

APPENDIXES :

*Creating a Standardized System for
Pre-Engineered Mass Timber Structural Frames
for Applications in Single Story Buildings*

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Masters of Science in Architecture | Mass Timber Focus

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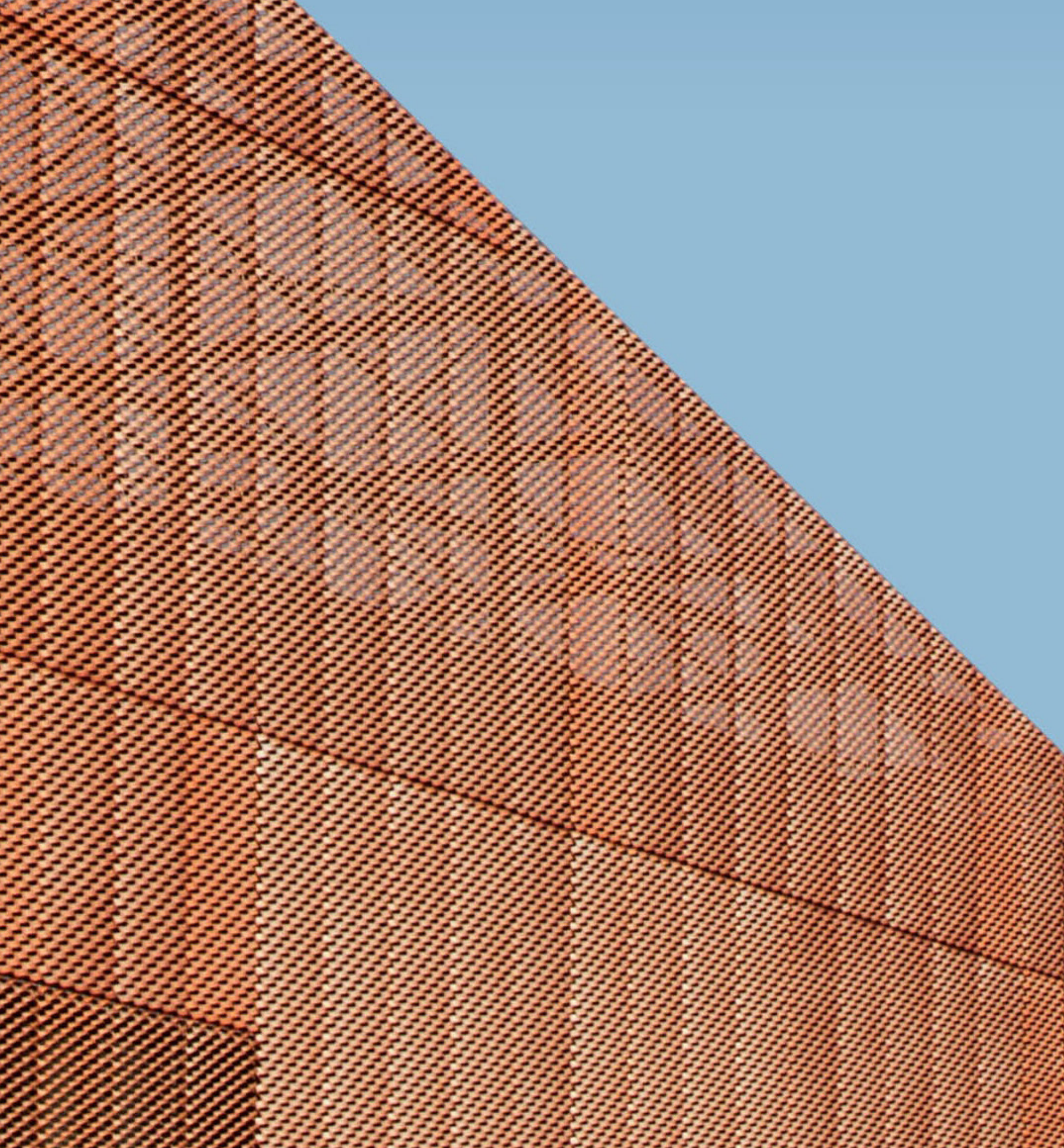


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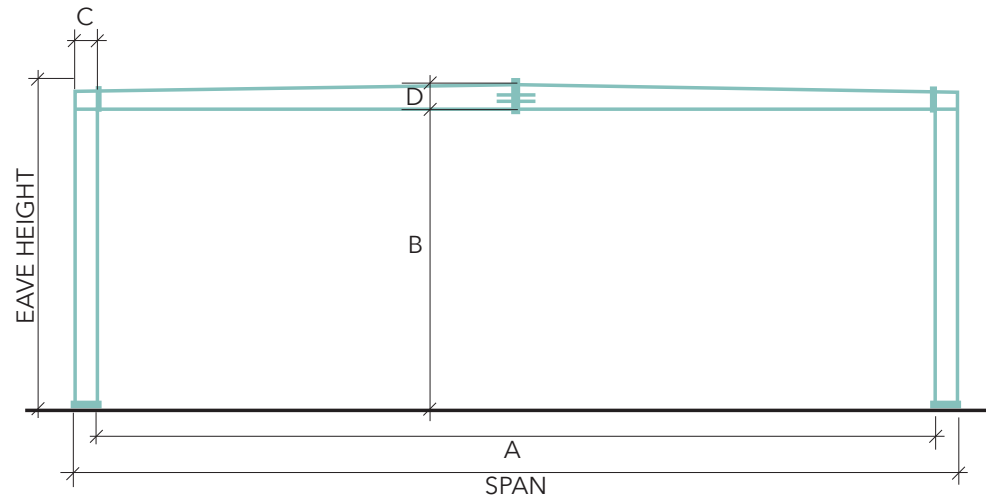
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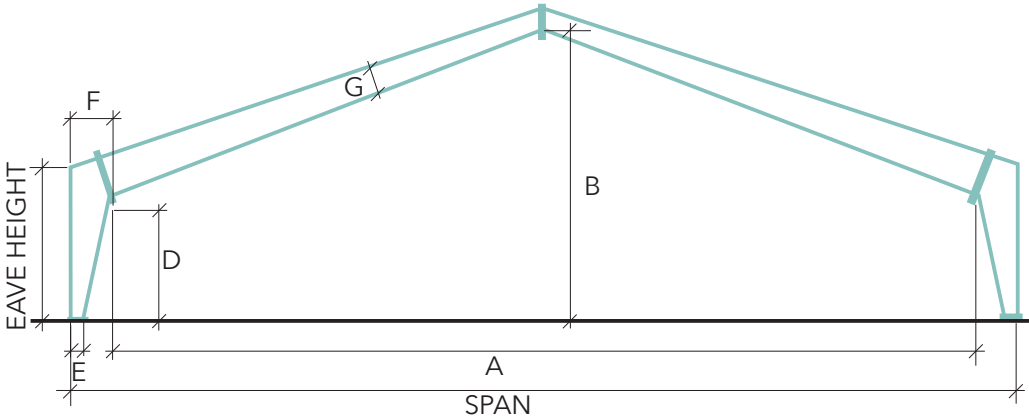
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APPENDIX 1 :
PRE - ENGINEERED METAL
BUILDING SPAN TALBES

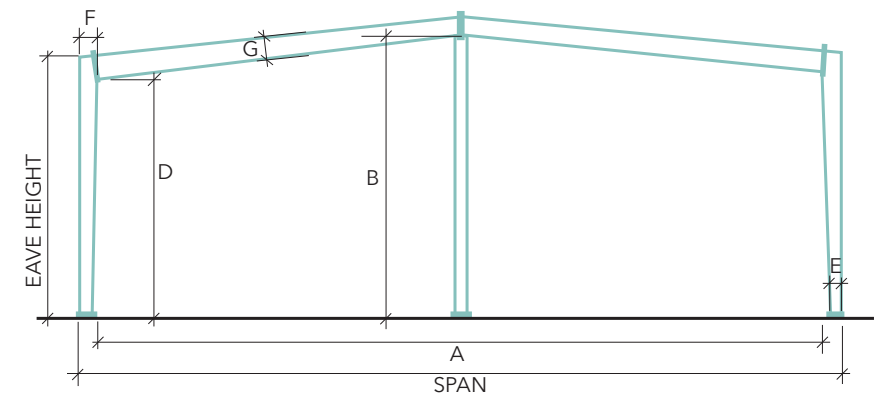
These span tables were taken from a RHINO Steel span tables provided for a variety of frame types. The applicable span tables were re-formatted and are as follows.



SPAN TABLE					
BLDG DIMENSIONS		A	B	C	D
SPAN	EAVE HEIGHT				
20' -0"	10'-0"	18'-8"	8'-6"	8"	8"
	12'-0"	18'-8"	10'-6"	8"	8"
	14'-0"	18'-6"	12'-6"	9"	9"
	16'-0"	18'-6"	14'-6"	9"	9"
	18'-0"	18'-6"	16'-6"	9"	9"
30' -0"	10'-0"	28'-8"	8'-6"	8"	8"
	12'-0"	28'-8"	10'-6"	8"	8"
	14'-0"	28'-6"	12'-6"	9"	9"
	16'-0"	28'-6"	14'-6"	9"	9"
	18'-0"	28'-6"	16'-6"	9"	9"
40'-0"	10'-0"	38'-4"	8'-6"	10"	10"
	12'-0"	38'-4"	10'-6"	10"	10"
	14'-0"	38'-0"	12'-6"	12"	12"
	16'-0"	38'-0"	14'-6"	12"	12"
	18'-0"	38'-0"	16'-6"	12"	12"
	20'-0"	38'-0"	18'-6"	12"	12"
50' -0"	10'-0"	48'-4"	8'-5"	10"	10"
	12'-0"	48'-4"	10'-5"	10"	10"
	14'-0"	48'-0"	12'-5"	10"	10"
	16'-0"	48'-0"	14'-5"	12"	12"
	18'-0"	48'-0"	16'-5"	12"	12"
	20'-0"	48'-0"	18'-5"	12"	12"
60' -0"	10'-0"	58'-4"	8'-4"	10"	10"
	12'-0"	58'-4"	10'-4"	10"	10"
	14'-0"	58'-4"	12'-4"	10"	10"
	16'-0"	58'-0"	14'-4"	12"	12"
	20'-0"	58'-0"	18'-4"	12"	12"
	24'-0"	58'-0"	22'-4"	12"	12"



SPAN TABLE							
BLDG DIMENSIONS		A	B	C	D	E	F
SPAN	EAVE HEIGHT						
30'-0"	10'-0"	25'-6"	12'-11"	8'-4"	8"	1'-6"	1'-0"
	12'-0"	25'-6"	14'-11"	10'-4"	8"	1'-6"	1'-0"
	14'-0"	25'-6"	16'-11"	12'-4"	8"	1'-6"	1'-0"
	16'-0"	25'-6"	18'-11"	14'-4"	8"	1'-6"	1'-0"
	20'-0"	25'-6"	22'-11"	18'-4"	8"	1'-6"	1'-0"
	24'-0"	25'-6"	26'-11"	22'-4"	8"	1'-6"	1'-0"
50'-0"	10'-0"	45'-0"	16'-3"	8'-2"	8"	1'-9"	1'-0"
	12'-0"	45'-0"	18'-3"	10'-2"	8"	1'-9"	1'-0"
	14'-0"	45'-0"	20'-3"	12'-2"	8"	1'-9"	1'-0"
	16'-0"	45'-0"	22'-3"	14'-2"	8"	1'-9"	1'-0"
	20'-0"	45'-0"	26'-3"	18'-2"	8"	1'-9"	1'-0"
	24'-0"	44'-11"	30'-3"	22'-2"	8"	1'-9"	1'-0"
60'-0"	12'-0"	54'-0"	19'-8"	9'-10"	8"	2'-3"	1'-4"
	14'-0"	54'-0"	21'-8"	11'-10"	8"	2'-3"	1'-4"
	16'-0"	54'-0"	23'-8"	13'-10"	8"	2'-3"	1'-4"
	20'-0"	53'-11"	27'-8"	17'-10"	8"	2'-3"	1'-4"
	24'-0"	53'-11"	31'-8"	21'-10"	8"	2'-3"	1'-4"
	24'-0"	53'-11"	31'-8"	21'-10"	8"	2'-3"	1'-4"
70'-0"	12'-0"	63'-5"	20'-11"	9'-7"	8"	2'-6"	1'-8"
	14'-0"	63'-5"	22'-11"	11'-7"	8"	2'-6"	1'-8"
	16'-0"	63'-5"	24'-11"	13'-7"	8"	2'-6"	1'-8"
	20'-0"	63'-5"	28'-11"	17'-7"	8"	2'-6"	1'-8"
	24'-0"	63'-5"	32'-11"	21'-7"	8"	2'-6"	1'-8"
	24'-0"	63'-5"	32'-11"	21'-7"	8"	2'-6"	1'-8"
80'-0"	12'-0"	72'-6"	22'-7"	9'-3"	8"	3'-0"	1'-8"
	14'-0"	72'-6"	24'-1"	11'-3"	8"	3'-0"	1'-8"
	16'-0"	72'-6"	26'-7"	13'-3"	8"	3'-0"	1'-8"
	20'-0"	72'-6"	30'-7"	17'-3"	8"	3'-0"	1'-8"
	24'-0"	72'-6"	34'-7"	21'-3"	8"	3'-0"	1'-8"
	24'-0"	72'-6"	34'-7"	21'-3"	8"	3'-0"	1'-8"
90'-0"	12'-0"	82'-5"	24'-2"	9'-3"	8"	3'-0"	1'-9"
	14'-0"	82'-5"	26'-2"	11'-3"	8"	3'-0"	1'-9"
	16'-0"	82'-5"	28'-2"	13'-3"	8"	3'-0"	1'-9"
	20'-0"	82'-5"	32'-2"	17'-3"	8"	3'-0"	1'-9"
	24'-0"	82'-5"	36'-2"	21'-3"	8"	3'-0"	1'-9"
	24'-0"	82'-5"	36'-2"	21'-3"	8"	3'-0"	1'-9"
100'-0"	12'-0"	91'-5"	26'-2"	8'-11"	1'-0"	3'-6"	1'-9"
	14'-0"	91'-5"	28'-2"	10'-11"	1'-0"	3'-6"	1'-9"
	16'-0"	91'-5"	30'-2"	12'-11"	1'-0"	3'-6"	1'-9"
	20'-0"	91'-5"	34'-2"	16'-11"	1'-0"	3'-6"	1'-9"
	24'-0"	91'-5"	38'-2"	20'-11"	1'-0"	3'-6"	1'-9"
	24'-0"	91'-5"	38'-2"	20'-11"	1'-0"	3'-6"	1'-9"
110'-0"	12'-0"	100'-11"	27'-6"	8'-8"	1'-0"	3'-9"	1'-9"
	14'-0"	100'-11"	29'-6"	10'-8"	1'-0"	3'-9"	1'-9"
	16'-0"	100'-11"	31'-6"	12'-8"	1'-0"	3'-9"	1'-9"
	20'-0"	100'-11"	35'-6"	16'-8"	1'-0"	3'-9"	1'-9"
	24'-0"	100'-11"	39'-6"	20'-8"	1'-0"	3'-9"	1'-9"
	24'-0"	100'-11"	39'-6"	20'-8"	1'-0"	3'-9"	1'-9"
120'-0"	12'-0"	110'-5"	29'-3"	8'-6"	1'-0"	4'-0"	1'-8"
	14'-0"	110'-5"	31'-3"	10'-6"	1'-0"	4'-0"	1'-8"
	16'-0"	110'-5"	33'-3"	12'-6"	1'-0"	4'-0"	1'-8"
	20'-0"	110'-5"	37'-3"	16'-6"	1'-0"	4'-0"	1'-8"
	24'-0"	110'-5"	41'-3"	20'-6"	1'-0"	4'-0"	1'-8"
	24'-0"	110'-5"	41'-3"	20'-6"	1'-0"	4'-0"	1'-8"



SPAN TABLE						
BLDG DIMENSIONS		A	B	C	D	E
SPAN	EAVE HEIGHT					
60'-0"	10'-0"	28'-0"	10'-4"	8'-1"	1'-3"	1'-6"
	12'-0"	28'-0"	12'-4"	10'-1"	1'-3"	1'-6"
	14'-0"	28'-0"	14'-4"	12'-1"	1'-3"	1'-6"
	16'-0"	28'-0"	16'-4"	14'-1"	1'-3"	1'-6"
	20'-0"	27'-9"	20'-1"	17'-11"	1'-6"	1'-9"
70'-0"	10'-0"	33'-0"	10'-4"	8'-1"	1'-3"	1'-11"
	12'-0"	33'-0"	12'-4"	10'-1"	1'-3"	1'-11"
	14'-0"	33'-0"	14'-4"	12'-1"	1'-3"	1'-11"
	16'-0"	33'-0"	16'-4"	14'-1"	1'-3"	1'-11"
	20'-0"	32'-9"	20'-1"	17'-11"	1'-6"	2'-2"
80'-0"	10'-0"	38'-0"	10'-8"	8'-1"	1'-3"	2'-0"
	12'-0"	38'-0"	12'-8"	10'-1"	1'-3"	2'-0"
	14'-0"	38'-0"	14'-8"	12'-1"	1'-3"	2'-0"
	16'-0"	38'-0"	16'-8"	14'-1"	1'-3"	2'-0"
	20'-0"	37'-8"	20'-6"	17'-11"	1'-6"	2'-2"
90'-0"	24'-0"	37'-8"	24'-6"	21'-11"	1'-6"	2'-2"
	12'-0"	42'-2"	12'-6"	9'-6"	2'-0"	2'-7"
	14'-0"	42'-2"	14'-6"	11'-6"	2'-0"	2'-7"
	16'-0"	42'-2"	16'-6"	13'-6"	2'-0"	2'-7"
	20'-0"	42'-2"	20'-6"	17'-6"	2'-0"	2'-7"
100'-0"	24'-0"	42'-2"	24'-6"	21'-6"	2'-0"	2'-7"
	12'-0"	47'-2"	12'-5"	9'-6"	2'-0"	3'-0"
	14'-0"	47'-2"	14'-5"	11'-6"	2'-0"	3'-0"
	16'-0"	47'-2"	16'-5"	13'-6"	2'-0"	3'-0"
	20'-0"	47'-2"	20'-5"	17'-6"	2'-0"	3'-0"
110'-0"	24'-0"	47'-2"	24'-5"	21'-6"	2'-0"	3'-0"
	12'-0"	52'-2"	12'-10"	9'-6"	2'-0"	3'-0"
	14'-0"	52'-2"	14'-10"	11'-6"	2'-0"	3'-0"
	16'-0"	52'-2"	16'-10"	13'-6"	2'-0"	3'-0"
	20'-0"	52'-2"	20'-10"	17'-6"	2'-0"	3'-0"
120'-0"	24'-0"	52'-2"	24'-10"	21'-6"	2'-0"	3'-0"
	12'-0"	57'-2"	12'-11"	9'-6"	2'-0"	3'-4"
	14'-0"	57'-2"	14'-11"	11'-6"	2'-0"	3'-4"
	16'-0"	57'-2"	16'-11"	13'-6"	2'-0"	3'-4"
	20'-0"	57'-2"	20'-11"	17'-6"	2'-0"	3'-4"
140'-0"	24'-0"	57'-2"	24'-11"	21'-6"	2'-0"	3'-4"
	12'-0"	67'-3"	13'-10"	9'-6"	2'-0"	3'-4"
	14'-0"	67'-3"	15'-10"	11'-6"	2'-0"	3'-4"
	16'-0"	67'-3"	17'-10"	13'-6"	2'-0"	3'-4"
	20'-0"	67'-3"	21'-10"	17'-6"	2'-0"	3'-4"
140'-0"	24'-0"	67'-3"	25'-10"	21'-6"	2'-0"	3'-4"

APPENDIX 2 : MASS PLYWOOD BEAM AND COLUMN SPAN TABLES

These span tables were found on Freres Engineered Wood's website and were used in the calculation of primary member sizes in the mass plywood frames.



BEAM SPAN TABLE - 3 PLY N DEPTH

DEPTH (IN)	7.75	6 PLF SELF WEIGHT										
LOADS (PLF)	150	300	450	600	750	900	1050	1200	1350	1500		
L / 240 (FT)	14.1	9.8	8.9	8.3	7.8	7.4	7.1	6.8	6.6			
L / 360 (FT)	12.3	9.8	8.6	7.8	7.2	6.8	6.4	6.2	5.9	5.7		
L / 480 (FT)	11.2	8.9	7.8	7.1	6.6	6.2	5.9	5.6	5.4	5.2		
MOMENT	16.7	11.8	9.6	8.3	7.5	6.8	6.3	5.9	5.6	5.3		
SHEAR	53.8	26.9	17.9	13.4	10.8	9.0	7.7	6.7	6.0	5.4		
DEPTH (IN)	9.375	7 PLF SELF WEIGHT										
LOADS (PLF)	150	400	650	900	1150	1400	1650	1900	2150	2400		
L / 240 (FT)	17.1	12.3	10.5	9.4	8.7	8.1	7.7	7.3	7.0	6.8		
L / 360 (FT)	14.9	10.8	9.2	8.2	7.6	7.1	6.7	6.4	6.1	5.9		
L / 480 (FT)	13.6	9.8	8.3	7.5	6.9	6.4	6.1	5.8	5.6	5.4		
MOMENT	19.9	12.2	9.5	8.1	7.2	6.5	6.0	5.6	5.2	5.0		
SHEAR	65.0	24.4	15.0	10.8	8.5	7.0	5.9	5.1	4.5	4.1		
DEPTH (IN)	11.75	9 PLF SELF WEIGHT										
LOADS (PLF)	150	500	850	1200	1550	1900	2250	2600	2950	3300		
L / 240 (FT)	21.4	14.3	12.0	10.7	9.8	9.2	8.7	8.3	7.9	7.6		
L / 360 (FT)	18.7	12.5	10.5	9.3	8.6	8.0	7.6	7.2	6.9	6.7		
L / 480 (FT)	17.0	11.4	9.5	8.5	7.8	7.3	6.9	6.6	6.3	6.1		
MOMENT	24.4	13.4	10.3	8.6	7.6	6.9	6.3	5.9	5.5	5.2		
SHEAR	81.5	24.4	14.4	10.2	7.9	6.4	5.4	4.7	4.1	3.7		
DEPTH (IN)	15.625	12 PLF SELF WEIGHT										
LOADS (PLF)	150	500	850	1200	1550	1900	2250	2600	2950	3300		
L / 240 (FT)	28.5	19.1	16.0	14.2	13.1	12.2	11.5	11.0	10.5	10.2		
L / 360 (FT)	24.9	16.6	13.9	12.4	11.4	10.7	10.1	9.6	9.2	8.9		
L / 480 (FT)	22.6	15.1	12.7	11.3	10.4	9.7	9.2	8.7	8.4	8.1		
MOMENT	31.7	17.4	13.3	11.2	9.9	8.9	8.2	7.6	7.2	6.8		
SHEAR	108.4	32.5	19.1	13.5	10.5	8.6	7.2	6.3	5.5	4.9		

BEAM TABLE FOOTNOTES

- NDS adjustment factors applied are as follows: CD = 1.0, Ct = 1.0, CM = 1.0, C_v = ($\frac{E}{E'}$)^{1/2}, C_L = 1.0.
- Design values, and volumetric adjustments were used in accordance with PR-L325.
- Displayed spans are limited to 4 times the qualified volume according to ASTM D5456.

HOW TO USE TABLE

- Calculate your controlling load combinations for each serviceability condition and strength performance.
- For each load combination, find the corresponding linear load in the “Load” row.
- Look down each column until encountering the row with the corresponding serviceability or strength check.
- Compare each entry's span in the table to find the minimum span, this is the controlling span.

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BEAM TABLE FOOTNOTES

- NDS adjustment factors applied are as follows: CD = 1.0, Ct = 1.0, CM = 1.0, C_v = ($\frac{E}{E'}$)^{1/2}, C_L = 1.0.
- Design values, and volumetric adjustments were used in accordance with PR-L325.
- Displayed spans are limited to 4 times the qualified volume according to ASTM D5456.

HOW TO USE TABLE

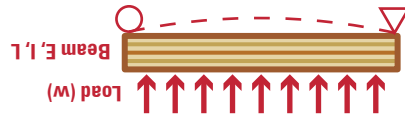
- Calculate your controlling load combinations for each serviceability condition and strength performance.
- For each load combination, find the corresponding linear load in the “Load” row.
- Look down each column until encountering the row with the corresponding serviceability or strength check.
- Compare each entry's span in the table to find the minimum span, this is the controlling span.

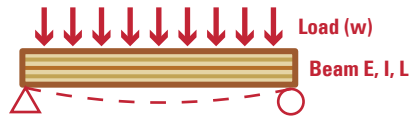
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BEAM SPAN TABLE - 5 PLY N DEPTH

DEPTH (IN)	9.375	12 PLF SELF WEIGHT										
LOADS (PLF)	150	300	450	600	750	900	1050	1200	1350	1500		
L / 240 (FT)	20.2	16.0	14.0	12.7	11.8	11.1	10.6	10.1	9.7	9.4		
L / 360 (FT)	17.7	14.0	12.2	11.1	10.3	9.7	9.2	8.8	8.5	8.2		
L / 480 (FT)	16.0	12.7	11.1	10.1	9.4	8.8	8.4	8.0	7.7	7.4		
MOMENT	25.6	18.1	14.8	12.8	11.4	10.4	9.7	9.0	8.5	8.1		
SHEAR	108.0	54.0	36.0	27.0	21.6	18.0	15.4	13.5	12.0	10.8		
DEPTH (IN)	11.75	15 PLF SELF WEIGHT										
LOADS (PLF)	150	400	650	900	1150	1400	1650	1900	2150	2400		
L / 240 (FT)	25.3	18.3	15.5	13.9	12.9	12.0	11.4	10.9	10.4	10.1		
L / 360 (FT)	22.1	16.0	13.6	12.2	11.2	10.5	10.0	9.5	9.1	8.8		
L / 480 (FT)	20.1	14.5	12.3	11.1	10.2	9.6	9.0	8.6	8.3	8.0		
MOMENT	31.5	19.3	15.1	12.8	11.4	10.3	9.5	8.8	8.3	7.9		
SHEAR	135.3	50.7	31.2	22.5	17.6	14.5	12.3	10.7	9.4	8.5		
DEPTH (IN)	15.625	20 PLF SELF WEIGHT										
LOADS (PLF)	150	500	850	1200	1550	1900	2250	2600	2950	3300		
L / 240 (FT)	33.7	22.6	18.9	16.9	15.5	14.5	13.7	13.0	12.5	12.0		
L / 360 (FT)	29.4	19.7	16.5	14.7	13.5	12.6	11.9	11.4	10.9	10.5		
L / 480 (FT)	26.7	17.9	15.0	13.4	12.3	11.5	10.8	10.3	9.9	9.5		
MOMENT	40.9	22.4	17.2	14.4	12.7	11.5	10.6	9.8	9.2	8.7		
SHEAR	179.9	54.0	31.8	22.5	17.4	14.2	12.0	10.4	9.1	8.2		
DEPTH (IN)	23.625	30 PLF SELF WEIGHT										
LOADS (PLF)	150	600	1050	1500	1950	2400	2850	3300	3750	4200		
L / 240 (FT)	51.0	32.1	26.6	23.7	21.7	20.2	19.1	18.2	17.4	16.8		
L / 360 (FT)	44.5	28.0	23.3	20.7	18.9	17.7	16.7	15.9	15.2	14.7		
L / 480 (FT)	40.4	25.5	21.1	18.8	17.2	16.1	15.2	14.4	13.8	13.3		
MOMENT	59.7	29.9	22.6	18.9	16.6	14.9	13.7	12.7	11.9	11.3		
SHEAR	272.0	68.0	38.9	27.2	20.9	17.0	14.3	12.4	10.9	9.7		





BEAM SPAN TABLE - 7 PLY N DEPTH

DEPTH (IN)	11.75	21 PLF SELF WEIGHT								
LOADS (PLF)	150	400	650	900	1150	1400	1650	1900	2150	2400
L / 240 (FT)	28.4	20.5	17.4	15.6	14.4	13.5	12.8	12.2	11.7	11.3
L / 360 (FT)	24.8	17.9	15.2	13.6	12.6	11.8	11.1	10.6	10.2	9.8
L / 480 (FT)	22.5	16.2	13.8	12.4	11.4	10.7	10.1	9.7	9.3	8.9
MOMENT	37.3	22.8	17.9	15.2	13.5	12.2	11.2	10.5	9.8	9.3
SHEAR	189.6	71.1	43.8	31.6	24.7	20.3	17.2	15.0	13.2	11.9
DEPTH (IN)	15.625	28 PLF SELF WEIGHT								
LOADS (PLF)	150	600	1050	1500	1950	2400	2850	3300	3750	4200
L / 240 (FT)	37.7	23.8	19.7	17.5	16.0	15.0	14.1	13.5	12.9	12.4
L / 360 (FT)	32.9	20.8	17.2	15.3	14.0	13.1	12.3	11.8	11.3	10.9
L / 480 (FT)	29.9	18.9	15.6	13.9	12.7	11.9	11.2	10.7	10.2	9.9
MOMENT	48.4	24.2	18.3	15.3	13.4	12.1	11.1	10.3	9.7	9.1
SHEAR	252.2	63.0	36.0	25.2	19.4	15.8	13.3	11.5	10.1	9.0
DEPTH (IN)	23.625	42 PLF SELF WEIGHT								
LOADS (PLF)	250	800	1350	1900	2450	3000	3550	4100	4650	5200
L / 240 (FT)	48.1	32.6	27.4	24.5	22.5	21.0	19.9	18.9	18.2	17.5
L / 360 (FT)	42.0	28.5	23.9	21.4	19.6	18.4	17.4	16.5	15.9	15.3
L / 480 (FT)	38.2	25.9	21.8	19.4	17.8	16.7	15.8	15.0	14.4	13.9
MOMENT	54.7	30.6	23.6	19.9	17.5	15.8	14.5	13.5	12.7	12.0
SHEAR	228.8	71.5	42.4	30.1	23.3	19.1	16.1	13.9	12.3	11.0
DEPTH (IN)	47.5	86 PLF SELF WEIGHT								
LOADS (PLF)	350	1000	1650	2300	2950	3600	4250	4900	5550	6200
L / 240 (FT)	86.4	60.9	51.6	46.2	42.5	39.7	37.6	35.9	34.4	33.2
L / 360 (FT)	75.5	53.2	45.0	40.3	37.1	34.7	32.9	31.3	30.1	29.0
L / 480 (FT)	68.6	48.4	40.9	36.6	33.7	31.5	29.9	28.5	27.3	26.3
MOMENT	87.8	51.9	40.4	34.2	30.2	27.4	25.2	23.5	22.0	20.9
SHEAR	328.5	115.0	69.7	50.0	39.0	31.9	27.1	23.5	20.7	18.5

BEAM TABLE FOOTNOTES

- ♦ NDS adjustment factors applied are as follows: $C_D = 1.0$, $C_t = 1.0$, $C_M = 1.0$, $C_v = (\frac{12}{d})^{\frac{1}{5}}$, $C_L = 1.0$.
- ♦ Design values, and volumetric adjustments were used in accordance with PR-L325.
- ♦ Displayed spans are limited to 4 times the qualified volume according to ASTM D5456.

HOW TO USE TABLE

- ♦ Calculate your controlling load combinations for each serviceability condition and strength performance.
- ♦ For each load combination, find the corresponding linear load in the “Load” row.
- ♦ Look down each column until encountering the row with the corresponding serviceability or strength check.
- ♦ Compare each entry’s span in the table to find the minimum span, this is the controlling span.

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F16 MASS PLY COLUMN LOADING TABLE (AXIAL LOADS ONLY) IN KIPS

LAY-UP	WIDTH & DEPTH	COLUMN HEIGHT (FT)											
ID	(in)	4	8	12	16	20	24	28	32	36	40	44	48
F16-2	2.04	4	1	0	0	0	0	0	0	0	0	0	0
F16-3	3.06	17	6	2	0	0	0	0	0	0	0	0	0
F16-4	4.08	36	17	8	4	0	0	0	0	0	0	0	0
F16-5	5.10	59	38	19	11	7	0	0	0	0	0	0	0
F16-6	6.12	87	69	38	22	14	10	0	0	0	0	0	0
F16-7	7.14	120	105	67	40	26	18	14	0	0	0	0	0
F16-8	8.16	157	145	106	67	44	31	23	18	0	0	0	0
F16-9	9.18	200	189	154	104	70	50	37	28	22	0	0	0
F16-10	10.20	247	238	208	152	105	75	56	43	34	28	0	0
F16-11	11.22	300	291	265	209	150	108	81	63	50	40	34	0
F16-12	12.24	357	349	326	275	205	151	113	88	70	57	47	40
F16-13	13.26	420	411	391	345	271	204	155	120	96	78	65	55
F16-14	14.28	487	479	461	420	347	267	205	161	128	105	87	74
F16-15	15.30	560	552	534	498	429	341	266	209	168	138	114	97
F16-16	16.32	637	629	613	580	517	426	337	268	216	177	147	125
F16-17	17.34	719	712	696	666	609	518	420	337	273	224	187	158
F16-18	18.36	807	799	784	756	704	618	512	416	339	280	234	198
F16-19	19.38	899	892	877	851	803	723	614	506	416	344	288	245
F16-20	20.40	997	989	975	950	906	832	724	607	503	419	352	299
F16-21	21.42	1099	1092	1078	1054	1013	945	841	718	601	503	424	361
F16-22	22.44	1206	1199	1186	1163	1124	1061	963	837	710	598	506	432
F16-23	23.46	1319	1311	1298	1276	1240	1181	1089	965	829	704	599	512
F16-24	24.48	1436	1429	1416	1394	1360	1305	1219	1099	958	821	702	603

COLUMN TABLE NOTES

- ♦ For use in dry condition.
- ♦ $P_r = F_c A_{parallel} C_D C_M C_t C_P$. Where slenderness ratio exceeds 50 to 1, no value is given.
- ♦ C_D , C_M and C_t are assumed to be 1.
- ♦ Table for preliminary analysis only.
- ♦ Table does not account for eccentric axial loading nor wind loads.
- ♦ Major force direction is parallel to column height.
- ♦ For different loading conditions, consult with Freres technical support.

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APPENDIX 3 : ENVIRONMENTAL PRODUCT DECLARATION - MASS PLYWOOD PANEL

The following report is a published environmental product declaration (EPD) from Freres Engineered Wood on the mass plywood panel product. This report was published in 2020.

Environmental Product Declaration



EPD for Mass Ply Panels produced by Freres Lumber in Lyons, Oregon



ASTM Certified Environmental Product Declaration

Program Operator	ASTM International 100 Barr Harbor Drive PO Box C700 West Conshohocken, PA, 19428-2959 USA www.astm.org  ASTM INTERNATIONAL Helping our world work better		
General Program Instructions and Version Number	ASTM Program Operator for Product Category Rules (PCR) and Environmental Product Declarations (EPDs) - General Program Instructions, version: 8.0		
Declaration Owner	Freres Lumber Company Inc. 40519 S Cedar Mill Rd. Lyons, Oregon 97358, USA Frereslumber.com 		
Declaration Number	EPD160		
Declared Product	Mass Ply Panels (MPP)		
Declared Unit	1 m ³ of MPP produced at Freres MPP facility in Lyons, Oregon		
Reference PCR and Version Number	ISO 21930:2017 Sustainability in Building Construction — Environmental Declaration of Building Products. [7] UL Environment: Product Category Rules for Building-Related Products and Services Part A: Calculation Rules for the Life Cycle Assessment and Requirements on the Project Report, v3.2 [13] Part B: Structural and Architectural Wood Products EPD Requirements, v1.0 [14]		
Description of Product's intended application and use	Mass Ply panels (MPP), is a veneer based engineered wood product that is characterized by large structural elements that use layers of wood for wall, floor, and roof construction [15].		
Markets of Applicability	Construction Sector, Mass timber design		
Date of Issue	November 5, 2020		
Period of Validity	November 4, 2025		
EPD Type	Product-specific EPD		
EPD Scope	Cradle to Gate		
Year of reported manufacturer primary data	2018		
LCA Software	SimaPro v9.0.0.49		
LCI Databases	USLCI [9], Ecoinvent 3.5 [14], Datasmart [8]		
LCIA Methodology	TRACI 2.1 [3]		
The sub-category PCR review was conducted by:	Dr. Thomas Gloria (chair) Industrial Ecology Consultants	Dr. Indro Ganguly University of Washington	Dr. Sahoo University of Georgia

LCA and EPD Developer This life cycle assessment was conducted in accordance with ISO 14044 and the reference PCR by:	CORRIM, Consortium for Research on Renewable Industrial Materials PO Box 2432 Corvallis, OR 97339 541-231-2726 www.corrim.org   Maureen Puettmann
This declaration was independently verified in accordance with ISO 14025:2006 . The UL Environment “Part A: Calculation Rules for the Life Cycle Assessment and Requirements on the Project Report,” v3.2 (December 2018), in conformance with ISO 21930:2017 , serves as the core PCR, with additional considerations from the USGBC/UL Environment Part A Enhancement (2017) . ☐ INTERNAL ☒ EXTERNAL	
Independent Verifier This life cycle assessment was independently verified in accordance with ISO 14044 and the reference PCR by:	Thomas P. Gloria, Ph.D. Industrial Ecology Consultants 35 Bracebridge Rd. Newton, MA 02459-1728 email: t.gloria@industrial-ecology.com 
Limitations - Environmental declarations from different programs (ISO 14025) may not be comparable. - Comparison of the environmental performance using EPD information shall consider all relevant information modules over the full life cycle of the products within the building. - This PCR allows EPD comparability only when the same functional requirements between products are ensured and the requirements of ISO 21930:2017 §5.5 are met. It should be noted that different LCA software and background LCI datasets may lead to differences results for upstream or downstream of the life cycle stages declared.	



COMPANY AND PRODUCT DESCRIPTION

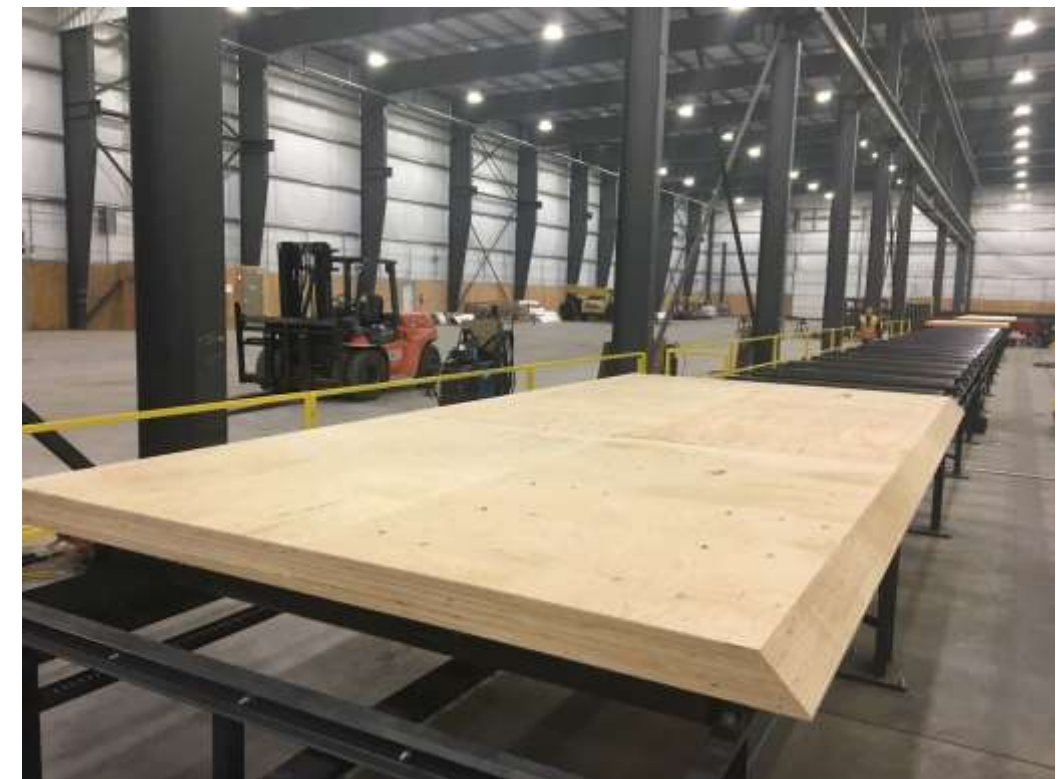
Freres Lumber Company

Established in 1922, Freres Lumber produces finished plywood products, lumber, veneers, structural composite lumber (SCL), and Mass Ply Panel (MPP) (since 12/2017) with around 450 employees. The company operates 2 veneer plants, a veneer drying facility, plywood plant, cogeneration facility, a stud mill, their own log and highway trucks, and the MPP production facility.

Mass Ply Panels

Mass Ply panels (MPP), is a veneer-based engineered wood product. MPP is a recent addition to the mass timber product line. Mass timber is a category of timber products typically characterized by large structural elements such as panels or beams that use multiple layers of wood for wall, floor, and roof construction. Products may include cross laminated timber, nail-laminated timber, glued-laminated timber, Mass Ply panels (MPP), laminated veneer lumber (LVL), and wood-concrete composites [15].

Mass Ply panels are made with Douglas-fir (*Pseudotsuga menziesii*). Phenol formaldehyde resin is the primary adhesive type used in SCL production and melamine formaldehyde resin is used in MPP production [15].



METHODOLOGICAL FRAMEWORK

Type of EPD and Life Cycle Stages

The underlying LCA [15] investigates the MPP product system from cradle to gate. This comprises the production stage including the information modules 'A1 Extraction and upstream production', 'A2 Transport to factory' and 'A3 Manufacturing' (Figure 1).

Building Life Cycle Information Modules															
Production stage			Construction Stage		Use stage							End-of-life stage			
Extraction and upstream production	Transport to factory	Manufacturing	Transport to site	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	De-Construction/ Demolition	Transport to waste processing or disposal	Waste processing	Disposal
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

Figure 1 Life Cycle Stages & Information Modules per ISO 21930. (MND: module not declared)



System Boundaries and Product Flow Diagram

The product system described in Figure 2 includes the following information modules and unit processes:

A1 Extraction and upstream production

A1 includes the cradle-to-gate production of SCL and resins that are used in MPP manufacture.

The upstream resource extraction includes removal of raw materials and processing, processing of secondary material input (e.g., recycling processes) after crossing the system boundary of the previous product system. A1 also includes reforestation processes that include nursery operations (which include fertilizer, irrigation, energy for greenhouses if applicable etc.), site preparation, as well as planting, fertilization, thinning and other management operations.

A2 Transport to facility

Average or specific transportation of raw materials (including secondary materials and fuels) from extraction site or source to manufacturing site (including any recovered materials from source to be recycled in the process).

A3 Manufacturing

Manufacturing of the MPP product, including packaging (MPP wrap).

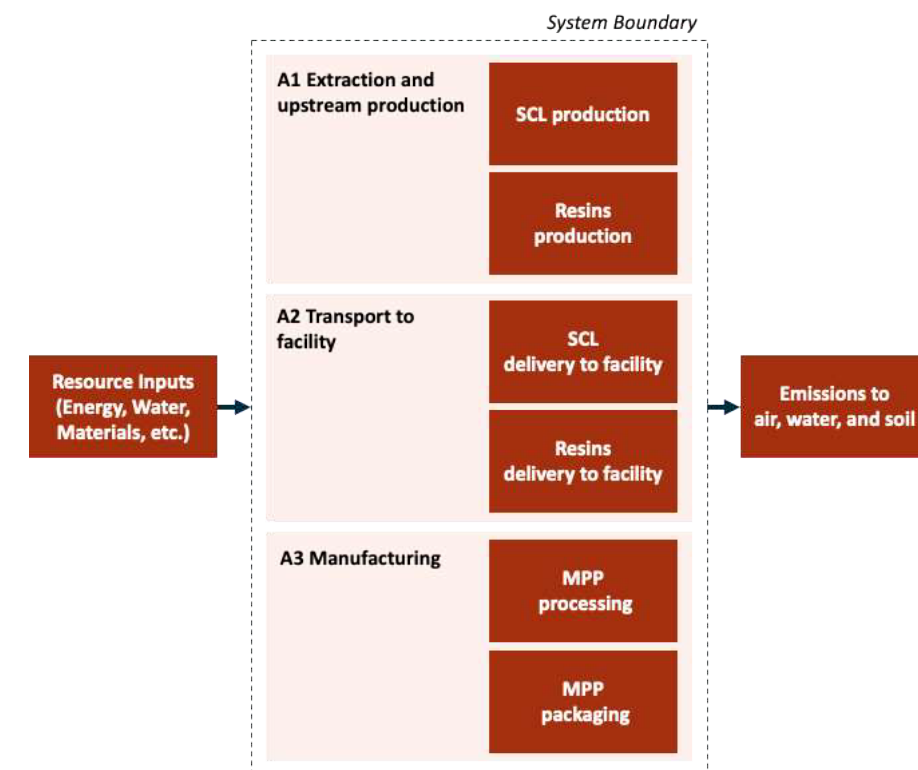


Figure 2: Cradle-to-Gate Mass Ply Panel Product System

Declared Unit

Table 1 shows the declared unit and additional product information.

Table 1: Declared Unit and Product Information

Declared Unit		
The declared unit is “the production of one cubic meter (1 m3) of MPP produced at Freres facility in Lyons, Oregon”.		
Property	Unit	Value
Mass	kg	546.0
Moisture Content	%	8%
Product Composition		
Structural Composite Lumber	%	97.8%
Resins	%	2.13%

Allocation Methods

Allocation is the method used to partition the environmental load of a process when several products or functions share the same process. Processing logs for the production of structural composite lumber involves multiple processes with multiple coproduct outputs. The production of MPP from SCL also produces multiple coproduct outputs. Both the SCL production process and MPP production process were allocated on a mass basis in accordance with UL PCR 2019 and ISO 21930:2017.

Cut-off Criteria

The cut-off criteria for all activity stage flows considered within the system boundary conform with ISO 21930: 2017 Section 7.1.8. Specifically, the cut-off criteria were applied as follows:

- All inputs and outputs for which data are available are included in the calculated effects and no collected core process data are excluded.
- A one percent cut-off is considered for renewable and non-renewable primary energy consumption and the total mass of inputs within a unit process. The sum of the total neglected flows does not exceed 5% of all energy consumption and mass of inputs.
- All flows known to contribute a significant impact or to uncertainty are included.
- The cut-off rules are not applied to hazardous and toxic material flows – all of which are included in the life cycle inventory.

No material or energy input or output was knowingly excluded from the system boundary.

Data Sources

Primary and secondary data sources, as well as the respective data quality assessment are documented in the underlying LCA project report in accordance with UL PCR 2019.

This EPD estimates the impacts of forest management from the industry average Pacific Northwest forest resources LCA. [10].

Third party verified ISO 14040/44 secondary LCI data sets contribute more than 67% of total impact to any of the required impact categories identified by the applicable PCR.

Treatment of Biogenic Carbon and Sustainable Forest Management Certification

Biogenic carbon emissions and removals are reported in accordance with ISO 21930 7.2.7. and 7.2.12. Detailed information is provided in the underlying LCA in Section 2.5.

ISO 21930 requires a demonstration of forest sustainability to characterize carbon removals with a factor of -1 kg CO₂e/kg CO₂. ISO 21930 Section 7.2.11 Note 2 states the following regarding demonstrating forest sustainability: “Other evidences such as national reporting under the United Nations Framework Convention on Climate Change (UNFCCC) can be used to identify forests with stable or increasing forest carbon stocks.” The United States UNFCCC annual report Table 6-1 provides annual NET GHG Flux Estimates for different land use categories. This reporting indicates non-decreasing forest carbon stocks and thus the source forests meet the conditions for characterization of removals with a factor of -1 kg CO₂e/kg CO₂.

Table 3 provides additional inventory parameters related to biogenic carbon removal and emissions.

ENVIRONMENTAL PARAMETERS DERIVED FROM LCA

Table 2 presents the LCIA and LCI parameter results for the declared unit of 1 m³ of MPP.

The impact categories and characterization factors (CF) for the LCIA were derived from the U.S. EPA Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts -TRACI 2.1 [3].

The total primary energy consumption is tabulated from the LCI results based on the Cumulative Energy Demand Method published by ecoinvent [14]. Lower heating value of primary energy carriers is used to calculate the primary energy values reported in the study.

Other inventory parameters concerning material use, waste, water use and biogenic carbon were drawn from the LCI results. We followed the ACLCA’s Guidance to Calculating non-LCIA Inventory Metrics in accordance with ISO 21930:2017 [1].

SimaPro 9.0.0.49 [11] was used to organize and accumulate the LCI data, and to calculate the LCIA results.

Table 2: LCIA Results Summary for Cradle-to-Gate production of 1 m3 of Mass Ply Panel.

Core Mandatory Impact Indicator			TOTAL	A1	A2	A3
Global warming potential, biogenic ¹	GWP _{BIO}	kg CO2e	259.16	(2,105.83)	0.18	2,364.80
Global warming potential, TRACI 2.1	GWP _{TRACI}	kg CO2e	259.16	199.47	0.18	59.51
Depletion potential of the stratospheric ozone layer	ODP	kg CFC11e	8.17E-06	6.97E-06	3.02E-10	1.20E-06
Acidification potential of soil and water sources	AP	kg SO2e	1.13	1.07	0.00	0.06
Eutrophication potential	EP	kg PO4e	0.29	0.28	0.00	0.01
Formation potential of tropospheric ozone	SFP	kg O3e	22.94	21.74	0.03	1.17
Abiotic depletion potential (ADP fossil) for fossil resources;	ADP _f	MJ, NCV	4,648.67	-	-	4,648.67
Fossil fuel depletion	FFD	MJ Surplus	700.06	548.48	0.34	151.24
Use of Primary Resources						
Renewable primary energy carrier used as energy	RPRE	MJ, NCV	5,075.60	5,063.57	0.0049	12.02
Renewable primary energy carrier used as material	RPRM	MJ, NCV	12,693.47	12,693.47		
Non-renewable primary energy carrier used as energy	NRPRE	MJ, NCV	4,876.60	3,951.71	2.29	922.60
Renewable primary energy carrier used as material	NRPRM	MJ, NCV	1,151.49	1,151.49	-	-
Secondary material, secondary fuel and recovered energy						
Renewable secondary fuel	RSF	MJ, NCV	1,260.04	1,260.04		
Mandatory Inventory Parameters						
Consumption of freshwater resources	FW	m3	0.58	0.57	0.00	0.01
Indicators Describing Waste						
Hazardous waste disposed	HWD	kg	5.00E-03	3.30E-03	0.00E-03	1.70E-03
Non-hazardous waste disposed	NHWD	kg	69.71	68.51	0.05	1.14
High-level radioactive waste, conditioned, to final repository	HLRW	m3	6.08E-08	6.07E-08	1.30E-12	1.48E-10
Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW	m3	3.21E-06	2.79E-06	6.31E-10	4.15E-07

To ensure transparency Table 3 shows additional inventory parameters related to biogenic carbon removal and emissions. The carbon dioxide flows are presented unallocated to consider co-products leaving the product system in information module A3. Even though, the system boundary of this study included only the information modules A1-A3, in accordance with ISO 21930, BCEK was reported in A5 and BCEP of the main product in C3/C4.

The net carbon emission across the entire life cycle is zero. It is assumed that all carbon removed from the atmosphere is eventually emitted to the atmosphere as CO₂. Total GWP_{BIO} includes biogenic carbon emissions and removals from the information modules A1-A3, A5 and C3/C4, leading to a net zero contribution of biogenic carbon to GWP_{BIO}. Therefore, in Table 2, results for total GWP_{TRACI} and total GWP_{BIO} are equal.

¹ This indicator includes both biogenic and fossil-based carbon released. The TRACI method was modified to included CO₂, biogenic removals and emissions

Table 3: Biogenic carbon inventory parameters for Mass Ply Panel

Additional Inventory Parameters		A1	A2	A3	A5	C3/C4	Total
		kg CO2e					
Biogenic Carbon Removal from Product	BCRP	(2,305.30)	-	0.00	0.00	0.00	(2,305.30)
Biogenic Carbon Emission from Product	BCEP	0.00	-	958.07	0.00	1,000.62	1,958.69
Biogenic Carbon Removal from Packaging	BCRK	-	-	(0.3712)	0.00	-	(0.3712)
Biogenic Carbon Emission from Packaging	BCEK	-	-	0.00	0.00	-	
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production	BCEW	-	-	346.98	0.00	-	346.98

INTERPRETATION AND LIMITATIONS

Comparability

Environmental declarations from different programs (ISO 14025) may not be comparable. Comparison of the environmental performance using EPD information shall consider all relevant information modules over the full life cycle of the products within the building. This PCR allows EPD comparability only when the same functional requirements between products are ensured and the requirements of ISO 21930:2017 §5.5 are met. In addition, to be compared EPDs must comply with the same core and sub-category PCRs (Part A and B) and include all relevant information modules. It should be noted that different LCA software and background LCI datasets may lead to differences results for upstream or downstream of the life cycle stages declared.

Forest Management

While this EPD does not address landscape level forest management impacts, potential impacts may be addressed through requirements put forth in regional regulatory frameworks, ASTM 7612-15 guidance, and ISO 21930 Section 7.2.11 including notes therein. These documents, combined with this EPD, may provide a more complete picture of environmental and social performance of wood products.

While this EPD does not address all forest management activities that influence forest carbon, wildlife habitat, endangered species, and soil and water quality, these potential impacts may be addressed through other mechanisms such as regulatory frameworks and/or forest certification systems which, combined with this EPD, will give a more complete picture of environmental and social performance of wood products.

Scope of the EPD

EPDs can complement but cannot replace tools and certifications that are designed to address environmental impacts and/or set performance thresholds – e.g. Type 1 certifications, health assessments and declarations, etc.

Data

National or regional life cycle averaged data for raw material extraction does not distinguish between extraction practices at specific sites and can greatly affect the resulting impacts.

Accuracy of Results

EPDs regularly rely on estimations of impacts; the level of accuracy in estimation of effect differs for any particular product line and reported impact when averaging data.

REFERENCES

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13. UL Environment (2019) Product Category Rule (PCR) Guidance for Building-Related Products and Services, Part B: Structural and Architectural Wood Products EPD Requirements
14. Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016) The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, 21, 1218–1230.
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APPENDIX 4 : ENVIRONMENTAL PRODUCT DECLARATION - PRIMARY STRUCTURAL STEEL FRAME

The following report is a published environmental product declaration (EPD) from Metal Building Manufacturers Association on primary structural steel frame components. This EPD is an industry average EPD of the metal building systems. This report was published in 2021.

ENVIRONMENTAL PRODUCT DECLARATION

Primary Structural Steel Frame Components

Metal Building Manufacturers Association
Industry-Wide EPD

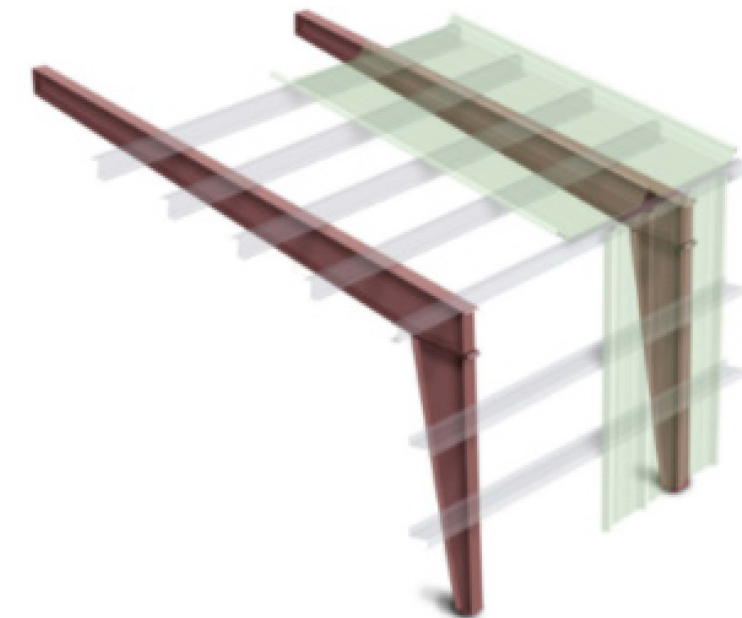
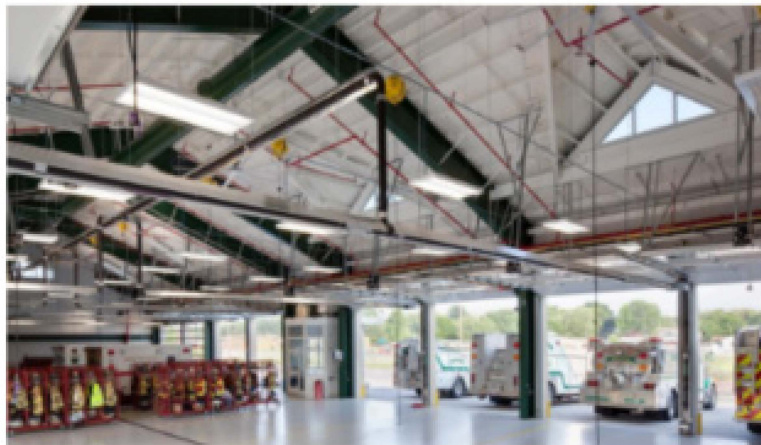


Illustration of primary structural steel framing (columns/beams) supporting secondary structural steel framing members (girts/purlins) with metal roof panel (standing seam or through fastened) and metal wall panel (through fastened) cladding.

Note: Primary structural steel framing featured in illustration above.



The Metal Building Manufacturers Association (MBMA), Cleveland, OH, was founded in 1956. Since that time, MBMA and its manufacturer members have worked together as partners to further its mission: to conduct research, to help advance building codes and standards, and to educate the construction community. MBMA's passion is to support a strong, sustainable metal building systems industry that meets the needs of building owners and society.

MBMA's members are deeply committed to the social, environmental and economic principles of sustainability. This pledge is aimed at improving the quality of life for everyone now without compromising the ability of future generations to meet their needs.

This industry average EPD includes only the Primary Structural Steel Frame components used in metal building systems. These components serve as the load carrying columns and beams of a metal building system.

Separate EPDs are available that address the secondary structural steel framing, and the exterior metal roof and wall panel cladding used to form a complete metal building system.

This industry average EPD is representative of the MBMA metal building systems members.

A complete list of members is available at https://www.mbma.com/System_Members.html



ENVIRONMENTAL PRODUCT DECLARATION



Primary Structural Steel Frame Components
Industry-Wide EPD

According to ISO 14025, ISO 21930:2017 and EN 15804



Declaration Information

Program Operator Name, Address, Logo & Website	UL Environment, 333Pfungsten Rd., Northbrook, IL 600611 https://www.ul.com
General Program Instructions & Version Number	UL Environment General Program Instructions v2.5, March 2020
Location of Explanatory Material	For any explanatory material, regarding this EPD, please contact Tony Bouquot (tbouquot@thomasamc.com)
Declaration Holder & Address	Metal Building Manufacturers Association 1300 Sumner Avenue Cleveland, OH 44115-2851
Declaration Number	4789771662.101.1
Declared Product & Functional Unit	Primary Structural Steel Frame Components-1 metric ton
Product Definition	A built-up structural steel component (column/beam) used in a metal building system (CSI code: 051200 Structural Steel Framing).
Reference PCR & Version Number	Part A: Product Category Rules for Building Related Products and Services (UL Environment, 2018, v3.2) Part B: Designated Steel Construction Product EPD Requirements (UL Environment, 2020, v2.0)
Markets of Applicability	USA – business-to-business focus
Date of Issue	April 01, 2021
Period of Validity	5 years
EPD Type	Industry-average
EPD Scope	Cradle-to-gate (modules A1 to A3)
Year(s) of Reported Manufacturer Primary Data	2019
LCA Software & Version Number	Sima Pro v9.1.1.1, 2021
LCI Database(s) & Version Number	ecoinvent 3.6, December 2019
LCIA Methodology & Version Number	US EPA TRACI v2.1+ IPCC 2013 (AR5)
The PCR Review was conducted by:	Thomas P. Gloria, PhD (Chair), t.gloria@industrial-ecology.com Ms. Brandie Sebastien, JBE Consultants Mr. James Littlefield, Independent Consultant

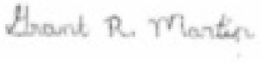
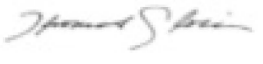
ENVIRONMENTAL PRODUCT DECLARATION



Primary Structural Steel Frame Components
Industry-Wide EPD

According to ISO 14025, ISO 21930:2017 and EN 15804



This declaration was independently verified in accordance with ISO 14025: 2006. The UL Environment "Part A: Calculation Rules for the Life Cycle Assessment and Requirements on the Project Report," v3.2 (September 2018), based on ISO 21930:2017 and EN 15804 + A1:2013, serves as the core PCR, with additional considerations from the USGBC/UL Environment Part A Enhancement (2017) ☐ INTERNAL ☒ EXTERNAL	 Grant R. Martin, UL Environment
This life cycle assessment was conducted in accordance with ISO 14044:2006 and the reference PCR by:	
This life cycle assessment was independently verified in accordance with ISO 14044:2006 and the reference PCR by:	 Tom Gloria, Industrial Ecology Consultant
LIMITATIONS The environmental impact results of steel 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 steel 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. Environmental declarations from different programs (ISO 14025) may not be comparable.	

This declaration is an environmental product declaration (EPD) in accordance with ISO 14025:2006 and ISO 21930:2017. EPDs rely on Life Cycle Assessment (LCA) to provide information on a number of environmental impacts of products over their life cycle. Exclusions: EPDs do not indicate that any environmental or social performance benchmarks are met, and there may be impacts that they do not encompass. LCAs do not typically address the site-specific environmental impacts of raw material extraction, nor are they meant to assess human health toxicity. EPDs can complement but cannot replace tools and certifications that are designed to address these impacts and/or set performance thresholds – e.g., Type 1 certifications, health assessments and declarations, environmental impact assessments, etc. Accuracy of Results: EPDs regularly rely on estimations of impacts, and the level of accuracy in estimation of effect differs for any particular product line and reported impact. Comparability: EPDs are not comparative assertions and are either not comparable or have limited comparability when they cover different life cycle stages, are based on different product category rules or are missing relevant environmental impacts. EPDs from different programs may not be comparable.

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Metal Building Manufacturers Association

The Metal Building Manufacturers Association (www.mbma.com) is a trade association established in 1956. The mission of the MBMA is to promote the design and construction of metal building systems in the low-rise, non-residential building marketplace. Metal building systems are commonly used to provide warehouses, manufacturing, office, retail, community, and religious buildings. The popularity of metal building systems has been driven by the design and aesthetic flexibility, the consistency and the speed of construction. MBMA building systems members fabricate the primary rigid frames, secondary framing, and component products such as metal roof and wall panel cladding systems.

Ownership of Industry Wide EPD

This EPD was developed for use by MBMA member companies, a complete list of whom can be found here: https://www.mbma.com/System_Members.html.

Product Description

Primary structural steel frames used in a metal building system are built-up using three welded steel plates to form an "I" section. The three plates include the uniform width of the two flanges (commonly derived from bar stock) and one tapered web section (commonly derived from hot rolled steel plate). The flanges are welded to the tapered web to form the tapered web I-section for the beam and columns, typically by an automatic welder. End plates with bolt holes are welded to the ends of the individual frame sections by a certified welder, along with other weldments and accessories. The primary frames are often coated with a rust-inhibiting primer or painted to meet project specifications. Once the columns and roof beams have been fabricated, completed with holes in webs and flanges for attachment of secondary structural members and bracing, the products are delivered to the jobsite.

Flexible Design

Metal building manufacturers custom design the primary structural steel frame components in accordance with the order documents. Order documents are based on the specified building code, loading conditions, and serviceability requirements. The primary frame will consist of two exterior columns and a rafter spanning the width of the building. Primary frames can also feature straight columns when the end use warrants such a design (for example in office or retail spaces with finished drywall interiors). Primary frame rafters can clear span over 61 m (200 ft), with a height that can exceed 18.3 m (60 ft) with frames commonly spaced from 6.1 m (20 ft) to 12.2 m (40 ft) apart. Interior columns can be used to support rafters for buildings wider than 200 feet, or to create a more economical design where the interior building layout allows.



Certified welder adding metal accessories to primary structural steel frame.

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Less Material

Most often, the weight of steel used in a metal building framing system is significantly less than hot-rolled steel frames due to the structural optimization of the tapered web design. By tapering the web, material is used where it is needed for strength and stability. Traditional hot-rolled steel frame designs and other competing materials do not take advantage of this material optimization. This weight savings inherently reduces the environmental impact of metal buildings when compared to traditional framing systems. Life cycle assessment software, such as the Athena Impact Estimator, can be used to confirm the environmental and material savings.

Metal Building System - EPD Family

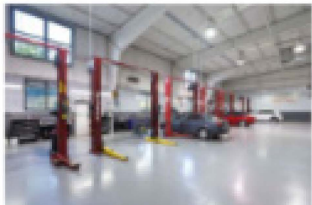
A complete metal building system is made up of primary structural steel frames (covered by this EPD), a secondary framing system (covered by Secondary Structural Steel Frame Component EPD), and metal roof and wall panel cladding (covered by the Rolled Formed Roof and Wall Panels EPD). All three EPDs may be found on the UL Environmental website available here: <http://productguide.ulenvironment.com>.

Range of Applications

Metal buildings are used for low rise, non-residential construction end uses. This includes smaller building designs for health care, religious, office, education and retail facilities, up to larger building designs for warehouses, aircraft hangars, manufacturing and sports facilities. These and other building end uses are shown below.



Healthcare



Automotive



Recreation



Religious



Aviation



Retail



Office



Agriculture



Storage / Warehouse

Environment



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Quality Control

Metal building primary structural steel frames, secondary framing and metal wall and roof cladding are all custom fabricated in a factory following strict quality assurance standards. Quality control is a major focus for all MBMA metal building manufacturers. MBMA worked with the International Accreditation Services (IAS), a subsidiary of the International Code Council (ICC), to develop the Accreditation Criteria for Inspection Programs for Manufacturers of Metal Building Systems (AC472). This comprehensive, third-party accreditation program is based on the special inspection requirements in the International Building Code (IBC) Chapter 17. This program provides code officials with a means to approve the inspection programs of manufacturers involved in the fabrication of a metal building system. It provides building owners and specifiers with an extra level of assurance the metal building system manufacturer's engineering, order, design and fabrication process all conform to high standards. All MBMA member companies are committed to quality control and they adhere to the strict criteria of the AC472 program.

Product Average

Primary gate-to-gate LCI manufacturing and input/output transportation data were collected for primary structural steel frame components for the reference year 2019. These data were collected from 14 MBMA member facilities from three discrete regions (East, Midwest, and Western US), to represent the US industry average geographic mix. These 14 plants were deemed representative of the specific processes and the MBMA's membership. The MBMA represents 41 different production facilities; as a result, the plant sample represents about 25% of all establishments. The 14 plants were combined on a production weighted basis to provide a weighted average profile for US production of primary structural steel frame components.

Product Codes, Specifications and Standards

The products considered in this EPD meet or exceed one or more of the following codes, specifications and standards:

Model Codes and Standards
International Building Code
State or Locally Adopted Code
ASCE/SEI 7 - Minimum Design Loads for Buildings and Other Structures
UL - Building Material Directory
UL - Fire Resistance Directory
Common Industry Standards
MBMA Metal Building Systems Manual
International Accreditation Services (IAS)
Accreditation Criteria 472 (AC472) - Accreditation Criteria for Inspection Programs for Manufacturers of Metal Building Systems
Specifications and Standards
American Institute of Steel Construction (AISC)
AISC 360 - Specification for Structural Steel Buildings
AISC 341 - Seismic Provisions for Structural Steel Buildings (when appropriate)
AISC 303 - Code of Standard Practice for Steel Buildings and Bridges
AISC Design Guide 3 - Serviceability for Steel Buildings

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American Welding Society (AWS)
AWS D1.1 / D1.1M - Structural Welding Code - Steel
AWS D1.3 / D1.3M - Structural Welding Code - Sheet Steel
ASTM International (ASTM)
ASTM A6/A6M - Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling
ASTM A36/A36M – Standard Specification for Carbon Structural Steel
ASTM A123/A123M – Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
ASTM A500/A500M – Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes
ASTM A529/A529M - Standard Specification for High-Strength Carbon-Manganese Steel of Structural Quality
ASTM A572/A572M - Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel
ASTM A992/A992M - Standard Specification for Structural Steel Shapes
ASTM A1011/A1011M - Standard Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength, Low-Alloy and High-Strength Low-Alloy with Improved Formability and Ultra-High Strength
ASTM A1018/A1018M - Standard Specification for Steel, Sheet and Strip, Heavy Thickness Coils, Hot-Rolled, Carbon, Commercial, Drawings, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, and Ultra-High Strength
ASTM F1554 – Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength
ASTM F3125 – Standard Specification for High Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 MPa) Minimum Tensile Strength, Inch and Metric Dimensions
Research Council on Structural Connections (RCSC)
Specification for Structural Joints Using High-Strength Bolts
The Society for Protective Coatings (SPSC)
SSPC Paint-15 – Steel Joist Shop Primer / Metal Building Primer

Material Composition

Table 1 lists the material inputs used in the production of primary structural steel frame components.

Hot rolled plate or bar is commonly used for flanges, webs, end plates and base plates. The typical product thickness used in a metal building manufacturing plate is between 3 mm (0.125 in) to 50 mm (2.0 in). Steel sections, such as pipe, angles, structural channels, and wide flange beams, are pre-formed or shaped prior to arriving at the metal building manufacturing plant in order to be cut to size. Interior columns may be either pipe columns or made out of wide flange I-beams. Bracing may utilize angle irons connected to the structure and structural channels may be used for spandrels.

For the production of primary structural frame components, the primary semi-finished steel inputs are hot-rolled plate (38%), bar (44%), and sections (19%). The semi-finished steel input is sourced from both the Electric Arc Furnace (EAF) and Basic Oxygen Furnace (BOF) routes, 88% and 12%, respectively and varies in thickness from 1.8 mm (0.071 in) to 38.1 mm (1.5 in).

Table 1: Material Composition

MBMA Product
Primary Structural Steel Frame Components
Input Materials
Hot rolled plate, hot rolled bar and sections of varying thicknesses

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According to ISO 14025, ISO 21930:2017 and EN 15804



Manufacturing

The gate-to-gate processes in the production of primary steel frame components include plate/bar/sections shearing, punching, splicing, tack welding, flange welding, finish welding and grinding, painting, touch up painting (if applicable), packaging, space conditioning and lighting, warehouse and loading, and pollution abatement equipment (as shown in Figure 1). The major process energy input is electricity followed by natural gas used for space conditioning and in the paint process. For every metric ton of primary frame component produced, a total of 1.066 metric tons of steel is required; this yields a 6.6% scrap rate for the processes leading to the production of primary structural frame components. The resulting fabrication steel scrap is 100% recyclable. The average inbound transportation of input materials and fuels to production facilities by truck, rail, and ocean freighter as well as the outbound transportation of manufacturing wastes and waste disposal processes are included.

Packaging

Packaging materials consist of one-way wood pallets and steel banding.

Transportation

Product transportation to the customer or construction site is outside the scope of this EPD (see Table 3).

Life Cycle Assessment Background Information

Declared Unit

Name	Quantity	Required Unit
Declared Unit	1	metric ton
Density	7,833	kg/m ³

Table 2: Declared Unit

The declared unit is one metric ton (1,000 kg) of the primary structural steel frame components, as shown in Table 2.

System Boundary

The underlying LCA product system boundary was limited to a cradle-to-gate analysis (as shown in Figure 1) or the production stage – Modules A1-A3 as depicted in Table 3 below. As per the scope of the PCR, construction, use and end-of-life stages are excluded from the product system boundary. The optional Module D is also excluded. No reference service life is specified for primary structural steel frames.

Estimates and Assumptions

Primary gate-to-gate LCI manufacturing and input transportation data were collected for primary structural steel frames production for the reference year 2019. Background data to support the LCA of primary frames were obtained from 2020 North American LCI profiles of semi-finished steel products (hot rolled plate, hot rolled bar and sections) and various proprietary and commercial databases as documented in the project background report. All background data are less than 10 years old. When selected background datasets, a conservative approach was applied in that datasets associated with higher impacts are used when there are multiple possible options.

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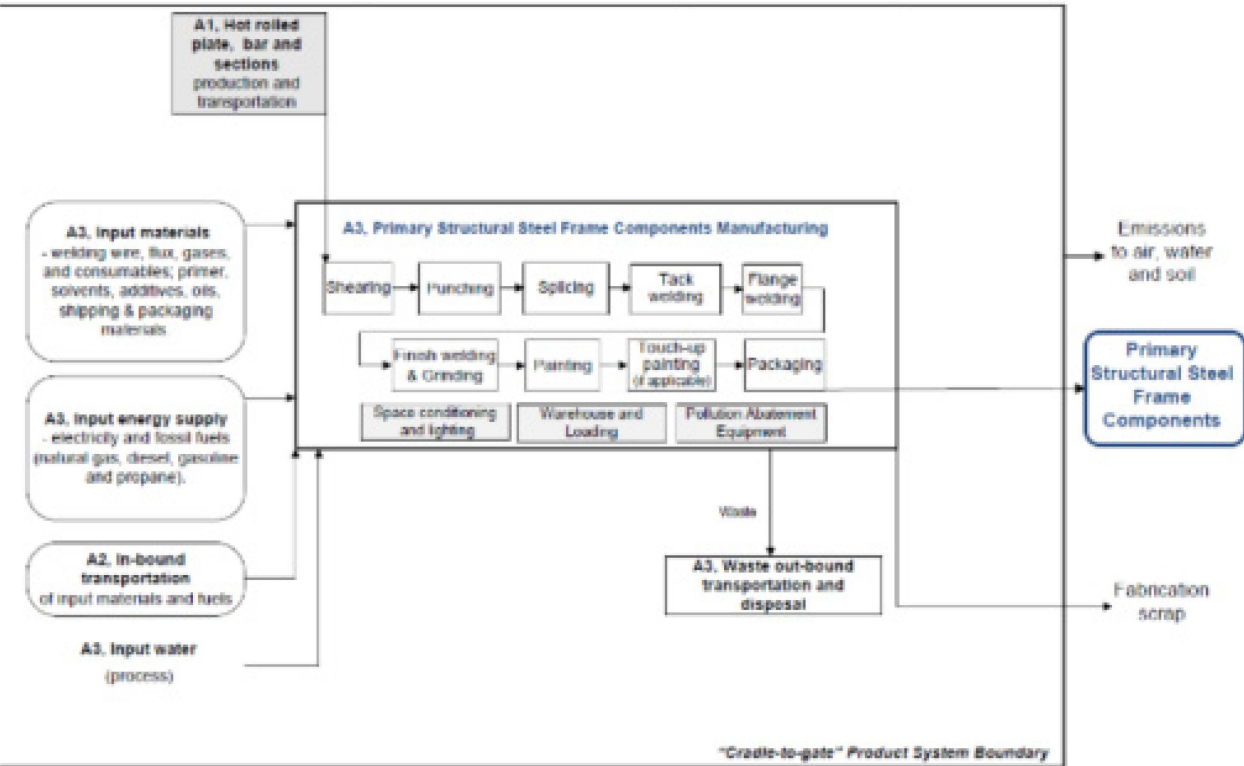
Primary Structural Steel Frame Components
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Cut-off Criteria

The cut-off criteria as per Part A, 2.9 and ISO 21930, 7.1.8 were followed for this EPD. All flow data reported by the participating MBMA facilities were included for the relevant process and product models. None of the reported flow data were excluded based on the cut-off criteria as specified in the PCR. No known flows are deliberately excluded from this EPD. This EPD excludes the following processes: (1) Capital goods and infrastructure required to produce MBMA products, and (2) Personnel related activity (travel, furniture, office operations and supplies).

Figure 1: Cradle-to-Gate System Boundary



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Table 3: Systems Boundaries

Production Stage			Construction Stage		Use Stage					End-of-Life Stage				Optional supplementary information beyond the system boundary
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
Extraction and upstream production	Transport to factory	Manufacturing	Transport to site	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	De-construction	Transport to waste processing or disposal	Waste processing	Disposal of waste	Potential net benefits from reuse, recycling and/or energy recovery beyond the system boundary
X	X	X	MND											
X = Included in LCA; MND = Module is not declared														

Data Quality

Representativeness:

- Time related coverage of the MBMA primary data: 2019.
- Secondary data: American Iron and Steel Institute North American LCI data for semi-finished steel products (2020) – cradle to gate, excluding end-of-life recycling, ecoinvent v.3.6 datasets, December 2019, US LCI datasets, September 2015, SimaPro 9.1.1.1, 2021. No secondary data sources are more than 10 years old.
- Geographical coverage: the geographical coverage is the US.
- Technological coverage: typical or average reflecting MBMA’s membership.

The LCI data is deemed representative for the production year and the industry and adequately reflects North American conditions and prevailing technologies.

Consistency: To ensure data consistency, all primary data were collected with the same level of detail, while all background data were consistently applied.

Reproducibility: Through disclosure of input and output flow data, selected datasets and methodological approaches as described in the project report, a third-party should be able to demonstrate results similar to this EPD using similar and consistent data sources and modeling approaches.

Uncertainty: A sensitivity check was conducted to assess the reliability of the EPD results and conclusions by determining how they are affected by uncertainties in the data or assumptions on calculation of LCIA and energy indicator results. The sensitivity check includes the results of the sensitivity analysis and Monte Carlo uncertainty analysis as documented in the project report.



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Allocation

Multiple product output: The MBMA plant participants produce an array of products used in the structure and envelope of metal buildings and, as such, allocation across shared processes was applied. As per the PCR and where necessary, "Mass" was used as the primary basis for allocation of the total inputs/outputs of the plant production system between primary frames, secondary frames, and roof and wall panel manufacturing lines. Data collection participants provided input and output data specific to each of four selected manufacturing processes. Then inputs/outputs were allocated over the total outputs of panel or framing on a mass basis.

Semi-finished steel products are integral commodities used in the production of upstream and the primary MBMA metal building products. As a result, 2020 peer-reviewed North American LCI data, according to the ISO 14040 series for these metal products, as generated by the American Iron and Steel Institute were applied in this LCA study. Semi finished steel product LCIA results and LCI data based on physical allocation approach are used. The physical allocation approach follows the partitioning methodology developed by worldsteel.

Life Cycle Assessment Results

Table 4 presents the life cycle impact assessment (LCIA), resource use and waste output flow results for the production stage (A1 to A3) per metric ton of primary structural frame. US EPA Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), version 2.1, 2012 impact categories are used as they provide a North American context for the mandatory category indicators to be included in this EPD. *It should be noted that LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.*

In addition to the impact results, this LCA supports several metrics related to resource consumption and waste generation. These data are informational as they do not provide a measure of impact on the environment.

Table 4: EPD Results Per Metric Ton of Primary Structural Steel Frame Components

Impact category and inventory indicators	Unit	A1	A2	A3	Total
Global warming potential, GWP-100 ⁽¹⁾ (IPCC 2013)	kg CO ₂ eq	1,231.2	99.6	137.2	1,468
Ozone depletion potential, ODP ⁽²⁾	kg CFC-11 eq	3.9E-12	6.8E-07	1.7E-05	1.8E-05
Smog formation potential, SFP ⁽²⁾	kg O ₃ eq	42.4	33.3	9.3	84.9
Acidification potential, AP ⁽²⁾	kg SO ₂ eq	2.8	1.3	0.4	4.5
Eutrophication potential, EP ⁽²⁾	kg N eq	0.13	0.08	0.61	0.82
Abiotic depletion potential, elements ADPe ⁽³⁾	kg Sb eq	7.9E-03	1.9E-07	9.6E-04	8.9E-03
Abiotic depletion potential, fossil ADPF ⁽³⁾	MJ LHV	13,956	1,355	1,773	17,084
Renewable primary resources used as an energy carrier (fuel), RPR _E	MJ LHV	893	0	690	1,583
Renewable primary resources with energy content used as material, RPR _M ⁽⁴⁾	MJ LHV	0	0	0	0
Non-renewable primary resources used as an energy carrier (fuel), NRPR _E	MJ LHV	15,662	1,370	2,150	19,182

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Impact category and inventory indicators	Unit	A1	A2	A3	Total
Non-renewable primary resources with energy content used as material, NRPR _M ⁽⁴⁾	MJ LHV	0	0	0	0
Secondary materials, SM ⁽⁴⁾	kg	974	0	0	974
Renewable secondary fuels, RSF ⁽⁴⁾	MJ LHV	0	0	0	0
Non-renewable secondary fuels, NRSF ⁽⁴⁾	MJ LHV	0	0	0	0
Recovered energy, RE ⁽⁴⁾	MJ LHV	0	0	0	0
Consumption of freshwater, FW ⁽⁴⁾	m ³	6.7	0	0.02	6.7
Hazardous waste disposed, HWD ⁽⁴⁾	kg	0.001	0	0	0.136
Non-hazardous waste disposed, NHWD ⁽⁴⁾	kg	8.7E-04	0.0	2.7	2.7
High-level radioactive waste, conditioned, to final repository, HLRW ⁽⁴⁾	m ³	1.5E-07	3.1E-11	2.3E-07	3.8E-07
Intermediate- and low-level radioactive waste, conditioned, to final repository, ILLRW ⁽⁴⁾	m ³	2.7E-04	2.3E-07	4.4E-06	2.7E-04
Components for re-use, CRU ⁽⁴⁾	kg	0	0	0	0
Materials for recycling, MR ⁽⁴⁾	kg	0.0	0.0	66.4	66.4
Materials for energy recovery, MER ⁽⁴⁾	kg	0	0	0	0
Recovered energy exported from the product system, EE ⁽⁴⁾	MJ LHV	0	0	0	0

Table Notes:

⁽¹⁾ Calculated as per U.S EPA TRACI v2.1, with IPCC 2013 (AR 5), SimaPro v 9.1.1.1.

GWP 100, excludes biogenic CO₂ removals and emissions associated with biobased products; 100-year time horizon GWP factors are provided by the IPCC 2013 Fifth Assessment Report (AR5), TRACI v2.1 with AR5, v1.05.

⁽²⁾ Calculated as per U.S EPA TRACI v2.1, SimaPro v 9.1.1.1.

⁽³⁾ ADPe and ADPf are calculated as per CML-IA Baseline v3.05, SimaPro v 9.1.1.1.

⁽⁴⁾ Calculated as per ACLCA ISO 21930 Guidance.

It is also noted that comparisons cannot be made between product-specific or industry average EPDs at the design stage of a project, before a building has been specified. 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 shall be converted to a functional unit basis before any comparison is attempted.

Any comparison of EPDs shall be subject to the requirements of ISO 21930. EPDs are not comparative assertions and are either not comparable or have limited comparability when they have different system boundaries, are based on different product category rules or are missing relevant environmental impacts. Such comparison can be inaccurate and could lead to erroneous selection of materials or products which are higher-impact, at least in some impact categories.

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Interpretation

Figure 2 below provides a percent contribution summary by information module (A1 – extraction and upstream production, A2 – transport to factory and A3 – manufacturing) for the LCIA indicators and energy resource use metrics. A contribution analysis revealed that the A3 Manufacturing accounted for 14% of the total primary energy use and 9% of the GWP-100 of the total cradle-to-gate product system. Potential environmental impacts for primary steel frame components are driven by the A1 semi-finished steel inputs. A3 Manufacturing is the second largest contributor to the Production stage EPD results, followed by the A2 Transportation. About 92% of the product system energy use (A1 to A3) is derived from fossil fuels, of which semi-finished steel input contribution is 82%. Similarly, semi-finished steel input accounts for 84% of the cradle-to-gate global warming potential (GWP).

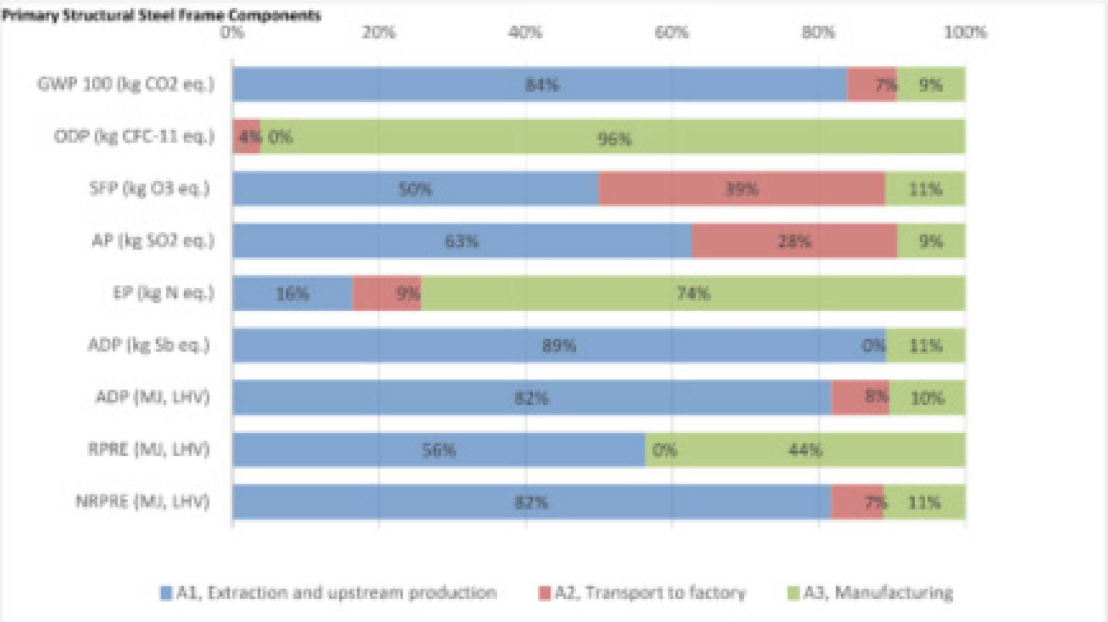


Figure 2: Percent Contribution by Production Stage Information Modules (A1, A2 and A3)

A Monte Carlo uncertainty analysis was also conducted to assess the combined uncertainty effect of the data variability on the LCIA and energy indicator results. As a statistical method, Monte Carlo analysis establishes the uncertainty range, which expresses the variance between the upper and lower confidence limit [97.5%, 2.5%], in the calculated EPD results. Based on the industry sample data, [minimum; maximum] range data was calculated per each input/output flow for the primary structural steel frame components. These data are used in the Monte Carlo uncertainty analysis. This uncertainty analysis assesses the combined uncertainty effect of the inventory data (both foreground and background). It should be noted that U.S. EPA TRACI v2.1 methodology has not specified any uncertainty information of the characterization factors per impact category. With a confidence level of 95%, the confidence interval of cradle-to-gate GWP-100 of the primary structural steel frame components is [+31%, -39%]. Based on 1,000 runs, such information provides a quantitative indication of the range of results that are likely for the manufacturer's specific products covered by the industry average EPD for primary structural steel frames.



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Additional Environmental Information

All 14 MBMA member facilities participating in the study are ISO 9001 and ISO 14001 certified or follow other company specific environmental management systems. Pollution abatement equipment typically used in the MBMA manufacturing facilities consist of fabric filter– low temperature (baghouse), dry filters and cartridge filters. No substances of high concern were identified in the framework of this EPD.

Disclaimer

This Environmental Product Declaration (EPD) conforms to ISO 14025, ISO 14040, ISO 14044, and ISO 21930. **Scope of Results Reported:** The PCR requires the reporting of a limited set of LCIA indicators and resource use metrics; therefore, there may be relevant environmental impacts beyond those disclosed by this EPD. The EPD does not indicate that any environmental or social performance benchmarks are met nor thresholds exceeded.

Accuracy of Results: This EPD has been developed in accordance with the PCR applicable for the identified product following the principles, requirements and guidelines of the ISO 14025, ISO 14040, ISO 14044, and ISO 21930 standards as well as ULE's general program instructions. The results in this EPD are estimations of potential impacts. The accuracy of results in different EPDs may vary as a result of value choices, background data assumptions and quality of data collected.

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APPENDIX 5 : ENVIRONMENTAL PRODUCT DECLARATION - STEEL FASTNERS

The following report is a published environmental product declaration (EPD) from Nucor Corporation on fabricated hot-rolled structural steel sections. This report was published in 2021.

ENVIRONMENTAL PRODUCT DECLARATION

FABRICATED HOT-ROLLED STRUCTURAL STEEL SECTIONS

NUCOR CORPORATION



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Nucor Corporation operates two ISO 14001-certified structural steel mills, Nucor-Yamato Steel and Nucor Steel Berkeley, that have the capacity to annually produce up to 3,250,000 tons of wide-flange steel beams, pilings and heavy structural steel products for fabricators, construction companies, manufacturers and steel service centers.

Nucor Corporation is North America's largest recycler, turning approximately 20 million net tons of scrap steel in 2019 into new steel. Nucor uses Electric Arc Furnace (EAF) technology at each of its 25 steel recycling facilities. EAFs use post-consumer scrap as its major feedstock, unlike traditional blast furnace steelmaking, which produces more than 70% of the world's steel using mined iron ore and metallurgical coal as feedstock.

Through its use of EAFs, Nucor's steelmaking CO2 emissions are one-half of the global average on a per ton basis, and Nucor's energy intensity is approximately one-quarter the global average.



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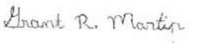


Fabricated Hot-Rolled Structural Steel Sections
Designated Steel Construction Product



According to ISO 14025,
EN 15804 and ISO 21930:2017

EPD PROGRAM AND PROGRAM OPERATOR NAME, ADDRESS, LOGO, AND WEBSITE	UL Environment 333 Pfingsten Road Northbrook, IL 60611 https://www.ul.com/ https://spot.ul.com
GENERAL PROGRAM INSTRUCTIONS AND VERSION NUMBER	General Program Instructions v.2.5 March 2020
MANUFACTURER NAME AND ADDRESS	Nucor Corporation, 1915 Rexford Road, Charlotte, North Carolina 28211
DECLARATION NUMBER	4789793365.102.1
DECLARED PRODUCT & FUNCTIONAL UNIT OR DECLARED UNIT	Fabricated Hot-Rolled Structural Steel Sections, 1 metric ton
REFERENCE PCR AND VERSION NUMBER	Part A: Calculation Rules for the LCA and Requirements Project Report, (IBU/UL Environment, V3.2, 12.12.2018) and Part B: Designated Steel Construction Product EPD Requirements (UL Environment, V2.0, 08.26.2020).
DESCRIPTION OF PRODUCT APPLICATION/USE	Hot rolled structural steel sections used in construction
PRODUCT RSL DESCRIPTION (IF APPL.)	N/A
MARKETS OF APPLICABILITY	North America
DATE OF ISSUE	January 1, 2021
PERIOD OF VALIDITY	5 Year
EPD TYPE	Product-Specific
EPD SCOPE	Cradle to gate
YEAR(S) OF REPORTED PRIMARY DATA	2019
LCA SOFTWARE & VERSION NUMBER	GaBi v10
LCI DATABASE(S) & VERSION NUMBER	GaBi 2020.2
LCIA METHODOLOGY & VERSION NUMBER	IPCC AR5 + TRACI 2.1

This PCR review was conducted by:	UL Environment
	PCR Review Panel
	epd@ulenvironment.com
This declaration was independently verified in accordance with ISO 14025: 2006. ☐ INTERNAL ☒ EXTERNAL	
	Grant R. Martin, UL Environment
This life cycle assessment was independently verified in accordance with ISO 14044 and the reference PCR by:	
	James Mellentine, Thrive ESG

LIMITATIONS
Exclusions: EPDs do not indicate that any environmental or social performance benchmarks are met, and there may be impacts that they do not encompass. LCAs do not typically address the site-specific environmental impacts of raw material extraction, nor are they meant to assess human health toxicity. EPDs can complement but cannot replace tools and certifications that are designed to address these impacts and/or set performance thresholds – e.g. Type 1 certifications, health assessments and declarations, environmental impact assessments, etc.

Accuracy of Results: EPDs regularly rely on estimations of impacts; the level of accuracy in estimation of effect differs for any particular product line and reported impact.

Comparability: EPDs from different programs may not be comparable. Full conformance with a PCR allows EPD comparability only when all stages of a life cycle have been considered. However, variations and deviations are possible". Example of variations: Different LCA software and background LCI datasets may lead to differences results for upstream or downstream of the life cycle stages declared.

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1. Product Definition and Information

Description of Organization

This environmental product declaration (EPD) represents recycled structural steel produced via an electric arc furnace (EAF) from Nucor-Yamato Steel in Armorel, Arkansas and Nucor Steel-Berkeley in Huger, South Carolina.

Nucor owns a controlling 51% interest in the Nucor-Yamato Steel (NYS) structural mill located in northeast Arkansas. Built in 1988, NYS employs more than 1000 teammates and has the capacity to produce over 2.3 million tons per year of wide-flange beams, H-piling, sheet piling, standard I-beams, channels and various other structural shapes. NYS is the largest structural beam mill in the Western Hemisphere. Using EAF steel recycling technology, last year NYS produced high-quality structural steel with 91.7 percent recycled content.

NYS is the only North American producer of high-strength, low-alloy beams. Common applications for the high-strength, low-alloy beams include gravity columns for high-rise buildings, long span trusses for stadiums and convention centers, and for all projects where seismic design is a critical factor.

Nucor also owns a steel beam mill in Berkeley County, South Carolina, that utilizes EAF steel recycling technology. Nucor Steel Berkeley was constructed in 1995. Considering Nucor's production capabilities and the mix of structural products generally produced and marketed, the total capacity of Nucor's two structural mills is estimated at approximately 3,250,000 tons per year.

Both NYS and Nucor Steel Berkeley use a special continuous casting method that produces a beam blank closer in shape to that of the finished beam than traditional methods. Structural steel products come in standard sizes and grades, which allows us to maintain inventory levels of these products to meet our customers' expected orders.

Product Description

Hot-rolled fabricated structural steel sections are used in building, bridge and industrial products. these products are rolled shapes such as parallel flange sections, structural angles, channels and tees that are detailed, cut, drilled, bolted, welded and otherwise processed at the fabricator to be prepared for installation.

Structural sections produced by Nucor are defined by the following ASTM standards:

- **AISC 303** - American Institute of Steel Construction "Code of Standard Practice for Steel Buildings and Bridges" Latest Edition
- **AISC 341** – American Institute of Steel Construction "Seismic Provisions for Structural Steel Buildings" Latest Edition
- **AISC 360** – American Institute of Steel Construction "Specification for Structural Steel Buildings" Latest Edition
- **ASTM** – American Society for Testing and Materials
- **AWS D1.1** - American Welding Society "Structural Welding Code – Steel" Latest Edition
- **AWS A1.5** – American Welding Society "Bridge Welding Code" Latest Edition
- **AWS D1.8** - American Welding Society "Structural Welding Code – Seismic Supplement" Latest Edition
- **AASHTO** - American Association of State Highway and Transportation Officials, LRFD Bridge Design Specifications, Customary U.S. Units, Latest Edition "

Product Average

The 2017 production data used in this EPD considers hot-rolled structural products produced by Nucor Corporation



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during the year. The products are manufactured at Nucor Yamato Steel and Nucor Steel Berkeley. Results are weighted according to production totals at the both locations based on the 2017 data. Facility-specific global warming potential results are provided in a separate table.

Application

Hot-rolled fabricated structural steel sections are used various construction capacities. These products are rolled into a variety shapes such as parallel flange sections, angles, channels and tees that are detailed, cut, drilled, bolted, welded, and otherwise processed at the fabricator in order to prepare them for installation.

Technical Requirements

Technical data for the studied product can be found in the table below.

Table 1. Technical data for steel product

NAME	VALUE	UNIT
Density	7,800	kg/m³
Melting point	1425-1540	°C
Electrical conductivity at 20°C	NA	% of IAC ⁸
Thermal conductivity	NA	W/(m-K)
Coefficient of thermal expansion	NA	m/m-°C
Modulus of elasticity	NA	N/mm²
Shear modulus	NA	N/mm²
Specific heat capacity	NA	J/kg-°C
Hardness, Brinell Number	80-100	HB
Yield strength	250-550	N/mm²
Ultimate tensile strength	410-655	N/mm²
Breaking elongation	13-20	%
Chemical composition	Varies by ASTM Specification/Grade	% by mass

Properties of Declared Product as Delivered

The sections can be fabricated (i.e., cut or otherwise modified) by a fabricator or shipped directly to a job site.

Material Composition

Structural steel sections are manufactured entirely from carbon steel. They do not contain any materials or substances for which there exists a route to exposure that leads to humans or flora/fauna in the environment being exposed to said materials or substances at levels exceeding safe health thresholds.

Manufacturing

Nucor manufactures structural sections from secondary steel (i.e., from steel scrap) via an electric arc furnace (EAF). Steel scrap is loaded into a refractory-lined vessel and melted via electric energy supplied through graphite electrodes. Oxy-fuel burners and other means of generating heat through chemical reactions are also employed. The chemistry of



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the molten steel is adjusted at this stage by adding material to attain a specific alloy composition and by removing impurities, which migrate to the slag. Once the desired chemical composition is attained, the molten steel is then cast into billets for eventual processing in the rolling mill located in the same facility.

At the rolling mill, the billets are reheated in a natural gas furnace and run through rollers to shape their profile. Any steel scrap generated is recycled internally (i.e., put back into the EAF). The finished products are packaged and loaded onto trucks for distribution to fabricators or job sites.

Fabrication results are taken from the American Institute of Steel Construction (AISC) average EPD (AISC, 2016).

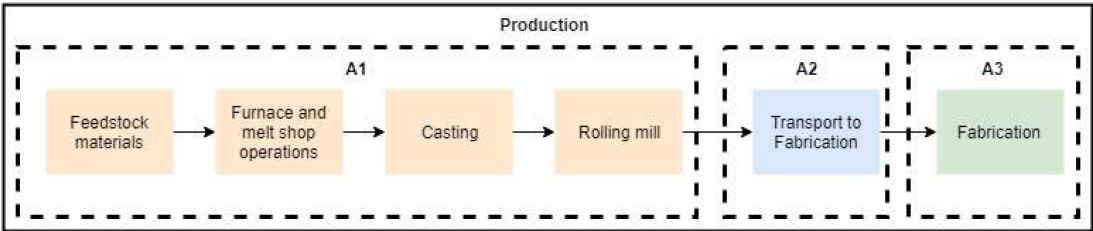


Figure 1: Flow chart for product system

Transportation

Transportation to the customer or construction site is outside the scope of this EPD.

Product Installation

Installation is outside the scope of this EPD.

Use

Product use is outside the scope of this EPD.

Reuse, Recycling, and Energy Recovery

Product reuse, recycling, and incineration for energy recovery is outside the scope of this EPD

Disposal

Product disposal is outside the scope of this EPD.

2. LCA Calculation Rules

Declared Unit

The declared unit is 1 metric ton of fabricated steel product. An alternative declared unit of 1 short ton is also presented.



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System Boundary

Per the PCR, this cradle-to-gate analysis provides information on the Product Stage of the steel product life cycle, including modules A1, A2, and A3.

PRODUCT STAGE			CONSTRUCT-ION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARY
Raw material supply	Transport	Manufacturing	Transport from gate to site	Assembly/Install	Use	Maintenance	Repair	Replacement	Refurbishment	Building Operational Energy Use During Product Use	Building Operational Water Use During Product Use	Deconstruction	Transport	Waste processing	Disposal	Reuse, Recovery, Recycling Potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

Cut-off Rules

No cut-off criteria are defined for this study. The system boundary was defined based on relevance to the goals of the study. For the processes within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts

Data Sources

The LCA model was created using the GaBi Software system for life cycle engineering, version 10, developed by Sphera (Sphera, 2020). Background life cycle inventory data for raw materials and processes were obtained from the GaBi 2020.2 database. Primary manufacturing data were provided by Nucor.

Data Quality

A variety of tests and checks were performed by the LCA practitioner throughout the project to ensure high quality of the completed LCA. Checks included an extensive review of project-specific LCA models as well as the background data used.

Geographical Coverage

Primary data represents production in the United States at the following Nucor facilities:

- Nucor Steel Berkeley (Huger, SC)
- Nucor-Yamato Steel (Blytheville, AR)

Fabrication is represented by average US structural sections fabrication data.



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Regionally specific datasets, where available, 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.

Period under Review

Primary data collected represent production during the 2017 calendar year. This analysis is intended to represent production in 2019.

Allocation

Co-products during steel mill operations are allocated using a method used developed by the World Steel Association and EUROFER (Worldsteel and EUROFER, 2014) to be in line with CEN EN 15804 (CEN, 2019). The methodology takes into account the manner in which changes in inputs and outputs affect the production of co-products. The method also takes into account material flows that carry specific inherent properties.

Mill outputs such as scale and baghouse dust are handled via system expansion in line with the Worldsteel and EUROFER methodology. Recovered materials are assumed to substitute on a 1:1 mass basis. Mill scale is substituted with iron ore and baghouse dust is substituted for zinc or iron ore, depending on its specific zinc and iron contents.

Estimates and Assumptions

The underlying study was conducted in accordance with the PCR. While this EPD has been developed by industry experts to best represent the product system, real life environmental impacts of fabricated steel products may extend beyond those defined in this document.

All of the raw materials and energy inputs have been modeled using processes and flows that closely follow actual production data on raw materials and processes. All of the reported material and energy flows have been accounted for.

Transportation distances were provided by some mills for the inbound transportation of purchased steel scrap. These distances were used to estimate scrap transport and applied to all purchased scrap, even for mills that did not provide data. Other key materials were assumed to be transported 250 miles via truck and 250 miles via rail.

3. LCA Results

North American life cycle impact assessment (LCIA) results are declared using TRACI 2.1 methodology, with the exception of GWP which uses the latest IPCC methodology (IPCC, 2014). LCIA results are relative expressions and do not predict actual impacts, the exceeding of thresholds, safety margins or risks.

Fabrication requires 1.07 metric ton of structural sections per 1 metric ton of fabricated product. A1 includes production of all 1.07 metric ton of structural sections.



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Table 2. LCIA results, per 1 metric ton

PARAMETER	UNIT	A1	A2	A3	TOTAL
GWP 100	kg CO ₂ eq.	1.10E+03	1.07E+01	1.10E+02	1.22E+03
ODP	kg CFC 11 eq.	4.67E-10	1.00E-09	3.38E-08	3.53E-08
AP	kg SO ₂ eq.	2.80E+00	4.96E-02	2.98E-01	3.15E+00
EP	kg N eq.	1.32E-01	4.20E-03	1.51E-02	1.51E-01
SFP	kg O ₃ eq.	4.49E+01	1.43E+00	2.92E+00	4.92E+01
ADP _{fossil}	MJ surplus	1.27E+03	1.72E+01	8.52E+01	1.37E+03

Table 3. LCIA results, per 1 short ton

PARAMETER	UNIT	A1	A2	A3	TOTAL
GWP 100	kg CO ₂ eq.	9.96E+02	9.70E+00	9.97E+01	1.10E+03
ODP	kg CFC 11 eq.	4.24E-10	9.08E-10	3.07E-08	3.20E-08
AP	kg SO ₂ eq.	2.54E+00	4.50E-02	2.70E-01	2.86E+00
EP	kg N eq.	1.20E-01	3.81E-03	1.37E-02	1.37E-01
SFP	kg O ₃ eq.	4.07E+01	1.30E+00	2.65E+00	4.47E+01
ADP _{fossil}	MJ surplus	1.15E+03	1.56E+01	7.73E+01	1.24E+03

Table 4. Resource use results, per 1 metric ton

PARAMETER	UNIT	A1	A2	A3	TOTAL
RPR _E	MJ LHV	6.70E+02	4.66E-03	1.08E-01	6.70E+02
RPR _M	MJ LHV	0	0	0	0
NRPR _E	MJ LHV	1.52E+04	1.52E-01	1.55E+00	1.52E+04
NRPR _M	MJ LHV	0	0	0	0
SM	kg	7.44E+02	0	3.31E-01	7.44E+02
RSF	MJ LHV	0	0	0	0
NRSF	MJ LHV	0	0	0	0
RE	MJ LHV	0	0	0	0
FW	m ³	4.40E+00	3.61E-02	5.10E-01	4.95E+00

Table 5. Resource use results, per 1 short ton

PARAMETER	UNIT	A1	A2	A3	TOTAL
RPR _E	MJ LHV	6.08E+02	4.23E-03	9.76E-02	6.08E+02
RPR _M	MJ LHV	0	0	0	0
NRPR _E	MJ LHV	1.38E+04	1.38E-01	1.41E+00	1.38E+04
NRPR _M	MJ LHV	0	0	0	0
SM	kg	6.75E+02	0	3.00E-01	6.75E+02





According to ISO 14025,
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PARAMETER	UNIT	A1	A2	A3	TOTAL
RSF	MJ LHV	0	0	0	0
NRSF	MJ LHV	0	0	0	0
RE	MJ LHV	0	0	0	0
FW	m³	3.99E+00	3.28E-02	4.62E-01	4.49E+00

Table 6. Output flows and waste categories results, per 1 metric ton

PARAMETER	UNIT	A1	A2	A3	TOTAL
HWD	kg	1.21E-01	1.70E-07	1.97E-05	1.21E-01
NHWD	kg	7.47E-02	1.48E-02	6.81E+00	6.90E+00
HLRW	kg	9.16E-04	3.92E-06	1.33E-04	1.05E-03
ILLRW	kg	7.67E-01	3.27E-03	1.11E-01	8.81E-01
CRU	kg	0	0	0	0
MR	kg	7.77E+00	0	7.33E+01	8.10E+01
MER	kg	0	0	0	0
EE	MJ LHV	0	0	0	0

Table 7. Output flows and waste categories results, per 1 short ton

PARAMETER	UNIT	A1	A2	A3	TOTAL
HWD	kg	1.10E-01	1.54E-07	1.78E-05	1.10E-01
NHWD	kg	6.77E-02	1.35E-02	6.18E+00	6.26E+00
HLRW	kg	8.31E-04	3.56E-06	1.20E-04	9.55E-04
ILLRW	kg	6.96E-01	2.97E-03	1.00E-01	7.99E-01
CRU	kg	0	0	0	0
MR	kg	7.05E+00	0	6.65E+01	7.35E+01
MER	kg	0	0	0	0
EE	MJ LHV	0	0	0	0

4. LCA Interpretation

The below figure presents the relative contribution of the A1, A2, and A3 modules to the total. ODP results for fabrication (A3) are driving overall impact due to anomalies in the background data used in the AISC EPD.



According to ISO 14025,
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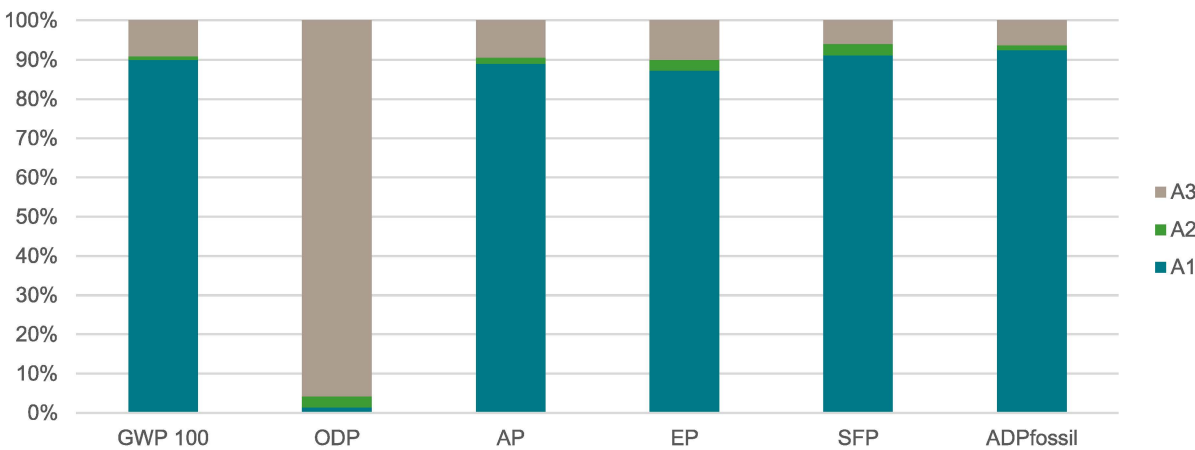


Figure 2: Relative contributions by module, IPCC AR5 + TRACI 2.1 impact categories

Within mill fabrication, the main drivers are iron/steel inputs, alloying materials, and electricity. Process emissions associated with the melt shop and rolling mill are relevant contributors to potential global warming impact and, to a lesser extent, acidification, eutrophication, and smog formation impact. Natural gas is a significant driver for ADP, fossil impacts. ODP impacts are driven by aluminum used as an alloying material. This is likely due to the use of Aluminum Association background data, which was deemed the most representative for all North American aluminum production.

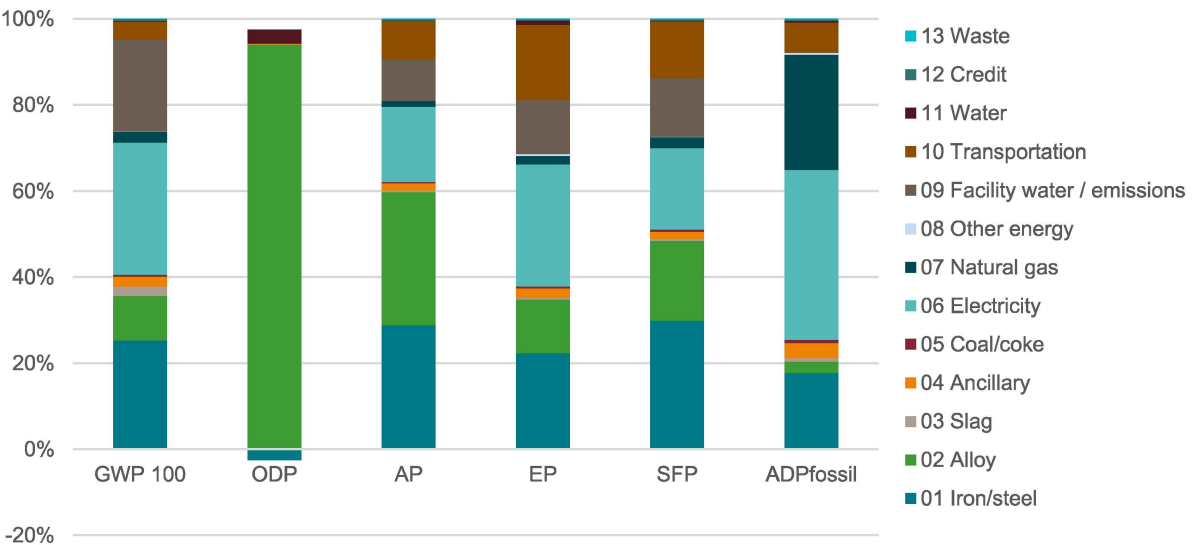


Figure 3: Relative contributions for module A1, IPCC AR5 + TRACI 2.1 impact categories



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Facility-Specific GWP100 Results

Nucor hot-rolled structural product may be shipped from one of two different mills. The results presented previously represent a production-weighted average of these facilities. To understand how the GWP may vary between sites, facility-specific GWP100 results are presented below, per metric ton. As mill products may be shipped to any number of fabricators, the US average AISC fabricator data was used for both sites and therefore does not change. Results are also presented for beam at the mill level, which excludes impacts from the additional material requirements associated with the scrap generated during fabrication.

Table 8: Facility-specific GWP100 results, per 1 metric ton

GWP [kg CO2 Eq.]	A1	A2	A3	TOTAL	CRADLE-TO-GATE, MILL PRODUCT
Nucor Steel Berkeley	1.71E+03	1.07E+01	1.10E+02	1.83E+03	1.60E+03
Nucor Yamato Steel	8.75E+02	1.07E+01	1.10E+02	9.96E+02	8.16E+02

Table 9: Facility-specific GWP100 results, per 1 short ton

GWP [kg CO2 Eq.]	A1	A2	A3	TOTAL	CRADLE-TO-GATE, MILL PRODUCT
Nucor Steel Berkeley	1.55E+03	9.70E+00	9.97E+01	1.66E+03	1.45E+03
Nucor Yamato Steel	7.94E+02	9.70E+00	9.97E+01	9.04E+02	7.40E+02

5. Additional Environmental Information

Environment and Health During Manufacturing

Refer to the Nucor Beam SDS¹ for additional environmental and health protection during the product manufacturing process. Be sure to follow all recommended handling and product manufacturing guidance.

Environmental Activities and Certifications

ISO 14001: The environmental performance of Nucor’s structural steel mills on continuous improvement through internal and external training, application of new technologies and how we communicate data and results. To provide a framework for Nucor teammates to follow, Nucor utilizes ISO 14001, which is the international standard that establishes specific requirements for an effective environmental management system (EMS). We are proud to announce that Nucor’s structural steel facilities have achieved ISO 14001:2015 certification.

Waste and Water Recycling: Nucor’s EAFs, including the ones at its structural steel mills, emit less than 1% of the particulate matter of a traditional steel blast furnace – and the company recycles 99 percent of the EAF dust its collects in its baghouses. Nucor also recognizes that water is a critical natural resource and is essential to our business and the communities in which we operate. We have worked extensively to improve water use efficiency in our processes. One hundred percent of the process water from our steelmaking operations is recycled multiple times at our structural

¹ https://assets.ctfassets.net/aax1cfbwhqog/UcLHwfmCRVoyrpxb15vZl/c73a00f2a213af726e2ef74584c79517/SDS-Bar_Steel.pdf



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steel mills. Currently there are no Nucor steel mill divisions located in a High or Extremely High Water Stress Area.

Nucor-Yamato Steel (NYS) Activities: NYS teammates received the Arkansas Recycling Coalition’s 2019 Community Involvement Award, which honors those that have “proven to be positive community role models by routinely researching and utilizing source reduction, landfill diversion and recycling as the primary solid waste management approach.” Secondly, these businesses have “visibly promoted recycling and sustainability within the community or region in which its facility is located.”

NYS has made significant contributions to advance waste reduction, recycling and sustainability in Arkansas, including:

- Armorer School recycling presentation and donation of classroom recycling containers (May 2018)
- Armorer School (K-12) recycling trailer (August 2018 and ongoing)
- Manilla School (K-12) recycling trailer (March 2019 and ongoing)
- Blytheville Relay for Life event recycling trailer (June 2018)
- Blytheville Chili Cook-Off recycling trailer (October 2018)
- Roy Pearson St. Jude Golf Tournament recycling trailer (October 2018)
- Blytheville Mayfest recycling trailer (May 2018)
- Holiday recycling (December 2018)
- Arbor Day presentation and tree giveaway (March 2019)
- Sending collected recycling to Abilities Unlimited in Blytheville, Arkansas (since 2007)

Nucor Steel Berkeley Activities: Nucor Steel Berkeley was constructed on 8000 acres on the Cooper River outside of Charleston, South Carolina. Of the 8000 acres, Nucor utilized 3000 acres for mill operations, and donated the remaining 5000 acres of environmentally and historically significant real property through a conservation easement to the Lord Berkeley Conservation Trust (“LBCT”). This property includes a large quantity of wetlands. As holder of the conservation easement, LBCT will be able to enforce the development and use restrictions contained in the easement in perpetuity. By granting the conservation easement, Nucor furthered its goal of being an environmentally friendly and responsible member of the Berkeley County community, and for its efforts, Nucor was awarded the Environmental Merit Award from South Carolina Soil & Water Conservation Society.

Like NYS, Nucor Steel Berkeley maintains a strong community presence, engaging in various outreach opportunities to improve the community in which we live and work. Every year, the Berkeley County Chamber of Commerce in South Carolina presents Transcend Awards, recognizing businesses that are making vital contributions to the county. In 2018, the Chamber named Nucor Steel Berkeley winner of the 2018 Industry Transcend Award, which recognizes a manufacturer that has risen above and beyond the ordinary contributions of a business in the community for the good of the entire region. The Chamber highlighted Nucor’s teammates’ dedication and described Nucor as a company heavily involved in local non-profits for the under-served, dedicated to the future success of the county’s children, and a contributor to a clean and safe environment.

In terms of safety, Nucor Steel Berkeley has also attained Voluntary Protection Program (VPP) certification from OSHA, which is OSHA’s highest level of recognition and demonstrates our commitment to leading the industry by example.

6. References

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UL Environment. (2020). *Part B: Designated Steel Construction Product EPD Requirements, v2.0.*

Worldsteel and EUROFER. (2014). *A methodology to determine the LCI of steel industry co-products.*



ENVIRONMENTAL PRODUCT DECLARATION

NUCOR®

Fabricated Hot-Rolled Structural Steel Sections
Designated Steel Construction Product



According to ISO 14025,
EN 15804 and ISO 21930:2017

7. Contact Information

Study Commissioner

NUCOR®

Nucor Corporation
1915 Rexford Road
Charlotte, North Carolina 28211
Ph: 704.366.7000
www.nucor.com

LCA Practitioner



Sphera Solutions, Inc.
130 E Randolph St, #2900
Chicago, IL 60601
<https://sphera.com/contact-us/>



APPENDIX 6 : TALLY REPORT - CLADDING EXPLORATIONS

The following report was created from Tally from user-specified materials. The report has the life cycle assessment broken down by life cycle stages, division and revit materials. The methodology for calculating the life cycle assessment is also included.

This report is for the cladding explorations.

50'-0" Frame Wall Explorations

Wall Option Explorations

5/31/2022



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Report Summary

Created with Tally

Non-commercial Version 2021.11.01.01

Author

Simone O'Halloran

Company

University of Oregon

Date

5/31/2022

Project

50'-0" Frame Wall Explorations

Location

Terminal 2, Port of Portland

Gross Area

5,000 ft²

Building Life

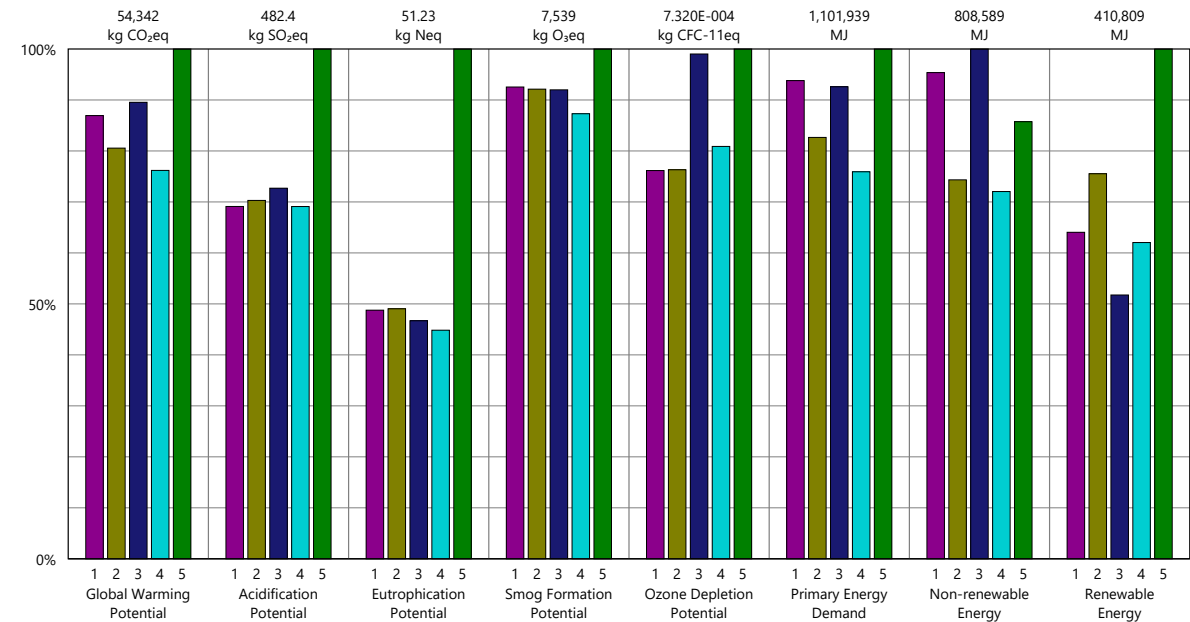
80 years

Boundaries

Cradle to grave, exclusive of biogenic carbon; see appendix for a full list of materials and processes

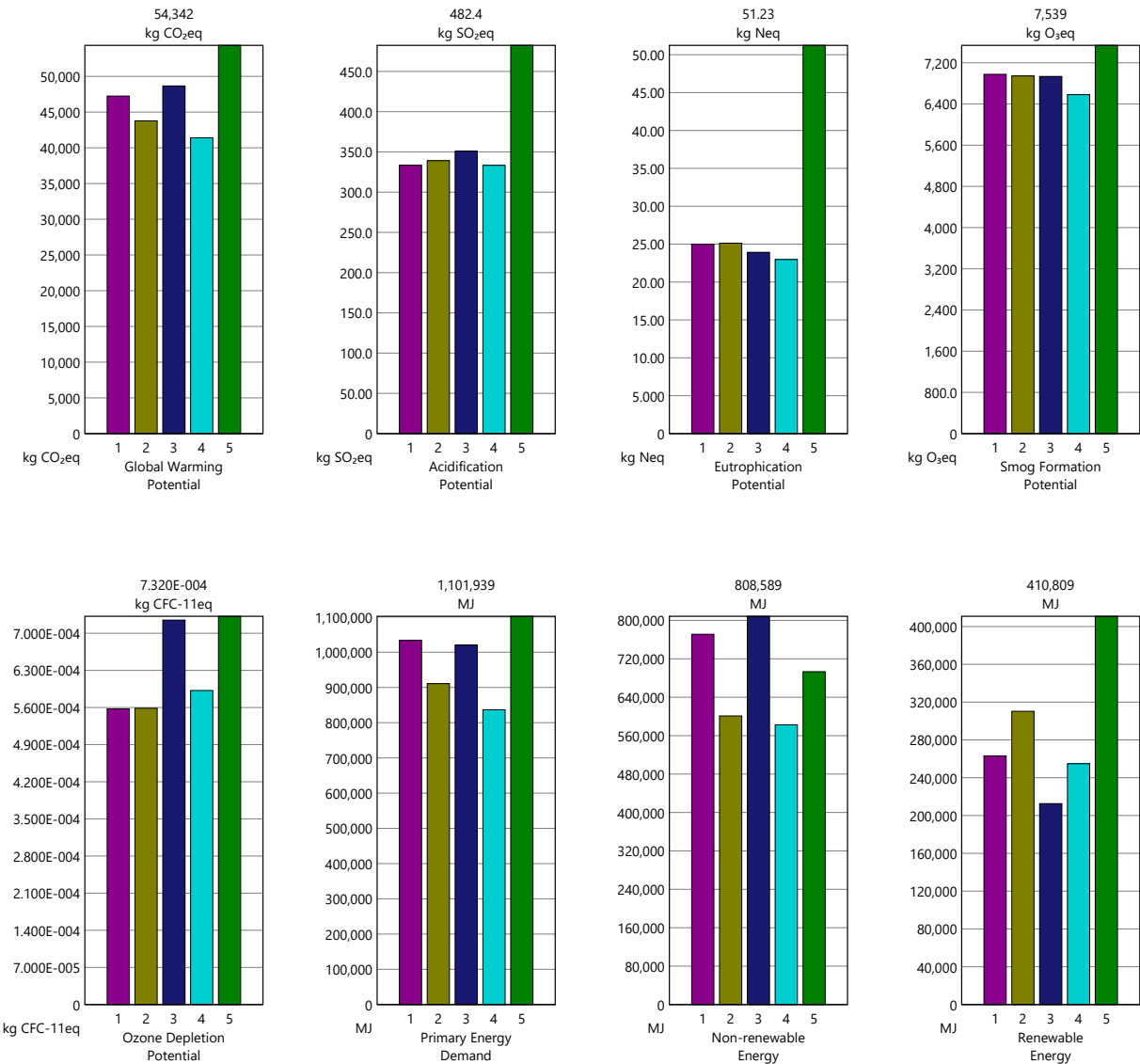
Goal and Scope of Assessment

The scope of this assesment is to compare different wall explorations to determine which one performs the best environmentally. The scope of this assesment does not include transporation impacts or biogenic carbon.



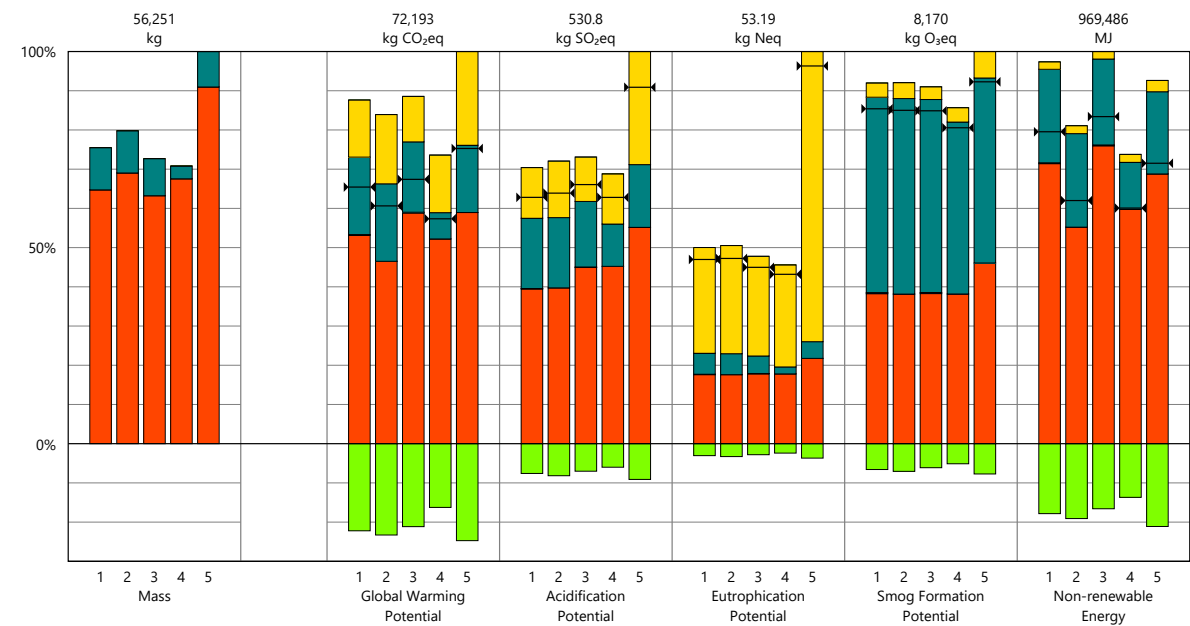
- Legend
- Design Options
- Batt Insulation - Plastic Interior, Metal Panel Exterior
 - Batt Insulation - Plywood Interior, Metal Panel Exterior
 - Insulated Panel - Plastic Interior, Metal Panel Exterior
 - Insulated Panel - Plywood Interior, Metal Panel Exterior
 - MPP Wall - Metal Panel (primary)

Report Summary (continued)



- Legend
- Design Options
- Batt Insulation - Plastic Interior, Metal Panel Exterior
 - Batt Insulation - Plywood Interior, Metal Panel Exterior
 - Insulated Panel - Plastic Interior, Metal Panel Exterior
 - Insulated Panel - Plywood Interior, Metal Panel Exterior
 - MPP Wall - Metal Panel (primary)

Results per Life Cycle Stage



Legend

Net value (impacts + credits)

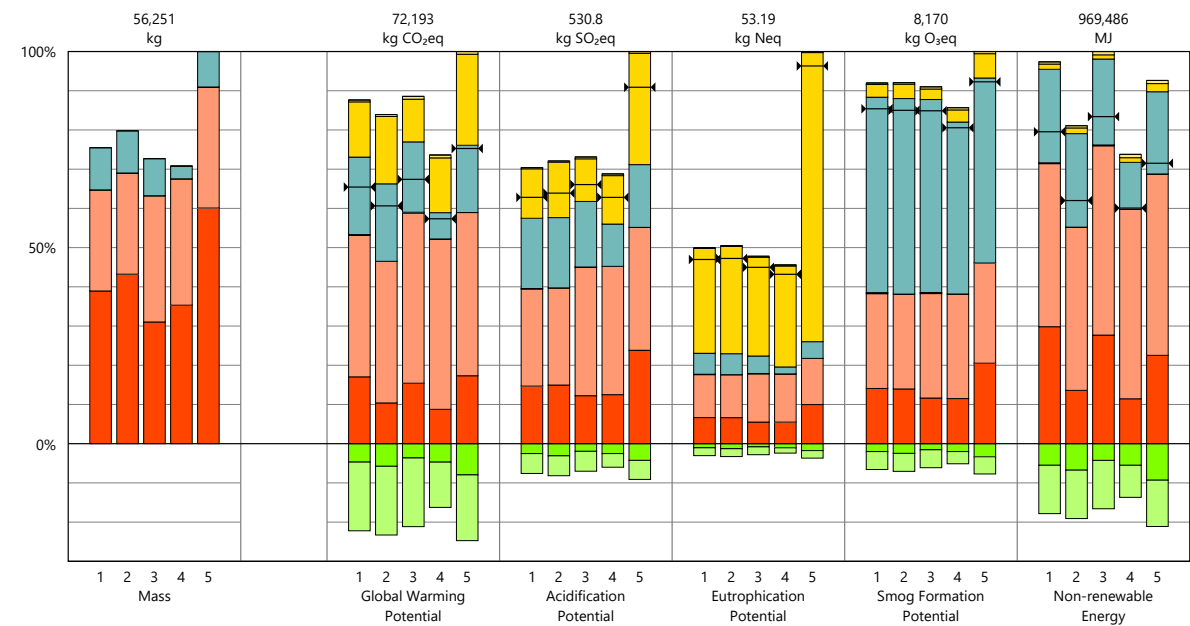
Design Options

Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
Option 5 - MPP Wall - Metal Panel (primary)

Life Cycle Stages

- Product [A1-A3]
- Transportation [A4]
- Maintenance and Replacement [B2-B5]
- End of Life [C2-C4]
- Module D [D]

Results per Life Cycle Stage, itemized by Division



Legend

Net value (impacts + credits)

Design Options

Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
Option 5 - MPP Wall - Metal Panel (primary)

Product [A1-A3]

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

Transportation [A4]

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

Maintenance and Replacement [B2-B5]

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

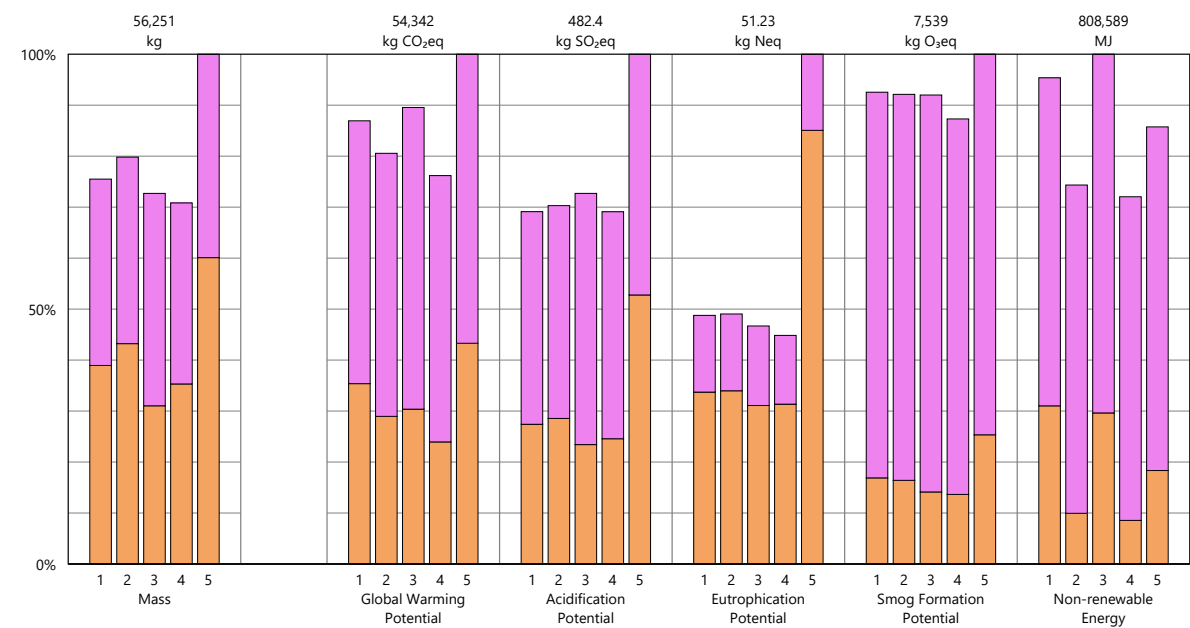
End of Life [C2-C4]

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

Module D [D]

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

Results per Division



Legend

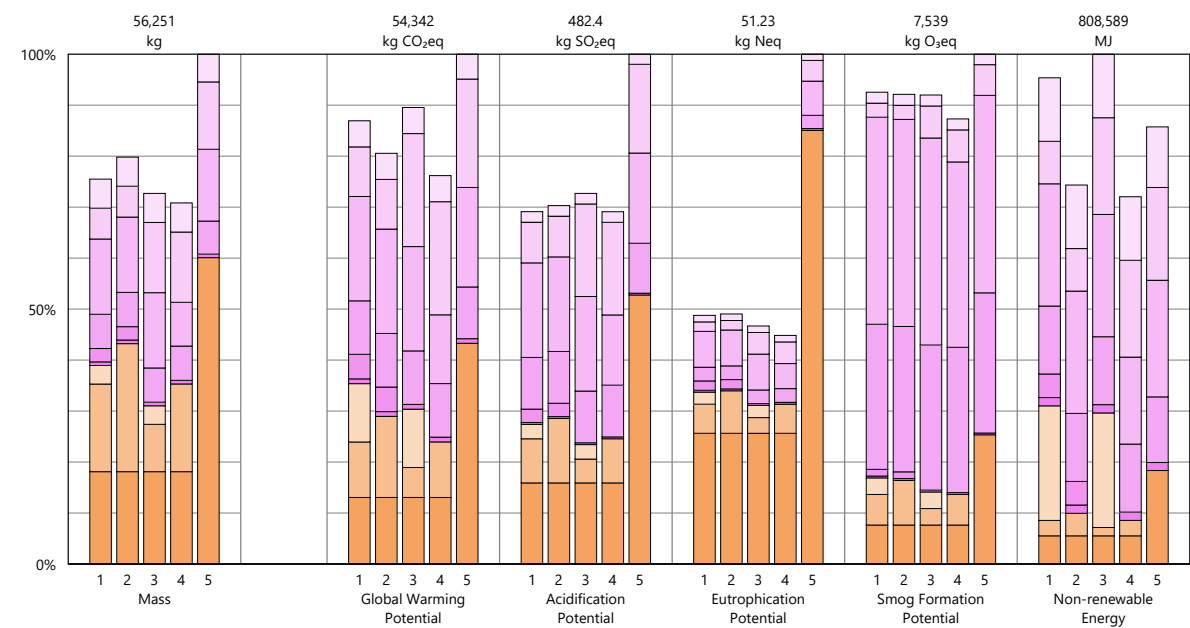
Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

Divisions

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

Results per Division, itemized by Tally Entry



Legend

Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

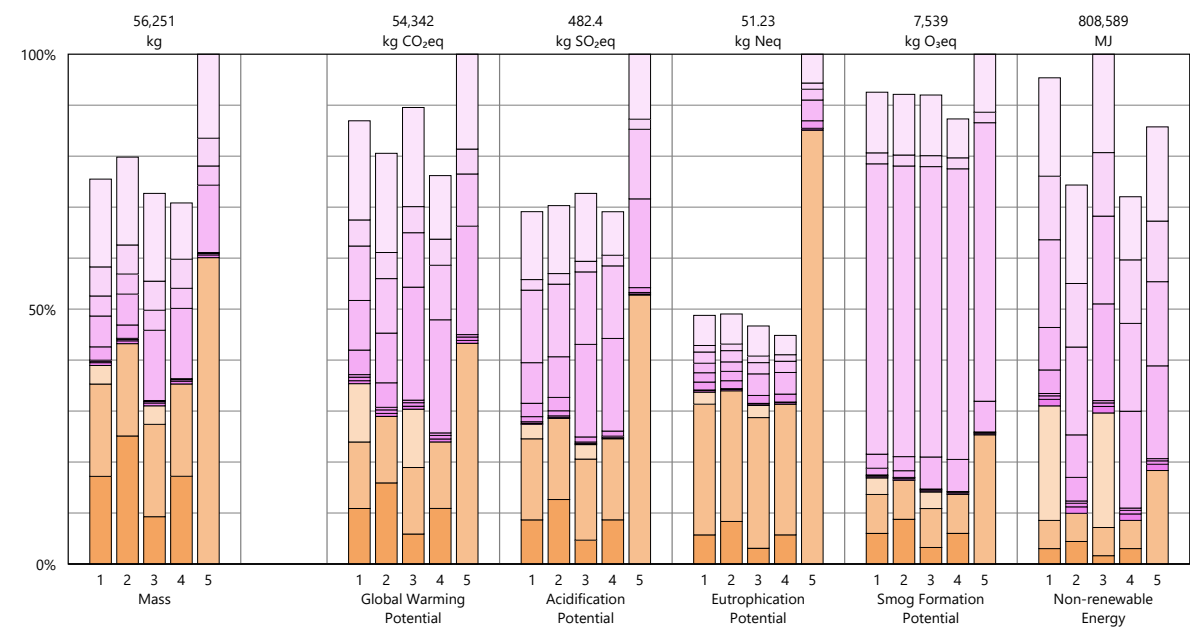
06 - Wood/Plastics/Composites

- Laminated veneer lumber (LVL)
- Plywood, interior grade
- Unreinforced polypropylene paneling

07 - Thermal and Moisture Protection

- Asphalt felt sheet
- Glass wool, batt or blown
- Metal roofing panels, formed
- Metal wall panel, formed
- Mineral wool, board, generic
- Self-adhering sheet waterproofing, modified bituminous sheet

Results per Division, itemized by Material



Legend

Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

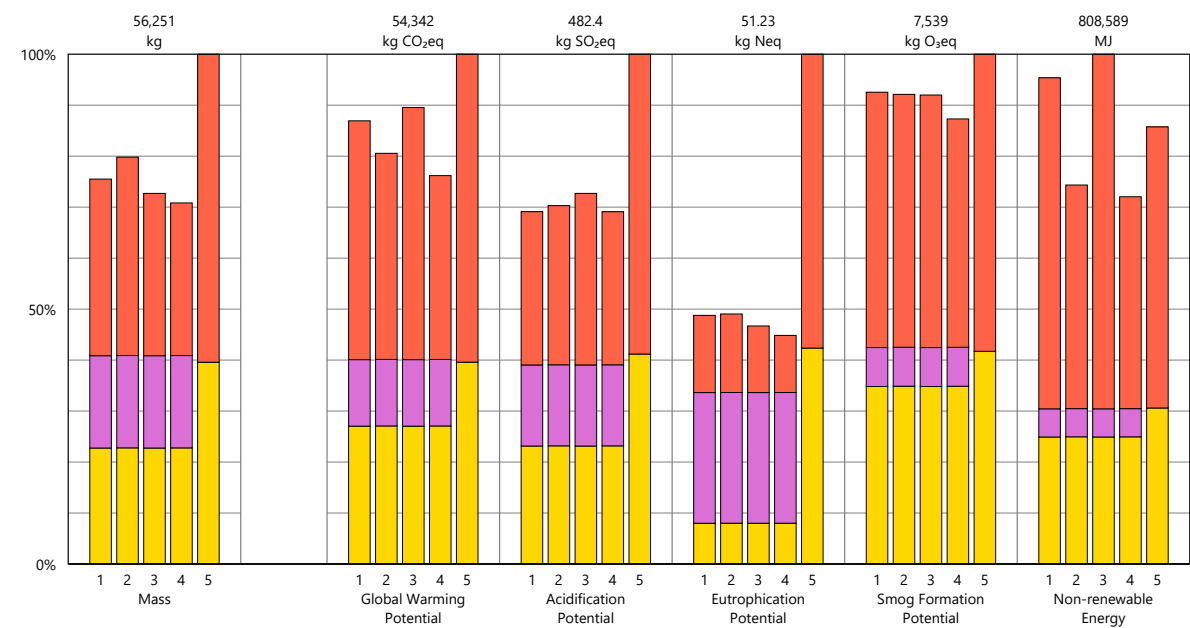
06 - Wood/Plastics/Composites

- Interior grade plywood, US, AWC - EPD
- Laminated veneer lumber (LVL), AWC - EPD
- Unreinforced polypropylene paneling

07 - Thermal and Moisture Protection

- Asphalt felt sheet, roofing underlayment, ARMA - EPD
- Fasteners, galvanized steel
- Fasteners, stainless steel
- Glass wool unfaced batt, Knauf, EcoBatt - EPD
- Mineral wool, low density, NAIMA - EPD
- Paint, enamel, solvent based
- SBS modified bitumen, cap sheet, ARMA - EPD
- Steel, sheet

Results per Revit Category



Legend

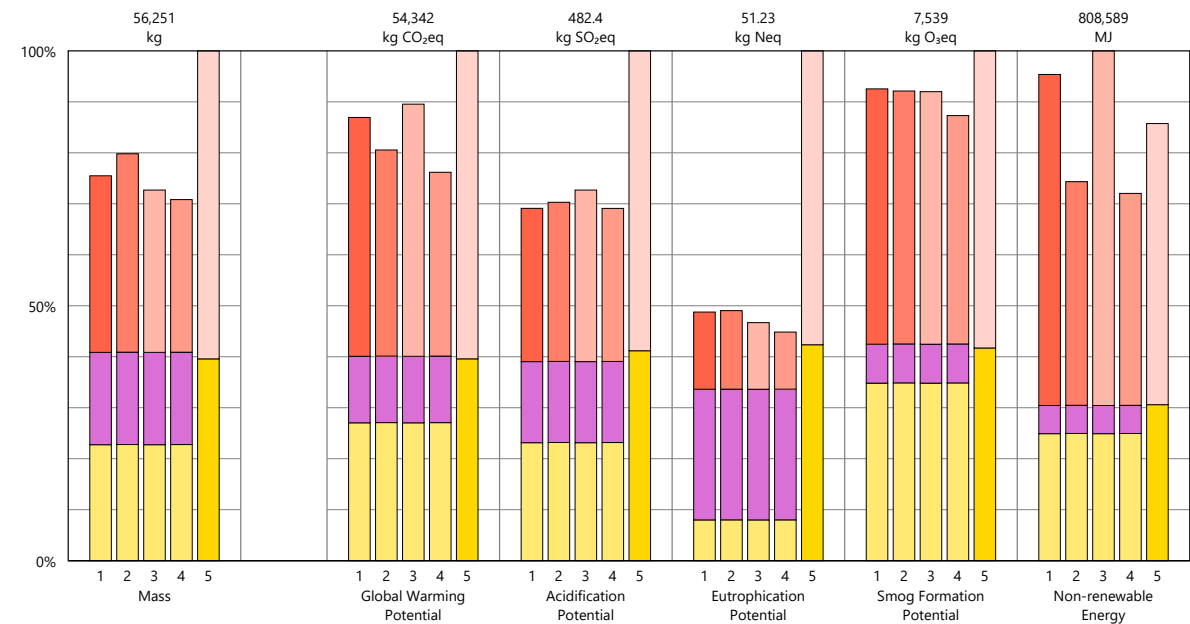
Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

Revit Categories

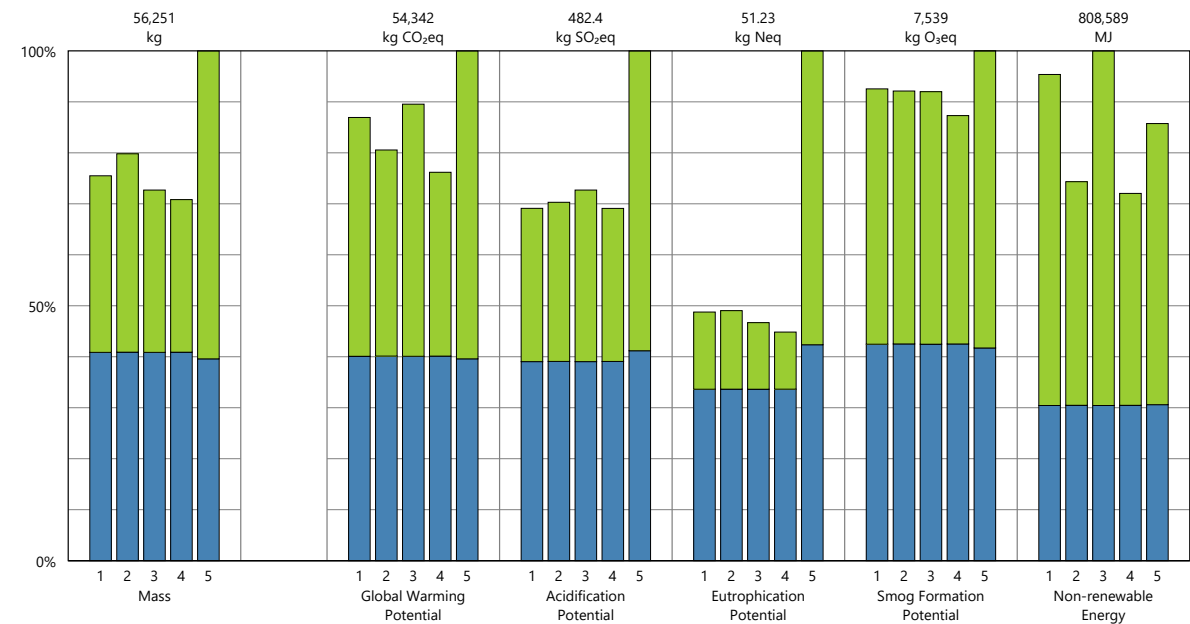
- Roofs
- Structure
- Walls

Results per Revit Category, itemized by Family



- Legend**
- Design Options**
- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
 - Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
 - Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
 - Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
 - Option 5 - MPP Wall - Metal Panel (primary)
- Roofs**
- MPP Roof Deck
 - Plywood Deck
- Structure**
- Glulam-Western Species-IL
- Walls**
- Batt - Plastic Interior, Metal Panel Exterior
 - Batt & Plywood
 - Insulated Panel - Metal - PLYWOOD
 - Insulated Panel - Plastic Interior, Metal Panel Exterior
 - MPP Wall

Results per Building Element



- Legend**
- Design Options**
- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
 - Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
 - Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
 - Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
 - Option 5 - MPP Wall - Metal Panel (primary)
- Building Elements**
- Superstructure
 - Enclosure

Calculation Methodology

LIFE CYCLE ASSESSMENT METHODS

The following provides a description of terms and methods associated with the use of Tally to conduct life cycle assessment for construction works and construction products. Tally methodology is consistent with LCA standards ISO 14040-14044, ISO 21930:2017, ISO 21931:2010, EN 15804:2012, and EN 15978:2011. For more information about LCA, please refer to these standards or visit www.choosetally.com.

Studied objects

The life cycle assessment (LCA) results reported represent an analysis of a single building, multiple buildings, or a comparative analysis of two or more building design options. The assessment may represent the complete architectural, structural, and finish systems of the building(s) or a subset of those systems. This may be used to compare the relative environmental impacts associated with building components or for comparative study with one or more reference buildings. Design options may represent a full or partial building across various stages of the design process, or they may represent multiple schemes of a full or partial building that are being compared to one another across a range of evaluation criteria.

Functional unit and reference unit

A functional unit is the quantified performance of a product, building, or system that defines the object of the study. The functional unit of a single building should include the building type (e.g. office, factory), relevant technical and functional requirements (e.g. regulatory requirements, energy performance), pattern of use (e.g. occupancy, usable floor area), and the required service life. For a design option comparison of a partial building, the functional unit is the complete set of building systems or products that perform a given function. It is the responsibility of the modeler to assure that reference buildings or design options are functionally equivalent in terms of scope and relevant performance. The expected life of the building has a default value of 60 years and can be modified by the modeler.

The reference unit is the full collection of processes and materials required to produce a building or portion thereof and is quantified according to the given goal and scope of the assessment over the full life of the building. If construction impacts are included in the assessment, the reference unit also includes the energy, water, and fuel consumed on the building site during construction. If operational energy is included in the assessment, the reference unit includes the electrical and thermal energy consumed on site over the life of the building.

Data source

Tally utilizes a custom designed LCA database that combines material attributes, assembly details, and architectural specifications with environmental impact data resulting from the collaboration between KieranTimberlake and thinkstep. LCA modeling was conducted in GaBi 8.5 using GaBi 2018 databases and in accordance with [GaBi databases and modeling principles](#).

The data used are intended to represent the US and the year 2017. Where representative data were unavailable, proxy data were used. The datasets used, their geographic region, and year of reference are listed for each entry. An effort was made to choose proxy datasets that are technologically consistent with the relevant entry.

Data quality and uncertainty

Uncertainty in results can stem from both the data used and their application. Data quality is judged by: its measured, calculated, or estimated precision; its completeness, such as unreported emissions; its consistency, or degree of uniformity of the methodology applied on a study serving as a data source; and geographical, temporal, and technological representativeness. The [GaBi LCI databases](#) have been used in LCA models worldwide in both industrial and scientific applications. These LCI databases have additionally been used both as internal and critically reviewed and published studies. Uncertainty introduced by the use of proxy data is reduced by using technologically, geographically, and/or temporally similar data. It is the responsibility of the modeler to appropriately apply the predefined material entries to the building under study.

System boundaries and delimitations

The analysis accounts for the full cradle to grave life cycle of the design options studied across all life cycle stages, including material manufacturing, maintenance and replacement, and eventual end of life. Optionally, the construction impacts and operational energy of the building can be included within the scope. Product stage impacts are excluded for materials and components indicated as existing or salvaged by the modeler. The modeler defines whether the boundary includes or excludes the flow of biogenic carbon, which is the carbon absorbed and generated by biological sources (e.g. trees, algae) rather than from fossil resources.

Architectural materials and assemblies include all materials required for the product’s manufacturing and use including hardware, sealants, adhesives, coatings, and finishing. The materials are included up to a 1% cut-off factor by mass except for known materials that have high environmental impacts at low levels. In these cases, a 1% cut-off was implemented by impact.

Calculation Methodology

LIFE CYCLE STAGES

The following describes the scope and system boudaries used to define each stage of the life cycle of a building or building product, from raw material acquisition to final disposal. For products listed in Tally as Environmental Product Declarations (EPD), the full life cycle impacts are included, even if the published EPD only includes the Product stage [A1-A3].

Product [EN 15978 A1 - A3]

This encompasses the full manufacturing stage, including raw material extraction and processing, intermediate transportation, and final manufacturing and assembly. The product stage scope is listed for each entry, detailing any specific inclusions or exclusions that fall outside of the cradle to gate scope. Infrastructure (buildings and machinery) required for the manufacturing and assembly of building materials are not included and are considered outside the scope of assessment.

Transportation [EN 15978 A4]

This counts transportation from the manufacturer to the building site during the construction stage and can be modified by the modeler.

Construction Installation [EN 15978 A5] (Optional)

This includes the anticipated or measured energy and water consumed on-site during the construction installation process, as specified by the modeler.

Maintenance and Replacement [EN 15978 B2-B5]

This encompasses the replacement of materials in accordance with their expected service life. This includes the end of life treatment of the existing products as well as the cradle to gate manufacturing and transportation to site of the replacement products. The service life is specified separately for each product. Refurbishment of materials marked as existing or salvaged by the modeler is also included.

Operational Energy [EN 15978 B6] (Optional)

This is based on the anticipated or measured energy and natural gas consumed at the building site over the lifetime of the building, as indicated by the modeler.

End of Life [EN 15978 C2-C4]

This includes the relevant material collection rates for recycling, processing requirements for recycled materials, incineration rates, and landfilling rates. The impacts associated with landfilling are based on average material properties, such as plastic waste, biodegradable waste, or inert material. Stage C2 encompasses the transport from the construction site to end-of-life treatment based on national averages. Stages C3-C4 account for waste processing and disposal, i.e., impacts associated with landfilling or incineration.

Module D [EN 15978 D]

This accounts for reuse potentials that fall beyond the system boundary, such as energy recovery and recycling of materials. Along with processing requirements, the recycling of materials is modeled using an avoided burden approach, where the burden of primary material production is allocated to the subsequent life cycle based on the quantity of recovered secondary material. Incineration of materials includes credit for average US energy recovery rates.

PRODUCT	CONSTRUCTION	USE	END-OF-LIFE	MODULE D
A1. Extraction A2. Transport (to factory) A3. Manufacturing	A4. Transport (to site) A5. Construction Installation	B1. Use B2. Maintenance B3. Repair B4. Replacement B5. Refurbishment B6. Operational energy B7. Operational water	C1. Demolition C2. Transport (to disposal) C3. Waste processing C4. Disposal	D. Benefits and loads beyond the system boundary from: 1. Reuse 2. Recycling 3. Energy recovery

Life-Cycle Stages as defined by EN 15978. Processes included in Tally modeling scope are shown in bold. Italics indicate optional processes.

Calculation Methodology

ENVIRONMENTAL IMPACT CATEGORIES

A characterization scheme translates all emissions and fuel use associated with the reference flow into quantities of categorized environmental impact. As the degree that the emissions will result in environmental harm depends on regional ecosystem conditions and the location in which they occur, the results are reported as impact potential. Potential impacts are reported in kilograms of equivalent relative contribution (eq) of an emission commonly associated with that form of environmental impact (e.g. kg CO₂eq).

The following list provides a description of environmental impact categories reported according to the TRACI 2.1 characterization scheme, the environmental impact model developed by the US EPA to quantify environmental impact risk associated with emissions to the environment in the United States. TRACI is the standard environmental impact reporting format for LCA in North America. Impacts associated with land use change and fresh water depletion are not included in TRACI 2.1. For more information on TRACI 2.1, reference Bare 2010, EPA 2012, and Guinée 2001. For further description of measurement of environmental impacts in LCA, see Simonen 2014.

Acidification Potential (AP)

kg SO₂eq

A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H⁺) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline, and the deterioration of building materials.

Eutrophication Potential (EP)

kg Neq

A measure of the impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems, increased biomass production may lead to depressed oxygen levels caused by the additional consumption of oxygen in biomass decomposition.

Global Warming Potential (GWP)

kg CO₂eq

A measure of greenhouse gas emissions, such as carbon dioxide and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may, in turn, have adverse impacts on ecosystem health, human health, and material welfare.

Ozone Depletion Potential (ODP)

kg CFC-11eq

A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth's surface with detrimental effects on humans and plants. As these impacts tend to be very small, ODP impacts can be difficult to calculate and are prone to a larger margin of error than the other impact categories.

Smog Formation Potential (SFP)

kg O₃eq

A measure of ground level ozone, caused by various chemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in sunlight. Human health effects can result in a variety of respiratory issues, including increasing symptoms of bronchitis, asthma, and emphysema. Permanent lung damage may result from prolonged exposure to ozone. Ecological impacts include damage to various ecosystems and crop damage.

Primary Energy Demand (PED)

MJ (lower heating value)

A measure of the total amount of primary energy extracted from the earth. PED tracks energy resource use, not the environmental impacts associated with the resource use. PED is expressed in energy demand from non-renewable resources and from renewable resources. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account when calculating this result.

Non-Renewable Energy Demand

MJ (lower heating value)

A measure of the energy extracted from non-renewable resources (e.g. petroleum, natural gas, etc.) contributing to the PED. Non-renewable resources are those that cannot be regenerated within a human time scale. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account when calculating this result.

Renewable Energy Demand

MJ (lower heating value)

A measure of the energy extracted from renewable resources (e.g. hydropower, wind energy, solar power, etc.) contributing to the PED. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account when calculating this result.

LCI Data

END-OF-LIFE [C2-C4]

A Life Cycle Inventory(LCI) is a compilation and quantification of inputs and outputs for the reference unit.The following LCI provides a summary of all energy, construction, transportation, and material inputs present in the study. Materials are listed in alphabetical order along with a list of all Revit families and Tally entries in which they occur, along with any notes and system boundaries accompanying their database entries. Each entry lists the detailed scope for the LCI data sources used from the GaBi LCI database and identifies the LCI data source.

For LCI data sourced from an Environmental Product Declaration (EPD), the product manufacturer, EPD identification number, and Program Operator are listed. Where the LCI source does not provide data for all life cycle stages, default North American average values are used. This is of particular importance for European EPD sources, as EPD data are generally only provided for the product stage, and North American average values are used for the remaining life cycle stages.

Where specific quantities are associated with a data entry, such as user inputs, energy values, or material mass, the quantity is listed on the same line as the title of the entry.

TRANSPORTATION [A4]

Default transportation values are based on the three-digit material commodity code in the 2012 Commodity Flow Survey by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation is not available.

Transportation by Barge
Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by barge.

LCI Source:
GLO: Average ship, 1500t payload capacity/ canal ts (2017)
US: Diesel mix at filling station ts (2014)

Transportation by Container Ship
Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by container ship.

LCI Source:
GLO: Container ship, 27500 dwt payload capacity, ocean going ts (2017)
US: Heavy fuel oil at refinery (0.3wt.% S) ts (2014)

Transportation by Rail
Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by cargo rail.

LCI Source:
GLO: Rail transport cargo - Diesel, average train, gross tonne weight 1000t / 726t payload capacity ts (2017)
US: Diesel mix at filling station ts (2014)

Transportation by Truck
Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by diesel truck.

LCI Source:
US: Truck - Trailer, basic enclosed / 45,000 lb payload - 8b ts (2017)
US: Diesel mix at filling station ts (2014)

LCI Data (continued)

END-OF-LIFE [C2-C4]

Specific end-of-life scenarios are detailed for each entry based on the US construction and demolition waste treatment methods and rates in the 2016 WARM Model by the US Environmental Protection Agency except where otherwise specified. Heterogeneous assemblies are modeled using the appropriate methodologies for the component materials.

End-of-Life Landfill

Scope:
Materials for which no recycling or incineration rates are known, no recycling occurs within the US at a commercial scale, or which are unable to be recycled are landfilled. This includes glass, drywall, insulation, and plastics. The solids contents of coatings, sealants, and paints are assumed to go to landfill, while the solvents or water evaporate during installation. Where the landfill contains biodegradable material, the energy recovered from landfill gas utilization is reflected as a credit in Module D.

LCI Source:
US: Glass/inert on landfill ts (2017)
US: Biodegradable waste on landfill, post-consumer ts (2017)
US: Plastic waste on landfill, post-consumer ts (2017)

Concrete End-of-Life

Scope:
Concrete (or other masonry products) are recycled into aggregate or general fill material or they are landfilled. It is assumed that 55% of the concrete is recycled. Module D accounts for both the credit associated with off-setting the production aggregate and the burden of the grinding energy required for processing.

LCI Source:
US: Diesel mix at refinery ts (2014)
GLO: Fork lifter (diesel consumption) ts (2016)
EU - 28 Gravel 2/32 ts (2017)
US: Glass/inert on landfill ts (2017)

Metals End-of-Life

Scope:
Metal products are modeled using the avoided burden approach. The recycling rate at end of life is used to determine how much secondary metal can be recovered after having subtracted any scrap input into manufacturing (net scrap). Net scrap results in an environmental credit in Module D for the corresponding share of the primary burden that can be allocated to the subsequent product system using secondary material as an input. If the value in Module D reflects an environmental burden, then the original product (A1-A3) contains more secondary material than is recovered.

LCI Source:
Aluminum - RNA: Primary Aluminum Ingot AA/ts (2010)
Aluminum - RNA: Secondary Aluminum Ingot AA/ts (2010)
Brass - GLO: Zinc mix ts (2012)
Brass - GLO: Copper (99.99% cathode) ICA (2013)
Brass - EU-28: Brass (CuZn20) ts (2017)
Copper - DE: Recycling potential copper sheet ts (2016)
Steel - GLO: Value of scrap worldsteel (2014)
Zinc - GLO: Special high grade zinc IZA (2012)

Wood End-of-Life

Scope:
End of Life waste treatment methods and rates for wood are based on the 2014 Municipal Solid Waste and Construction Demolition Wood Waste Generation and Recovery in the United States report by Dovetail Partners, Inc. It is assumed that 63.5% of wood is sent to landfill, 22% to incineration, and 14.5% to recovery.

LCI Source:
US: Untreated wood in waste incineration plant ts (2017)
US: Wood product (OSB, particle board) waste in waste incineration plant ts (2017)
US: Wood products (OSB, particle board) on landfill, post-consumer ts (2017)
US: Untreated wood on landfill, post-consumer ts (2017)
RNA: Softwood lumber CORRIM (2011)

LCI Data

PRODUCT [A1-A3]

Materials and components are listed in alphabetical order along with a list of all Revit families and Tally entries in which they occur. The masses given here refer to the quantity of each material used over the building's life-cycle, which includes both Product [A1-A3] and Use [B2-B5] stages.

Additional provided data describing scope boundaries for each life cycle stage may be useful for interpretation of the impacts associated with the specific material or component. Each material or component is listed with its service life, or period of time after installation it is expected to meet the service requirements prior to replacement or repair. This value is indicated in parentheses next to the mass of the material associated with the listed Revit family. Values for transportation distance or service life shown with an asterisk (*) indicate user-defined changes to default values. Values for service life shown with a dagger (†) indicate materials identified by the modeler as existing or salvaged.

Asphalt felt sheet, roofing underlayment, ARMA - EPD 1,552.4 kg
Used in the following Revit families:
MPP Roof Deck 301.9 kg (80 yrs*)
Plywood Deck 1,250.6 kg (80 yrs*)

Used in the following Tally entries:
Asphalt felt sheet

Description:
Asphalt felt sheet, exclusive of spray adhesive for roofing and wall application. Type II felt, also called No. 30 asphalt felt, is the minimum accepted by the IBC and IRC for underlayment and interlayment. Data based on industry-wide EPD from the Asphalt Roofing Manufacturers Association.

Life Cycle Inventory:
For information and quantities, see EPD

Product Scope:
Cradle to gate

Transportation Distance:
By truck: 0 km*

End-of-Life Scope:
5% Recycled into bitumen
95% Landfilled (inert waste)

Module D Scope:
Avoided burden credit for recycling into bitumen, includes grinding energy

LCI Source:
RNA: Underlayment, asphalt shingle roofing system component - ARMA (A1-A3) ts (2012)

EPD Source:
4787168709.101.1

EPD Designation Holder:
Asphalt Roofing Manufacturers Association (ARMA)

EPD Program Operator:
UL Environment

EPD Expiration:
10/28/2021

Fasteners, galvanized steel 829.7 kg
Used in the following Revit families:
MPP Roof Deck 161.3 kg (80 yrs*)
Plywood Deck 668.4 kg (80 yrs*)

Used in the following Tally entries:
Asphalt felt sheet
Metal roofing panels, formed

Description:
Galvanized steel part, appropriate for use as fasteners and specialized hardware (bolts, rails, clips, etc.).

Life Cycle Inventory:
100% Galvanized steel

Product Scope:
Cradle to gate

Transportation Distance:
By truck: 0 km*

End-of-Life Scope:
70% Recovered
30% Landfilled (inert material)

Module D Scope:
Product has 16% scrap input while remainder is processed and credited as avoided burden

LCI Source:
GLO: Steel wire rod worldsteel (2014)
GLO: Steel turning ts (2017)
GLO: Electrolytic galvanisation (1 m² steel sheet part, electrolytic) ts (2017)
GLO: Value of scrap worldsteel (2014)

Fasteners, stainless steel 517.4 kg
Used in the following Revit families:
Batt - Plastic Interior, Metal Panel Exterior 104.4 kg (80 yrs)
Batt & Plywood 104.5 kg (80 yrs)
Insulated Panel - Metal - PLYWOOD 104.5 kg (80 yrs)
Insulated Panel - Plastic Interior, Metal Panel Exterior 104.4 kg (80 yrs)
MPP Wall 99.6 kg (80 yrs)

Used in the following Tally entries:
Metal wall panel, formed

Description:
Stainless steel part, appropriate for use as fasteners and specialized hardware (bolts, rails, clips, etc.). Data based on industry-wide EPDs for primary and secondary metal from the World Steel Association.

Life Cycle Inventory:
100% Stainless steel

Product Scope:
Cradle to gate

Transportation Distance:
By truck: 0 km*

End-of-Life Scope:
98% Recovered
2% Landfilled (inert material)

Module D Scope:
Product has 58% scrap input while remainder is processed and credited as avoided burden

LCI Source:
RER: Stainless steel Quarto plate (304) Eurofer (2010)
GLO: Steel turning ts (2017)
US: Electricity grid mix ts (2014)
RER: Stainless steel flat product (304) - value of scrap Eurofer (2010)

Glass wool unfaced batt, Knauf, EcoBatt - EPD 2,948.7 kg
Used in the following Revit families:
Batt - Plastic Interior, Metal Panel Exterior 1,474.1 kg (75 yrs)
Batt & Plywood 1,474.6 kg (75 yrs)

Used in the following Tally entries:
Glass wool, batt or blown

Description:
Knauf Insulation's batts and rolls are glasswool thermal and acoustical products that have very high post-consumer glass content and a bio-based a thermosetting resin that gives the product shape. R-values of 11 to 49. Available with kraft, foil, or flame-rated FSK-25 foil facings. EPD is representative of products manufactured in the US and for sale in North America (NA).

Life Cycle Inventory:
For information and quantities, see EPD

Product Scope:
Cradle to gate, including packaging disposal

Transportation Distance:
By truck: 0 km*

50'-0" Frame Wall Explorations

Wall Option Explorations

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LCI Data (continued)

End-of-Life Scope: 100% Landfilled	Module D Scope: Recovered wood products credited as avoided burden.
LCI Source: EPD (NA), Knauf Insulation (2013)	LCI Source: RNA: Laminated veneer lumber (LVL) CORRIM (2011)
EPD Source: 4786058564.101.1	EPD Source: 13CA24184.105.1
EPD Designation Holder: Knauf Insulation	EPD Designation Holder: American Wood Council and Canadian Wood Council
EPD Program Operator: UL Environment	EPD Program Operator: UL Environment
EPD Expiration: 7/12/2019	EPD Expiration: 7/12/2019
Interior grade plywood, US, AWC - EPD	Mineral wool, low density, NAIMA - EPD
Used in the following Revit families: Batt - Plastic Interior, Metal Panel Exterior Batt & Plywood Insulated Panel - Metal - PLYWOOD Plywood Deck	Used in the following Revit families: Insulated Panel - Metal - PLYWOOD Insulated Panel - Plastic Interior, Metal Panel Exterior MPP Roof Deck MPP Wall Plywood Deck
38,690.3 kg	29,739.5 kg
Used in the following Tally entries: Plywood, interior grade	Used in the following Tally entries: Mineral wool, board, generic
Description: Plywood, unfinished. Industry-wide EPD from the American Wood Council.	Description: Rockwool (mineral wool) board light density. Industry-wide EPD from the North America Insulation Manufacturers Association. EPD representative of conditions in North America.
Life Cycle Inventory: For information and quantities, see EPD	Life Cycle Inventory: For information and quantities, see EPD
Product Scope: Cradle to gate, uncoated	Product Scope: Cradle to gate
Transportation Distance: By truck: 0 km*	Transportation Distance: By truck: 0 km*
End-of-Life Scope: 14.5% Recovered 22% Incinerated with energy recovery 63.5% Landfilled (wood product waste)	End-of-Life Scope: 100% Landfilled (inert waste)
Module D Scope: Recovered wood products credited as avoided burden.	LCI Source: US: Rock board insulation (light density) NAIMA (2007)
LCI Source: RNA: Softwood plywood CORRIM (2011)	EPD Source: 4786060412.102.1
EPD Source: 13CA24184.103.1	EPD Designation Holder: North American Insulation Manufacturer's Association (NAIMA)
EPD Designation Holder: American Wood Council and Canadian Wood Council	EPD Program Operator: UL Environment
EPD Program Operator: UL Environment	EPD Expiration: 11/8/2018
EPD Expiration: 4/16/2019	
Laminated veneer lumber (LVL), AWC - EPD	Paint, enamel, solvent based
Used in the following Revit families: Glulam-Western Species-IL MPP Roof Deck MPP Wall	Used in the following Revit families: Batt - Plastic Interior, Metal Panel Exterior Batt & Plywood Insulated Panel - Metal - PLYWOOD Insulated Panel - Plastic Interior, Metal Panel Exterior MPP Roof Deck MPP Wall Plywood Deck
74,555.4 kg	10,970.2 kg
Used in the following Tally entries: Laminated veneer lumber (LVL)	Used in the following Tally entries: Metal roofing panels, formed Metal wall panel, formed
Description: Laminated veneer lumber sheet stock. Industry-wide EPD from the American Wood Council. EPD representative of conditions in the US.	Description: Solvent-based enamel paint, appropriate for use on metals
Life Cycle Inventory: For information and quantities, see EPD	Life Cycle Inventory: 17% Binding agent 16% Pigments and fillers 67% Solvent
Product Scope: Cradle to gate	Product Scope: Cradle to gate, including emissions during application
Transportation Distance: By truck: 0 km*	
End-of-Life Scope: 14.5% Recovered 22% Incinerated with energy recovery 63.5% Landfilled (wood product waste)	

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50'-0" Frame Wall Explorations

Wall Option Explorations

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LCI Data (continued)

Transportation Distance: By truck: 0 km*		LCI Source: RNA: Steel finished cold rolled coil worldsteel (2007) GLO: Steel sheet stamping and bending (5% loss) ts (2017) US: Electricity grid mix ts (2014) US: Lubricants at refinery ts (2014) GLO: Compressed air 7 bar (medium power consumption) ts (2014) GLO: Value of scrap worldsteel (2014)	
End-of-Life Scope: 33% Solids landfilled (plastic waste)			
LCI Source: DE: Solvent paint white (EN15804 A1-A3) ts (2017)			
SBS modified bitumen, cap sheet, ARMA - EPD	15,896.2 kg	Unreinforced polypropylene paneling	4,097.2 kg
Used in the following Revit families: Batt - Plastic Interior, Metal Panel Exterior Batt & Plywood Insulated Panel - Metal - PLYWOOD Insulated Panel - Plastic Interior, Metal Panel Exterior MPP Wall	3,208.3 kg (80 yrs) 3,209.4 kg (80 yrs) 3,210.2 kg (80 yrs) 3,208.2 kg (80 yrs) 3,059.9 kg (80 yrs)	Used in the following Revit families: Batt - Plastic Interior, Metal Panel Exterior Insulated Panel - Plastic Interior, Metal Panel Exterior Used in the following Tally entries: Unreinforced polypropylene paneling Description: Extruded polypropylene solid sheet stock Life Cycle Inventory: 100% Polypropylene granulate (PP) Product Scope: Cradle to gate Transportation Distance: By truck: 1299 km End-of-Life Scope: 100% landfilled (plastic waste) LCI Source: US: Polypropylene granulate (PP) ts (2017) GLO: Plastic extrusion profile (unspecific) ts (2017) US: Electricity grid mix ts (2014) US: Thermal energy from natural gas ts (2014) US: Lubricants at refinery ts (2014) GLO: Compressed air 7 bar (medium power consumption) ts (2014)	2,048.6 kg (80 yrs*) 2,048.6 kg (80 yrs*)
Used in the following Tally entries: Self-adhering sheet waterproofing, modified bituminous sheet			
Description: Styrene-butadiene-styrene (SBS)-modified bituminous cap sheet. Industry-wide EPD from the Asphalt Roofing Manufacturers Association. EPD representative of conditions in North America.			
Life Cycle Inventory: For information and quantities, see EPD			
Product Scope: Cradle to gate			
Transportation Distance: By truck: 0 km*			
End-of-Life Scope: 100% Landfilled (plastic waste)			
LCI Source: RNA: Atactic-polypropylene (APP)-modified bitumen (asphalt) roofing cap sheet - ARMA (A1-A3) (2012)			
EPD Source: 4787168709.105.1			
EPD Designation Holder: Asphalt Roofing Manufacturers Association (ARMA)			
EPD Program Operator: UL Environment			
EPD Expiration: 10/28/2021			
Steel, sheet	44,546.2 kg		
Used in the following Revit families: Batt - Plastic Interior, Metal Panel Exterior Batt & Plywood Insulated Panel - Metal - PLYWOOD Insulated Panel - Plastic Interior, Metal Panel Exterior MPP Roof Deck MPP Wall Plywood Deck	6,962.0 kg (45 yrs) 6,964.4 kg (45 yrs) 3,483.1 kg (80 yrs*) 6,961.8 kg (45 yrs) 2,631.9 kg (80 yrs) 6,639.9 kg (45 yrs) 10,903.2 kg (80 yrs)		
Used in the following Tally entries: Metal roofing panels, formed Metal wall panel, formed			
Description: Steel sheet			
Life Cycle Inventory: 100% Steel sheet			
Product Scope: Cradle to gate			
Transportation Distance: By truck: 0 km*			
End-of-Life Scope: 98% Recovered 2% Landfilled (inert material)			
Module D Scope: Product has 16% scrap input while remainder is processed and credited as avoided burden			

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APPENDIX 7 : TALLY REPORT - CLADDING EXPLORATIONS BIOGENIC CARBON

The following report was created from Tally from user-specified materials. The report has the life cycle assessment broken down by life cycle stages, division and revit materials. The methodology for calculating the life cycle assessment is also included.

This report is for the cladding explorations and includes the impact from biogenic carbon.

50'-0" Frame Wall Explorations

Wall Option Explorations

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Project Name

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Design option comparison

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Report Summary

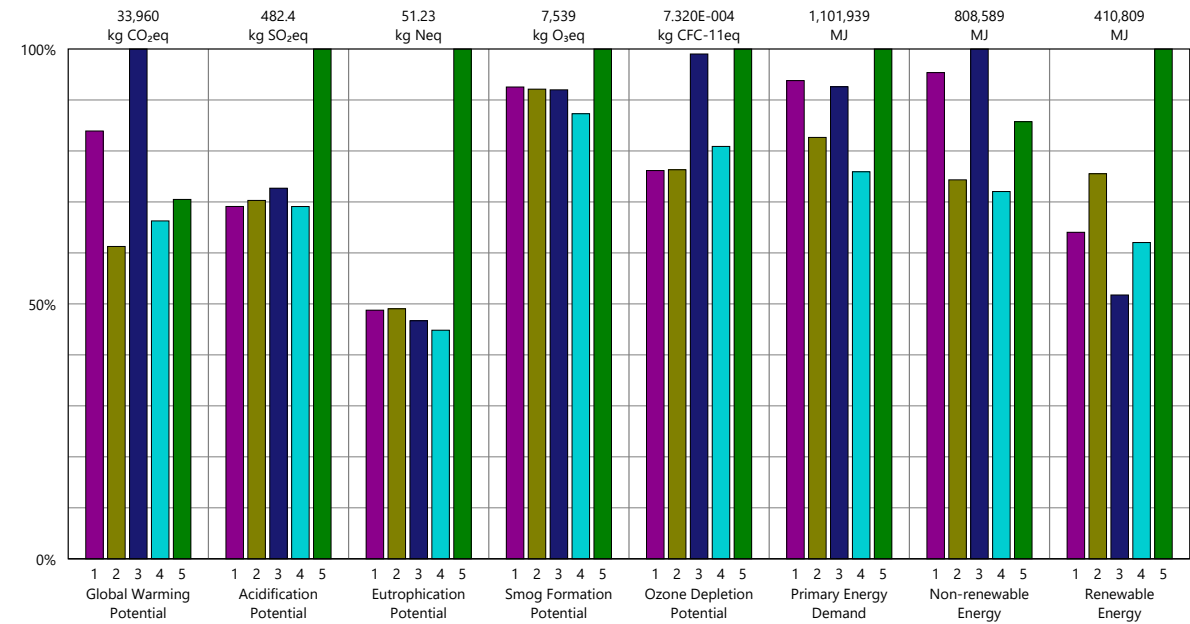
Created with Tally
Non-commercial Version 2021.11.01.01

Goal and Scope of Assessment
1235

Author smopdx1
Company 12345
Date 5/31/2022

Project Project Name
Location Enter address here
Gross Area 5,000 ft²
Building Life 80 years

Boundaries Cradle to grave, inclusive of
biogenic carbon; see appendix for a
full list of materials and processes

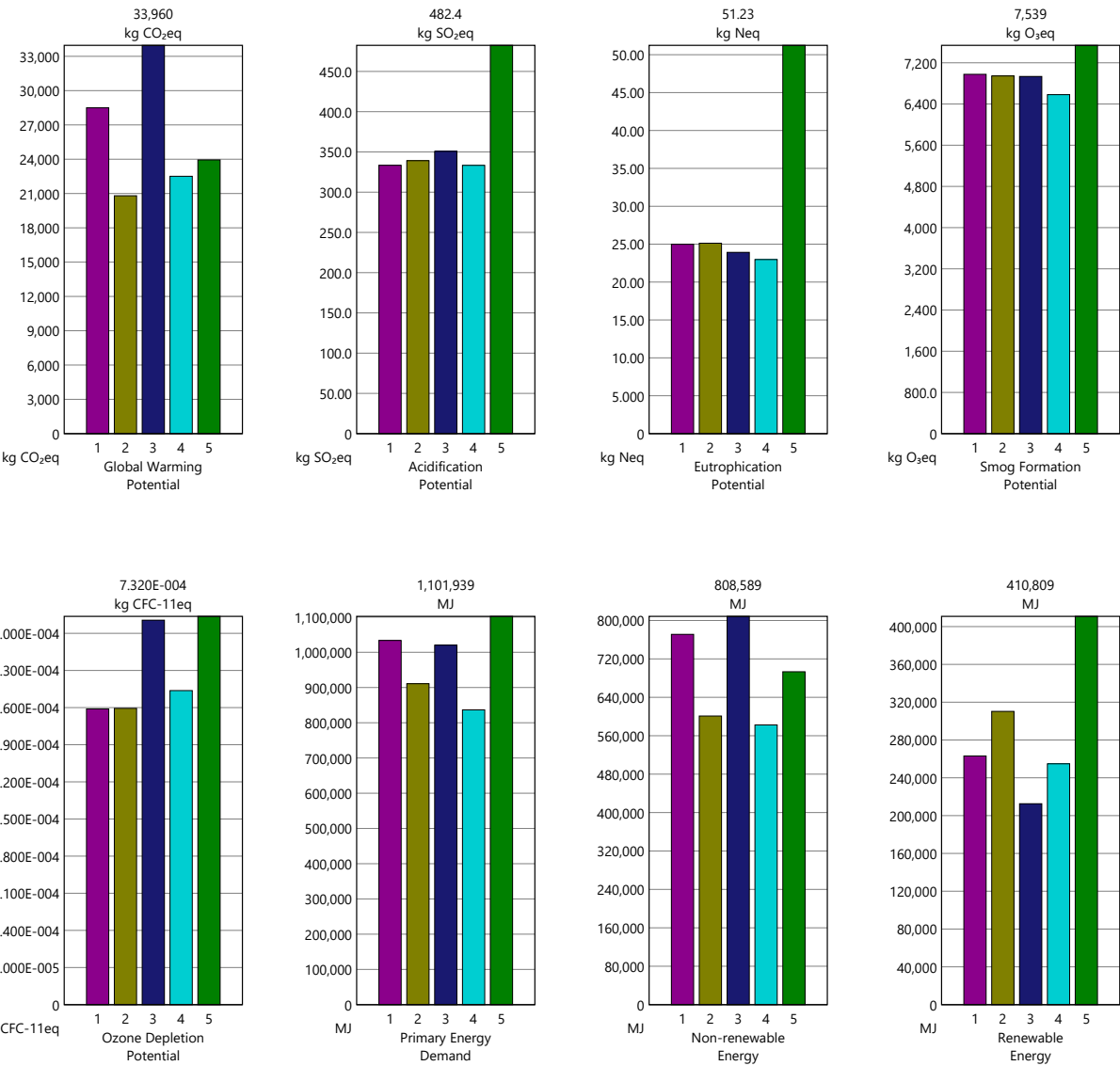


Legend

Design Options

- Batt Insulation - Plastic Interior, Metal Panel Exterior
- Batt Insulation - Plywood Interior, Metal Panel Exterior
- Insulated Panel - Plastic Interior, Metal Panel Exterior
- Insulated Panel - Plywood Interior, Metal Panel Exterior
- MPP Wall - Metal Panel (primary)

Report Summary (continued)

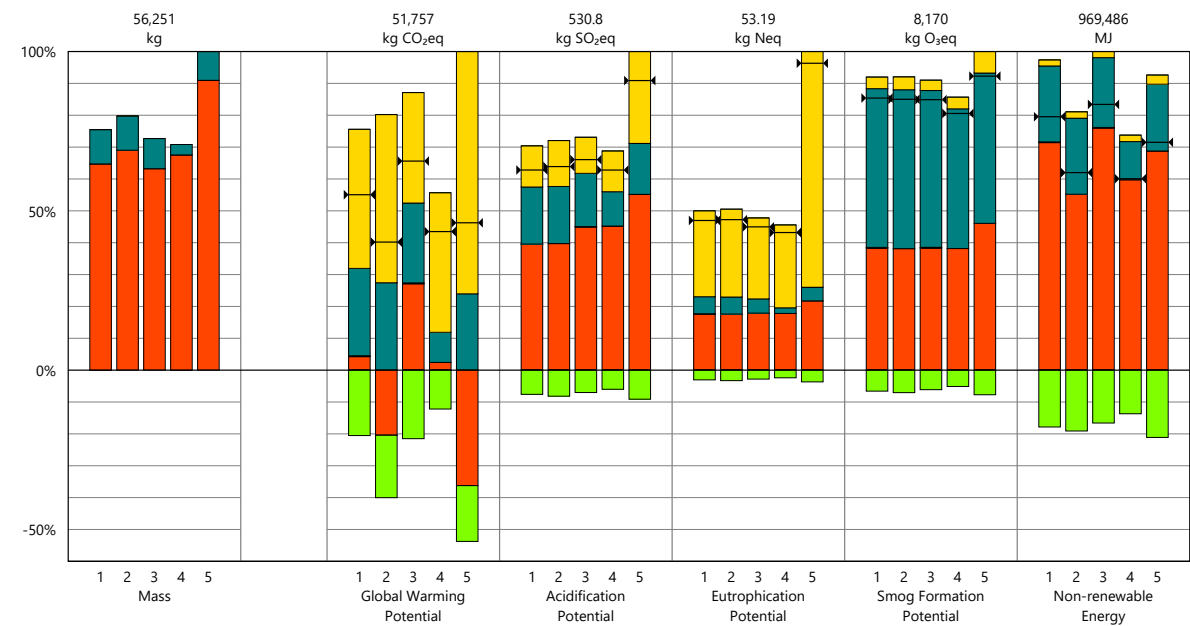


Legend

Design Options

- Batt Insulation - Plastic Interior, Metal Panel Exterior
- Batt Insulation - Plywood Interior, Metal Panel Exterior
- Insulated Panel - Plastic Interior, Metal Panel Exterior
- Insulated Panel - Plywood Interior, Metal Panel Exterior
- MPP Wall - Metal Panel (primary)

Results per Life Cycle Stage



Legend

Net value (impacts + credits)

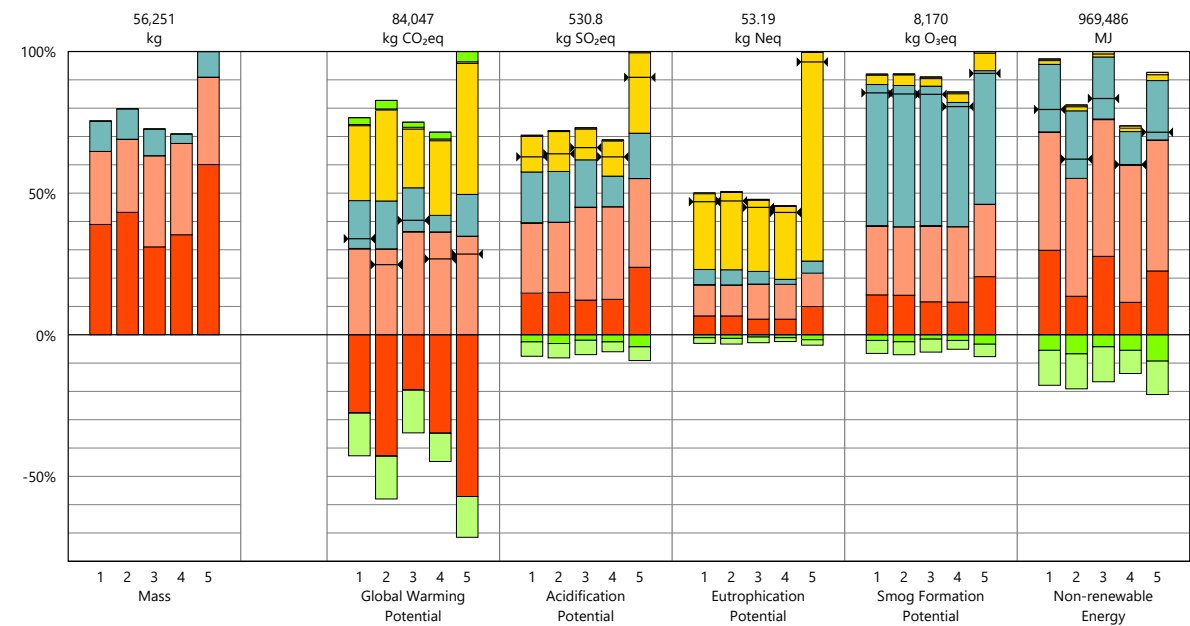
Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

Life Cycle Stages

- Product [A1-A3]
- Transportation [A4]
- Maintenance and Replacement [B2-B5]
- End of Life [C2-C4]
- Module D [D]

Results per Life Cycle Stage, itemized by Division



Legend

Net value (impacts + credits)

Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

Product [A1-A3]

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

Transportation [A4]

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

Maintenance and Replacement [B2-B5]

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

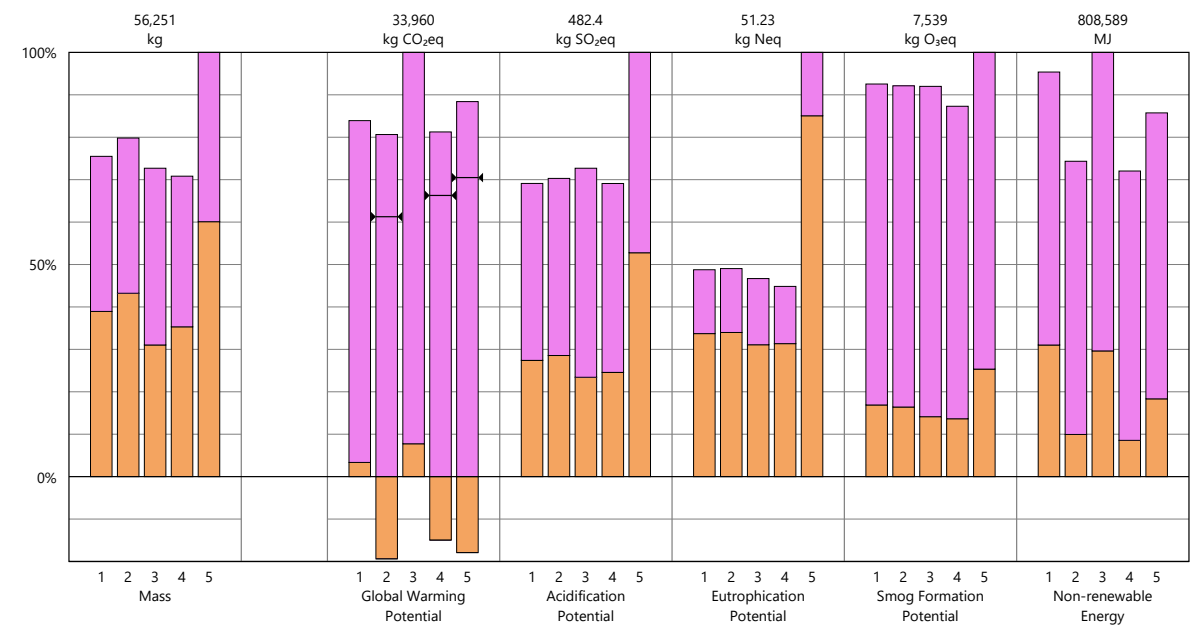
End of Life [C2-C4]

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

Module D [D]

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

Results per Division



Legend

Net value (impacts + credits)

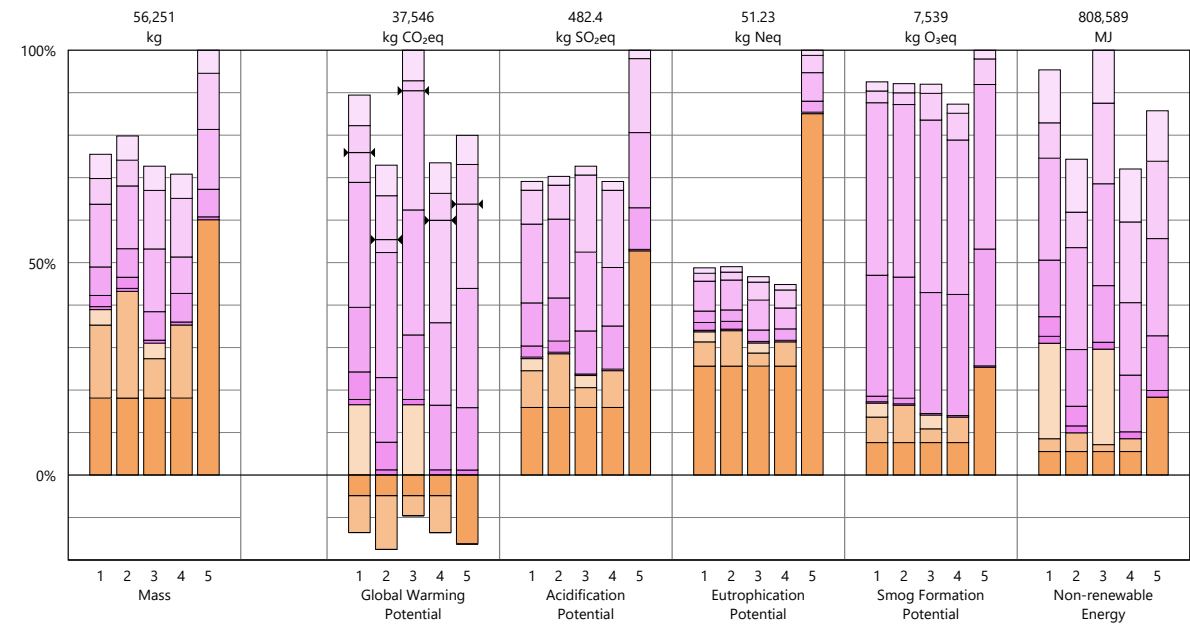
Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

Divisions

- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection

Results per Division, itemized by Tally Entry



Legend

Net value (impacts + credits)

Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

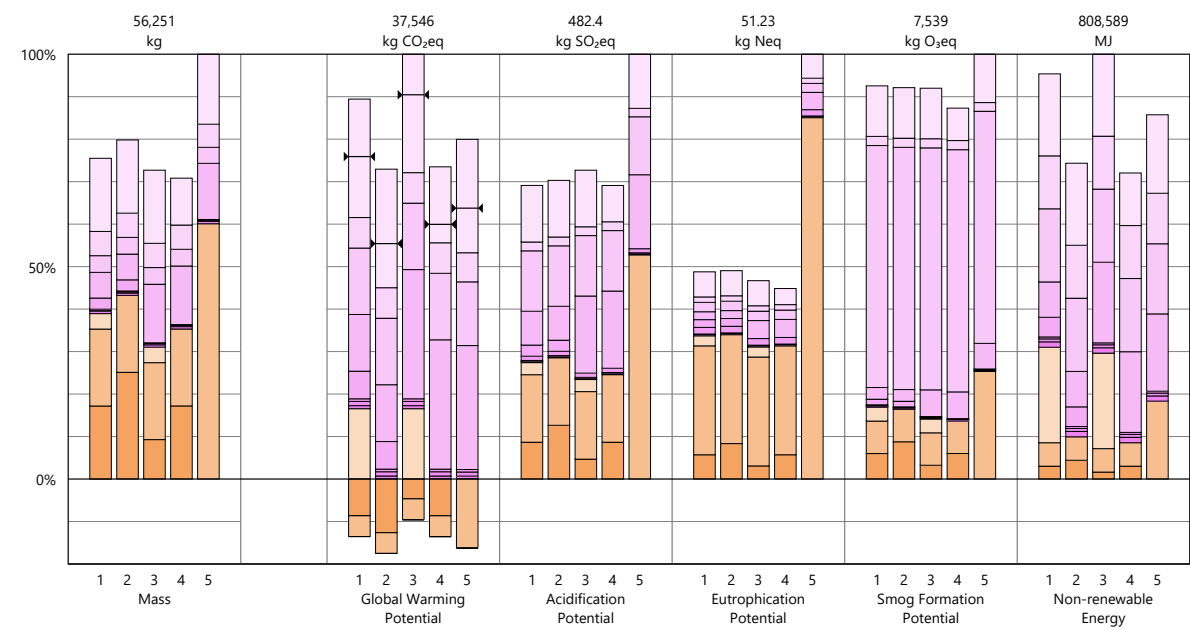
06 - Wood/Plastics/Composites

- Laminated veneer lumber (LVL)
- Plywood, interior grade
- Unreinforced polypropylene paneling

07 - Thermal and Moisture Protection

- Asphalt felt sheet
- Glass wool, batt or blown
- Metal roofing panels, formed
- Metal wall panel, formed
- Mineral wool, board, generic
- Self-adhering sheet waterproofing, modified bituminous sheet

Results per Division, itemized by Material



Legend

Net value (impacts + credits)

Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

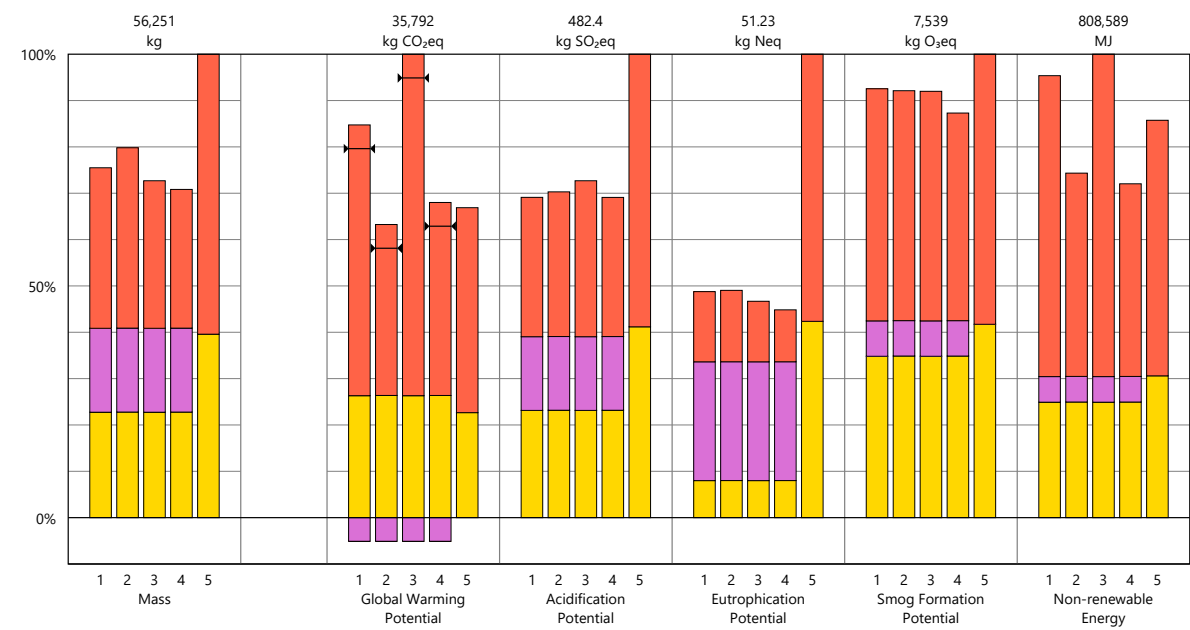
06 - Wood/Plastics/Composites

- Interior grade plywood, US, AWC - EPD
- Laminated veneer lumber (LVL), AWC - EPD
- Unreinforced polypropylene paneling

07 - Thermal and Moisture Protection

- Asphalt felt sheet, roofing underlayment, ARMA - EPD
- Fasteners, galvanized steel
- Fasteners, stainless steel
- Glass wool unfaced batt, Knauf, EcoBatt - EPD
- Mineral wool, low density, NAIMA - EPD
- Paint, enamel, solvent based
- SBS modified bitumen, cap sheet, ARMA - EPD
- Steel, sheet

Results per Revit Category



Legend

Net value (impacts + credits)

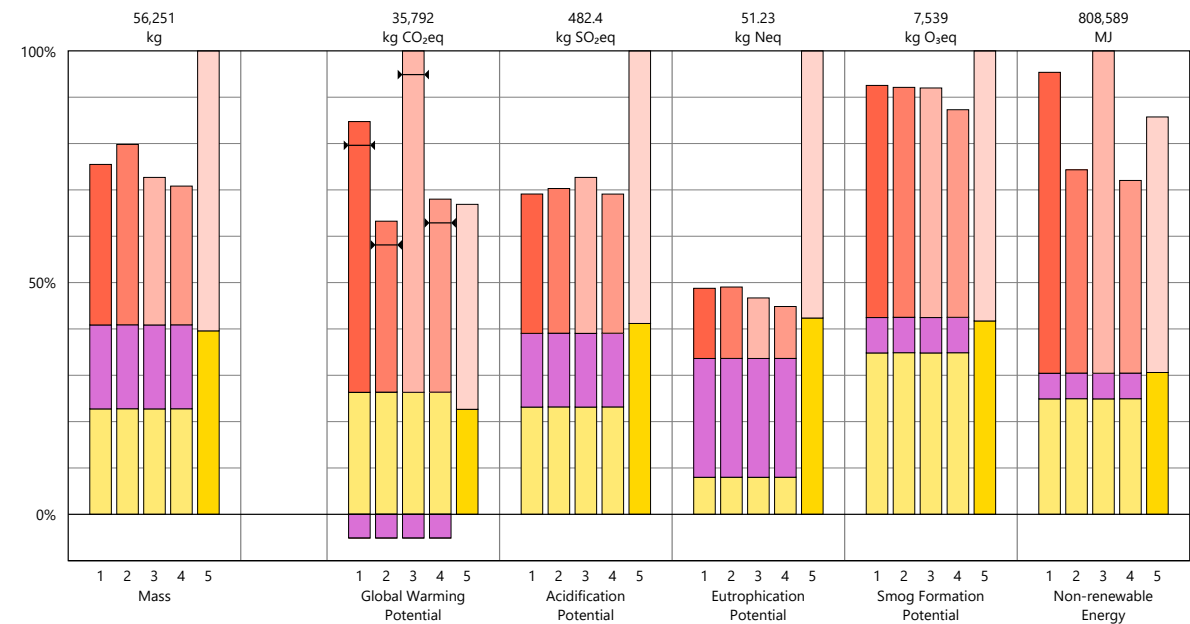
Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

Revit Categories

- Roofs
- Structure
- Walls

Results per Revit Category, itemized by Family



Legend

Net value (impacts + credits)

Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

Roofs

- MPP Roof Deck
- Plywood Deck

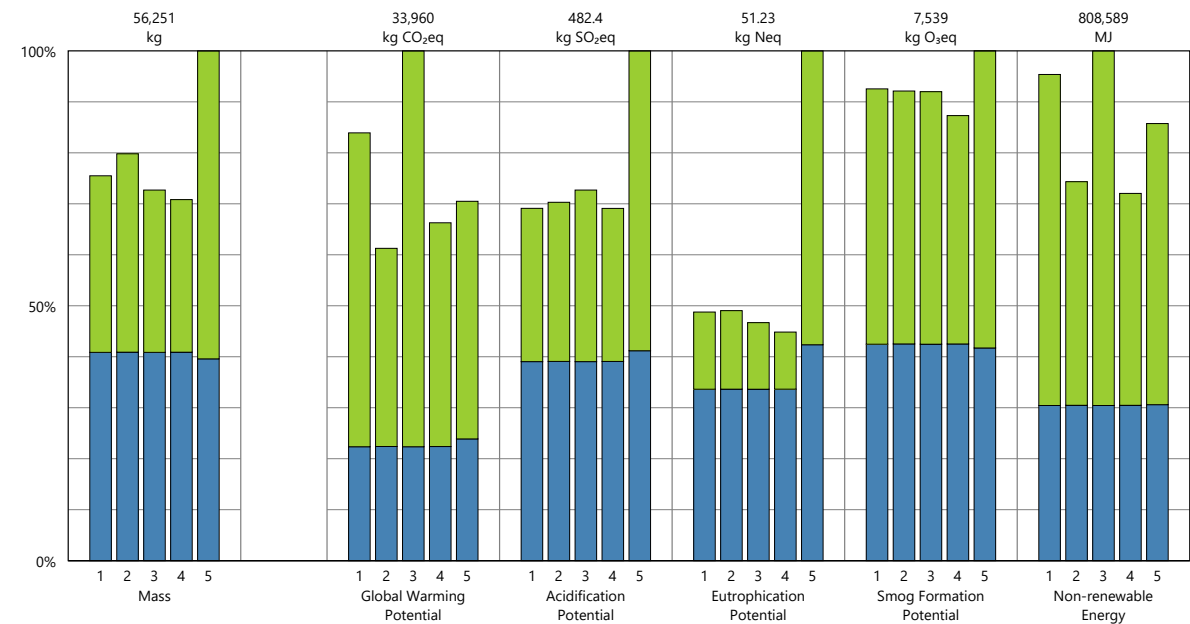
Structure

- Glulam-Western Species-IL

Walls

- Batt - Plastic Interior, Metal Panel Exterior
- Batt & Plywood
- Insulated Panel - Metal - PLYWOOD
- Insulated Panel - Plastic Interior, Metal Panel Exterior
- MPP Wall

Results per Building Element



Legend

Design Options

- Option 1 - Batt Insulation - Plastic Interior, Metal Panel Exterior
- Option 2 - Batt Insulation - Plywood Interior, Metal Panel Exterior
- Option 3 - Insulated Panel - Plastic Interior, Metal Panel Exterior
- Option 4 - Insulated Panel - Plywood Interior, Metal Panel Exterior
- Option 5 - MPP Wall - Metal Panel (primary)

Building Elements

- Superstructure
- Enclosure

Calculation Methodology

LIFE CYCLE ASSESSMENT METHODS

The following provides a description of terms and methods associated with the use of Tally to conduct life cycle assessment for construction works and construction products. Tally methodology is consistent with LCA standards ISO 14040-14044, ISO 21930:2017, ISO 21931:2010, EN 15804:2012, and EN 15978:2011. For more information about LCA, please refer to these standards or visit www.choosetally.com.

Studied objects

The life cycle assessment (LCA) results reported represent an analysis of a single building, multiple buildings, or a comparative analysis of two or more building design options. The assessment may represent the complete architectural, structural, and finish systems of the building(s) or a subset of those systems. This may be used to compare the relative environmental impacts associated with building components or for comparative study with one or more reference buildings. Design options may represent a full or partial building across various stages of the design process, or they may represent multiple schemes of a full or partial building that are being compared to one another across a range of evaluation criteria.

Functional unit and reference unit

A functional unit is the quantified performance of a product, building, or system that defines the object of the study. The functional unit of a single building should include the building type (e.g. office, factory), relevant technical and functional requirements (e.g. regulatory requirements, energy performance), pattern of use (e.g. occupancy, usable floor area), and the required service life. For a design option comparison of a partial building, the functional unit is the complete set of building systems or products that perform a given function. It is the responsibility of the modeler to assure that reference buildings or design options are functionally equivalent in terms of scope and relevant performance. The expected life of the building has a default value of 60 years and can be modified by the modeler.

The reference unit is the full collection of processes and materials required to produce a building or portion thereof and is quantified according to the given goal and scope of the assessment over the full life of the building. If construction impacts are included in the assessment, the reference unit also includes the energy, water, and fuel consumed on the building site during construction. If operational energy is included in the assessment, the reference unit includes the electrical and thermal energy consumed on site over the life of the building.

Data source

Tally utilizes a custom designed LCA database that combines material attributes, assembly details, and architectural specifications with environmental impact data resulting from the collaboration between KieranTimberlake and thinkstep. LCA modeling was conducted in GaBi 8.5 using GaBi 2018 databases and in accordance with [GaBi databases and modeling principles](#).

The data used are intended to represent the US and the year 2017. Where representative data were unavailable, proxy data were used. The datasets used, their geographic region, and year of reference are listed for each entry. An effort was made to choose proxy datasets that are technologically consistent with the relevant entry.

Data quality and uncertainty

Uncertainty in results can stem from both the data used and their application. Data quality is judged by: its measured, calculated, or estimated precision; its completeness, such as unreported emissions; its consistency, or degree of uniformity of the methodology applied on a study serving as a data source; and geographical, temporal, and technological representativeness. The [GaBi LCI databases](#) have been used in LCA models worldwide in both industrial and scientific applications. These LCI databases have additionally been used both as internal and critically reviewed and published studies. Uncertainty introduced by the use of proxy data is reduced by using technologically, geographically, and/or temporally similar data. It is the responsibility of the modeler to appropriately apply the predefined material entries to the building under study.

System boundaries and delimitations

The analysis accounts for the full cradle to grave life cycle of the design options studied across all life cycle stages, including material manufacturing, maintenance and replacement, and eventual end of life. Optionally, the construction impacts and operational energy of the building can be included within the scope. Product stage impacts are excluded for materials and components indicated as existing or salvaged by the modeler. The modeler defines whether the boundary includes or excludes the flow of biogenic carbon, which is the carbon absorbed and generated by biological sources (e.g. trees, algae) rather than from fossil resources.

Architectural materials and assemblies include all materials required for the product’s manufacturing and use including hardware, sealants, adhesives, coatings, and finishing. The materials are included up to a 1% cut-off factor by mass except for known materials that have high environmental impacts at low levels. In these cases, a 1% cut-off was implemented by impact.

Calculation Methodology

LIFE CYCLE STAGES

The following describes the scope and system boudaries used to define each stage of the life cycle of a building or building product, from raw material acquisition to final disposal. For products listed in Tally as Environmental Product Declarations (EPD), the full life cycle impacts are included, even if the published EPD only includes the Product stage [A1-A3].

Product [EN 15978 A1 - A3]

This encompasses the full manufacturing stage, including raw material extraction and processing, intermediate transportation, and final manufacturing and assembly. The product stage scope is listed for each entry, detailing any specific inclusions or exclusions that fall outside of the cradle to gate scope. Infrastructure (buildings and machinery) required for the manufacturing and assembly of building materials are not included and are considered outside the scope of assessment.

Transportation [EN 15978 A4]

This counts transportation from the manufacturer to the building site during the construction stage and can be modified by the modeler.

Construction Installation [EN 15978 A5] (Optional)

This includes the anticipated or measured energy and water consumed on-site during the construction installation process, as specified by the modeler.

Maintenance and Replacement [EN 15978 B2-B5]

This encompasses the replacement of materials in accordance with their expected service life. This includes the end of life treatment of the existing products as well as the cradle to gate manufacturing and transportation to site of the replacement products. The service life is specified separately for each product. Refurbishment of materials marked as existing or salvaged by the modeler is also included.

Operational Energy [EN 15978 B6] (Optional)

This is based on the anticipated or measured energy and natural gas consumed at the building site over the lifetime of the building, as indicated by the modeler.

End of Life [EN 15978 C2-C4]

This includes the relevant material collection rates for recycling, processing requirements for recycled materials, incineration rates, and landfilling rates. The impacts associated with landfilling are based on average material properties, such as plastic waste, biodegradable waste, or inert material. Stage C2 encompasses the transport from the construction site to end-of-life treatment based on national averages. Stages C3-C4 account for waste processing and disposal, i.e., impacts associated with landfilling or incineration.

Module D [EN 15978 D]

This accounts for reuse potentials that fall beyond the system boundary, such as energy recovery and recycling of materials. Along with processing requirements, the recycling of materials is modeled using an avoided burden approach, where the burden of primary material production is allocated to the subsequent life cycle based on the quantity of recovered secondary material. Incineration of materials includes credit for average US energy recovery rates.

PRODUCT	CONSTRUCTION	USE	END-OF-LIFE	MODULE D
A1. Extraction A2. Transport (to factory) A3. Manufacturing	A4. Transport (to site) A5. Construction Installation	B1. Use B2. Maintenance B3. Repair B4. Replacement B5. Refurbishment B6. Operational energy B7. Operational water	C1. Demolition C2. Transport (to disposal) C3. Waste processing C4. Disposal	D. Benefits and loads beyond the system boundary from: 1. Reuse 2. Recycling 3. Energy recovery

Life-Cycle Stages as defined by EN 15978. Processes included in Tally modeling scope are shown in bold. Italics indicate optional processes.

Calculation Methodology

ENVIRONMENTAL IMPACT CATEGORIES

A characterization scheme translates all emissions and fuel use associated with the reference flow into quantities of categorized environmental impact. As the degree that the emissions will result in environmental harm depends on regional ecosystem conditions and the location in which they occur, the results are reported as impact potential. Potential impacts are reported in kilograms of equivalent relative contribution (eq) of an emission commonly associated with that form of environmental impact (e.g. kg CO₂eq).

The following list provides a description of environmental impact categories reported according to the TRACI 2.1 characterization scheme, the environmental impact model developed by the US EPA to quantify environmental impact risk associated with emissions to the environment in the United States. TRACI is the standard environmental impact reporting format for LCA in North America. Impacts associated with land use change and fresh water depletion are not included in TRACI 2.1. For more information on TRACI 2.1, reference Bare 2010, EPA 2012, and Guinée 2001. For further description of measurement of environmental impacts in LCA, see Simonen 2014.

Acidification Potential (AP)kg SO₂eq

A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule’s capacity to increase the hydrogen ion (H⁺) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline, and the deterioration of building materials.

Eutrophication Potential (EP)kg Neq

A measure of the impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems, increased biomass production may lead to depressed oxygen levels caused by the additional consumption of oxygen in biomass decomposition.

Global Warming Potential (GWP)kg CO₂eq

A measure of greenhouse gas emissions, such as carbon dioxide and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may, in turn, have adverse impacts on ecosystem health, human health, and material welfare.

Ozone Depletion Potential (ODP)kg CFC-11eq

A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth’s surface with detrimental effects on humans and plants. As these impacts tend to be very small, ODP impacts can be difficult to calculate and are prone to a larger margin of error than the other impact categories.

Smog Formation Potential (SFP)kg O₃eq

A measure of ground level ozone, caused by various chemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in sunlight. Human health effects can result in a variety of respiratory issues, including increasing symptoms of bronchitis, asthma, and emphysema. Permanent lung damage may result from prolonged exposure to ozone. Ecological impacts include damage to various ecosystems and crop damage.

Primary Energy Demand (PED)MJ (lower heating value)

A measure of the total amount of primary energy extracted from the earth. PED tracks energy resource use, not the environmental impacts associated with the resource use. PED is expressed in energy demand from non-renewable resources and from renewable resources. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account when calculating this result.

Non-Renewable Energy DemandMJ (lower heating value)

A measure of the energy extracted from non-renewable resources (e.g. petroleum, natural gas, etc.) contributing to the PED. Non-renewable resources are those that cannot be regenerated within a human time scale. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account when calculating this result.

Renewable Energy DemandMJ (lower heating value)

A measure of the energy extracted from renewable resources (e.g. hydropower, wind energy, solar power, etc.) contributing to the PED. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account when calculating this result.

LCI Data

END-OF-LIFE [C2-C4]

A Life Cycle Inventory(LCI) is a compilation and quantification of inputs and outputs for the reference unit.The following LCI provides a summary of all energy, construction, transportation, and material inputs present in the study. Materials are listed in alphabetical order along with a list of all Revit families and Tally entries in which they occur, along with any notes and system boundaries accompanying their database entries. Each entry lists the detailed scope for the LCI data sources used from the GaBi LCI database and identifies the LCI data source.

For LCI data sourced from an Environmental Product Declaration (EPD), the product manufacturer, EPD identification number, and Program Operator are listed. Where the LCI source does not provide data for all life cycle stages, default North American average values are used. This is of particular importance for European EPD sources, as EPD data are generally only provided for the product stage, and North American average values are used for the remaining life cycle stages.

Where specific quantities are associated with a data entry, such as user inputs, energy values, or material mass, the quantity is listed on the same line as the title of the entry.

TRANSPORTATION [A4]

Default transportation values are based on the three-digit material commodity code in the 2012 Commodity Flow Survey by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation is not available.

Transportation by Barge
Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by barge.

LCI Source:
GLO: Average ship, 1500t payload capacity/ canal ts (2017)
US: Diesel mix at filling station ts (2014)

Transportation by Container Ship
Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by container ship.

LCI Source:
GLO: Container ship, 27500 dwt payload capacity, ocean going ts (2017)
US: Heavy fuel oil at refinery (0.3wt.% S) ts (2014)

Transportation by Rail
Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by cargo rail.

LCI Source:
GLO: Rail transport cargo - Diesel, average train, gross tonne weight 1000t / 726t payload capacity ts (2017)
US: Diesel mix at filling station ts (2014)

Transportation by Truck
Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by diesel truck.

LCI Source:
US: Truck - Trailer, basic enclosed / 45,000 lb payload - 8b ts (2017)
US: Diesel mix at filling station ts (2014)

Project Name

Design option comparison

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LCI Data (continued)

END-OF-LIFE [C2-C4]

Specific end-of-life scenarios are detailed for each entry based on the US construction and demolition waste treatment methods and rates in the 2016 WARM Model by the US Environmental Protection Agency except where otherwise specified. Heterogeneous assemblies are modeled using the appropriate methodologies for the component materials.

End-of-Life Landfill

Scope:
Materials for which no recycling or incineration rates are known, no recycling occurs within the US at a commercial scale, or which are unable to be recycled are landfilled. This includes glass, drywall, insulation, and plastics. The solids contents of coatings, sealants, and paints are assumed to go to landfill, while the solvents or water evaporate during installation. Where the landfill contains biodegradable material, the energy recovered from landfill gas utilization is reflected as a credit in Module D.

LCI Source:
US: Glass/inert on landfill ts (2017)
US: Biodegradable waste on landfill, post-consumer ts (2017)
US: Plastic waste on landfill, post-consumer ts (2017)

Concrete End-of-Life

Scope:
Concrete (or other masonry products) are recycled into aggregate or general fill material or they are landfilled. It is assumed that 55% of the concrete is recycled. Module D accounts for both the credit associated with off-setting the production aggregate and the burden of the grinding energy required for processing.

LCI Source:
US: Diesel mix at refinery ts (2014)
GLO: Fork lifter (diesel consumption) ts (2016)
EU - 28 Gravel 2/32 ts (2017)
US: Glass/inert on landfill ts (2017)

Metals End-of-Life

Scope:
Metal products are modeled using the avoided burden approach. The recycling rate at end of life is used to determine how much secondary metal can be recovered after having subtracted any scrap input into manufacturing (net scrap). Net scrap results in an environmental credit in Module D for the corresponding share of the primary burden that can be allocated to the subsequent product system using secondary material as an input. If the value in Module D reflects an environmental burden, then the original product (A1-A3) contains more secondary material than is recovered.

LCI Source:
Aluminum - RNA: Primary Aluminum Ingot AA/ts (2010)
Aluminum - RNA: Secondary Aluminum Ingot AA/ts (2010)
Brass - GLO: Zinc mix ts (2012)
Brass - GLO: Copper (99.99% cathode) ICA (2013)
Brass - EU-28: Brass (CuZn20) ts (2017)
Copper - DE: Recycling potential copper sheet ts (2016)
Steel - GLO: Value of scrap worldsteel (2014)
Zinc - GLO: Special high grade zinc IZA (2012)

Wood End-of-Life

Scope:
End of Life waste treatment methods and rates for wood are based on the 2014 Municipal Solid Waste and Construction Demolition Wood Waste Generation and Recovery in the United States report by Dovetail Partners, Inc. It is assumed that 63.5% of wood is sent to landfill, 22% to incineration, and 14.5% to recovery.

LCI Source:
US: Untreated wood in waste incineration plant ts (2017)
US: Wood product (OSB, particle board) waste in waste incineration plant ts (2017)
US: Wood products (OSB, particle board) on landfill, post-consumer ts (2017)
US: Untreated wood on landfill, post-consumer ts (2017)
RNA: Softwood lumber CORRIM (2011)

Project Name

Design option comparison

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LCI Data

PRODUCT [A1-A3]

Materials and components are listed in alphabetical order along with a list of all Revit families and Tally entries in which they occur. The masses given here refer to the quantity of each material used over the building's life-cycle, which includes both Product [A1-A3] and Use [B2-B5] stages.

Additional provided data describing scope boundaries for each life cycle stage may be useful for interpretation of the impacts associated with the specific material or component. Each material or component is listed with its service life, or period of time after installation it is expected to meet the service requirements prior to replacement or repair. This value is indicated in parentheses next to the mass of the material associated with the listed Revit family. Values for transportation distance or service life shown with an asterisk (*) indicate user-defined changes to default values. Values for service life shown with a dagger (†) indicate materials identified by the modeler as existing or salvaged.

Asphalt felt sheet, roofing underlayment, ARMA - EPD 1,552.4 kg
Used in the following Revit families:
MPP Roof Deck 301.9 kg (80 yrs*)
Plywood Deck 1,250.6 kg (80 yrs*)

Used in the following Tally entries:
Asphalt felt sheet

Description:
Asphalt felt sheet, exclusive of spray adhesive for roofing and wall application. Type II felt, also called No. 30 asphalt felt, is the minimum accepted by the IBC and IRC for underlayment and interlayment. Data based on industry-wide EPD from the Asphalt Roofing Manufacturers Association.

Life Cycle Inventory:
For information and quantities, see EPD

Product Scope:
Cradle to gate

Transportation Distance:
By truck: 0 km*

End-of-Life Scope:
5% Recycled into bitumen
95% Landfilled (inert waste)

Module D Scope:
Avoided burden credit for recycling into bitumen, includes grinding energy

LCI Source:
RNA: Underlayment, asphalt shingle roofing system component - ARMA (A1-A3) ts (2012)

EPD Source:
4787168709.101.1

EPD Designation Holder:
Asphalt Roofing Manufacturers Association (ARMA)

EPD Program Operator:
UL Environment

EPD Expiration:
10/28/2021

Fasteners, galvanized steel 829.7 kg
Used in the following Revit families:
MPP Roof Deck 161.3 kg (80 yrs*)
Plywood Deck 668.4 kg (80 yrs*)

Used in the following Tally entries:
Asphalt felt sheet
Metal roofing panels, formed

Description:
Galvanized steel part, appropriate for use as fasteners and specialized hardware (bolts, rails, clips, etc.).

Life Cycle Inventory:
100% Galvanized steel

Product Scope:
Cradle to gate

Transportation Distance:
By truck: 0 km*

End-of-Life Scope:
70% Recovered
30% Landfilled (inert material)

Module D Scope:
Product has 16% scrap input while remainder is processed and credited as avoided burden

LCI Source:
GLO: Steel wire rod worldsteel (2014)
GLO: Steel turning ts (2017)
GLO: Electrolytic galvanisation (1 m² steel sheet part, electrolytic) ts (2017)
GLO: Value of scrap worldsteel (2014)

Fasteners, stainless steel 517.4 kg
Used in the following Revit families:
Batt - Plastic Interior, Metal Panel Exterior 104.4 kg (80 yrs)
Batt & Plywood 104.5 kg (80 yrs)
Insulated Panel - Metal - PLYWOOD 104.5 kg (80 yrs)
Insulated Panel - Plastic Interior, Metal Panel Exterior 104.4 kg (80 yrs)
MPP Wall 99.6 kg (80 yrs)

Used in the following Tally entries:
Metal wall panel, formed

Description:
Stainless steel part, appropriate for use as fasteners and specialized hardware (bolts, rails, clips, etc.). Data based on industry-wide EPDs for primary and secondary metal from the World Steel Association.

Life Cycle Inventory:
100% Stainless steel

Product Scope:
Cradle to gate

Transportation Distance:
By truck: 0 km*

End-of-Life Scope:
98% Recovered
2% Landfilled (inert material)

Module D Scope:
Product has 58% scrap input while remainder is processed and credited as avoided burden

LCI Source:
RER: Stainless steel Quarto plate (304) Eurofer (2010)
GLO: Steel turning ts (2017)
US: Electricity grid mix ts (2014)
RER: Stainless steel flat product (304) - value of scrap Eurofer (2010)

Glass wool unfaced batt, Knauf, EcoBatt - EPD 2,948.7 kg
Used in the following Revit families:
Batt - Plastic Interior, Metal Panel Exterior 1,474.1 kg (75 yrs)
Batt & Plywood 1,474.6 kg (75 yrs)

Used in the following Tally entries:
Glass wool, batt or blown

Description:
Knauf Insulation's batts and rolls are glasswool thermal and acoustical products that have very high post-consumer glass content and a bio-based a thermosetting resin that gives the product shape. R-values of 11 to 49. Available with kraft, foil, or flame-rated FSK-25 foil facings. EPD is representative of products manufactured in the US and for sale in North America (NA).

Life Cycle Inventory:
For information and quantities, see EPD

Product Scope:
Cradle to gate, including packaging disposal

Transportation Distance:
By truck: 0 km*

Project Name

Design option comparison

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LCI Data (continued)

End-of-Life Scope: 100% Landfilled		Module D Scope: Recovered wood products credited as avoided burden.	
LCI Source: EPD (NA), Knauf Insulation (2013)		LCI Source: RNA: Laminated veneer lumber (LVL) CORRIM (2011)	
EPD Source: 4786058564.101.1		EPD Source: 13CA24184.105.1	
EPD Designation Holder: Knauf Insulation		EPD Designation Holder: American Wood Council and Canadian Wood Council	
EPD Program Operator: UL Environment		EPD Program Operator: UL Environment	
EPD Expiration: 7/12/2019		EPD Expiration: 7/12/2019	
Interior grade plywood, US, AWC - EPD	38,690.3 kg	Mineral wool, low density, NAIMA - EPD	29,739.5 kg
Used in the following Revit families:		Used in the following Revit families:	
Batt - Plastic Interior, Metal Panel Exterior	4,447.3 kg (80 yrs*)	Insulated Panel - Metal - PLWWOOD	4,348.8 kg (80 yrs*)
Batt & Plywood	8,897.8 kg (80 yrs*)	Insulated Panel - Plastic Interior, Metal Panel Exterior	4,346.1 kg (80 yrs*)
Insulated Panel - Metal - PLWWOOD	4,450.0 kg (80 yrs*)	MPP Roof Deck	3,286.0 kg (80 yrs*)
Plywood Deck	20,895.2 kg (80 yrs*)	MPP Wall	4,145.2 kg (80 yrs*)
		Plywood Deck	13,613.3 kg (80 yrs*)
Used in the following Tally entries:		Used in the following Tally entries:	
Plywood, interior grade		Mineral wool, board, generic	
Description:		Description:	
Plywood, unfinished. Industry-wide EPD from the American Wood Council.		Rockwool (mineral wool) board light density. Industry-wide EPD from the North America Insulation Manufacturers Association. EPD representative of conditions in North America.	
Life Cycle Inventory:		Life Cycle Inventory:	
For information and quantities, see EPD		For information and quantities, see EPD	
Product Scope:		Product Scope:	
Cradle to gate, uncoated		Cradle to gate	
Transportation Distance:		Transportation Distance:	
By truck: 0 km*		By truck: 0 km*	
End-of-Life Scope:		End-of-Life Scope:	
14.5% Recovered		100% Landfilled (inert waste)	
22% Incinerated with energy recovery			
63.5% Landfilled (wood product waste)			
Module D Scope:		LCI Source:	
Recovered wood products credited as avoided burden.		US: Rock board insulation (light density) NAIMA (2007)	
LCI Source:		EPD Source:	
RNA: Softwood plywood CORRIM (2011)		4786060412.102.1	
EPD Source:		EPD Designation Holder:	
13CA24184.103.1		North American Insulation Manufacturer's Association (NAIMA)	
EPD Designation Holder:		EPD Program Operator:	
American Wood Council and Canadian Wood Council		UL Environment	
EPD Program Operator:		EPD Expiration:	
UL Environment		11/8/2018	
EPD Expiration:			
4/16/2019			
Laminated veneer lumber (LVL), AWC - EPD	74,555.4 kg	Paint, enamel, solvent based	10,970.2 kg
Used in the following Revit families:		Used in the following Revit families:	
Glulam-Western Species-IL	40,751.4 kg (80 yrs*)	Batt - Plastic Interior, Metal Panel Exterior	1,240.6 kg (15 yrs)
MPP Roof Deck	14,947.9 kg (80 yrs*)	Batt & Plywood	1,241.0 kg (15 yrs)
MPP Wall	18,856.0 kg (80 yrs*)	Insulated Panel - Metal - PLWWOOD	1,241.3 kg (15 yrs)
		Insulated Panel - Plastic Interior, Metal Panel Exterior	1,240.5 kg (15 yrs)
Used in the following Tally entries:		MPP Roof Deck	937.9 kg (15 yrs)
Laminated veneer lumber (LVL)		MPP Wall	1,183.2 kg (15 yrs)
Description:		Plywood Deck	3,885.7 kg (15 yrs)
Laminated veneer lumber sheet stock. Industry-wide EPD from the American Wood Council. EPD representative of conditions in the US.		Used in the following Tally entries:	
Life Cycle Inventory:		Metal roofing panels, formed	
For information and quantities, see EPD		Metal wall panel, formed	
Product Scope:		Description:	
Cradle to gate		Solvent-based enamel paint, appropriate for use on metals	
Transportation Distance:		Life Cycle Inventory:	
By truck: 0 km*		17% Binding agent	
End-of-Life Scope:		16% Pigments and fillers	
14.5% Recovered		67% Solvent	
22% Incinerated with energy recovery		Product Scope:	
63.5% Landfilled (wood product waste)		Cradle to gate, including emissions during application	

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LCI Data (continued)

Transportation Distance: By truck: 0 km*		LCI Source: RNA: Steel finished cold rolled coil worldsteel (2007) GLO: Steel sheet stamping and bending (5% loss) ts (2017) US: Electricity grid mix ts (2014) US: Lubricants at refinery ts (2014) GLO: Compressed air 7 bar (medium power consumption) ts (2014) GLO: Value of scrap worldsteel (2014)	
End-of-Life Scope: 33% Solids landfilled (plastic waste)			
LCI Source: DE: Solvent paint white (EN15804 A1-A3) ts (2017)			
SBS modified bitumen, cap sheet, ARMA - EPD		15,896.2 kg	
Used in the following Revit families: Batt - Plastic Interior, Metal Panel Exterior Batt & Plywood Insulated Panel - Metal - PLYWOOD Insulated Panel - Plastic Interior, Metal Panel Exterior MPP Wall		3,208.3 kg (80 yrs) 3,209.4 kg (80 yrs) 3,210.2 kg (80 yrs) 3,208.2 kg (80 yrs) 3,059.9 kg (80 yrs)	
Used in the following Tally entries: Self-adhering sheet waterproofing, modified bituminous sheet			
Description: Styrene-butadiene-styrene (SBS)-modified bituminous cap sheet. Industry-wide EPD from the Asphalt Roofing Manufacturers Association. EPD representative of conditions in North America.			
Life Cycle Inventory: For information and quantities, see EPD			
Product Scope: Cradle to gate			
Transportation Distance: By truck: 0 km*			
End-of-Life Scope: 100% Landfilled (plastic waste)			
LCI Source: RNA: Atactic-polypropylene (APP)-modified bitumen (asphalt) roofing cap sheet - ARMA (A1-A3) (2012)			
EPD Source: 4787168709.105.1			
EPD Designation Holder: Asphalt Roofing Manufacturers Association (ARMA)			
EPD Program Operator: UL Environment			
EPD Expiration: 10/28/2021			
Steel, sheet		44,546.2 kg	
Used in the following Revit families: Batt - Plastic Interior, Metal Panel Exterior Batt & Plywood Insulated Panel - Metal - PLYWOOD Insulated Panel - Plastic Interior, Metal Panel Exterior MPP Roof Deck MPP Wall Plywood Deck		6,962.0 kg (45 yrs) 6,964.4 kg (45 yrs) 3,483.1 kg (80 yrs*) 6,961.8 kg (45 yrs) 2,631.9 kg (80 yrs) 6,639.9 kg (45 yrs) 10,903.2 kg (80 yrs)	
Used in the following Tally entries: Metal roofing panels, formed Metal wall panel, formed			
Description: Steel sheet			
Life Cycle Inventory: 100% Steel sheet			
Product Scope: Cradle to gate			
Transportation Distance: By truck: 0 km*			
End-of-Life Scope: 98% Recovered 2% Landfilled (inert material)			
Module D Scope: Product has 16% scrap input while remainder is processed and credited as avoided burden			
		Unreinforced polypropylene paneling	
		4,097.2 kg	
		Used in the following Revit families: Batt - Plastic Interior, Metal Panel Exterior Insulated Panel - Plastic Interior, Metal Panel Exterior	
		2,048.6 kg (80 yrs*) 2,048.6 kg (80 yrs*)	
		Used in the following Tally entries: Unreinforced polypropylene paneling	
		Description: Extruded polypropylene solid sheet stock	
		Life Cycle Inventory: 100% Polypropylene granulate (PP)	
		Product Scope: Cradle to gate	
		Transportation Distance: By truck: 1299 km	
		End-of-Life Scope: 100% landfilled (plastic waste)	
		LCI Source: US: Polypropylene granulate (PP) ts (2017) GLO: Plastic extrusion profile (unspecific) ts (2017) US: Electricity grid mix ts (2014) US: Thermal energy from natural gas ts (2014) US: Lubricants at refinery ts (2014) GLO: Compressed air 7 bar (medium power consumption) ts (2014)	

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APPENDIX 8 : ANNOTATED BIBLIOGRAPHY

This annotated bibliography provides references for this proposal. These sources were gathered through a literature review. This bibliography is meant to be a starting point for this project and therefore is not exhaustive and will be built upon as my project evolves throughout the year.

ANNOTATED BIBLIOGRAPHY

Ahmed, Shafayet, and Ingrid Arocho. 2021. **"Analysis of Cost Comparison and Effects of Change Orders during Construction: Study of a Mass Timber and a Concrete Building Project."** Journal of Building Engineering 33.

Summary : This paper provides a cost comparison between aspects of the construction process for a mass timber building and a comparable concrete building. The results show that there is a 6.43% higher construction cost for the timber building, with 5.62% of that high cost coming from change orders associated with the project. This study also suggested some remedies to avoid change orders during the construction phase of the project, citing communication and coordination as the key drivers of the cost increase.

Binderholz. 2018. **"University of Arkansas Library Storage."** 2018. binderholz.com/en-us/mass-timber-solutions/university-of-arkansas-library-storage-usa/. eference

Summary : This case study on the CLT supplier Binderholz's website discusses the details of the long span CLT tilt up library warehouse building that was constructed in 2018. The structure of the building is comprised of CLT BBS for the walls and roofs that rest on top of the load bearing glulam shell. The combination of the CLT walls and roofs with the glulam frame allows the warehouse to be constructed with as few supports as possible.

Blake, Aaron, Jamie Jang, and Emory Baldwin. 2021. **"Post + Panel : Mass Timber Succeeds Concrete Tilt-Up : Rethinking the Industrial Archetype."**

Summary : A presentation from a certificate program put on by the TallWood Design Institute in June 2021. The group presentation was looking at prototyping a mass timber tilt up construction to compete with concrete tilt. The group looked at both the cost and environmental outcomes of the two buildings.

Cameron, Grant. 2020. **"Langford, B.C. Build One of Canada's First Mass Timber Warehouses Using CLT -."** Journal of Commerce by Construction Connect, 2020. <https://canada.constructconnect.com/joc/news/projects/2020/08/langford-b-c-build-one-of-canadas-first-mass-timber-warehouses-using-clt>.

Summary : This article outlines the new CLT warehouse and showroom that was constructed in Langford BC, just outside Victoria. The 10,000-sf building was constructed of 5-ply CLT wall panels that were tilted up. The contractor was only experienced with concrete tilt up construction but noted in the article that the tilt up CLT was much easier to construct and faster than concrete.

Cockrell, Debbie. 2019. **"Cross-Laminated Timber Comes to Warehouse Development in Tacoma."** The News Tribune, 2019. Mass Timber Warehouse Under Construction

Summary : This article outlines the new CLT warehouse that was developed by Kidder Matthews in Tacoma Washington. Within the article, the vice president of the development company states that their client wanted to try something new, other than a concrete tilt construction. The new 10,000 square foot building shell is constructed of CLT tiled wall panels.

Cole, Raymond J, David Rousseau, and Stephen Taylor. 1992. **"Environmental Audits of Alternate Structural Systems for Warehouse Buildings."** Canadian Journal of Civil Engineering 19 (5): 886-95.

Summary : This paper presents environmental audits for four typical warehouse buildings, concrete masonry, tilt-up, steel system and wood. The study's definition of environmental audit is the

total energy consumption and emissions through extraction, processing materials for building products to the point where they can be installed in a building. All four building systems used the same warehouse plan to ensure consistency between systems. The analysis showed that between 74 and 79 percent of the total energy required for production of materials was from the long span members across all systems.

Cuadrado, Jesus, Mikel Zubizarreta, Belinda Pelaz, and Ignacio Marcos. 2015. **"Methodology to Assess the Environmental Sustainability of Timber Structures."** Construction and Building Materials 86: 149-58.

Summary: In this study the researchers present a methodology of "Environmental Sustainability Index for Timber Structures". This index is not meant to compare timber to other building materials however, it is meant to compare individual timber members on product characterization, manufacturing and assembly, optimization in resource use, waste management and environmental impact.

Dietsch, Philipp, Andreas Gamper, Michael Merk, and Stefan Winter. 2015. **"Monitoring Building Climate and Timber Moisture Gradient in Large-Span Timber Structures."** Journal of Civil Structural Health Monitoring 5 (2): 153-65. <https://doi.org/10.1007/s13349-014-0083-6>.

Summary : This paper analyzes the most common visible areas of damage in large span timber structures, cracking within the lamellas of any glue laminated timber element. A significant percent of the cracks can be tracked back to the change in moisture distribution throughout climatic conditions and the seasons. The objective of the study is to identify where the damage is likely to occur and try to determine a cause. Recommendations for best practice from the study are to try to limit a fast decrease or increase of the timber moisture content.

Gawade, M D, and U. P Waghe. 2018. **"Study of pre-engineered building concept."** Journal of Research in Engineering and Applied Sciences. <https://doi.org/10.46565/jreas.2018.v03i03.003>.

Summary : Analysis from a research team from the Queen's University Belfast, looking at optimizing the design of long span steel portal frames. Within their methodology they analyzed span width, weight of individual members, axial capacity, moment capacity, and shear area for their optimization model. After analyzing 15 systems, the buckling stability of the member sections and serviceability limits of the frame (deflection) were the two main governing constraints in the optimization of the portal frames.

Koppelhuber, Joerg, Bernhard Bauer, Johannes Wall, and Detlef Heck. 2017. **"Industrialized Timber Building Systems for an Increased Market Share - A Holistic Approach Targeting Construction Management and Building Economics."** In Procedia Engineering, 171:333-40. Elsevier Ltd. <https://doi.org/10.1016/j.proeng.2017.01.341>.

Summary : The high potential for timber construction systems lies in the short installation period required on site. The ability for pre-fabrication of 2d elements and 3d modules is shown as a strong argument for widespread timber use, however the study claims that the lack of knowledge in this area often associated with higher costs than conventional building systems.

ANNOTATED BIBLIOGRAPHY

"Mass Timber Warehouse Under Construction - Studio 531 Architects." 2020. Studio 531 Architects. 2020.

Summary : This case study is the first CLT warehouse in Canada, located in Victoria, BC the structure was a turnkey building for a plumbing company. The structure is CLT wall panels and a glulam frame. The construction of the structure only took two weeks.

Mayencourt, Paul, and Caitlin Mueller. 2020. **"Hybrid Analytical and Computational Optimization Methodology for Structural Shaping: Material-Efficient Mass Timber Beams."** Engineering Structures 215 (July): 110532. <https://doi.org/10.1016/J.ENGSTRUCT.2020.110532>.

Summary : This paper investigates how timber beam shaping can contribute to structural material savings in timber construction. This case study implements the shape optimization and presents the savings in materials in a range of span and beam configurations. This paper offers a shaping methodology for the structural optimization of mass timber beams and identifies objectives for the development of digital manufacturing techniques of a more standardized structure for the implementation in buildings. This paper concludes that up to 70 percent of the structural materials in mass timber beams could be theoretically saved, therefore reducing the wood fiber and carbon footprint of the building as well as reducing the cost of the members. This study shows designers that expressing the load path within the structural material can produce a large material savings.

McKinstry, Ross, James B.P. Lim, Tiku T. Tanyimboh, Duoc T. Phan, and Wei Sha. 2015. **"Optimal Design of Long-Span Steel Portal Frames Using Fabricated Beams."** Journal of Constructional Steel Research 104: 104-14. <https://doi.org/10.1016/j.jcsr.2014.10.010>.

Summary : Analysis from a research team from the Queen's University Belfast, looking at optimizing the design of long span steel portal frames. Within their methodology they analyzed span width, weight of individual members, axial capacity, moment capacity, and shear area for their optimization model. After analyzing 15 systems, the buckling stability of the member sections and serviceability limits of the frame (deflection) were the two main governing constraints in the optimization of the portal frames. 90% of all single-story buildings in the UK are built with steel portal frames – large market for M.T. to slip into.

Patil, Santosh S. 2018. **"A Study on the Structural Analysis and Design of Pre-Engineered Buildings for Different Geometries."** International Journal for Research in Applied Science and Engineering Technology 6 (6): 184-90. <https://doi.org/10.22214/ijraset.2018.6033>.

Summary : The advantages of the pre-engineered building system is examined in this study. Looking at three different models of industrial structures (ranging from 10 meter to 30-meter span keeping the length of the building consistent) that are all pre-engineered buildings and analyzing for the structural analysis, costs, time of construction and the self-weight of the structures.

Pujadas-Gispert, Ester, David Sanjuan-Delmás, and Alejandro Josa. 2018. **"Environmental Analysis of Building Shallow Foundations: The Influence of Prefabrication, Typology, and Structural Design Codes."** Journal of Cleaner Production 186 (June): 407-17. <https://doi.org/10.1016/j.jclepro.2018.03.105>.

Summary : This research looks at how shallow foundations may reduce the emissions from concrete. Within their methodology, the concrete foundation was identified as the highest yield of environmental impacts due to the steel and concrete required. This study looks on how shallow foundations can reduce the materials needed in the foundation to lower the emissions and embodied energy of a building.

Silva, Marielle Ferreira, Laddu Bhagya Jayasinghe, Daniele Waldmann, and Florian Hertweck. 2020. **"Recyclable Architecture: Prefabricated and Recyclable Typologies."** Sustainability (Switzerland) 12 (4). <https://doi.org/10.3390/su12041342>.

Summary : This paper looks at existing prefabricated typologies and analyzes them based on their implementation to be assembled, disassembled, and re-arrange the members. The results show that the implementation of a modular, dismountable architectural concept is not only feasible and reasonable, but ensures adoption throughout time and material reusability which reduces construction waste and CO2 emissions.