Embodied Carbon Case Study: Casework and Countertops

Many digital tools are available to help architects estimate the embodied carbon footprint of materials and assemblies in order to make decisions that will reduce the embodied carbon in a building or a renovation. This white paper presents a method for modeling GWP (global warming potential) of casework and countertop materials using Tally, the Revit-based plugin, and a new spreadsheet-based calculator for casework.

Background

As we were developing a process for embodied carbon (EC) accounting on our projects, we realized that currently available EC modeling tools did not account for a number of interior finishes, including casework and countertops. This is potentially a significant gap. Two recent studies published by the Carbon Leadership Forum (CLF), including Embodied Carbon Benchmark Study, LCA for Low Carbon Construction (2017) and LCA of Tenant Improvement in Commercial Office Buildings (2019), estimate the embodied carbon for tenant improvement (TI) elements average 45 – 135 kg CO2eq/m2, compared to commercial office building structures, foundations and enclosures in the range of 200 – 500 kg CO2eq/m2. However, the typical recurrence interval of TI is every 10 – 20 years, and thus over a building's lifetime, the cumulative impact of recurring TI is on the same order of magnitude as that of the rest of the building.

In office buildings, flooring and ceilings are some of the highest volume materials. However, in other project typologies such as multifamily housing, hospitality, and healthcare, casework and countertops are a significant volume of new material, duplicated across a number of units. To understand the embodied carbon impact of different casework and countertop choices, we developed a calculator.

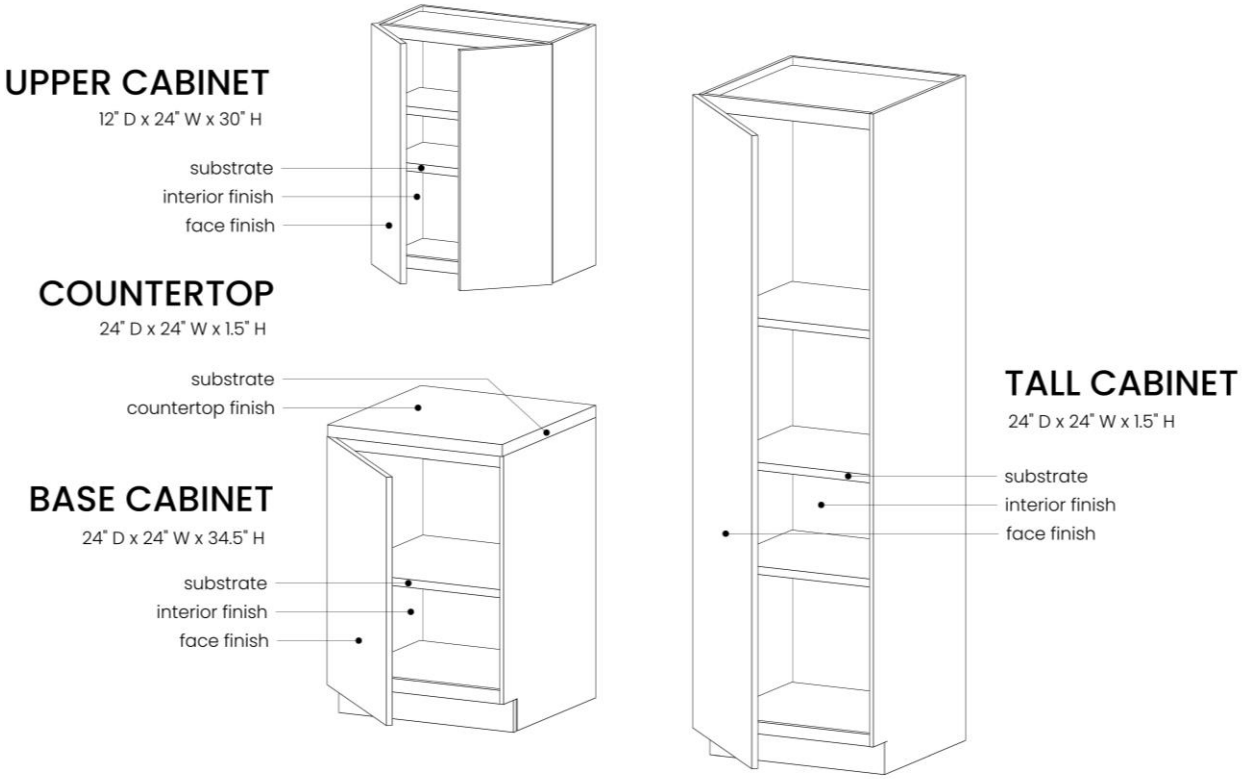


Fig.1 Casework components modeled in Revit included a base cabinet and countertop (24" depth), upper cabinet (12" depth), and tall cabinet (24" depth).

Comparing casework and countertop material options

During a Tally assessment of two multifamily residential projects modeled in Revit, it was revealed that the casework and countertop model objects were not included in Tally's estimated carbon footprint. The casework and countertop Revit families were not recognized by the current version of the Tally software, and as a result the plugin was not able to assign materials from the LCA database.

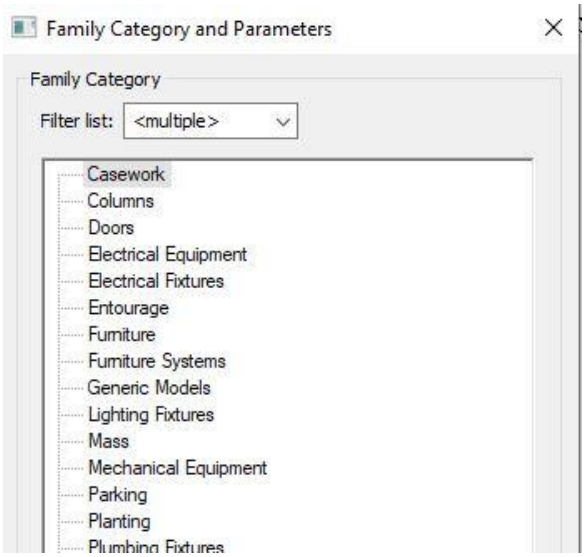


Fig. 2 Revit includes casework families

Fig. 3 Casework families not among the categories recognized by Tally

As a workaround to make our casework and countertops visible to Tally, we built a series of "cabinets" using wall and floor families, modified in terms of thickness and assembly, with typical casework substrate and finish materials assigned from the Tally library. For example, countertops were modeled using floor families, modified with layers to represent the substrate and finish layers, in the appropriate thicknesses. A wall family was modified to include a substrate plus interior and exterior finish layers. Where applicable, adhesives and finish coatings were selected as accessory materials. We modeled a standard module of 2 lineal feet for each assembly, then divided the result by 2 to arrive at a quantity of embodied carbon per lineal foot.

Casework types and example brands

Linoleum + substrate (e.g. Forbo)
PLAM (melamine plastic laminate) + substrate (e.g. Wilsonart or Formica)
Wood veneer + substrate
Color-thru wood fiber board (e.g. Forescolor or Valchromat)
Cement bonded particle board (e.g. Viroc)
Solid wood
Plywood
OSB (oriented strand board)

Countertop types and example brands

Solid surface resinous with natural or synthetic aggregate (e.g. Dupont Corian or LG Hi-Macs)
Engineered stone with resin binder (e.g. Cambria Quartz)
Stone, natural quarried
Concrete
PLAM (plastic laminate, e.g. Wilsonart or Formica)
Stainless steel + substrate
Linoleum + substrate (e.g. Forbo)
Cement bonded particle board (e.g. Viroc)
Color-thru wood fiber board (e.g. Forescolor or Valchromat)
Solid wood or butcher block

CABINET TYPES

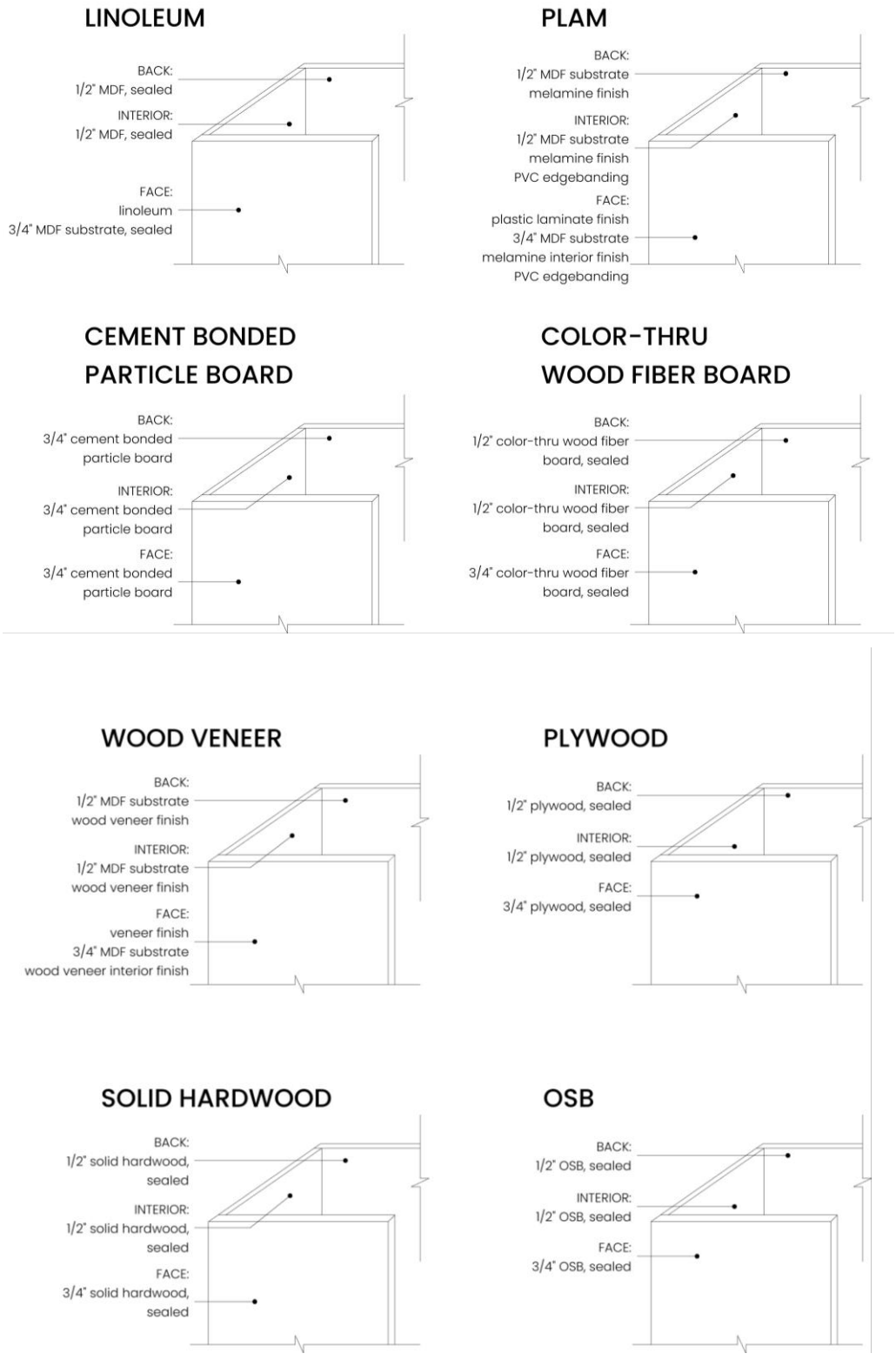


Fig. 4 Cabinet/casework assemblies with materials and substrates called out

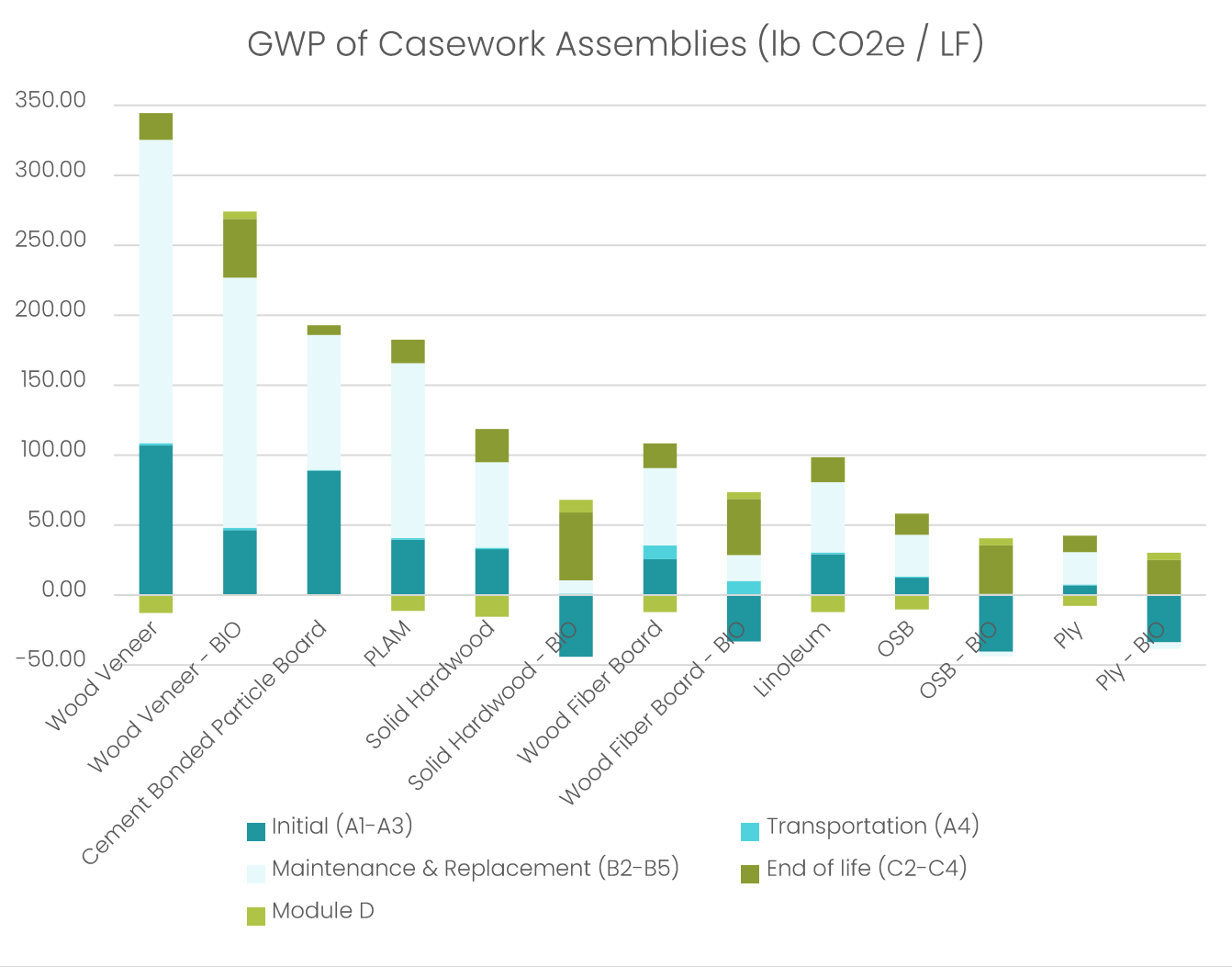


Fig. 5 GWP per lineal foot of base cabinet, shown in lb CO2 equivalent per LF (relative results are typical of upper and tall cabinets).

Casework comparison

Wood veneer cabinets showed the highest GWP, measured in lbs CO_2e (carbon dioxide equivalent) per lineal foot. Based on detailed LCA data from the Tally modeling results, the high carbon intensity is primarily due to the frequency of maintenance and replacement and a high initial GWP of production for wood veneer. In this study, the option to include biogenic carbon in the Tally simulation[1] (i.e. accounting for a certain amount of carbon dioxide sequestered in the growing of wood) was used selectively as an approximation for specifying certified wood products[2], such as FSC (Forest Stewardship Council) certification and shown in above graph for each material as "__ - BIO." The rationale was that certified wood products come from sustainably managed forests, where harvesting practices ensure that carbon is truly being sequestered, whereas in non-certified forests, unsustainable harvesting practices offset the carbon sequestered by tree growth, countering the ability to make claims of carbon sequestration through use of wood.

[1] Note: The team relied on Tally's built-in methodology for considering biogenic carbon. We did not evaluate Tally's definition or LCA scope or data.

[2] Comments welcome on this method of approximating a certified wood product GWP in Tally. It may be that certified wood actually has an even lower footprint than shown by this approximation.

Surprisingly, in calculating the impact of wood veneer, even when biogenic carbon was selected in Tally, i.e. where the veneer was modeled as if it were FSC certified, the GWP of wood veneer was still higher than any other casework option. By contrast, hardwood plywood and OSB showed the lowest GWP per LF, followed by linoleum laminate with an MDF substrate, and color-through wood fiber board. In all cases, the certified wood option would result in the lowest carbon footprint, due to improved forest conservation and management practices.

Highest GWP casework options and possible alternatives

	Highest GWP casework	**Consider instead…**
1	Wood veneer	Hardwood plywood (especially FSC certified)
2	Cement bonded particle board	Color-through wood fiber board (esp. FSC certified)
3	PLAM	Linoleum, laminated to FSC certified substrate
4	Solid hardwood	Hardwood plywood (esp. FSC certified)

Best casework choices, listed in order from lowest GWP (based on LCA data from Tally plugin)

1. Plywood, especially FSC certified
2. OSB, especially FSC certified
3. Linoleum laminate with FSC certified substrate
4. Color-through wood fiber board (choose a brand that comes FSC certified as standard)

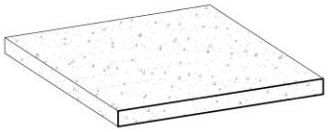
Comments on product specification / wish list

- In practice, color-through wood fiberboard is relatively affordable and the color-through property is aesthetically compatible with many design options. It is recommended to seal edges and surfaces with a clear coat. Choose a zero VOC coating.
- Linoleum laminate may be an option to replace plastic laminate in a number of applications. It would be helpful to have more shared data in the industry on successful applications of this option.

COUNTERTOP TYPES

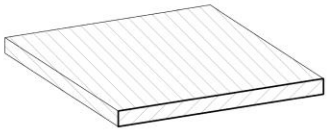
CONCRETE

FINISH: concrete - 1-1/2"



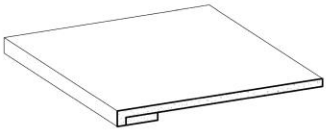
STONE

FINISH: natural stone - 1-1/2"



PLAM

FINISH: plastic laminate
3/4" MDF substrate
PVC Edgebanding

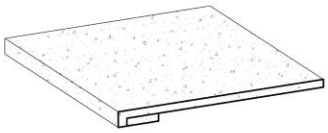


LINOLEUM

FINISH: linoleum
3/4" Plywood substrate
Sealed exposed edge

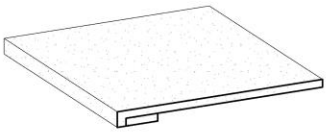
CEMENT BONDED PARTICLE BOARD

FINISH: cement bonded particle board - 3/4"
Exposed edge



COLOR-THRU WOOD FIBER BOARD

FINISH: color-thru wood fiber board - 3/4"
Sealed exposed edge

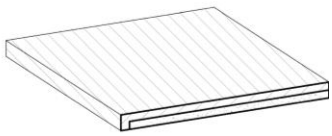


STAINLESS

FINISH: stainless steel- 16 ga.
3/4" MDF substrate

ENGINEERED STONE

FINISH: engineered stone - 3/4"
3/4" MDF substrate



SOLID SURFACE

FINISH: solid surface - 3/4"
3/4" MDF substrate

WOOD

FINISH: solid hardwood - 1-1/2"

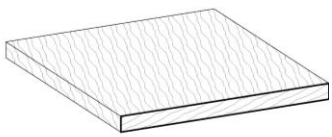


Fig. 6 Countertop assemblies with finish and substrate layers called out

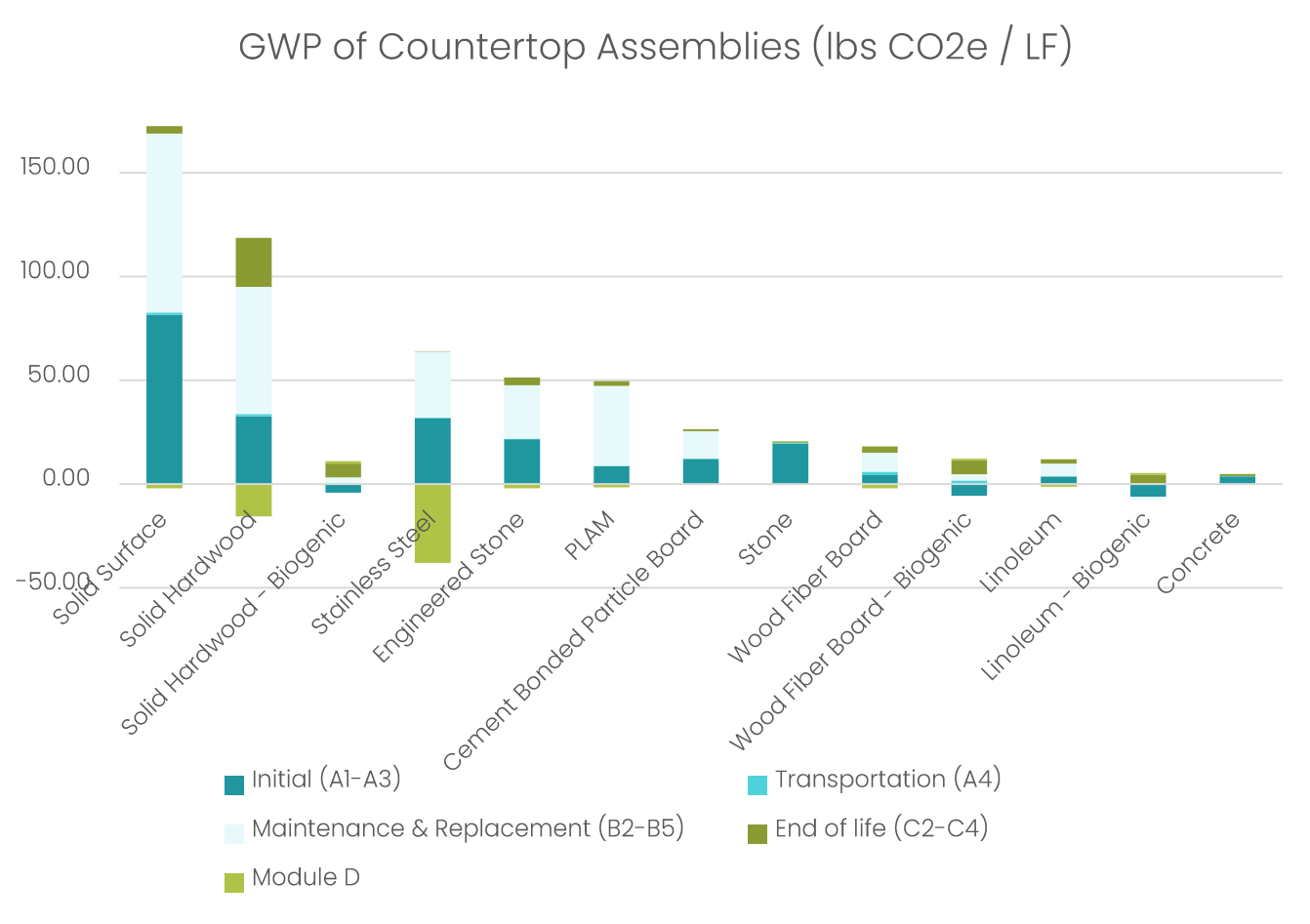


Fig. 7 Graph of GWP per lineal foot of countertop

Countertop comparison

Per lineal foot, the GWP of solid surface countertop (defined as resinous with natural or synthetic aggregate) measured highest. There is currently a large demand for solid surface in the building product market, because it is often less expensive than natural stone, but similarly durable, and offers flexibility in design aesthetics and integration of plumbing fixtures. According to the Tally model, this footprint is mainly due to product manufacturing as well as maintenance and replacement carbon impacts.

Solid hardwood counters showed a large discrepancy in carbon footprint based on whether biogenic carbon is counted, in other words, whether it is made using sustainably sourced wood.

In the case of stainless steel countertops, the green bar below the line indicating module D carbon is based on an assumption of recyclability of metal. However, it should be noted that if glued to a substrate, recycling may be hindered, so module D may not be realistic in adhered applications.

Based on data available in Tally, some natural materials such as linoleum have a very small GWP, even when accounting for the fact that most linoleum used in US-based projects is manufactured in Italy. More information is needed to understand this low footprint. However, in both flooring and casework applications, linoleum appears to be a promising low-GWP material.

Our research team was somewhat surprised to see that the GWP of quarried stone was relatively low compared to solid surface and engineered stone. We recommend careful attention to how far they are traveling, and sourcing from quarries that adhere to the ANSI/NSC 373-2019 standard Sustainable Production of Natural Dimension Stone.

Similarly, the carbon impact of concrete in structural applications led us to believe that it would be among the higher-GWP countertop materials, but according to modeling results, this is not the case. This appears to be based on the low volume of cement used in a countertop, as compared to a foundation or structure.

Highest EC countertop options and possible alternatives

	Highest GWP countertop	**Consider instead…**
1	Solid surface resinous	Engineered stone, natural stone, or concrete. **Also consider salvaged and resurfaced countertop options.**
2	Solid hardwood / butcher block	Specify FSC-certified solid wood or butcher block, supporting responsibly managed forests
3	PLAM	Linoleum laminate with FSC certified substrate (nice work surface, but may not work in wet applications such as a kitchen)

Best countertop choices, listed in order from lowest GWP (based on LCA data from Tally plugin)

1. Concrete
2. Linoleum
3. Wood fiber board
4. Natural stone
5. PLAM

Comments on products / wish list

- Would be great if there were ways to reduce the GWP of solid surface through innovation, due to the popularity of this project, for example through use of a biobased resin.
- Similarly, innovations in PLAM would be beneficial to improve human health impacts. Laminated to a wood substate that is non-formaldehyde (NF) and composed of FSC-certified wood is a relatively inexpensive and durable option that is low GWP. However, melamine is known to be a problematic chemical in terms of human health, and many standard substrates are not formaldehyde-free by default.
- Wood fiber board can work in limited applications as a countertop material, for example non-wet locations in an office. Color-thru wood fiber board allows sanding and resealing. It is recommended to seal edges and surfaces with a clear coat. Choose a zero VOC coating.

- Linoleum is a versatile material that can be formed to curved substrates.
- Concrete offers a lot of flexibility, however it requires a skilled tradesperson to build, and is always custom.
- No life cycle data was available through Tally to compare the following material types:
    - Recycled glass in cementitious binder (e.g. IceStone) may be a good countertop material, but GWP information was not available for this study. Life cycle data from glass/cement countertop manufacturers would enable this comparison.
    - Resinous recycled paper countertop (e.g. Paperstone or Richlite)
    - Metal laminates (e.g. Chemetal)

<u>Notes on modeling</u>

- Tally reports and Excel tables are available upon request.
- Building lifespan was set to Tally default of 60 years, and all materials were also left at default Tally settings for replacement frequencies.
- To model natural stone countertops, grout was removed from the existing Tally profile and the thickness of material was changed.
- A new Tally profile was created for the Wood Fiber Board by inputting custom travel distance to account for the transportation to the United States from Korea (manufacturing location).
- The models did not include a countertop backsplash.
- The team relied on Tally's built-in methodology for considering biogenic carbon. We did not evaluate Tally's definition or LCA scope or data. This would be a good recommendation as part of generating a more in-depth comparison in a future report.

Estimating EC impact of casework and countertops on a project

A quantity takeoff of casework, measured in lineal feet (LF), is typically done during construction documents, to estimate material costs. This takeoff number is used to calculate the embodied carbon impact of casework. For convenience, a Revit schedule could be created to display LF per casework component automatically. [The casework calculator is available as part of the Sustainability Metrics Drawing Set Template which can be downloaded at https://msrdesign.com/generative-impacts.]

Casework Embodied Carbon Calculator

Enter square footage	84120	sf
GWP per square foot		
All	8.201	lb CO2e / sf
New	8.201	lb CO2e / sf
Salvaged	0.000	lb CO2e / sf

		and countertop materials*	Salvaged casework and countertops	GWP per LF, kg CO2e	GWP per LF, lb CO2e		takeoff (QTO) in lineal feet (LF)	NEW GWP based on QTO, lb CO2e	SALVAGED GWP by group, lb CO2e	Notes
Casework Group 3								**10465.7**	**0.0**	MAIL / PACKAGE
	base cabinets	LINOLEUM	N/A	421.245838	86.28	0.00	5	431.4	0.0	
	upper cabinets	PLY	N/A	125.345797	25.67	0.00		0.0	0.0	
	tall cabinets	N/A	N/A	0	0.00	0.00		0.0	0.0	
	countertop	ENG. STONE	N/A	241.219349	49.41	0.00	203.1	10034.3	0.0	
Casework Group 4								**4615.0**	**0.0**	WOOD
	base cabinets	N/A	N/A	0	0.00	0.00		0.0	0.0	
	upper cabinets	N/A	N/A	0	0.00	0.00		0.0	0.0	
	tall cabinets	N/A	N/A	0	0.00	0.00		0.0	0.0	
	countertop	WOOD	N/A	86.1651446	17.65	0.00	261.5	4615.0	0.0	
								New	**Salvaged**	
							Total	**689826**		GWP, lb CO2e
									0	GWP, lb CO2e
							Grand total	**689826**		

Fig. 8 Data from Tally entered in the casework + countertop spreadsheet calculator, to arrive at GWP impact of these materials per sf of project area

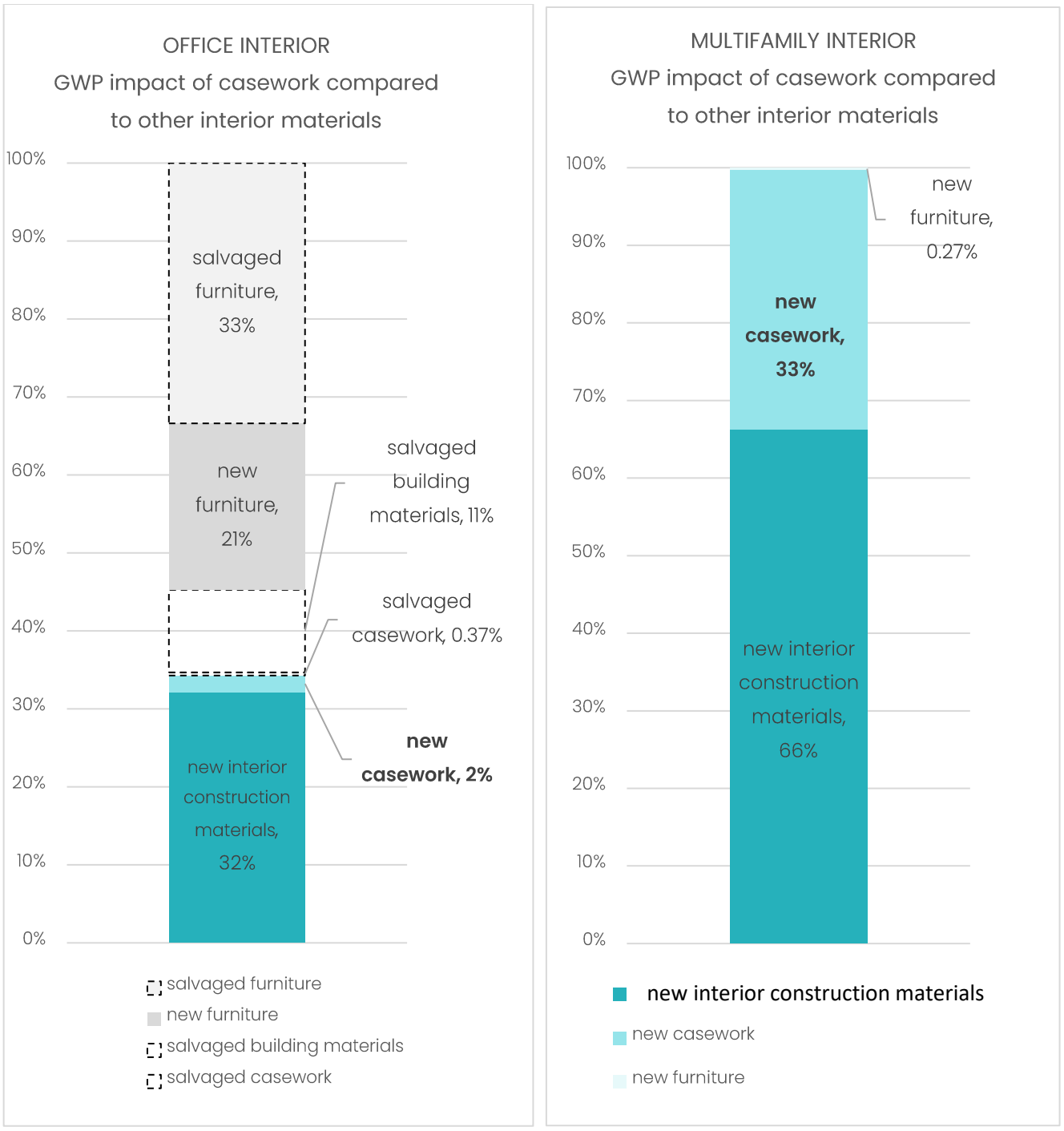


Fig. 9 Office TI versus market rate multifamily interior-only project, GWP impact of casework and countertops. Note that since this case study examines two renovation projects, the full scope of elements that would be included in new construction (such as envelope and structure) are not included.

Discussion

The total GWP impact of casework in a 14,000 sf office space (Figure 9) was found to be relatively low, approximately 2% compared to other finishes. This is due to factors such as the relatively small volume of casework compared to the size of the space, and the specific products that were selected (on this office project, the cabinets were constructed of FSC-certified plywood, and the natural stone countertop was a salvaged material).

By contrast, in an 84,000 sf multifamily interior renovation project, casework and countertops were found to be one third of the total GWP calculation which included floors, ceilings, walls, doors and interior glazing.

In both of these interior-only case studies, the proportional impact of casework and countertops is higher than it would be in a new construction or major renovation project that included new envelope and structure. However, in multifamily, hospitality, healthcare, laboratory, and other project typologies with built-in work surfaces and storage, the volume of casework and countertops is likely to be proportionally high, even in the case of new construction, and the GWP impact significant, whether new construction or minor renovation. Based on these findings, casework and millwork should not be overlooked when considering the GWP of both new and renovation projects.

Recommendations for clients and designers

- **Natural casework materials, especially those with strong environmental certifications, have a lower embodied carbon footprint** in general than petroleum-based materials
    - FSC and other material certifications have a meaningful impact on reducing harm to ecosystems when procuring and manufacturing raw materials
- **Consider using salvaged material**, or refinishing instead of tearing out and starting over
- **Consider design details for deconstruction and reuse**, especially when using high-EC materials such as solid surface or stone countertops, in a context where they are likely to be removed and replaced. Consider mechanical fasteners instead of adhesives.
- **Consider materials that age well**; where signs of wear are likely to be considered a patina or wabi-sabi, which may prolong their useful life or allow for refinishing
- **Always balance embodied carbon considerations with health and toxicity impacts, and other variables**. Are all ingredients transparently disclosed by the manufacturer, and does it contain chemicals of concern such as formaldehyde, antimicrobials, flame retardants, PFAS, that end users (or manufacturing workers) will be exposed to through touch or by breathing? Select Red List Free finishes and substrates.

Future development of Tally and other plugins

- It would be beneficial to designers if EC modeling software recognized Revit millwork families and other items such as furniture, in order to more fully understand the GWP of interior finish materials.
- For interior materials, the lifespan is often much shorter than that of the structure or envelope. It would be helpful for EC modeling tools to allow for different assumptions on the recurrence period of interior renovations based on the project typology, for example a public library, which may undergo renovation every 15+ years, versus hospitality, which may be renovated within 5 years or fewer.
  new interior construction materials

References

The Carbon Leadership Forum:

LCA of MEP Systems and Tenant Improvements. Web-published study:
https://carbonleadershipforum.org/lca-of-mep-systems-and-tenant-improvements/

Embodied Carbon Benchmark Study: LCA for Low Carbon Construction (February 2017)
https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/38017/CLF%20Embodied%20Carbon%20Benchmark%20Study.pdf

Life Cycle Assessment of Tenant Improvement in Commercial Office Buildings (April 2019)
https://static1.squarespace.com/static/5c73f31eb10f25809eb82de2/t/5d62eb9231149d00015e0db3/1566763927728/2LCAofTenantImprovementsinCommercialOfficeBuildingsFinalReport.pdf

Contact

Please send comments and questions to generativeimpacts@msrdesign.com

Note:

- *Casework calculator available as part of the Sustainability Metrics Drawing Set Template* which can be downloaded at https://msrdesign.com/generative-impacts
- *Tally reports and Excel tables are available upon request.*

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