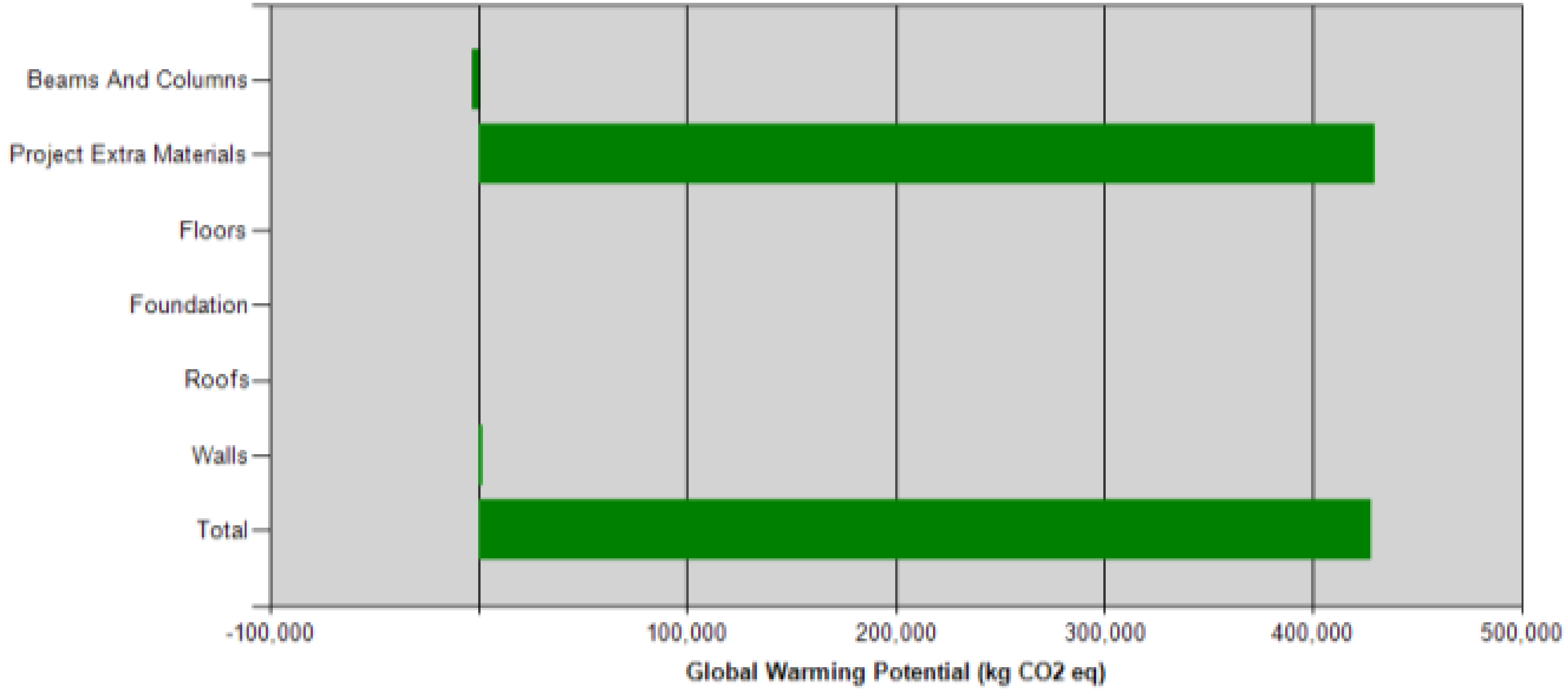
Products Selected	Installed Cost	Product Life	Distance Ship/Other Overseas	Distance in US truck	vacuum/wk	sweep-dry mop/wk
Average Hardwood	$4.87	60	0	500	0	1
Average Ceramic Tile	$1.42	60	0	500	0	1



ATHENA Impact Estimator for Buildings







ATHENA Impact Estimator for Buildings

By Assembly Groups

LCA Measures	Unit	Foundations	Walls	Columns and Beams	Roofs	Floors	Project Extra Materials	Total
Global Warming Potential	kg CO2 eq	0.00E+00	2.06E+03	-3.06E+03	0.00E+00	0.00E+00	4.29E+05	**4.28E+05**
Acidification Potential	kg SO2 eq	0.00E+00	3.91E+01	1.45E+01	0.00E+00	0.00E+00	1.83E+03	**1.88E+03**
HH Particulate	kg PM2.5 eq	0.00E+00	9.72E+00	1.78E+01	0.00E+00	0.00E+00	5.41E+02	**5.68E+02**
Eutrophication Potential	kg N eq	0.00E+00	2.27E+00	2.02E+00	0.00E+00	0.00E+00	5.70E+02	**5.74E+02**
Ozone Depletion Potential	kg CFC-11 eq	0.00E+00	7.34E-05	3.40E-04	0.00E+00	0.00E+00	1.02E-02	**1.06E-02**

By Life Cycle Stages

		PRODUCT (A1 to A3)	CONSTRUCTION PROCESS (A4 & A5)	USE (B2, B4 & B6)			END OF LIFE (C1 to C4)	BEYOND BUILDING LIFE (D)	TOTAL EFFECTS	
LCA Measures	**Unit**	**Total**	**Total**	**Replacement Total**	**Operational Energy Use Total**	**Total**	**Total**	**Total**	**A to C**	**A to D**
Global Warming Potential	kg CO2 eq	**3.41E+05**	**7.80E+04**	1.54E+03	1.66E+06	**1.67E+06**	**1.46E+04**	**-6.29E+03**	**2.10E+06**	**2.09E+0**
Acidification Potential	kg SO2 eq	**1.19E+03**	**4.98E+02**	1.36E+01	1.12E+04	**1.12E+04**	**1.79E+02**	**-8.01E-01**	**1.31E+04**	**1.31E+0**
HH Particulate	kg PM2.5 eq	**4.78E+02**	**8.09E+01**	4.11E+00	1.99E+03	**2.00E+03**	**6.25E+00**	**-3.51E-01**	**2.56E+03**	**2.56E+0**
Eutrophication Potential	kg N eq	**4.72E+02**	**9.06E+01**	6.85E-01	5.30E+02	**5.30E+02**	**1.12E+01**	**-4.12E-02**	**1.10E+03**	**1.10E+0**
Ozone Depletion Potential	kg CFC-11 eq	**9.26E-03**	**1.34E-03**	4.45E-05	3.95E-02	**3.96E-02**	**5.81E-07**	**0.00E+00**	**5.02E-02**	**5.02E-0**
Smog Potential	kg O3 eq	**2.17E+04**	**1.38E+04**	1.69E+02	3.63E+04	**3.65E+04**	**5.85E+03**	**-8.10E+00**	**7.78E+04**	**7.78E+0**
Total Primary Energy	MJ	**2.92E+06**	**8.31E+05**	2.20E+04	2.88E+07	**2.88E+07**	**2.15E+05**	**-1.60E+03**	**3.27E+07**	**3.27E+0**
Non-Renewable Energy	MJ	**2.76E+06**	**8.10E+05**	1.74E+04	2.86E+07	**2.86E+07**	**2.15E+05**	**-1.60E+03**	**3.24E+07**	**3.24E+0**

Thank You!

Sponsor:

U.S. Department of State

USASCP U.S.-ASEAN SMART CITIES PARTNERSHIP

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