Embodied Carbon & The Built Environment

Image source: www.nationalgeographic.com

Presenter

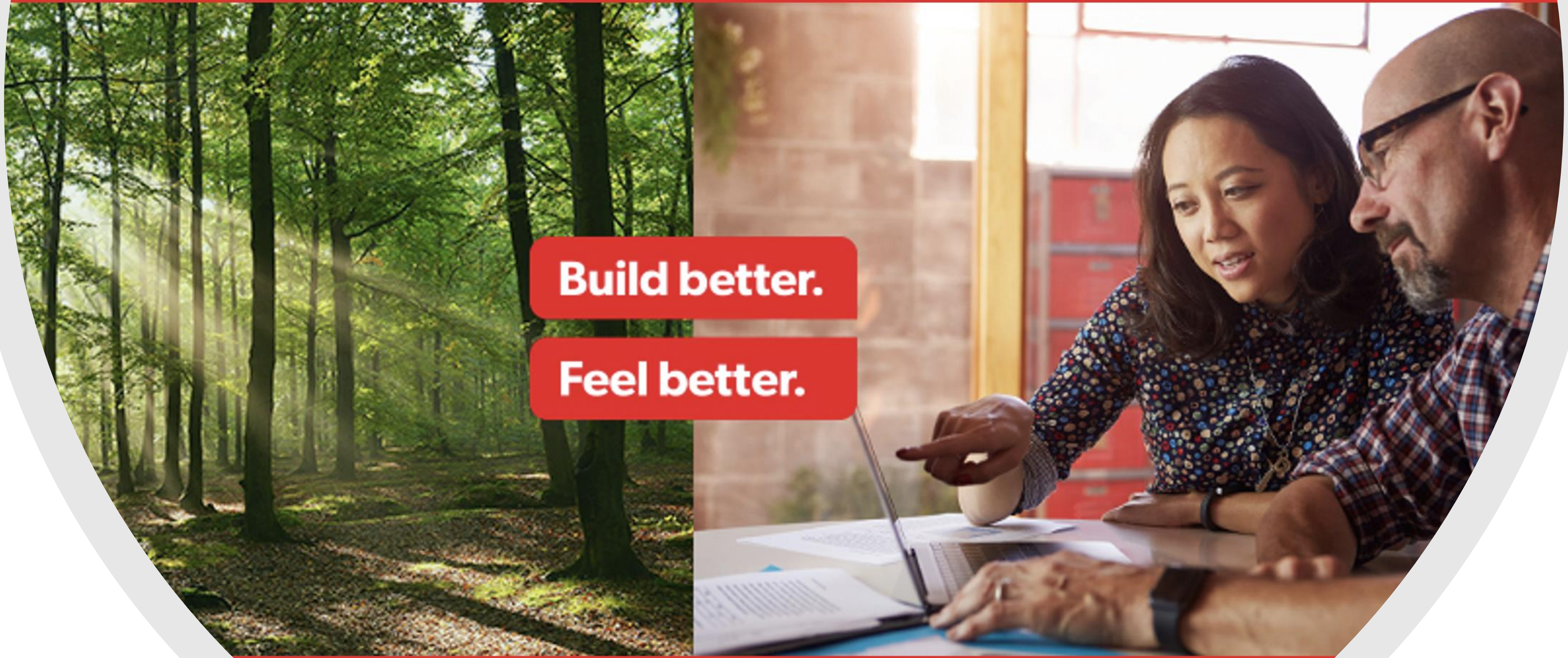
Philippe St-Jean, LEED AP, WELL AP, CPHC

Sustainable Construction Consultant

philippe.st-jean@handprintconsulting.ca

PASSIVEHOUSE CANADA

Build better.
Feel better.



What is embodied carbon?

- Embodied emissions are defined as the greenhouse gas emissions (GHG) released during the extraction, transportation, manufacturing, construction, demolition and disposal of a given material or product.
- Embodied GHG emissions are primarily released prior to, and during, a building's construction.

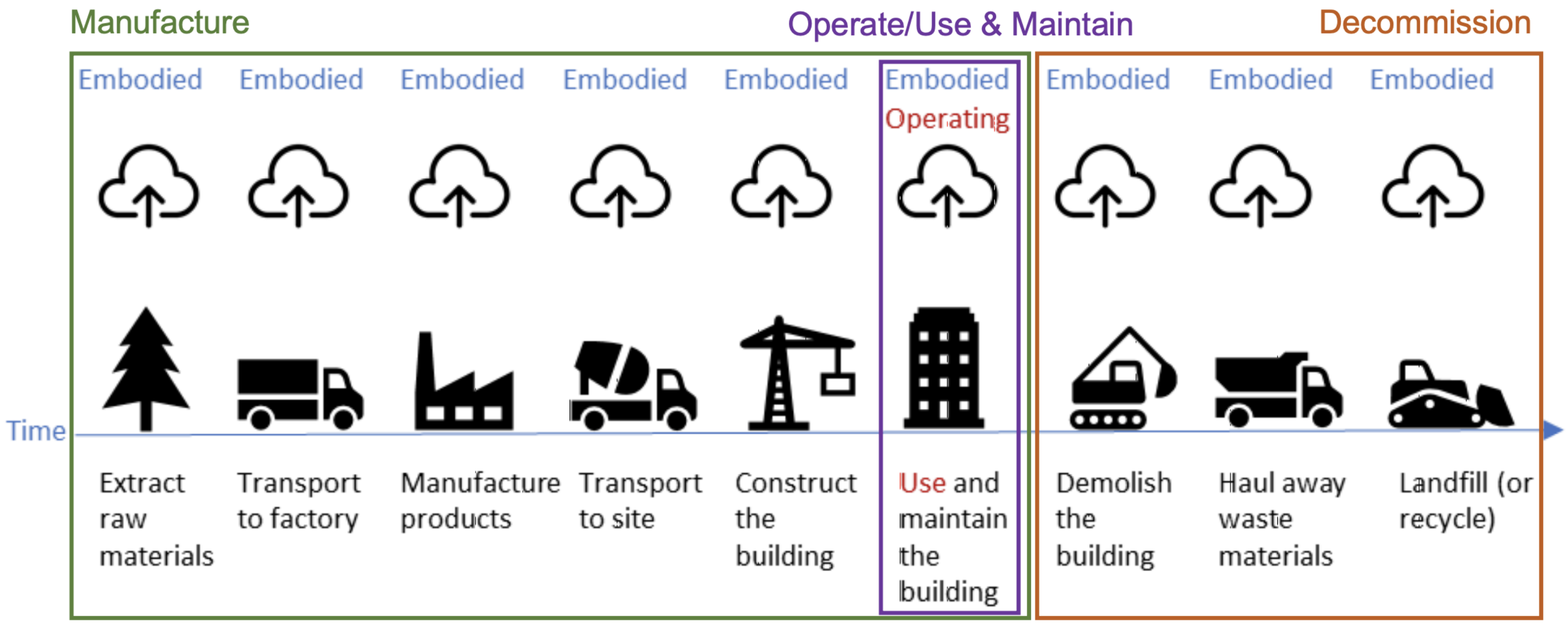
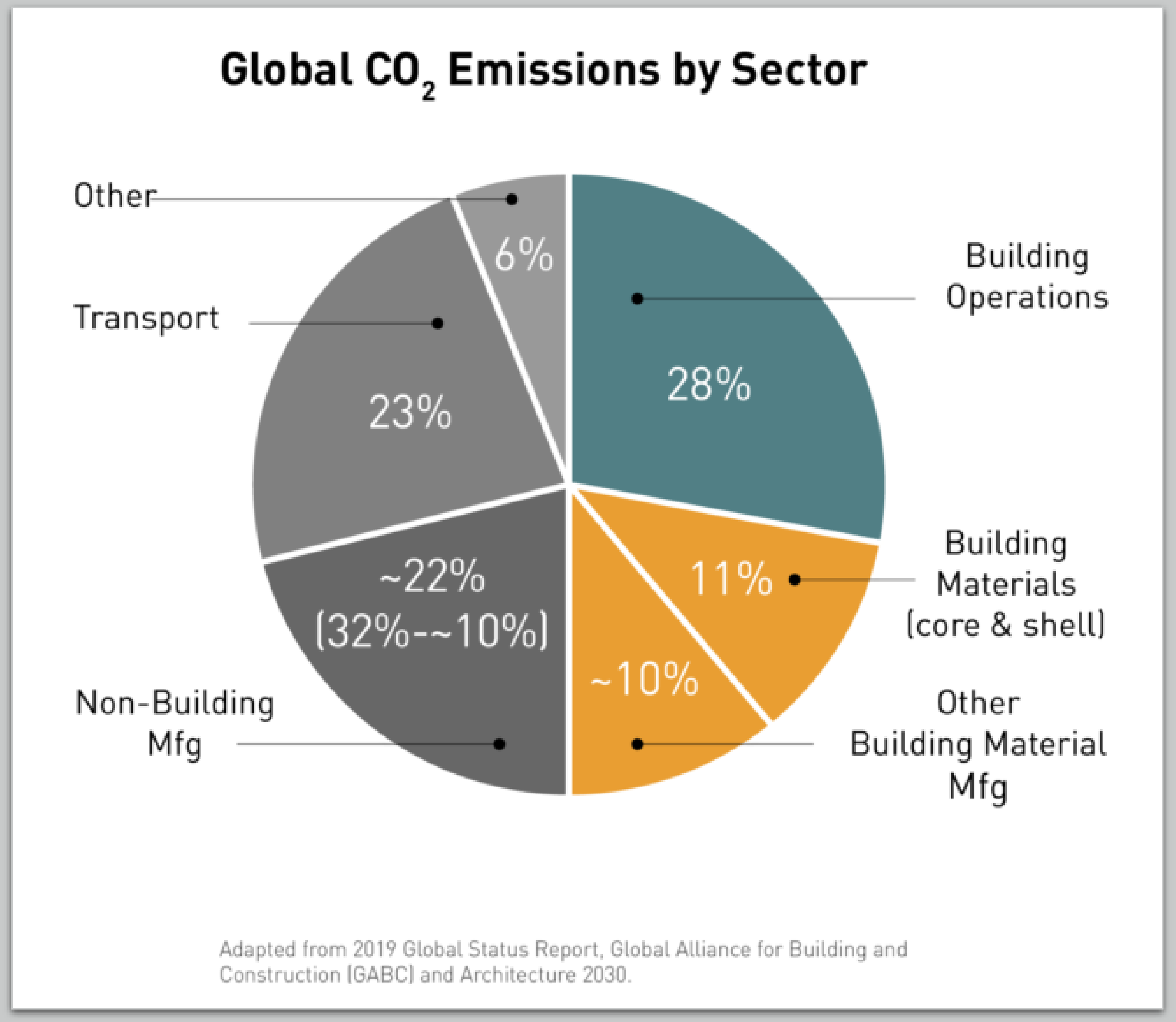


Figure 1: Life cycle GHG emissions from various building life cycle stages

Image source: Zizzo Strategy (2017). *Embodied Carbon in Construction Policy Primer for Ontario*.

What are the GHG emissions of buildings?

- Emissions related to the built environment represent roughly half of all global annual GHG emissions.



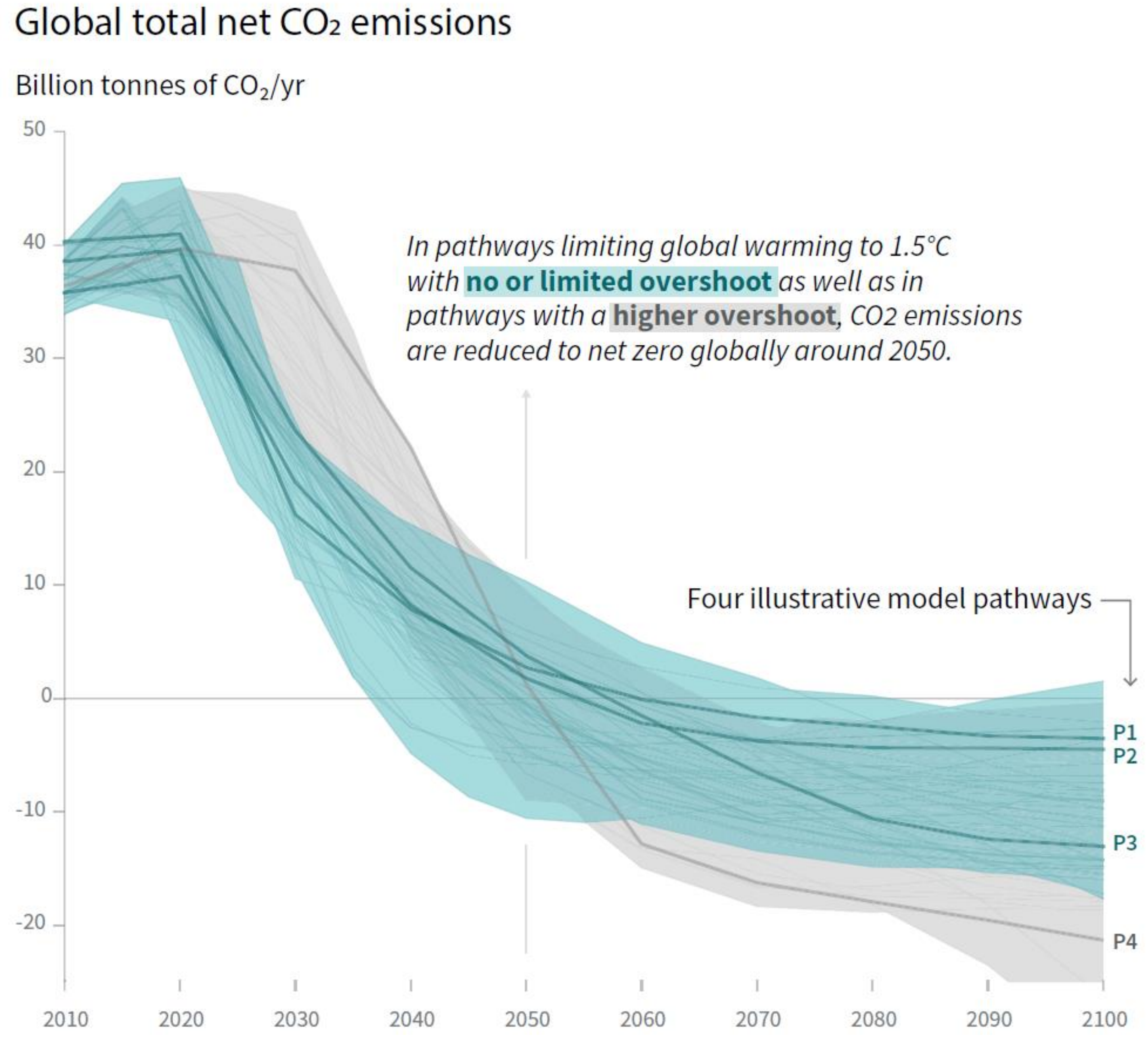


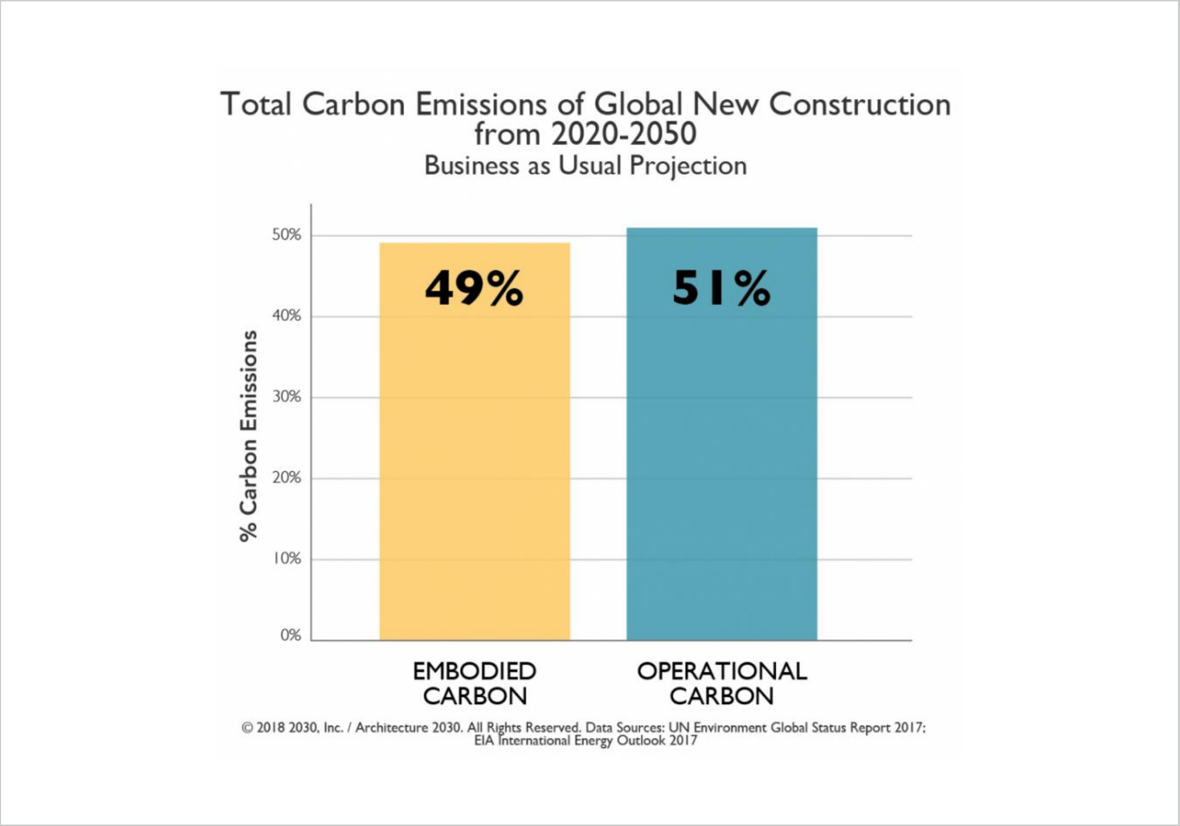
Image source: *Summary for Policymakers*, IPCC, 2018

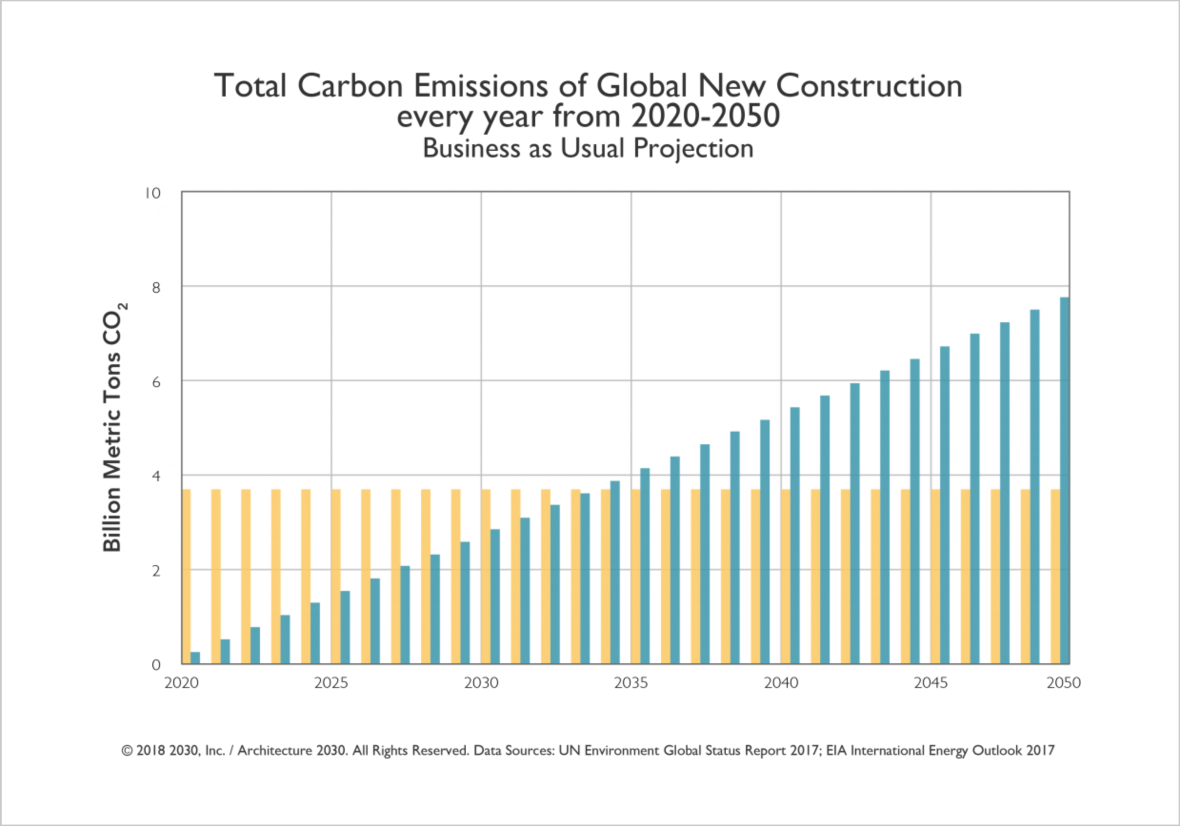
How do we avoid catastrophic climate change?

- Global GHG emissions must fall by roughly 45% from 2010 levels by 2030.
- 'Net zero' GHG emissions by 2050.
- From 2020 to 2030 roughly 80-90% of the GHG emissions from new construction will be embodied carbon.

Why is the embodied carbon of buildings important?

- If we maintain business as usual, the embodied GHG emissions of new construction from 2020-2050 will equal operational emissions over that same period.
- If current trends continue, it is likely that embodied emissions surpass operational emissions.





How are building GHG emissions evolving?

- As buildings become more energy efficient and energy grids decarbonize, operational carbon plays a smaller role.
- As construction materials and assemblies become more complex, embodied carbon plays a larger role.

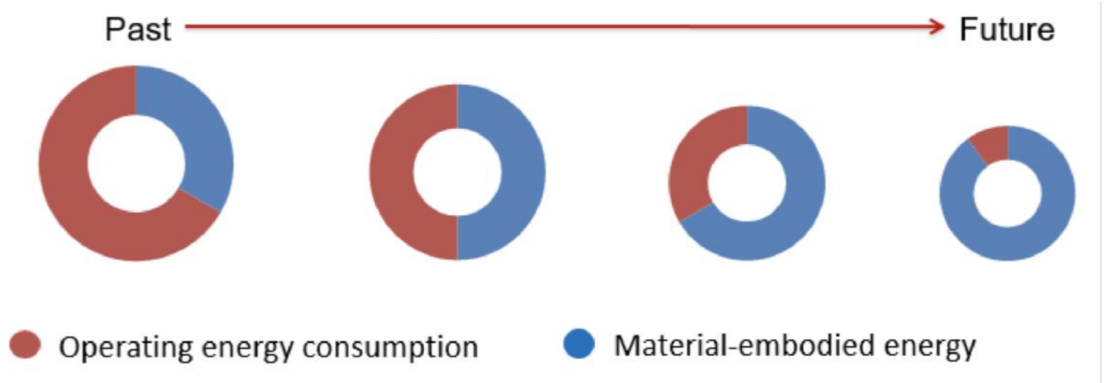


Image source: Zizzo Strategy (2017). *Embodied Carbon in Construction Policy Primer for Ontario*.

Finding D: The total GWP for MEP systems (excluding refrigerants) of typical commercial office buildings in the PNW ranges are:

Building type	Building model	Electrical ($kgCO_2eq/m^2$)	Mechanical ($kg\ CO_2eq/m^2$)	Plumbing ($kgCO_2eq/m^2$)	Total Range ($kgCO_2eq/m^2$)
Standard	Large Standard	7.1	35.6	6.2	48.9
	Medium Standard	11.7	43.2-48.2	6.4	61.3-66.3
	Small Standard	6.3	27.8-44	7.1	41.2- 57.4
	XSmall Standard	4.6	29.5-35.4	7.2	41.3-47.2
High performance	Large HP	8.6	56.6-60.0	6.2	71.4-74.8
	Medium HP	8.8-9.0	39.8-53.5	6.4	55.1-74.6
	Small HP	15.9	35.8-42.1	7.1	58.9-65.1
	XSmall HP	13.3	45.4-46.4	7.2	65.9-67.0

XSmall 186-2323 (m^2); Small 929-7432 (m^2); Medium 1858-27871 (m^2); Large 11148-74322 (m^2).

Source: The Carbon Leadership Forum. (2019). *Life Cycle Assessment of Mechanical, Electrical, and Plumbing in Commercial Office Buildings.*

How does MEP in High Performance Buildings compare?

- The embodied carbon of MEP is greater in high performance buildings, even when refrigerants are excluded from the calculation.

Why are full lifecycle analyses so important?

- Over the service life of a building, maintenance and improvements can produce embodied GHG emissions roughly equivalent to initial construction.

Table 1. Initial embodied carbon impacts at low, medium, and high estimate levels.

	Embodied carbon (kg CO_2e/m^2)		
Component	**Low estimate**	**Medium estimate**	**High estimate**
Initial MEP	40	60	75
Initial TI	45	90	135
Initial construction	300	400	500
Initial construction + MEP+TI	385	550	710

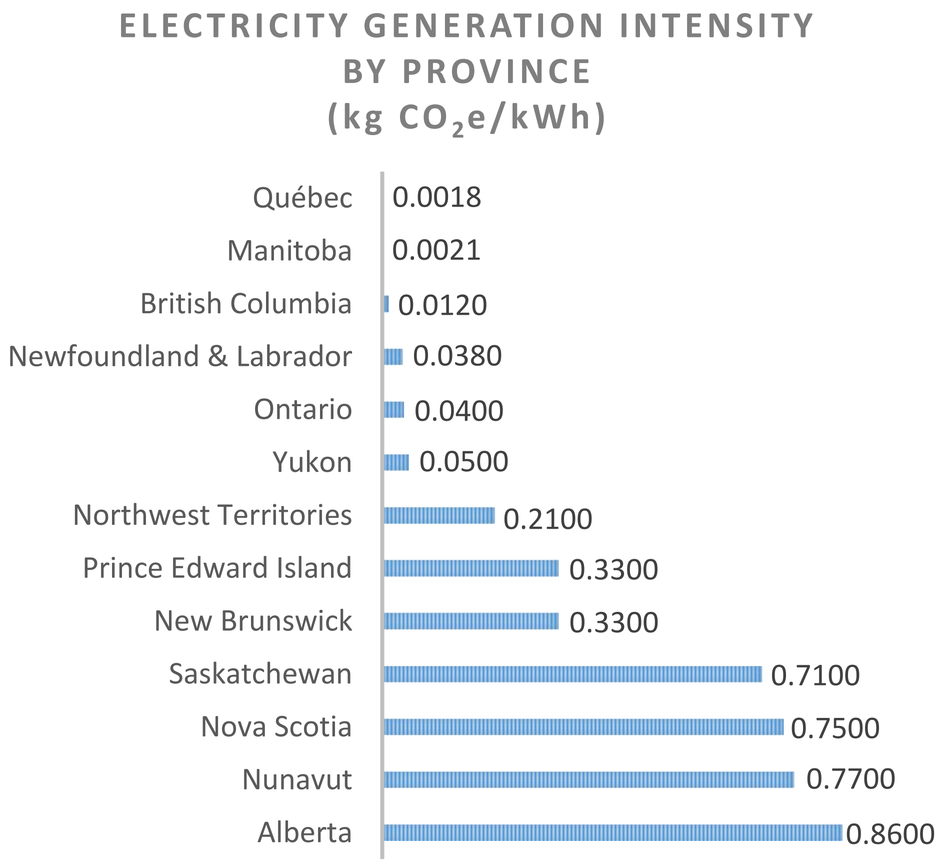
As an example from Figure 4, **Table 2** uses the medium estimate level to present the total impacts of recurring MEP and TI at 45 years.

Table 2. Total embodied carbon due to recurring installations at the medium estimate level.

	Embodied carbon (kg CO_2e/m^2), medium estimate			
Component	**Year 0**	**Year 15**	**Year 30**	**Year 45**
Recurring MEP	60	120	180	240
Recurring TI	90	180	270	360
Initial construction	400	400	400	400
Initial construction + recurring MEP+TI	550	700	850	1000

Source: The Carbon Leadership Forum. (2015). *Estimates of Embodied Carbon for Mechanical, Electrical, Plumbing and Tenant Improvements.*

What role does project location play on emissions?



Data source: Energy Star Portfolio Manager Greenhouse Gas Emissions Technical Reference

<u>To put these emission factors into perspective:</u>

The average Canadian commercial / institutional building consumes 275 kWh/m^2a.*

For a building with 550 $kgCO_2e/m^2$ of embodied emissions and energy sourced exclusively from the local electrical grid, operational emissions would equal embodied emissions after approximately:

- 1100 years in Quebec
- 160 years in B.C.
- 50 years in Ontario
- 2 years in Alberta

*Data source: Laboratory Benchmarking Tool - https://lbt.i2sl.org/buildings/charts.

Profile of Embodied Emissions

To what can embodied emissions be attributed?

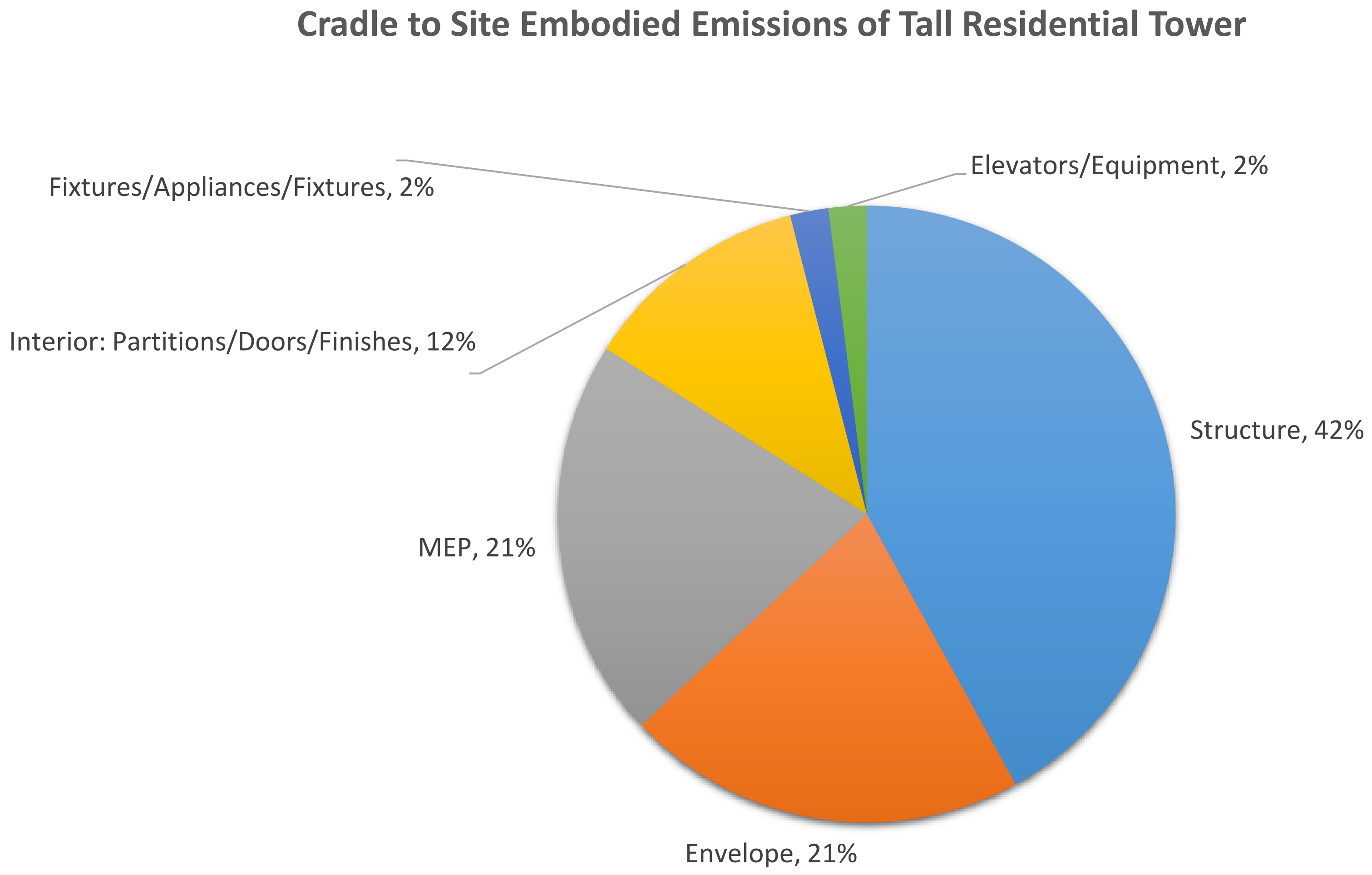
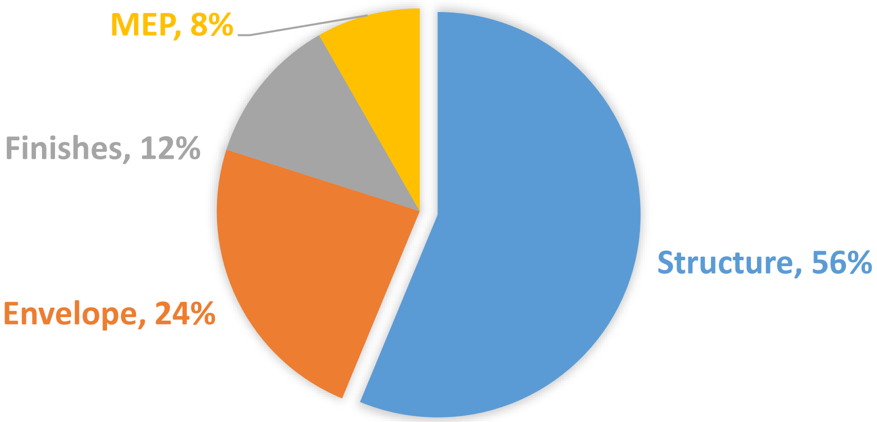


Chart adapted from: Simonen, K. (2015). Testing whole building LCA: Research and Practice. In Proc., 2015 AIA/ACSA Intersections Symposium.

Can we reduce embodied emissions?

PORTOLA VALLEY TOWN CENTER – BASE CASE
449,000 kg CO_2e



PORTOLA VALLEY TOWN CENTER – AS BUILT
305,000 kg CO_2e

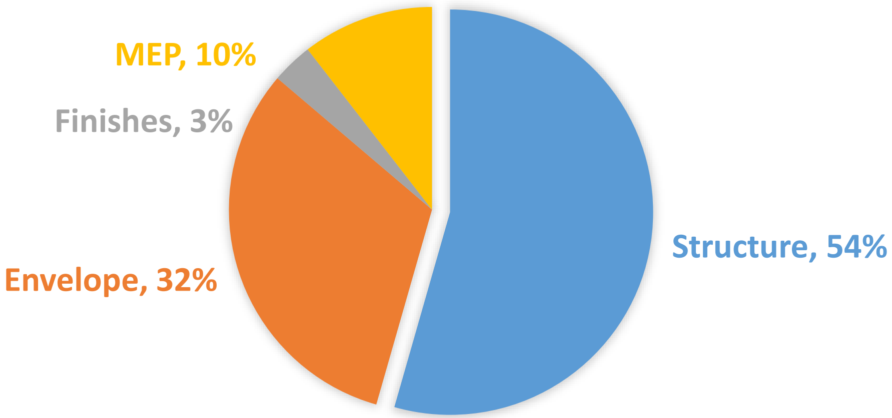


Image source: Larry Strain, Siegel & Strain Architects (2018). *Integrating Whole Building Life Cycle Assessment.*

Can we reduce embodied GHG emissions?

- There can be a greater potential to reduce embodied carbon through efficient design and material specification than through choice of framing material.

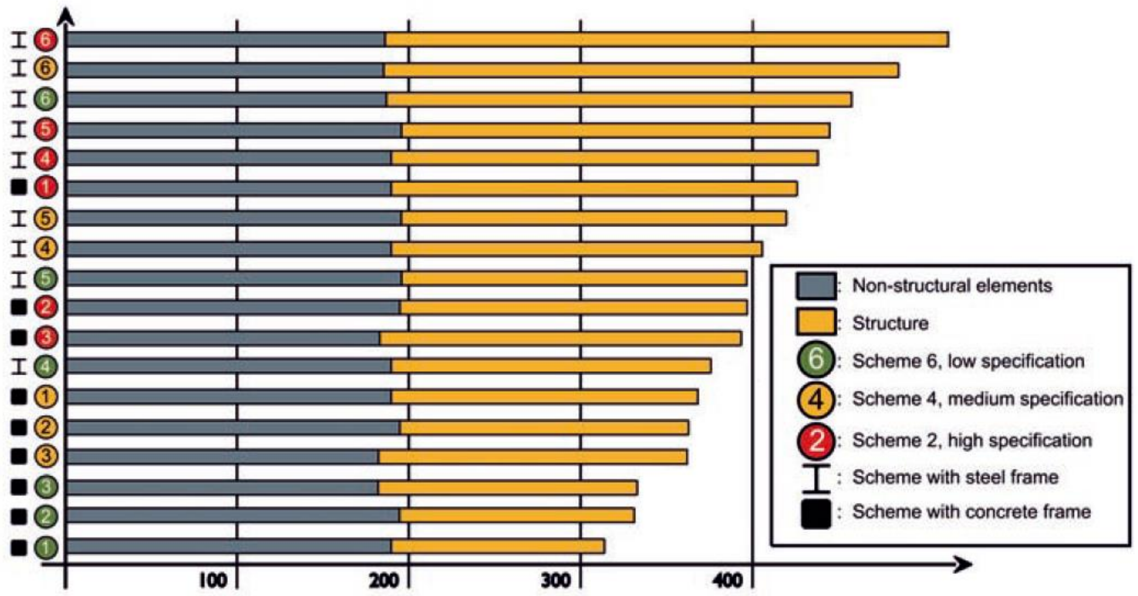
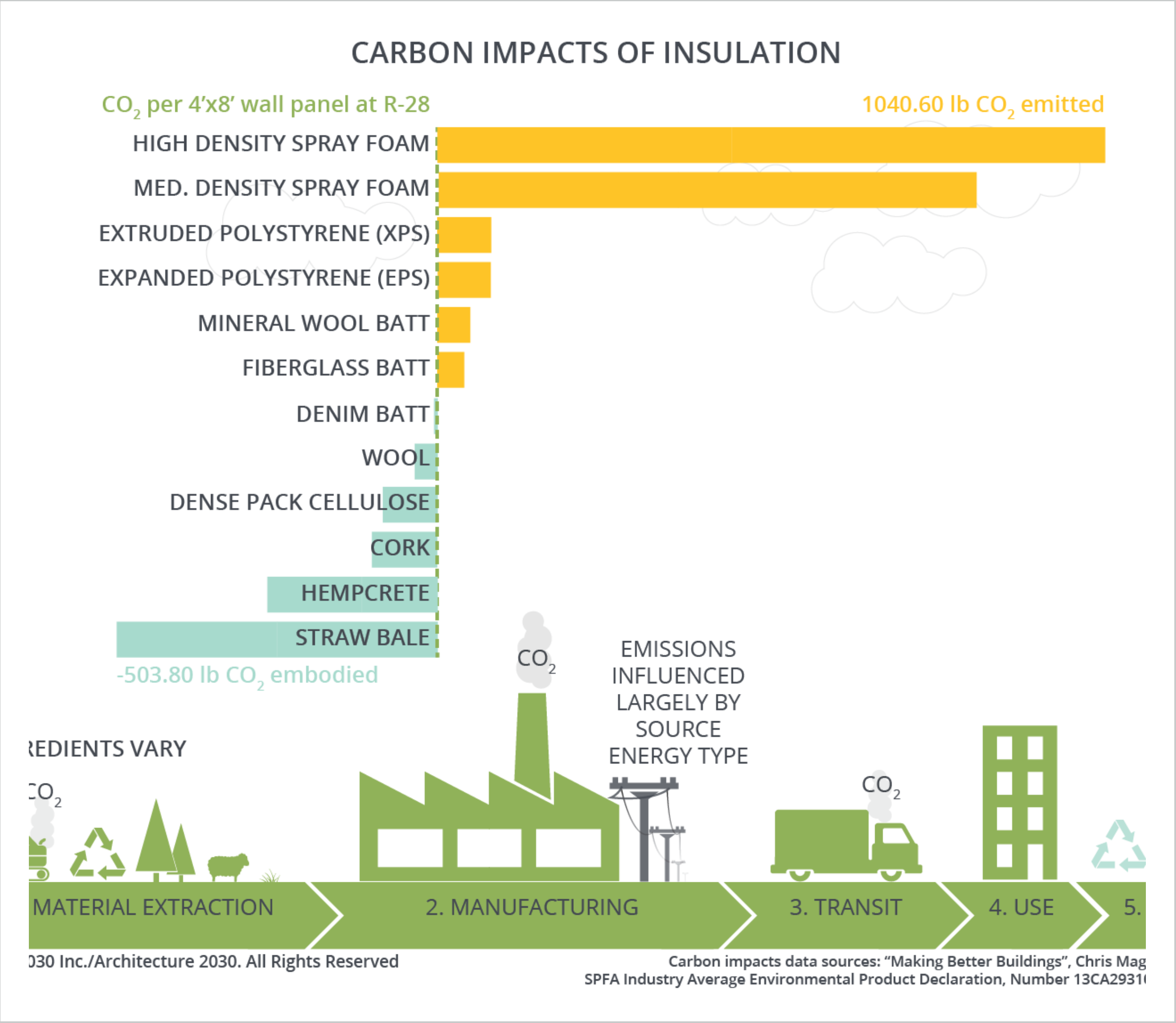


Image source: ARUP (2012). *Embodied CO2 of Structural Frames*

How do insulation materials compare?

- Properly sourced insulation materials can contribute to reducing both embodied carbon emissions and operational carbon emissions.



How do structural concrete and timber compare?

- Sustainably sourced timber can sequester a substantial amount of carbon.

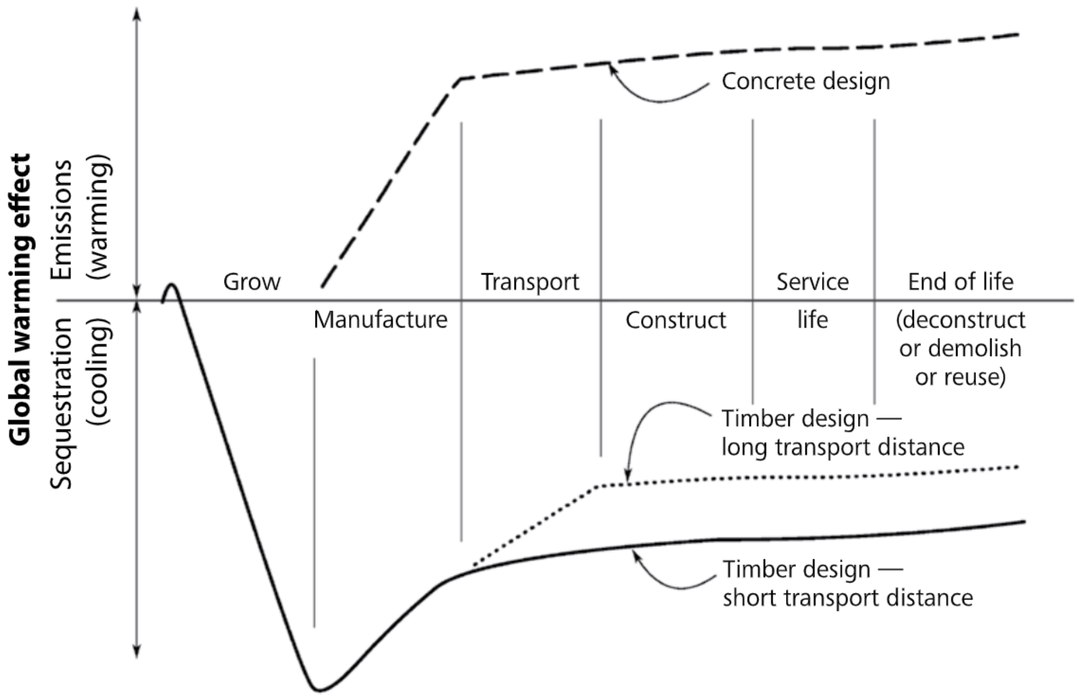


Fig. 4.4: *Comparison of carbon emissions between timber design and concrete design over life cycle of structural materials in 12-story tower.* Credit: Arup / Bruce King

Image source: King, B. (2017). *The New Carbon Architecture: Building to Cool the Climate*. New Society Publishers

Why is material sourcing so important?

- Timber sourced from unsustainable practices can have a similar carbon footprint to concrete.

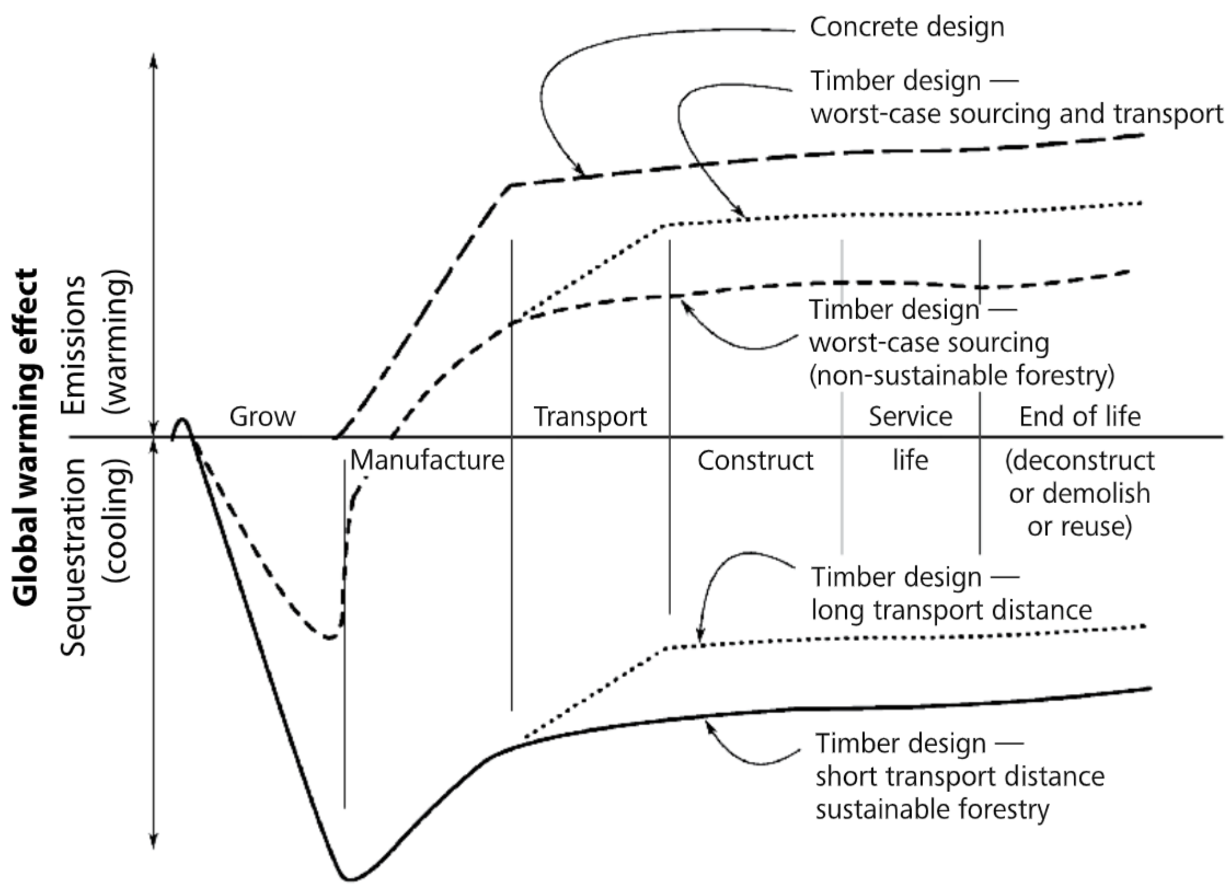


Fig. 4.5: *Comparison of carbon emissions between timber design and concrete design over life cycle of structural materials in 12-story tower, when wood is not sourced from sustainably managed forests.*

Credit: Arup / Bruce King

Image source: King, B. (2017). *The New Carbon Architecture: Building to Cool the Climate*. New Society Publishers

Embodied Carbon Profile of MEP

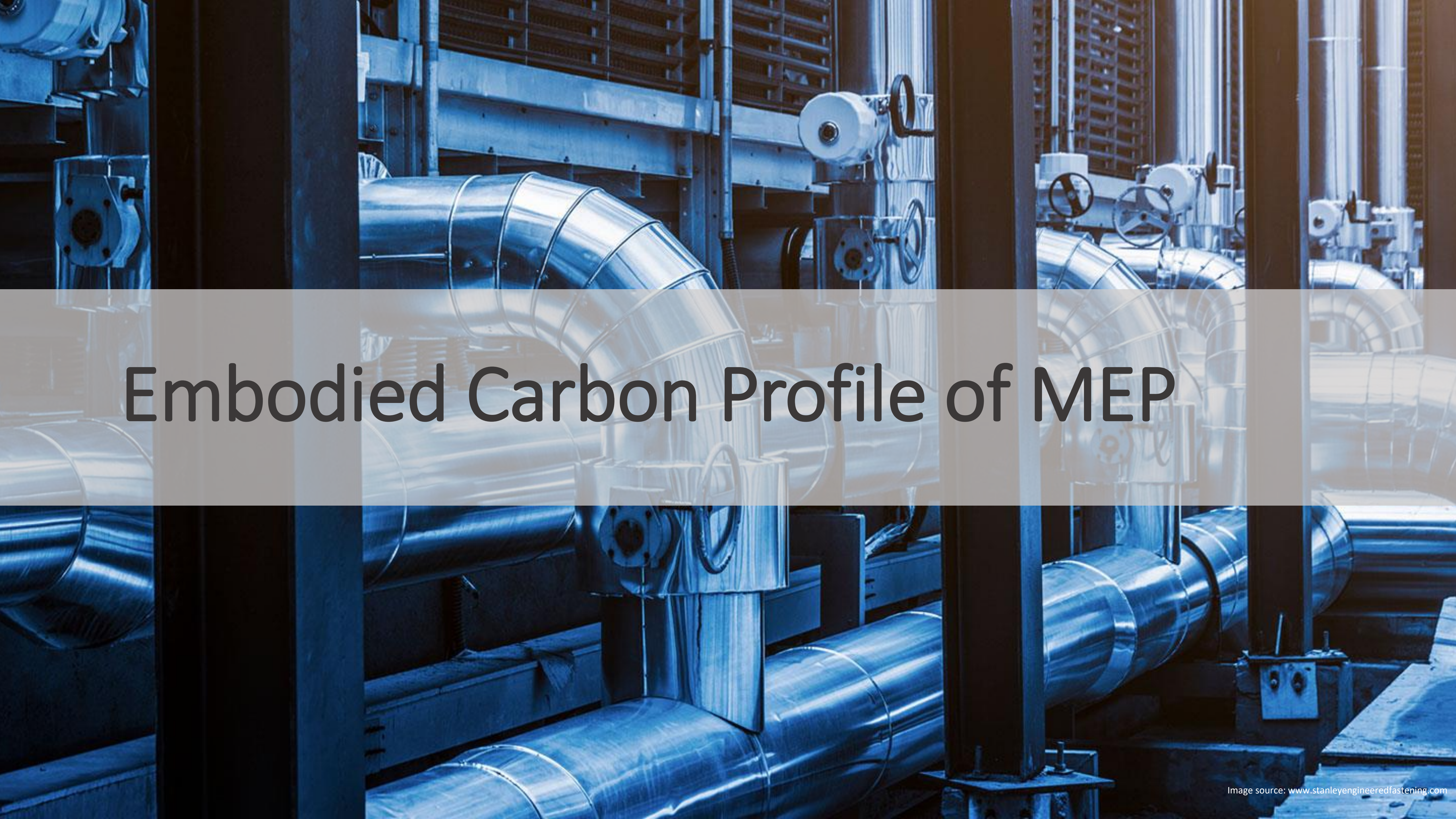


Image source: www.stanleyengineeredfastening.com

To what can embodied emissions be attributed?

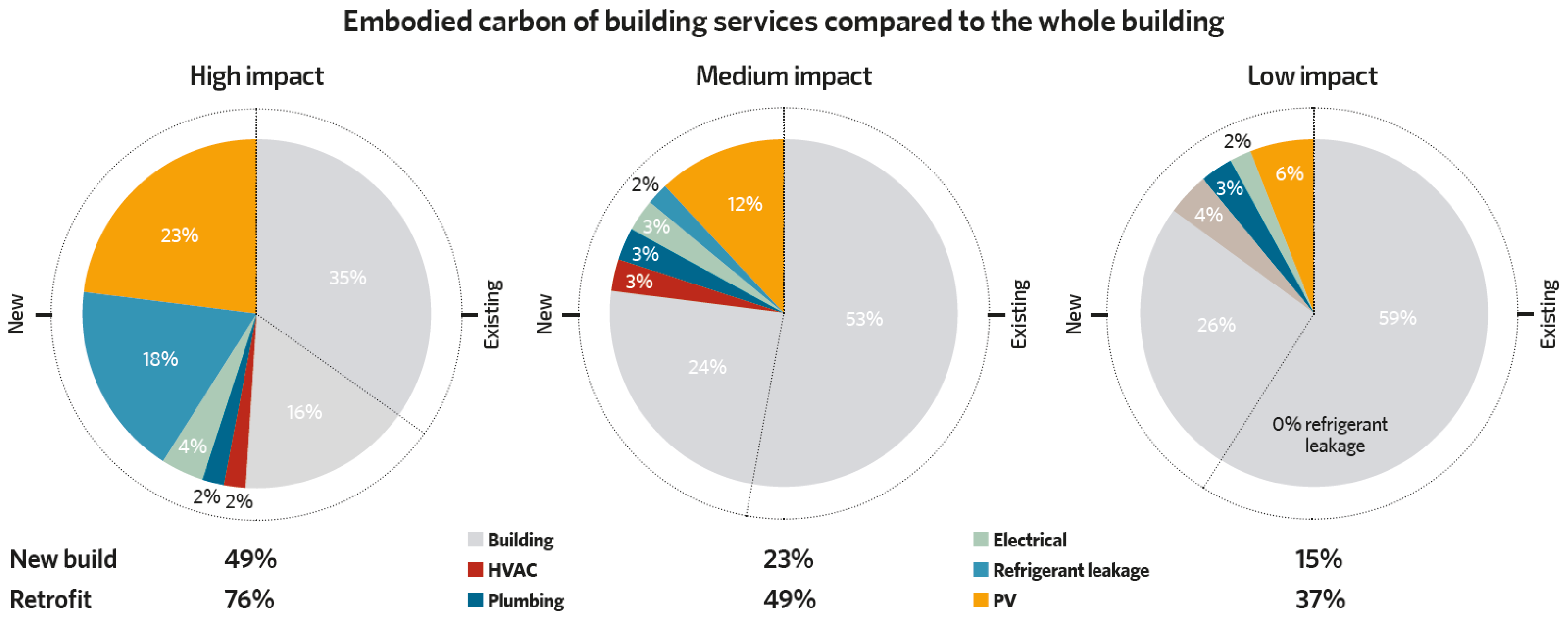


Figure 1: The high impact scenario refrigerant leakage accounts for a large proportion of embodied carbon

Image source: Hamot, L. (2019). *Getting to Grips with Whole-Life Carbon.* CIBSE Journal.

To what can embodied emissions be attributed?

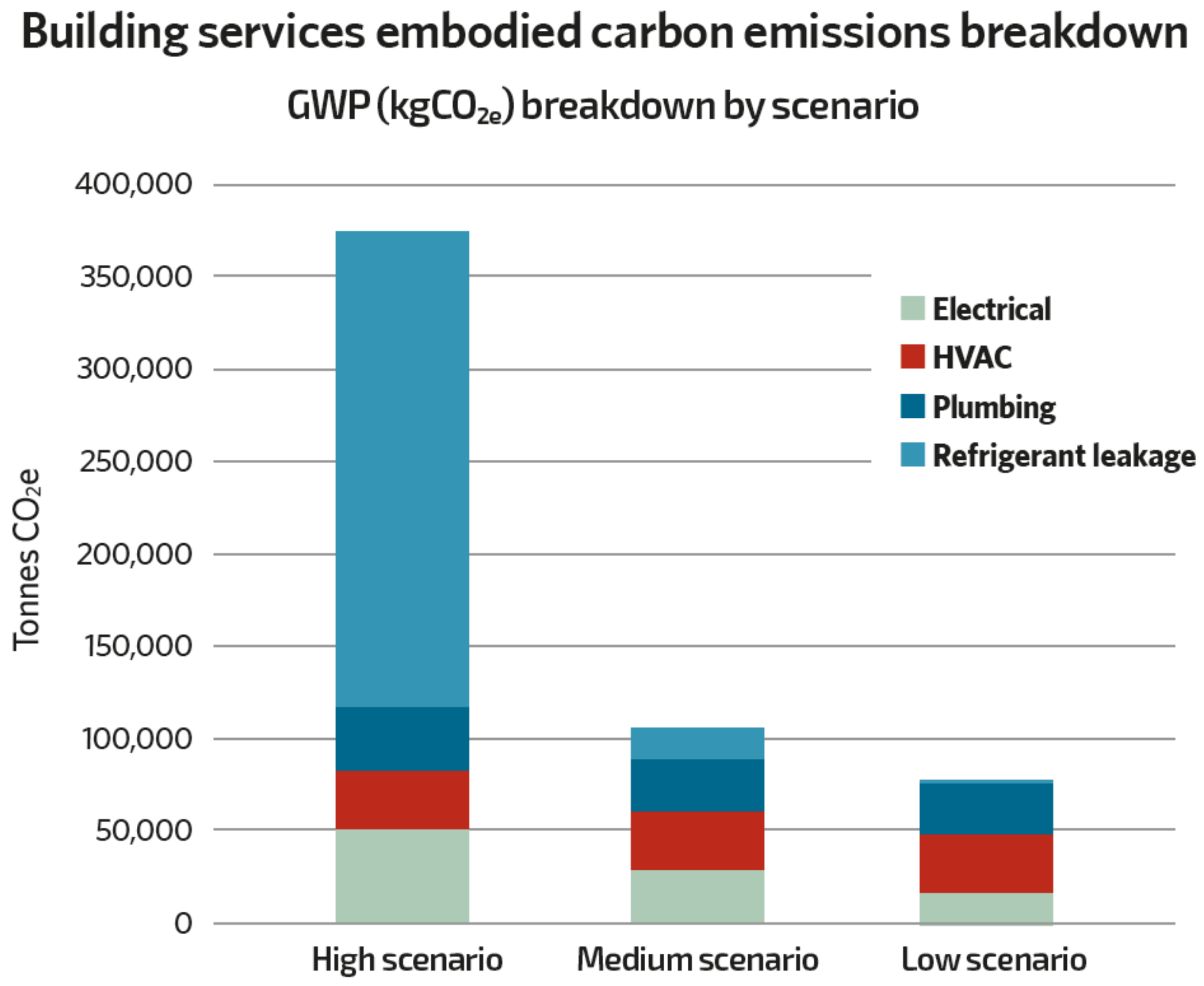


Figure 2: Electrical, HVAC and plumbing have broadly similar embodied carbon emissions

Image source: Hamot, L. (2019). *Getting to Grips with Whole-Life Carbon.* CIBSE Journal.

To what can embodied emissions be attributed?

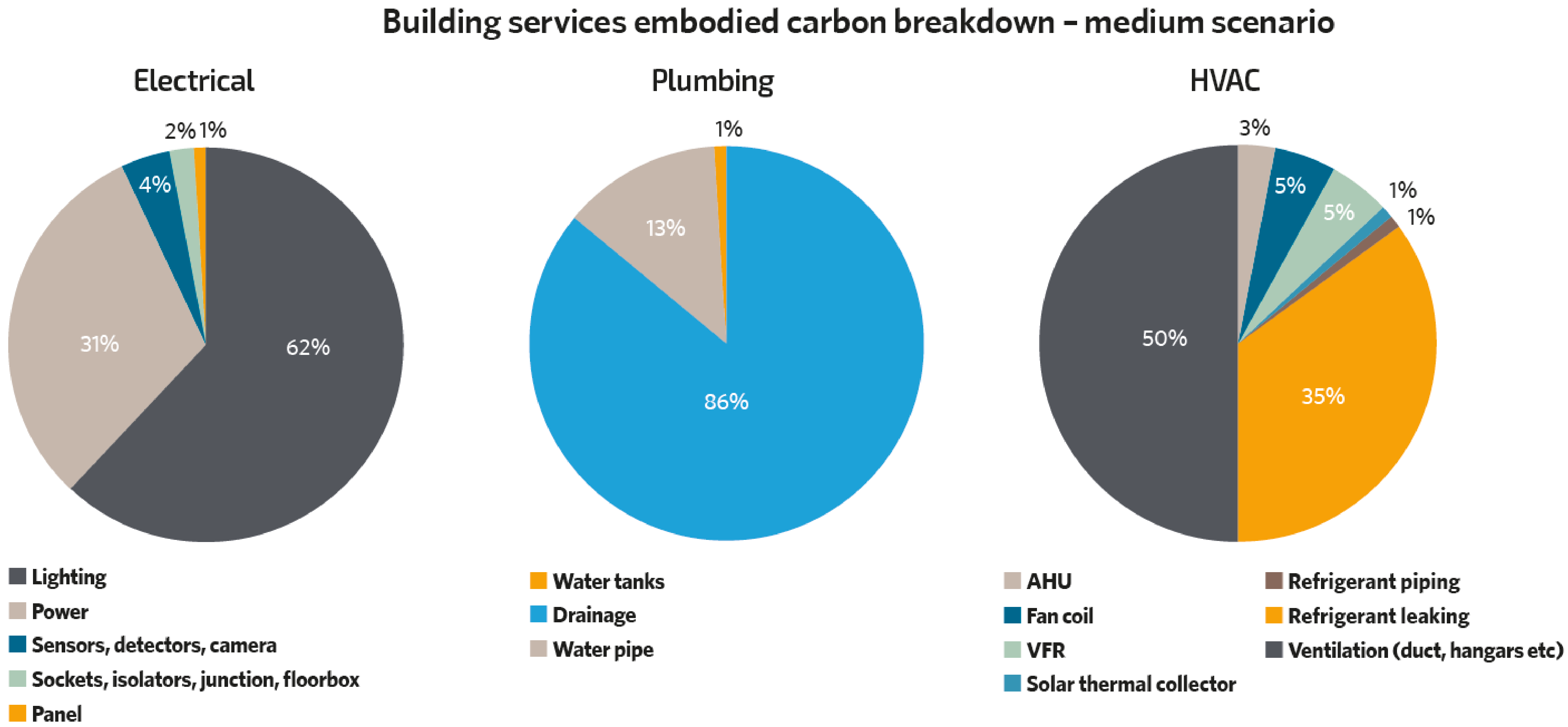


Figure 3: Embodied carbon broken down by building service. The medium scenario is described in Figure 2

Image source: Hamot, L. (2019). *Getting to Grips with Whole-Life Carbon.* CIBSE Journal.

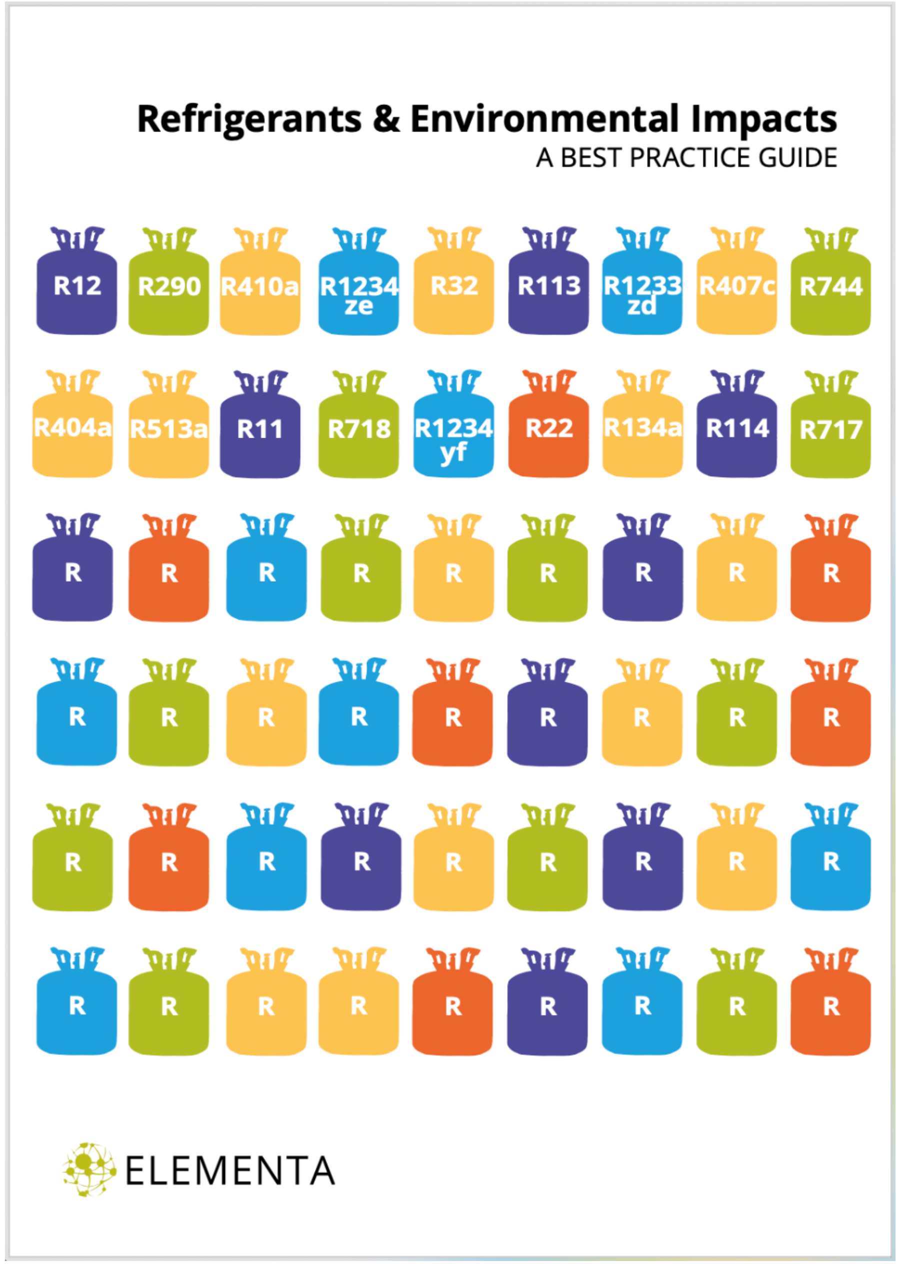
Refrigerants

Image source: www.facilityexecutive.com

How can the impact of refrigerants be mitigated?

1. Exhaust all passive measures to reduce or eliminate active heating and cooling;
2. Evaluate all non-refrigerant and combustion-free systems;
3. Select refrigerants with the lowest overall GWP.

Although R410a has 146% the GWP of R134a, if leaked to the atmosphere a 500kW air-cooled chiller using R410a has a 62% lower potential GWP impact than one using R134a.



Refrigerant leakage assumptions are shown in Table 6.

Table 6: Assumptions on refrigerants; installation in 2019

	Heat pumps			VRF		
	Low	Med	High	Low	Med	High
GWP	1	150	2088	1	150	2088
Annual leakage/ End of life recovery	1%/ 99%	3.8%/ 98%	6%/ 90%	1%/ 99%	6%/ 90%	10%/ 85%

Figure 7: Installing in 2019-New builds

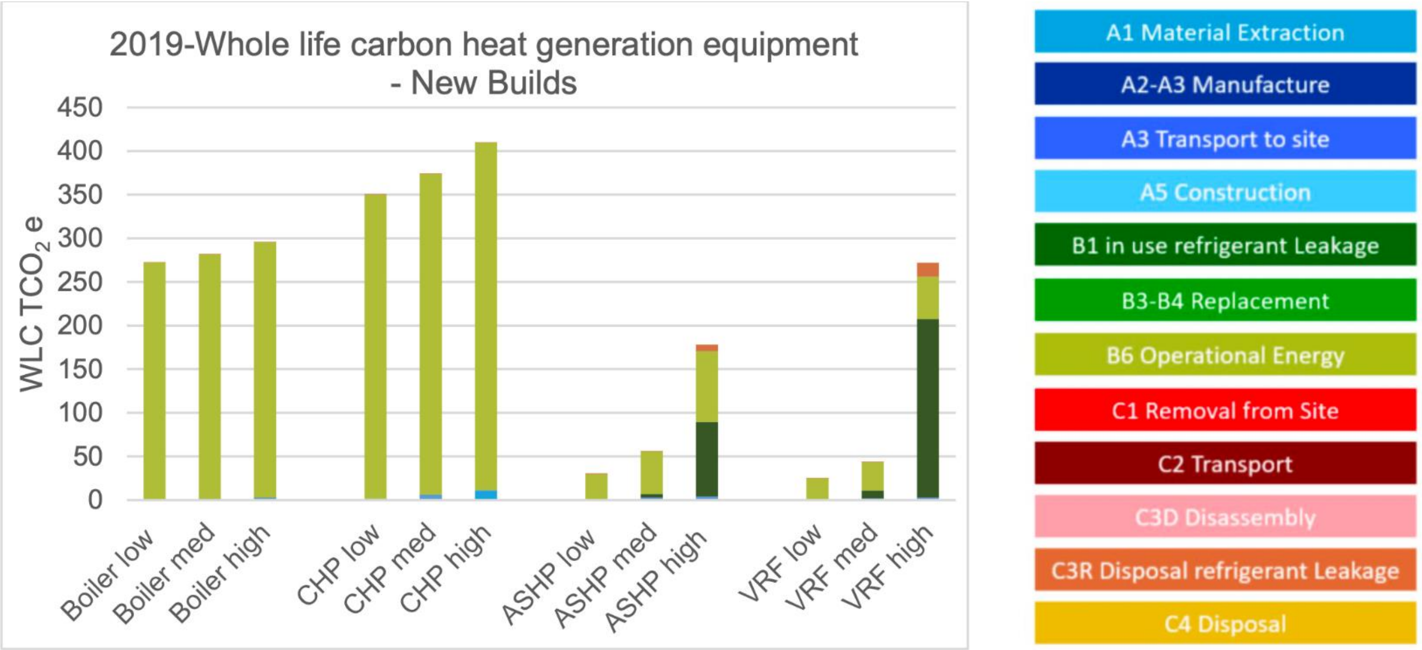


Image source: Baganel George, C., Hamot, L., Levey, R., (2019). *Understanding the importance of Whole Life Carbon in the selection of heat-generation equipment.* CIBSE Technical Symposium.

Which HVAC system is best?

- The main components of an HVAC system that affect refrigerant volume are the heat exchangers.
- The market is transitioning towards flooded evaporators and condensers with increased efficiency but increased refrigerant volumes.
- For VRF systems, the refrigerant charge is usually greater than with centralised water-based systems. There is additional risk due to refrigerant charge occurring on-site.

Which HVAC system is best?

Refrigerant leakage assumptions are shown in Table 6.

Table 6: Assumptions on refrigerants; installation in 2019

	Heat pumps			VRF		
	Low	Med	High	Low	Med	High
GWP	1	150	2088	1	150	2088
Annual leakage/ End of life recovery	1%/ 99%	3.8%/ 98%	6%/ 90%	1%/ 99%	6%/ 90%	10%/ 85%

Figure 8 : Installing in 2019- Passivhaus type building

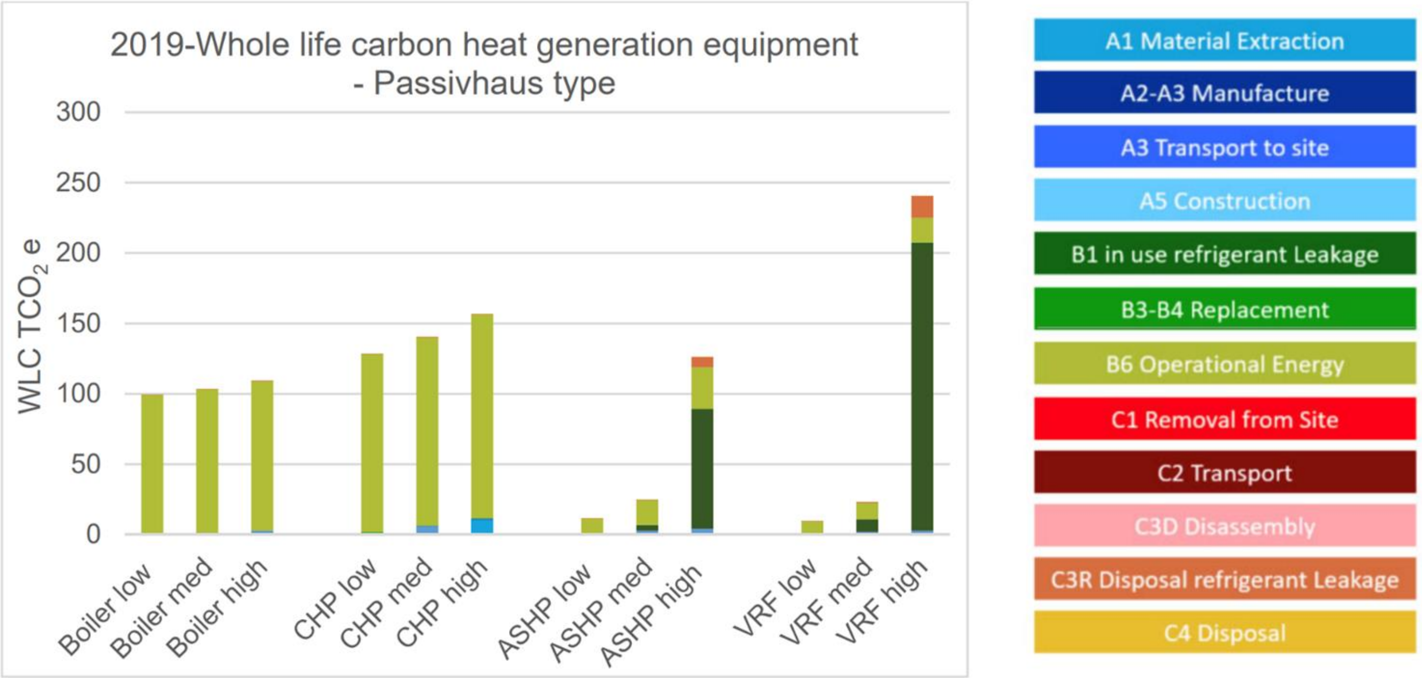


Image source: Baganel George, C., Hamot, L., Levey, R., (2019). *Understanding the importance of Whole Life Carbon in the selection of heat-generation equipment.* CIBSE Technical Symposium.

- The main components of an HVAC system that affect refrigerant volume are the heat exchangers.
- The market is transitioning towards flooded evaporators and condensers with increased efficiency but increased refrigerant volumes.
- For VRF systems, the refrigerant charge is usually greater than with centralised water-based systems. There is additional risk due to refrigerant charge occurring on-site.

What refrigerants to choose?

- R513a (GWP=631) is a potential substitute for R134a (GWP=1430) with no equipment modifications. The change would result in approximately a 4% reduction in performance.
- R1234yf (GWP<1) is a potential substitute for R134a (GWP=1430). However, R1234yf has low flammability.
- R514a (GWP <1) is a potential substitute for R134a (GWP=1430) in low pressure heat pumps/chillers but cannot be used for high pressure systems.
- There are currently no commercially available direct substitutes for R410a (GWP = 2088).
- There are currently no commercially available direct substitutes for R407c (GWP = 2107).

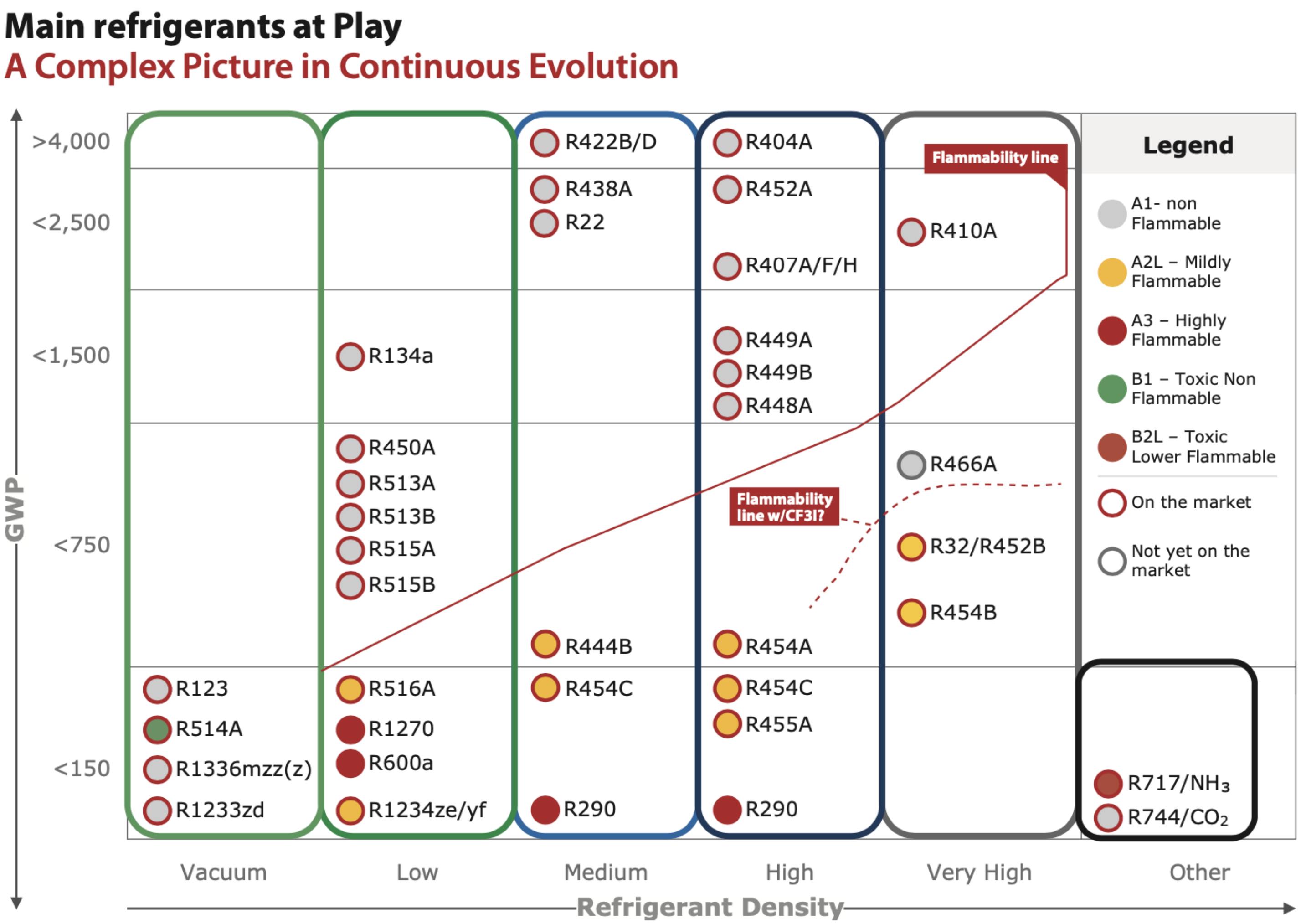


Image source: Danfoss (2018). *Refrigerant options now and in the future*.

Conclusion

Image source: www.greenbuildingcanada.ca

Buildings can be part of the solution

- Buildings powered by renewable energy and constructed of carbon sequestering materials can contribute to reducing greenhouse gas emissions during their service life.

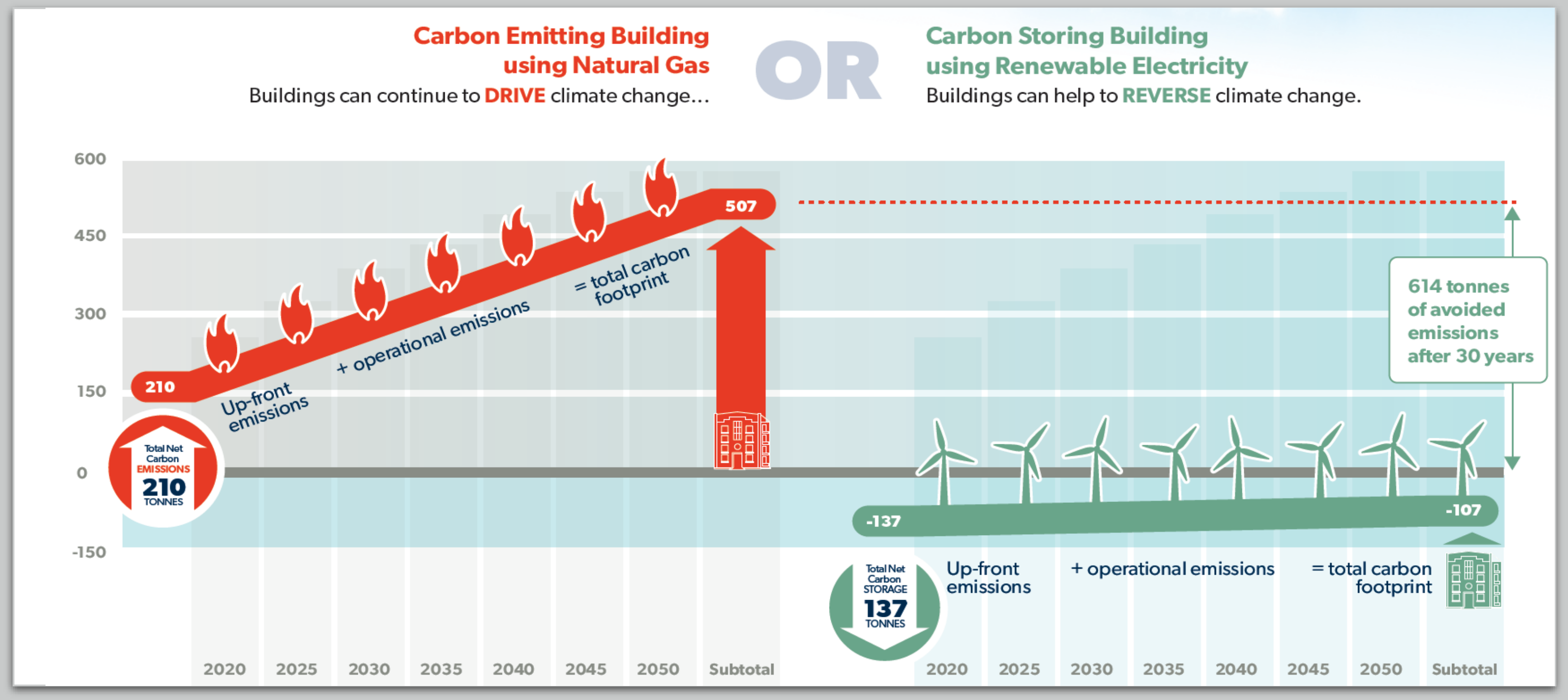


Image source: Builders for Climate Action (2019). *Low-Rise Buildings as a Climate Change Solution.*

Resources

https://www.oneclicklca.com/library/
http://carbonleadershipforum.org/
https://materialspalette.org/
http://endeavourcentre.org/
http://www.athenasmi.org/resources/about-lca/
https://choosetally.com/
https://www.buildingtransparency.org/en/
https://www.marincounty.org/depts/cd/divisions/sustainability/low-carbon-concrete-project

Thank You