The Putney School New Dorms

Lowering Total Carbon Emissions

Strategies for Design and Construction

Maclay Architects

Andrew M. Shapiro, Energy Balance, Inc
Jacob Deva Racusin, New Frameworks

Westford Symposium on Building Science XXVII
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***Putney School Dorms*:**
Structure of Presentation

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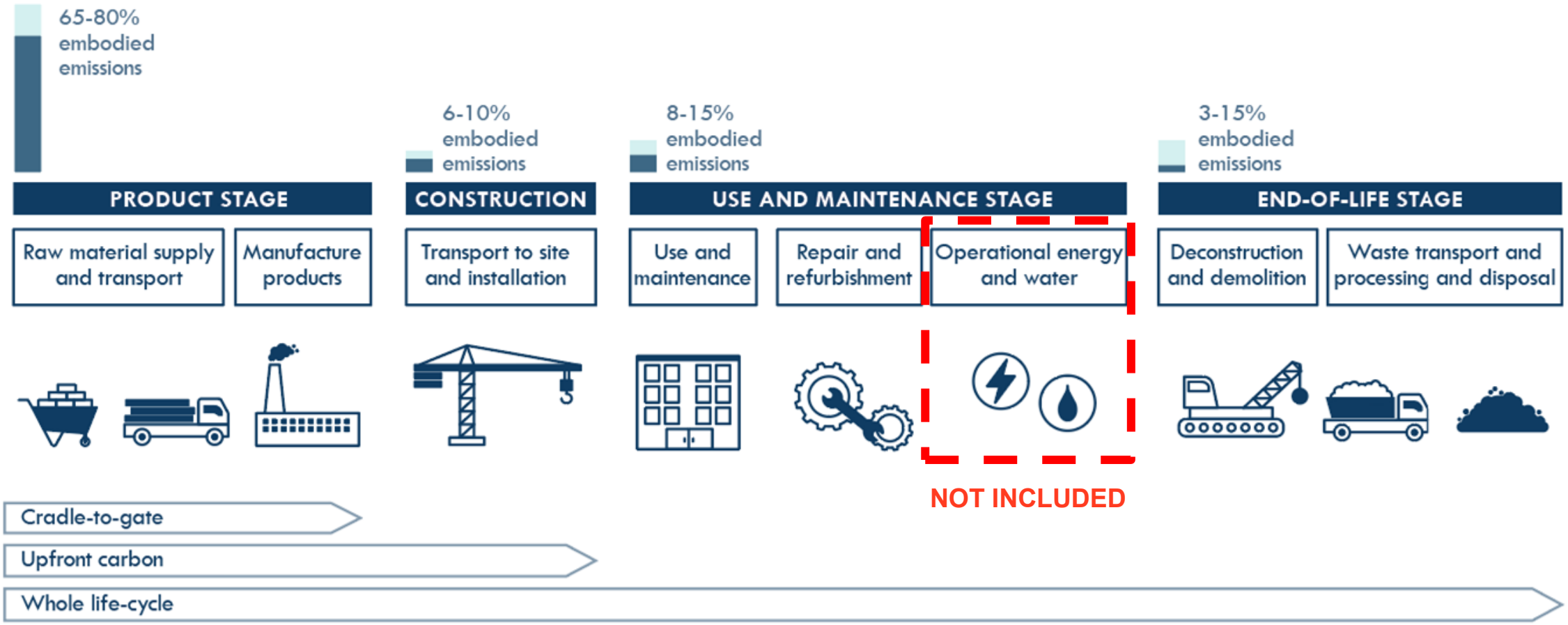
1. Carbon Analysis Framing
2. Project Case Study: Putney School Dormitories
3. Analyzing Embodied and Operational Emissions Over Time
4. Carbon Storage and Time Value of Carbon
5. RESNET 1550 and Next Steps in Total Carbon Reduction

Embodied CO_2e Life Cycle Stage Calculations



Basic embodied carbon math

Material quantity

From plan take-offs

Emission factor

From EPDs or other approved data source

Product emissions

kg CO2e

per life cycle phase

Estimating material carbon emissions

Emission data sources

EPD – Product Impacts

Declared Unit: 1 m^3

Construction Material

Amount per Unit	
Global Warming Potential	450 $kgCO_2e$
Emitted	475 $kgCO_2e$
Sequestered	-25 $kgCO_2e$
Ozone Depletion	0.00 kgCFC11e
Acidification Potential	3.01 $kgSO_2e$
Eutrophication Potential	0.15 kgNe
Smog Formation	0.63 kgO_3e
Primary Energy Demand	3020 MJ
Non-renewable	3045 MJ
Renewable	25 MJ

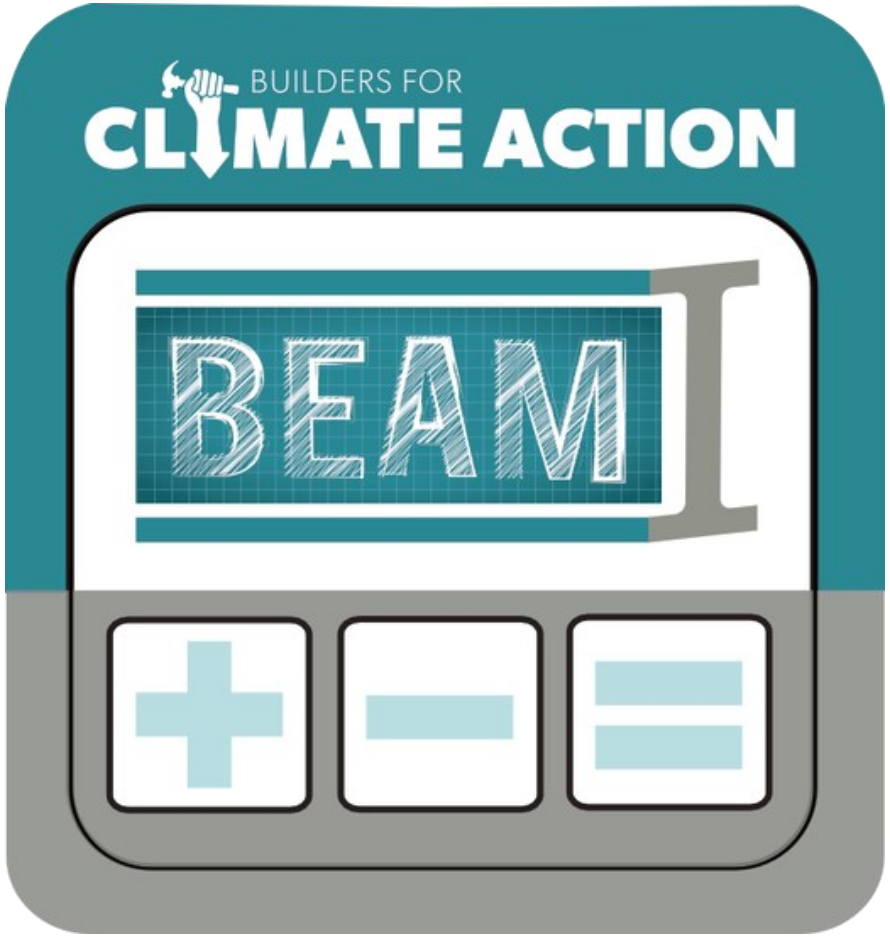
An **Environmental Product Declaration** (EPD) "quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function."

The EPD methodology follows ISO series 14040 & 14025 requirements.

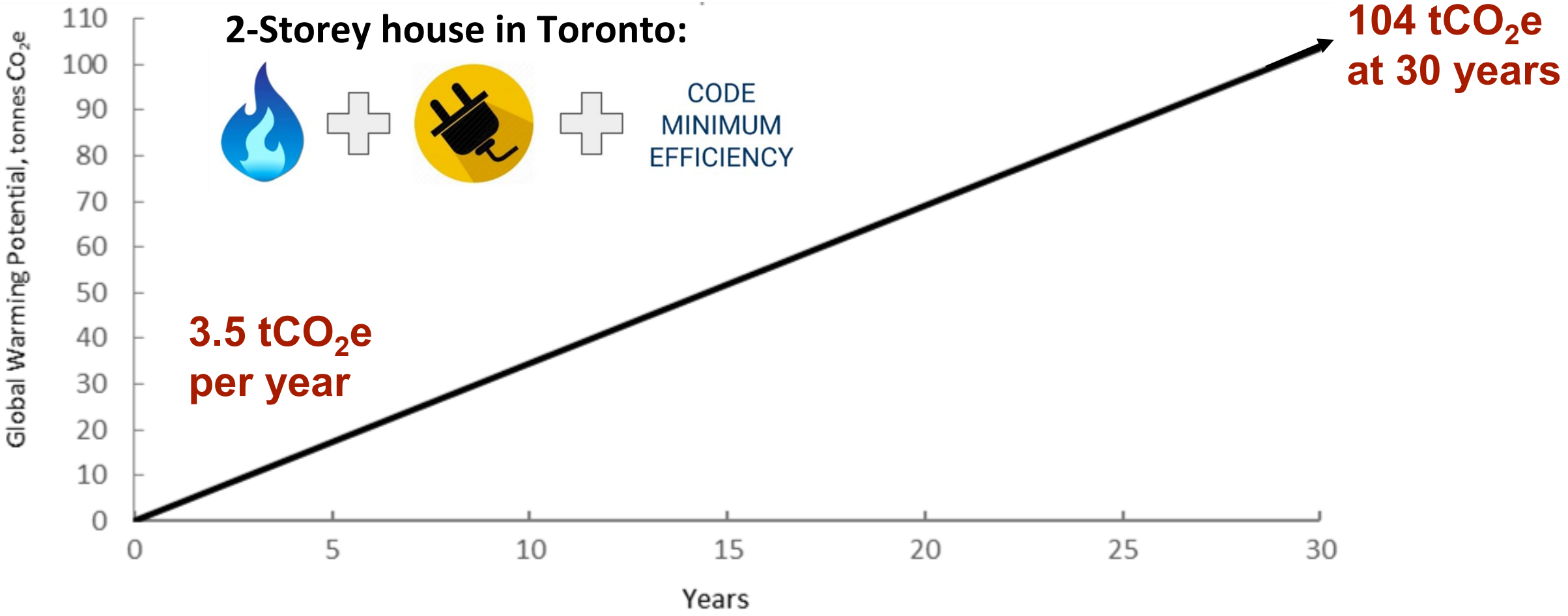
Reports in kg CO2e.

BEAM Material CO_2 Emissions Estimator (A1-A3)

- Direct side-by-side material comparisons
- Assembly comparisons
- Design development
- Whole building models and comparisons
- Includes carbon storing materials

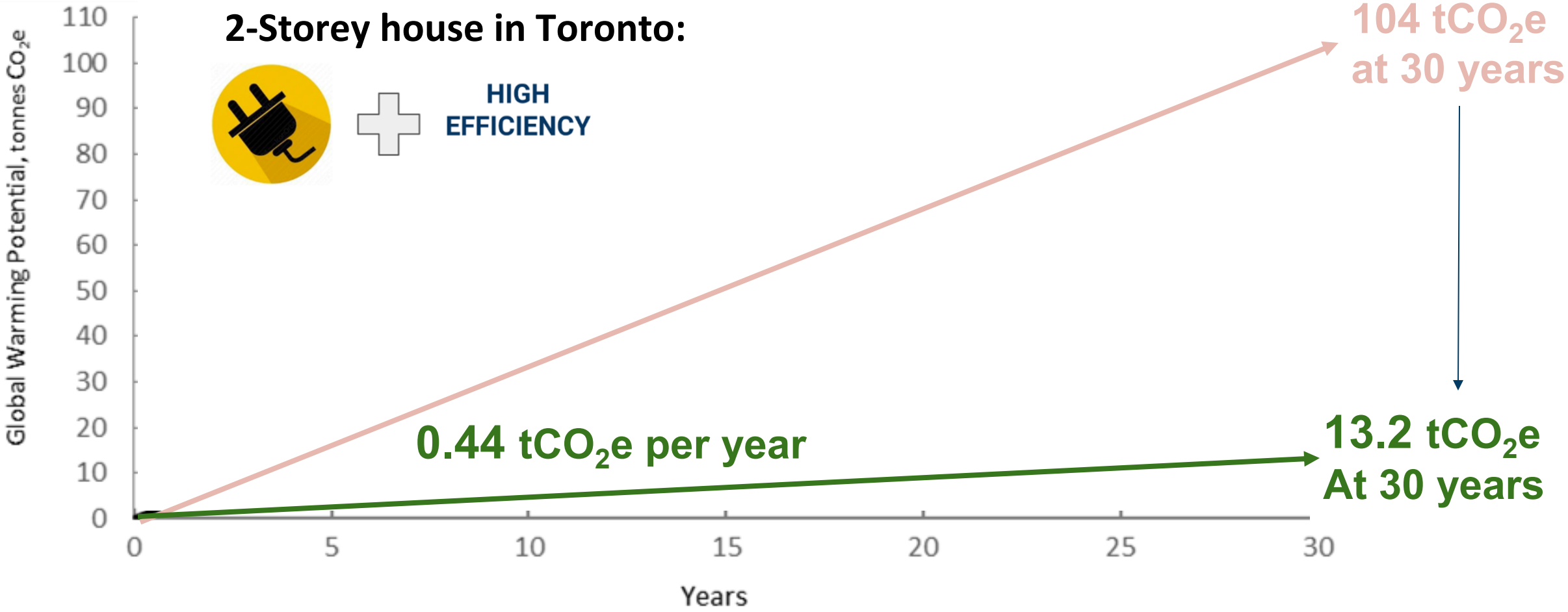


Cumulative Operational CO_2e Emissions – *Business as usual*



Source: Builders for Climate Action

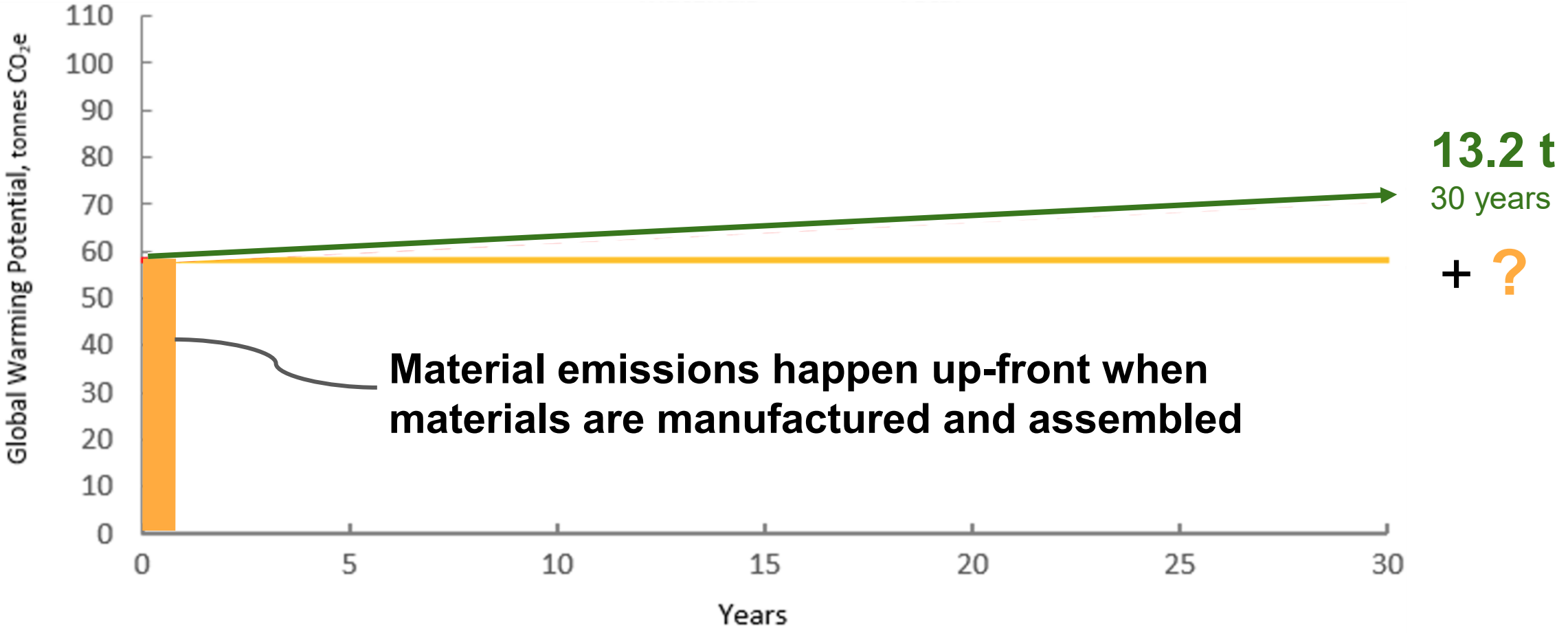
Cumulative Operational CO_2e Emissions – *High Efficiency*



Measuring and reducing OC is well understood…

Source: Builders for Climate Action

High Embodied + Low Operational CO_2e Emissions



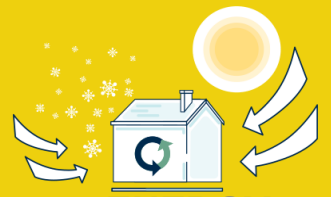
Source: Builders for Climate Action

We need to reduce both!

Material Carbon Emissions

+

Operational Carbon Emissions



ENERGY USE INTENSITY

×

ENERGY SOURCE EMISSIONS

=

CARBON INTENSITY

Graphic : Builders for Climate Action

The Putney School New Dorms:
Structure of Presentation

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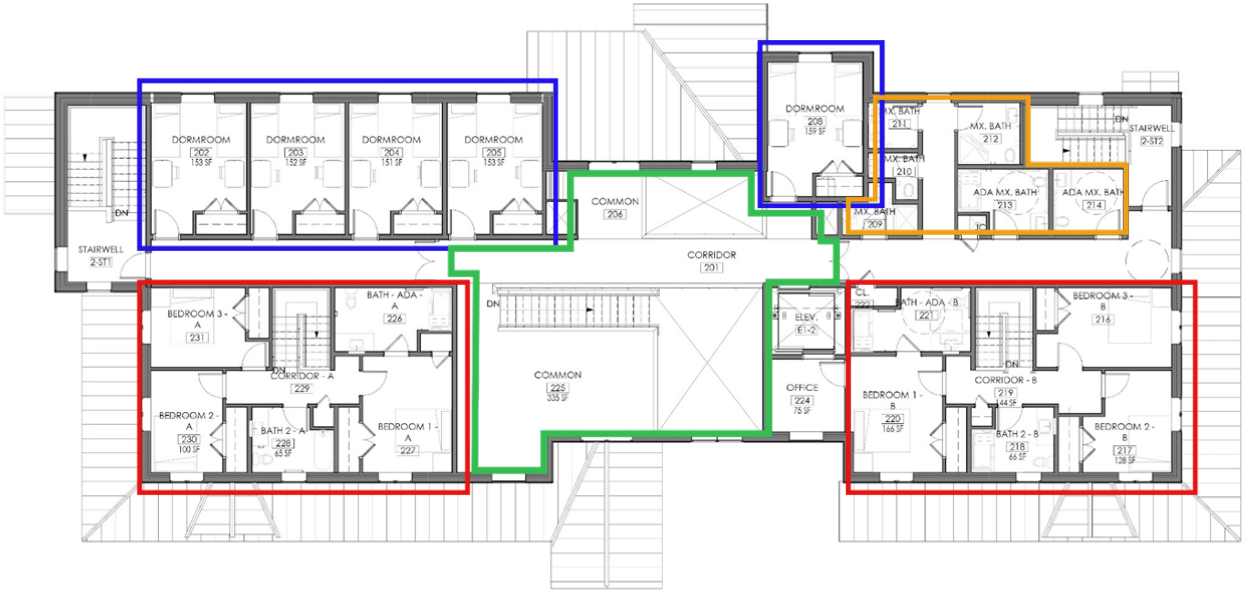
1. The building and context
2. Operational Energy and CO2e Modeling (2 options)
3. Embodied CO2e in Materials (3 options)
4. Total Carbon Picture Over Time (2 options)
5. Lessons Learned


Hepper House
Gund House

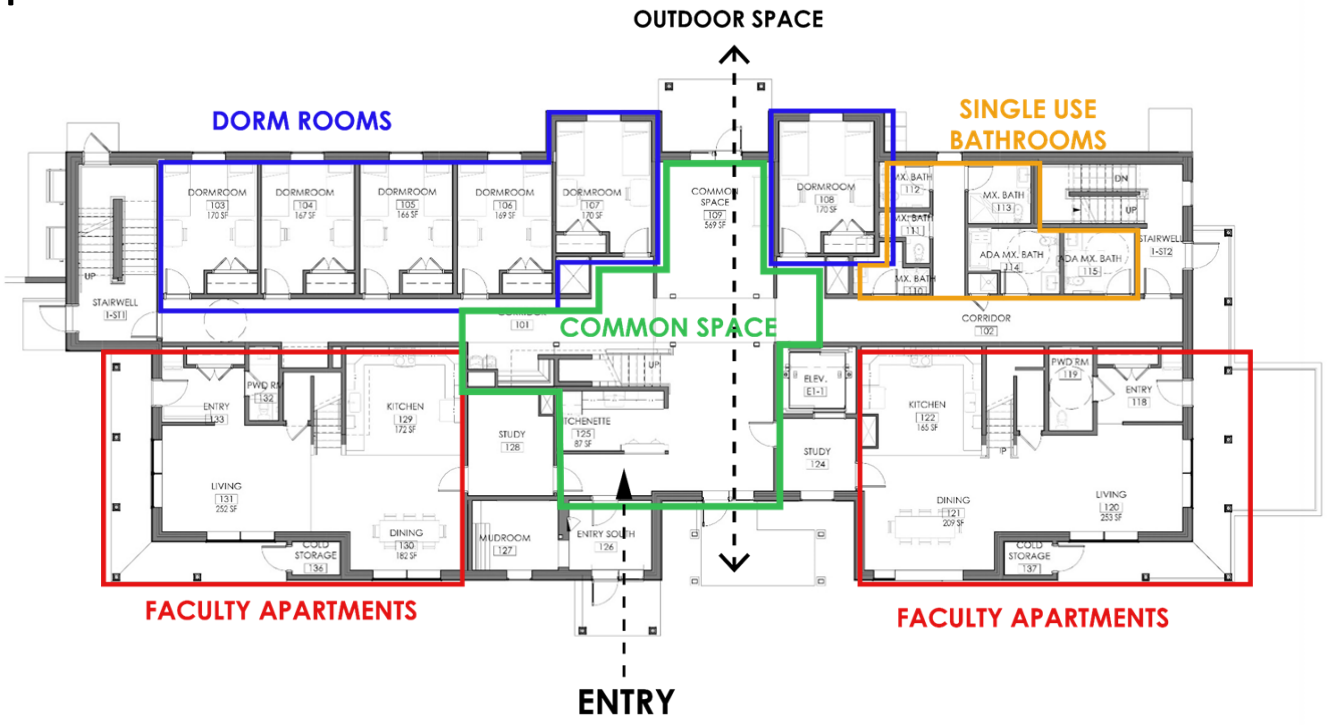
The Putney School New Dorms:
Two Buildings, Nearly Identical

Gund House

Hepper House



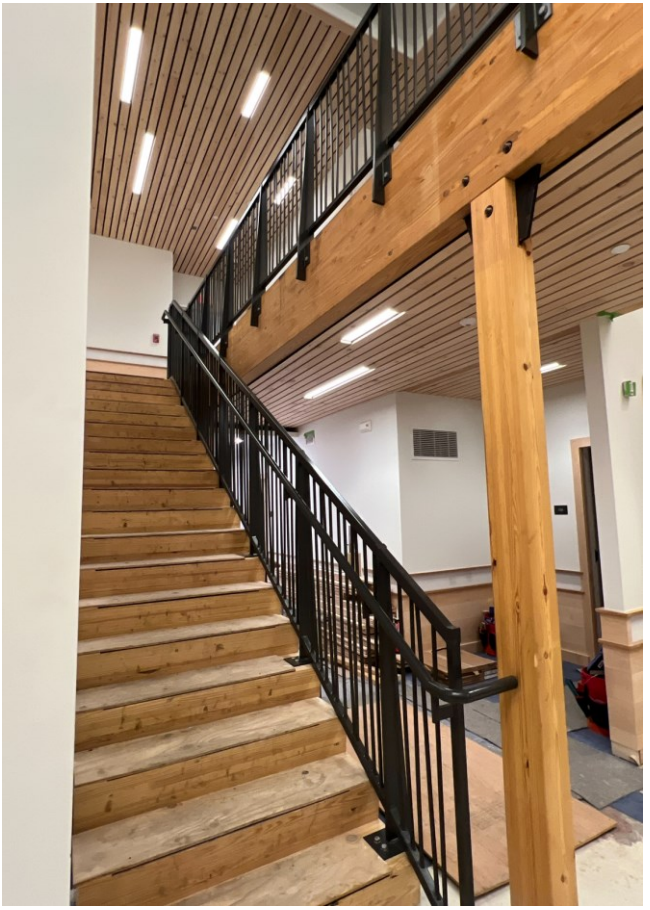
Second Floor Plan



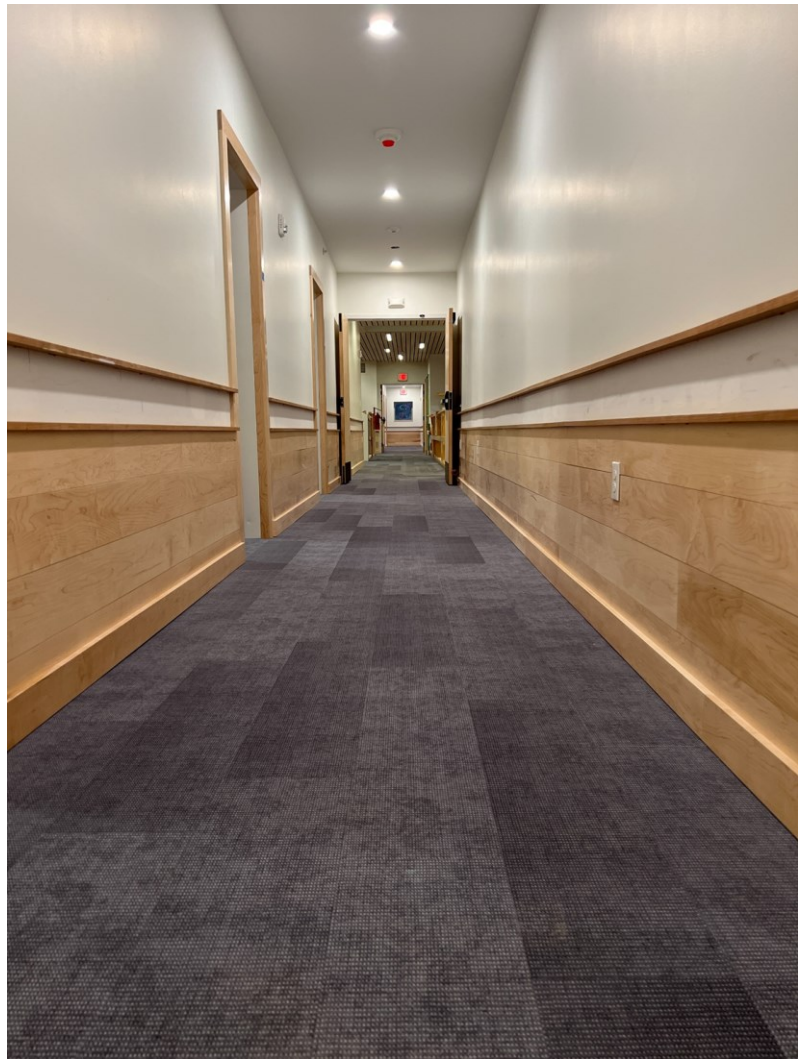
First Floor Plan

The Putney School New Dorms:
Embodied Carbon – Material Considerations

Original interior rendering:



Double-height common space for students



Wood accents anticipating student involvement

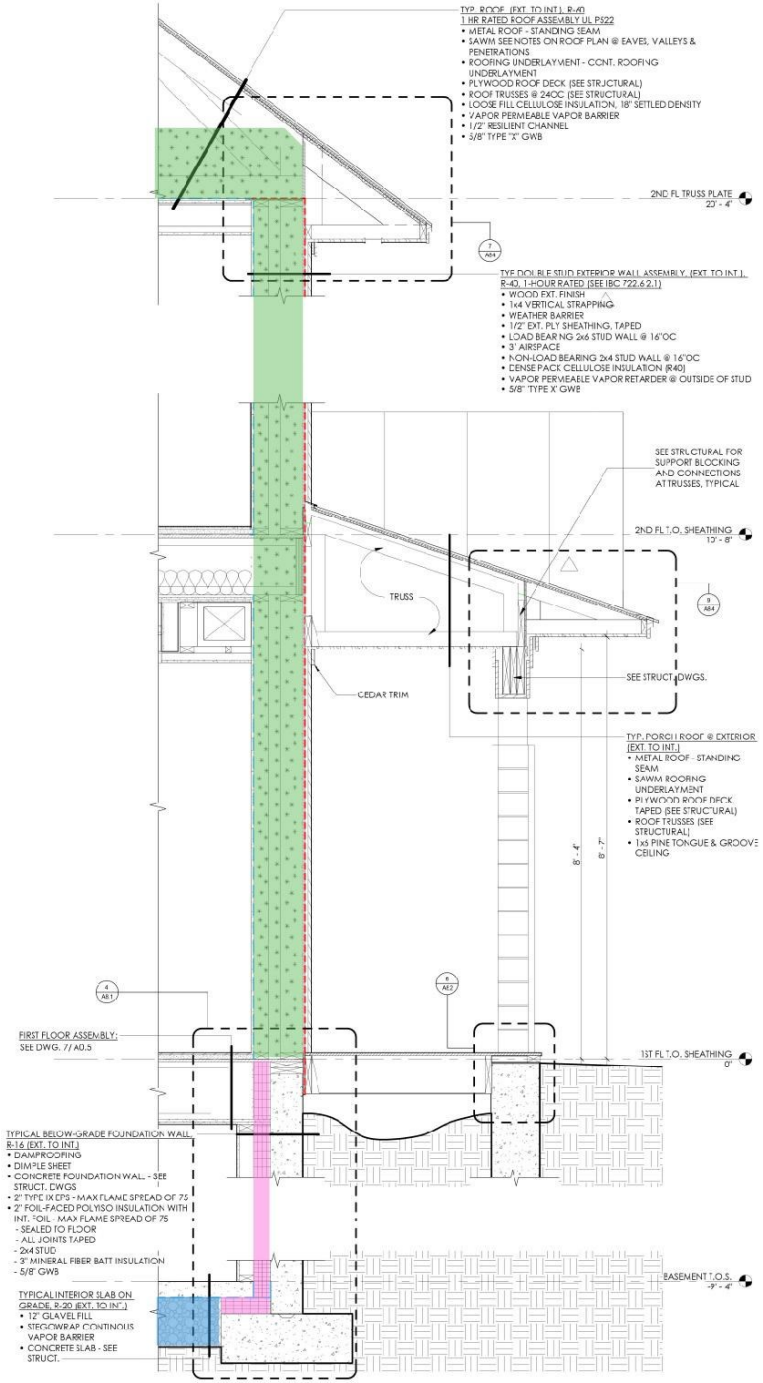
The Putney School New Dorms: Embodied Carbon & Insulation

18” of Blown Cellulose
R-60

12” of Wet Spray Cellulose
R-40

4” of EPS + Polyiso
R-16

12” of Glavel
R-20



The Putney School New Dorms:
Cement Replacement in Concrete

	% Cement Replacement
	Specification
Footings	25% - 70%
Walls, columns, piers	25% - 50%
Interior slab	0 - 25%
Exterior slab	15 - 25%

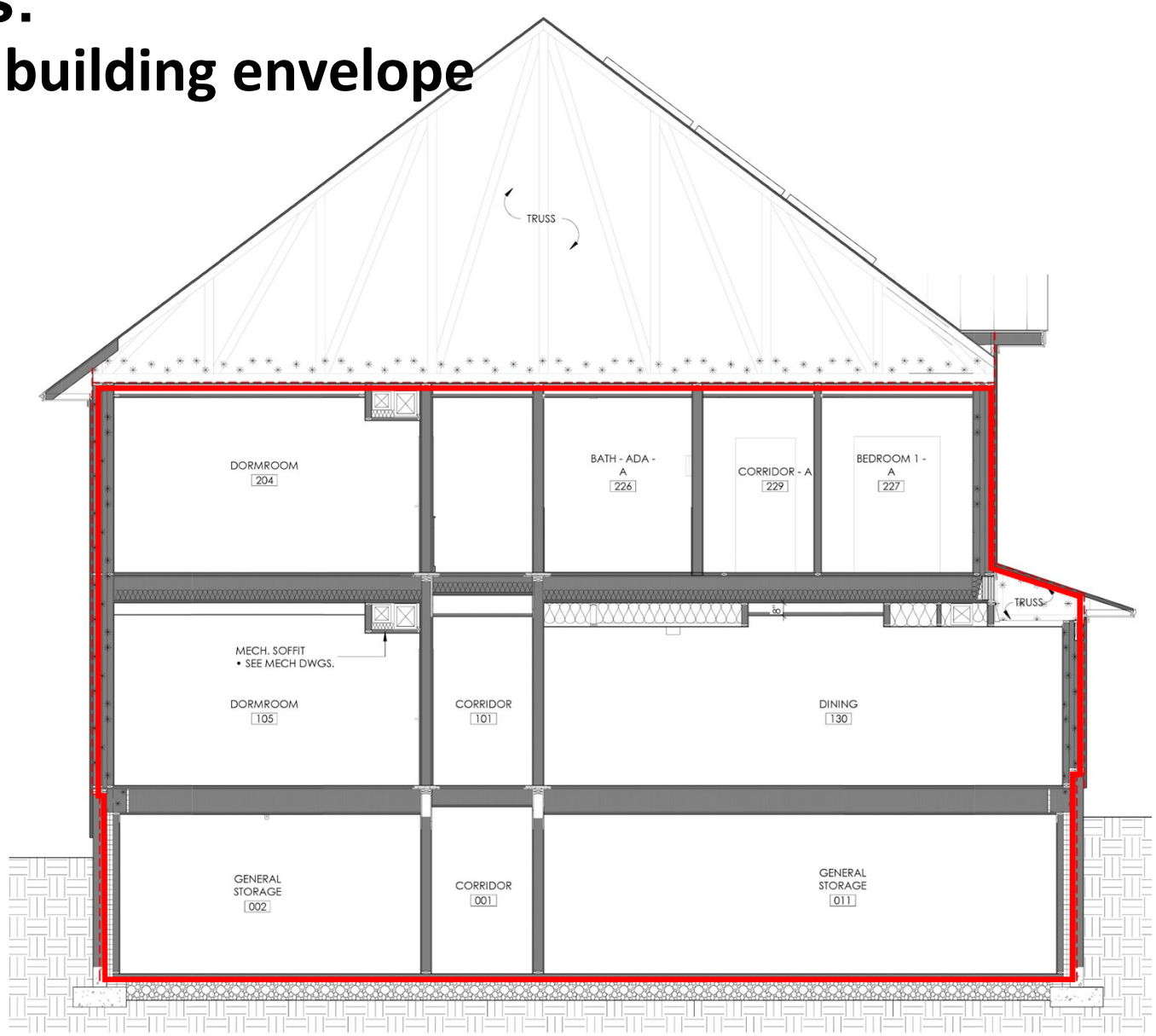
The Putney School New Dorms:
Cement Replacement in Concrete

	% Cement Replacement	
	Specification	**Achieved**
Footings	**25% - 70%**	**25%**
Walls, columns, piers	**25% - 50%**	**25%**
Interior slab	**0 - 25%**	**0%**
Exterior slab	**15 - 25%**	**15%**

The Putney School New Dorms:
Embodied Carbon & Concrete

The Putney School New Dorms:
Lowering Operational Emissions at building envelope

Final blower door test of 0.035
CFM50 /SF of Envelope (6 sides)



The Putney School New Dorms:
Continuous Air Barrier

The Putney School New Dorms –
Energy and CO2e Modeling

Three options analyzed:

1. **Code building baseline, 2020 CBES**
2. **Baseline net zero ready building – Net zero ready performance built as if embodied CO2e was NOT considered**
3. **Lower embodied carbon net zero ready – Building as built**

The Putney School New Dorms –

Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, RBES	Baseline Net Zero Ready Building	Lower Embodied Casrbon Net Zero Ready
Windows	R-3.3 low-e, argon	R-5 tripane, dual low-e, argon	R-5 tripane, dual low-e, argon

The Putney School New Dorms –

Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, RBES	Baseline Net Zero Ready Building	Lower Embodied Casrbon Net Zero Ready
Doors	R-2.7	R-3.3	R-3.3

The Putney School New Dorms –
Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, RBES	Baseline Net Zero Ready Building	Lower Embodied Casrbon Net Zero Ready
Concrete	100% cement		Footings - 75% cement
			Walls, columns, piers - 75% cement
			Interior slab - 100% cement
			Exterior slab - 85% cement

The Putney School New Dorms –
Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, RBES	Baseline Net Zero Ready Building	Lower Embodied Casrbon Net Zero Ready
Insulation	Basement Walls, 3" XPS foam	Basement Walls, 2" XPS foam + 2" foil-faced Polyiso foam	Basement Walls, 2" XPS foam + 2" foil-faced Polyiso foam
	No subslab insulation	4" sub-slab XPS insulation, on 7" crushed stone.	12" R-20 Glavel
	Walls: R-21 fiberglass + R-7.5 XPS , poly VB	Walls: R-21 mineral fiber + 4" XPS continuous, poly VB	Walls: 12" R-40 double stud wall with cellulose, Intello+ variable vapor retarder
	Attic R-49 fiberglass batts	Attic R-80 mineral fiber batts	Attic R-80 loose fill cellulose

The Putney School New Dorms –

Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, RBES	Baseline Net Zero Ready Building	Lower Embodied Casrbon Net Zero Ready
Cladding	Fiber cement siding		Locally milled Eastern Cedar
Cladding finish	3 coats water-based paint		3 coats oil-based semi-transparent stain
Roofing	Standing seam metal		

The Putney School New Dorms –
Operational Energy and CO2e Modeling

Building Enclosure	Code building baseline, RBES	Baseline Net Zero Ready Building	Lower Embodied Casrbon Net Zero Ready
Interior partitions	cold formed steel studs		wood studs
gypsum board	typical		USG EcoSmart gypsum board except where fire rated
Interior finishes	commercially available wainscoting	commercially available wainscoting	Locally milled wainscoting, NY state

The Putney School New Dorms –
Operational Energy and CO2e Modeling

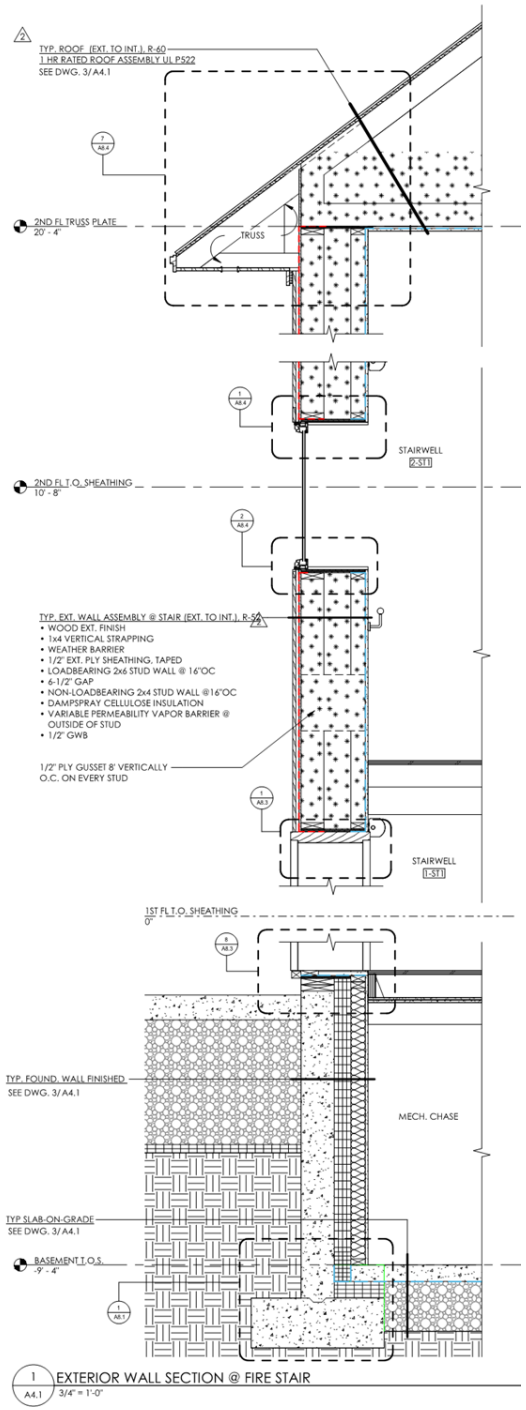
Building Enclosure	Code building baseline, RBES	Baseline Net Zero Ready Building	Lower Embodied Casrbon Net Zero Ready
Air leakage rate	**0.3** cfm50/sq.ft. shell, 6 sides	**.05** cfm50/sq.ft. shell, 6 sides	.05 cfm50/sq.ft. shell, 6 sides

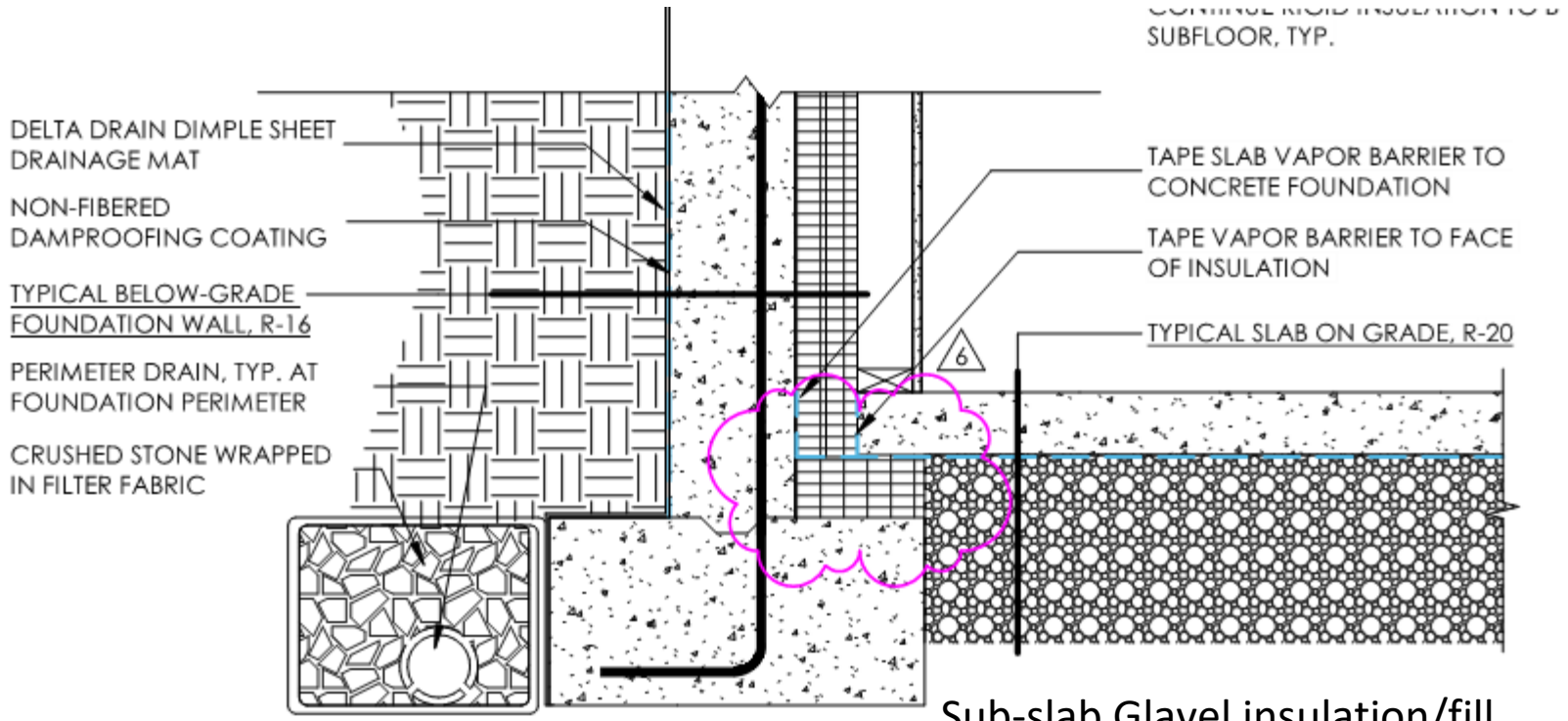
Achieved 0.035 cfm50/sq.ft. shell

The Putney School New Dorms –
Operational Energy and CO2e Modeling

Mechanicals	CBECS 2020 Code Compliant	Baseline Net Zero Building	Lower Embodied Casrbon Net Zero Ready
Commissioning	No	Yes	Yes
Ventilation	800 cfm total, 50% enthalpy recovery; 66% sensible recovery, 1.2cfm/watt		
Hot Water	From boiler, 75% efficient delivery plus recirc loop losses	Solar hot water, backup with heat pump, with drainwater heat recovery on dorm showers, no recirc	
Heat	propane 90 AFUE boiler at 85% seasonal efficiency, fan coils	ASHP annual heat COP 2.3,	
Cooling	Split system AC with coils in ductwork		ASHP cooling
Setpoint	70F heating 72F cooling		
Lighting	100% LED		

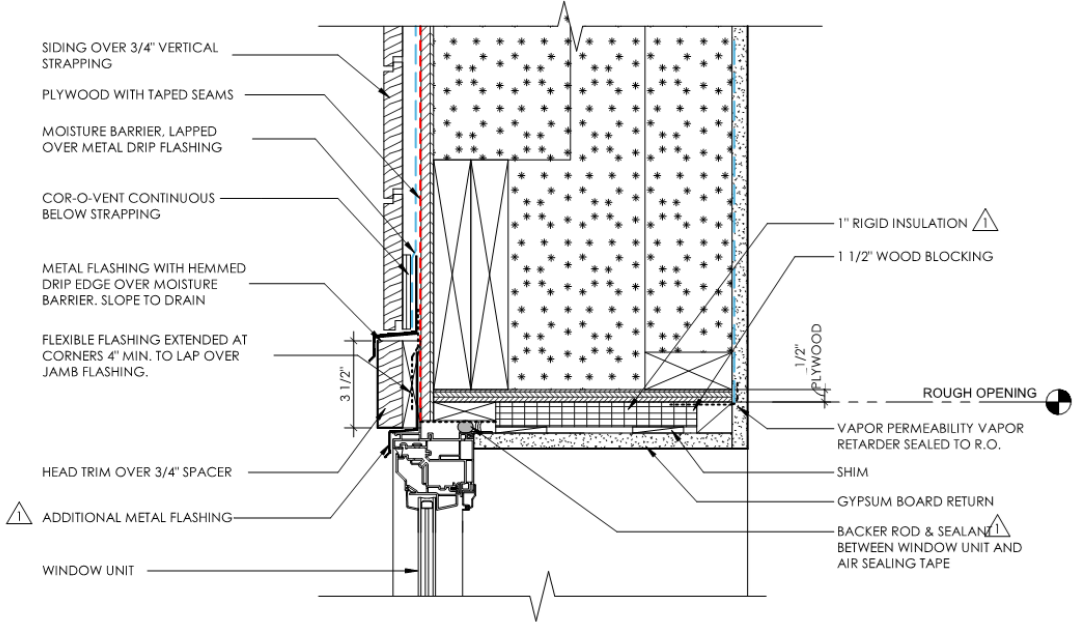
The Putney School New Dorms – Building Enclosure



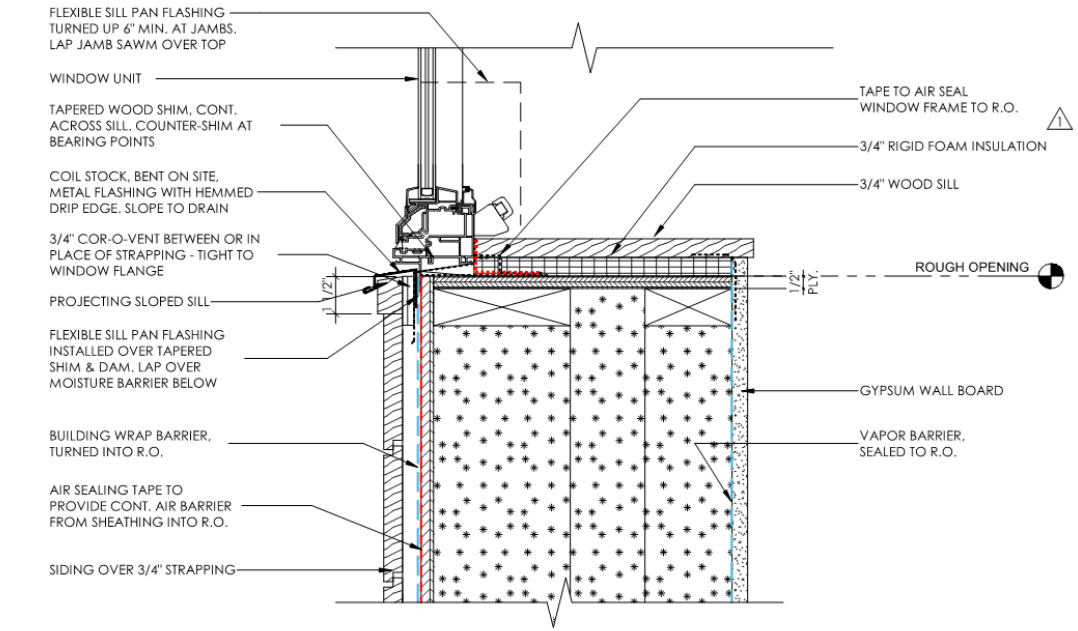


Sub-slab Glavel insulation/fill

The Putney School New Dorms –
Building Enclosure

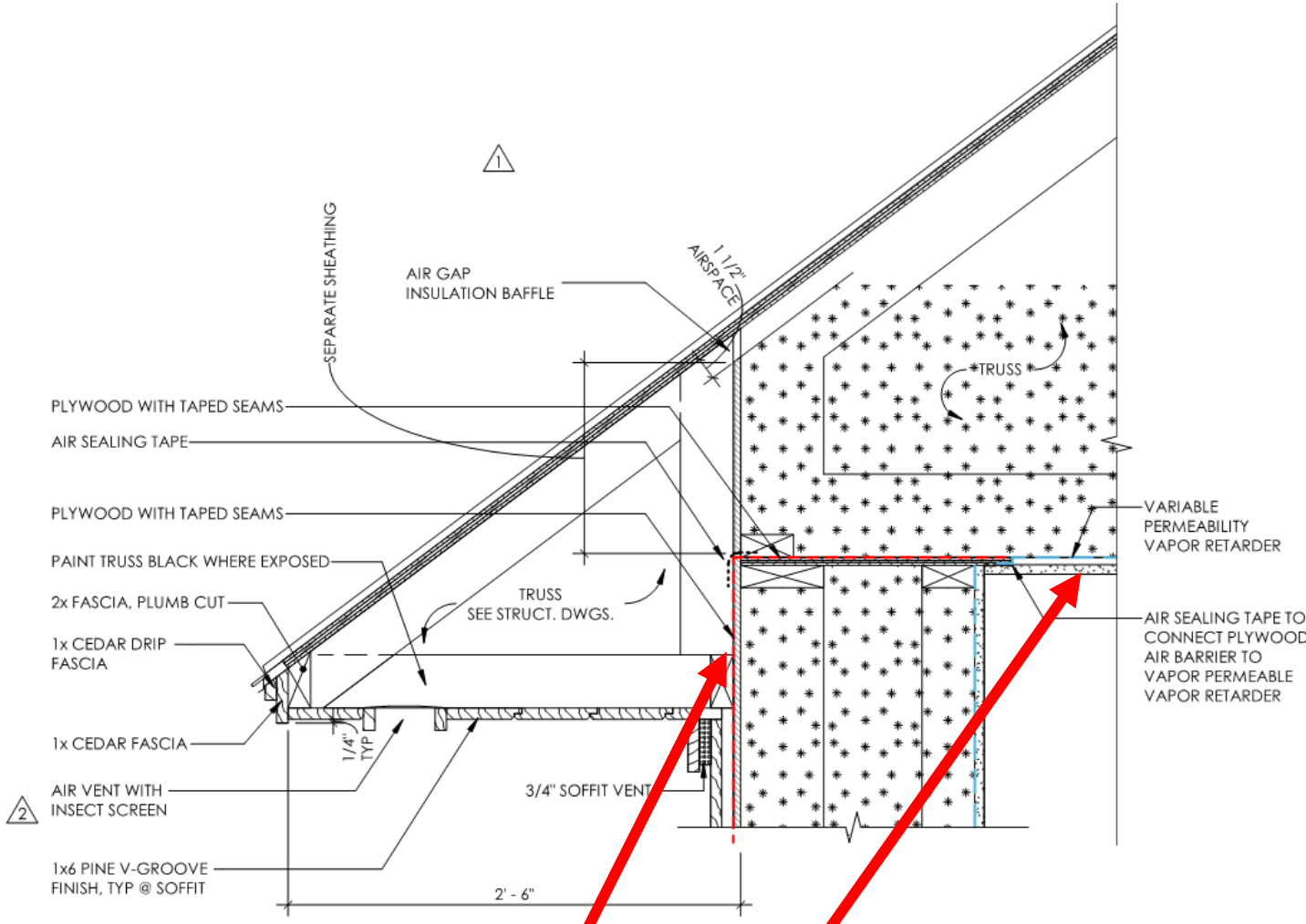


1 / A8.4 TYP WINDOW HEAD
3" = 1'-0"



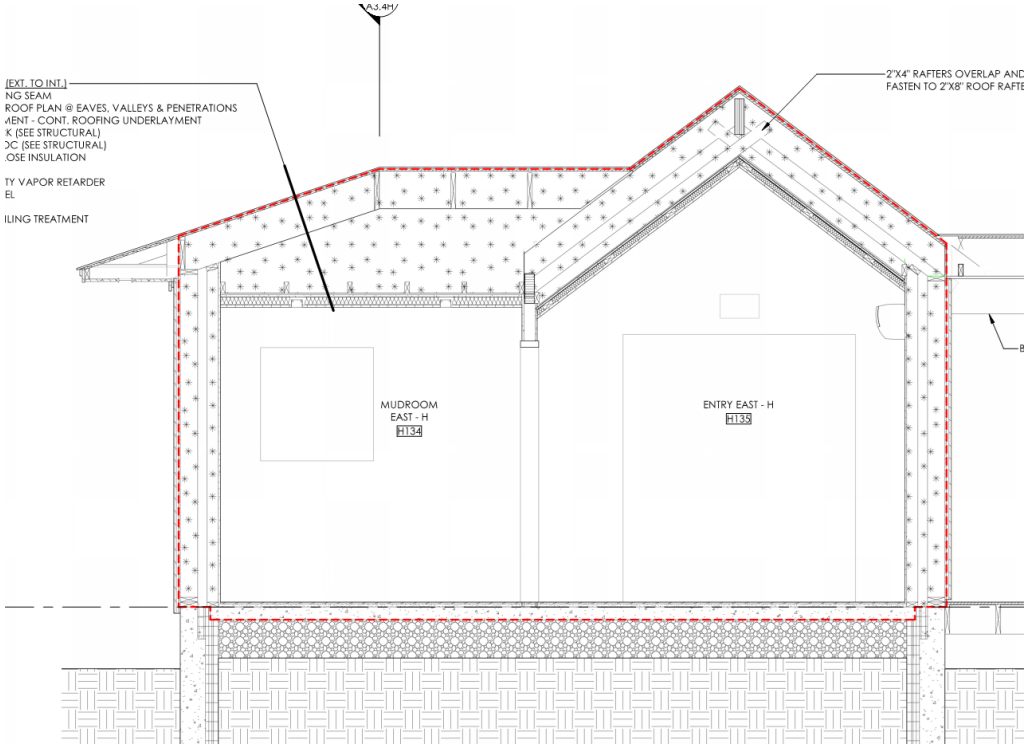
2 / A8.4 TYP WINDOW SILL
3" = 1'-0"

ROUGH OPENING



Air barrier moves from outside to inside

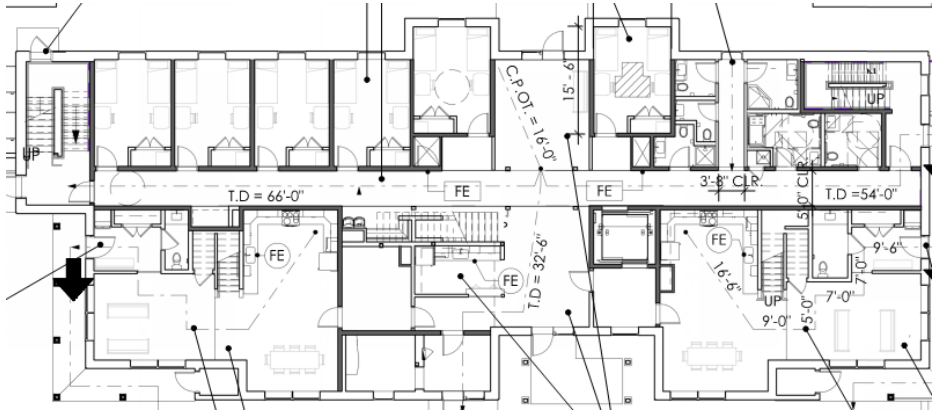
Uplift and deflection of 40 ft trusses required complex detailing



The Putney School New Dorms –

Building Enclosure

Building floorplan complexity increases cost of achieving a high performance enclosure



First floor has 22 corners; second floor has fewer corners

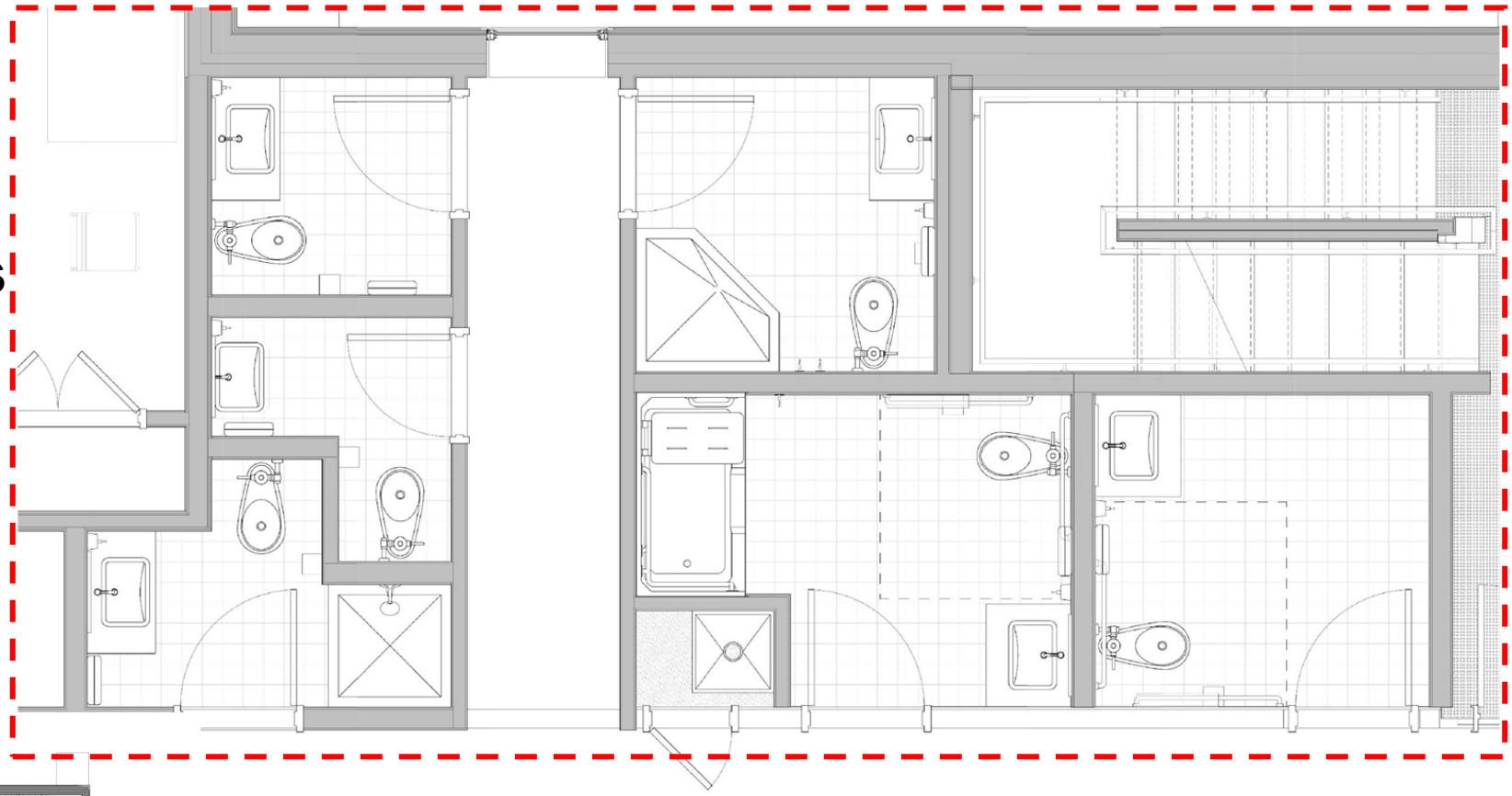
The Putney School New Dorms –

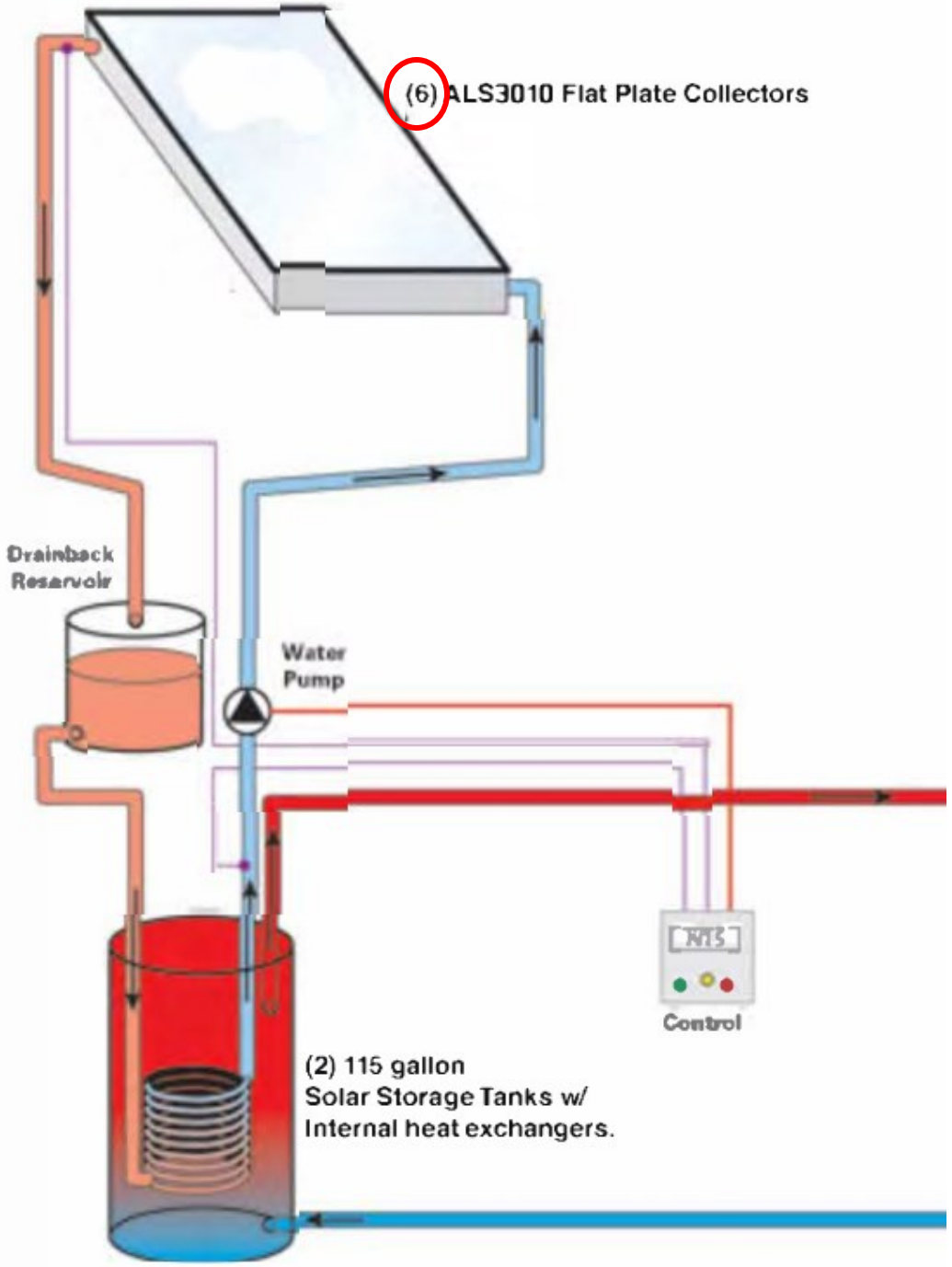
Operational Energy and CO2e Modeling

Hot Water	From boiler, 75% efficient delivery plus recirc loop losses	Solar hot water, backup with heat pump, with drainwater heat recovery on dorm showers, resistance electric top-up	Solar hot water, backup with heat pump, with drainwater heat recovery on dorm showers, resistance electric top-up
MEP Commissioning	No	Yes	Yes
Lighting	100% LED	100% LED	100% LED

Drainwater heat recovery system captures about 50% of heat going down the drain

Ganged bathrooms allow shower drainwater heat recovery from dorm room showers – two floors similar dorm room showers and avoids need for recirc hot water system





Closed Loop Drain-Back Solar Hot Water

Buildings are to be used in summer!

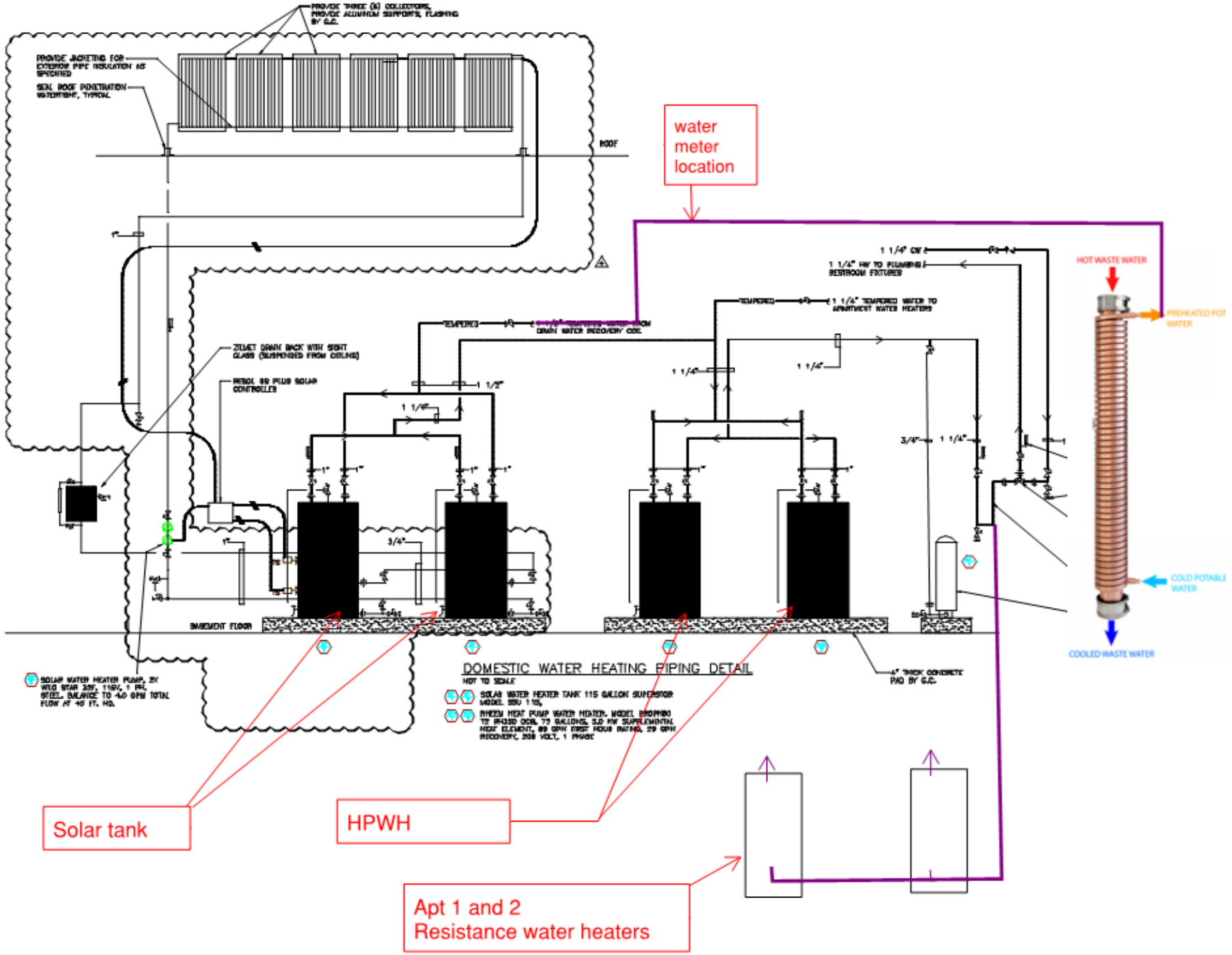
1. Near zero pressure in system
2. Collectors empty except when heating
3. Stainless tanks, copper piping
4. Very long antifreeze life
5. Very long system life
6. Modeled 50% savings of 15 MWh/year load

>>> Hot water out

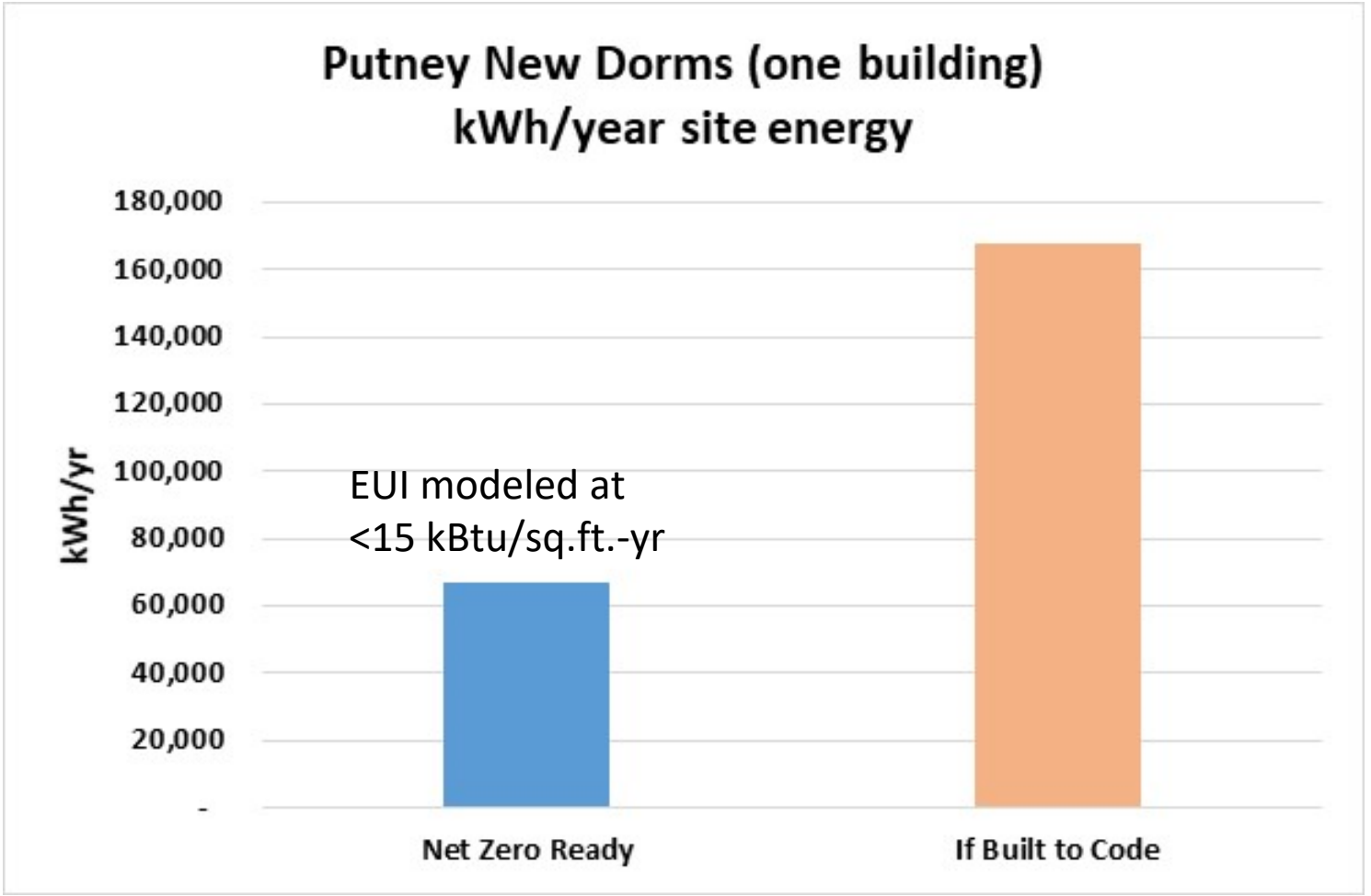
<<< Cold water in

RM

Hot water system

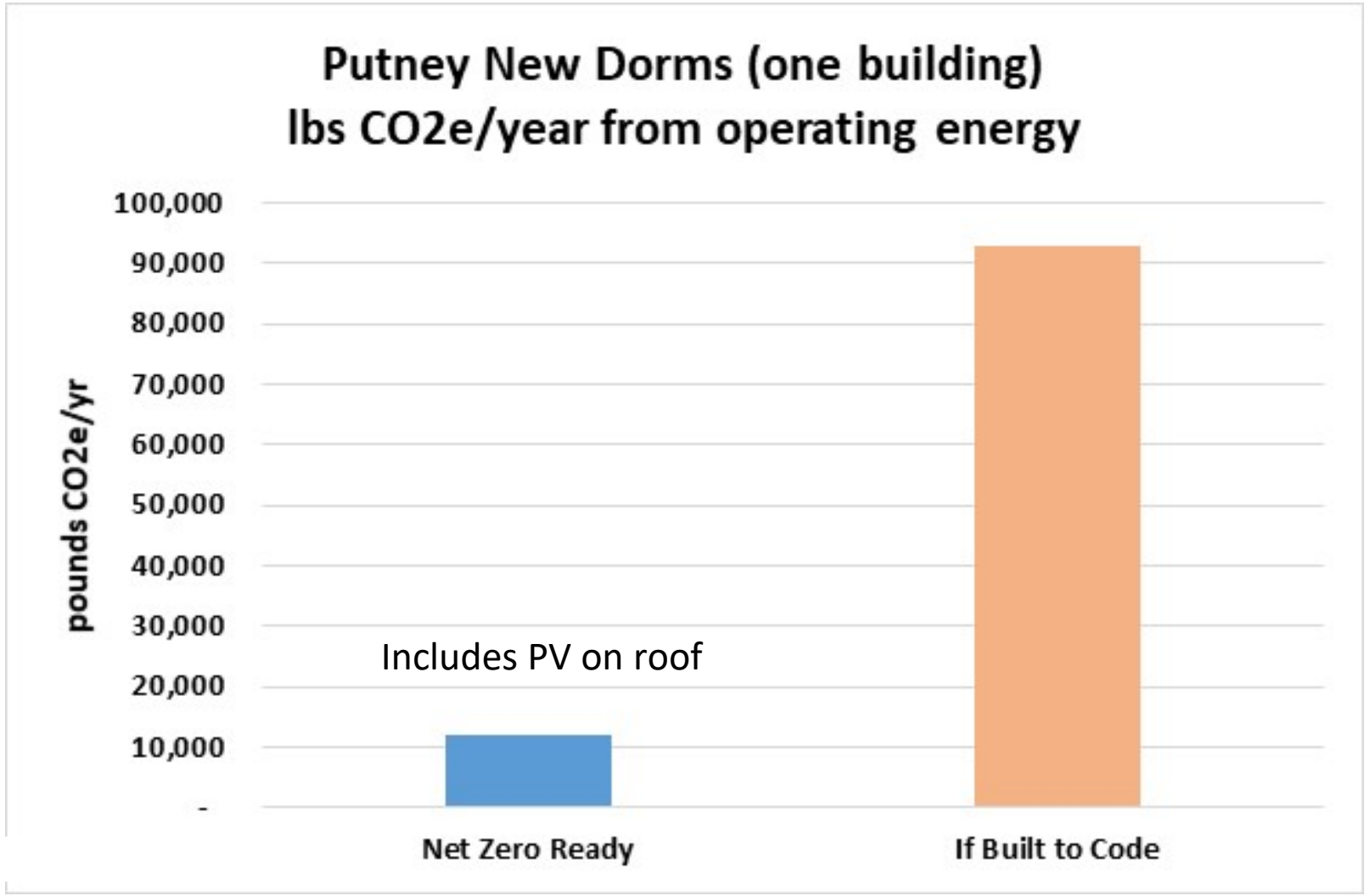


The Putney School New Dorms –
Operational Energy - Modeled



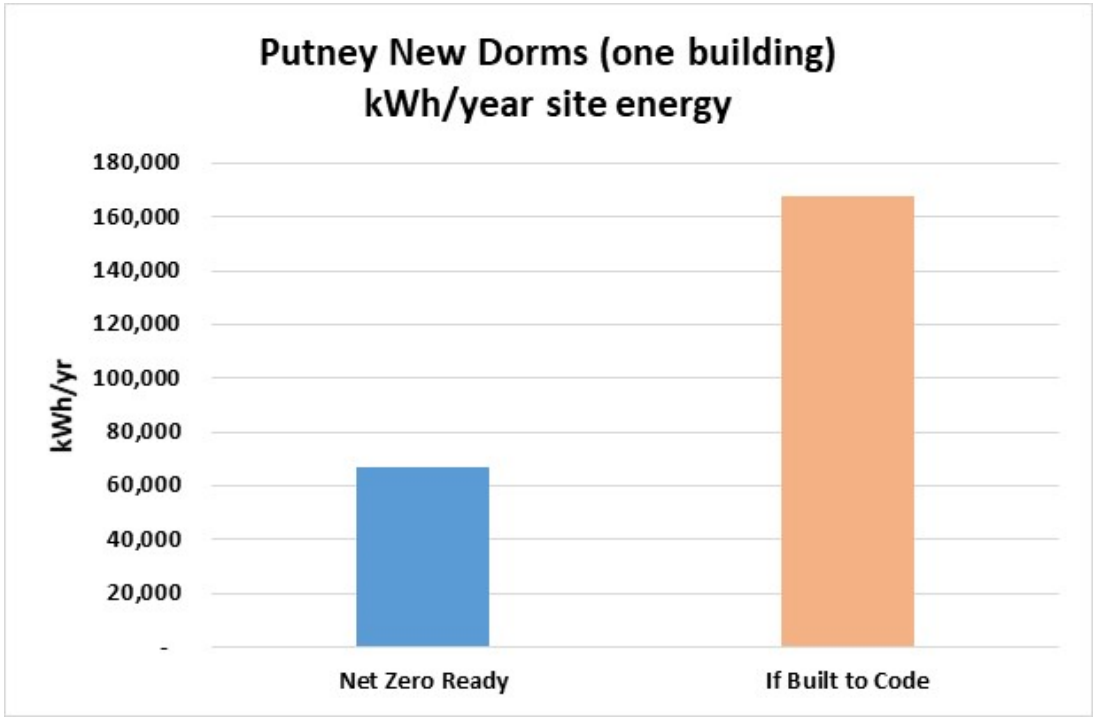
The Putney School New Dorms –

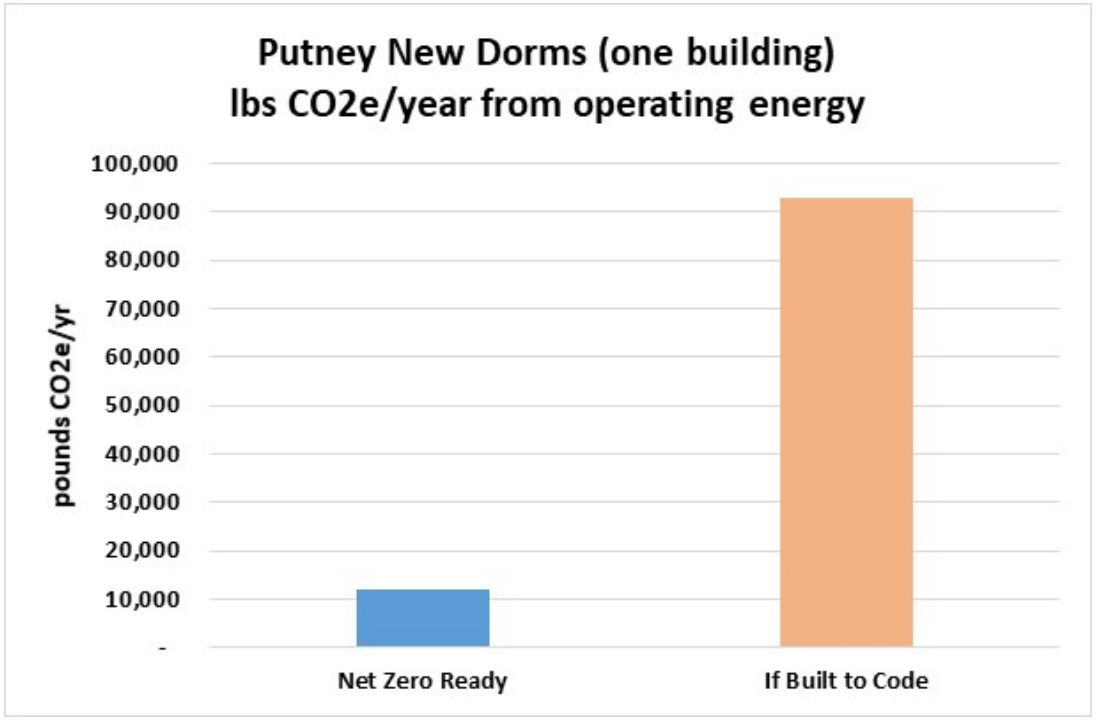
Operational Energy CO2e Emissions - Modeled



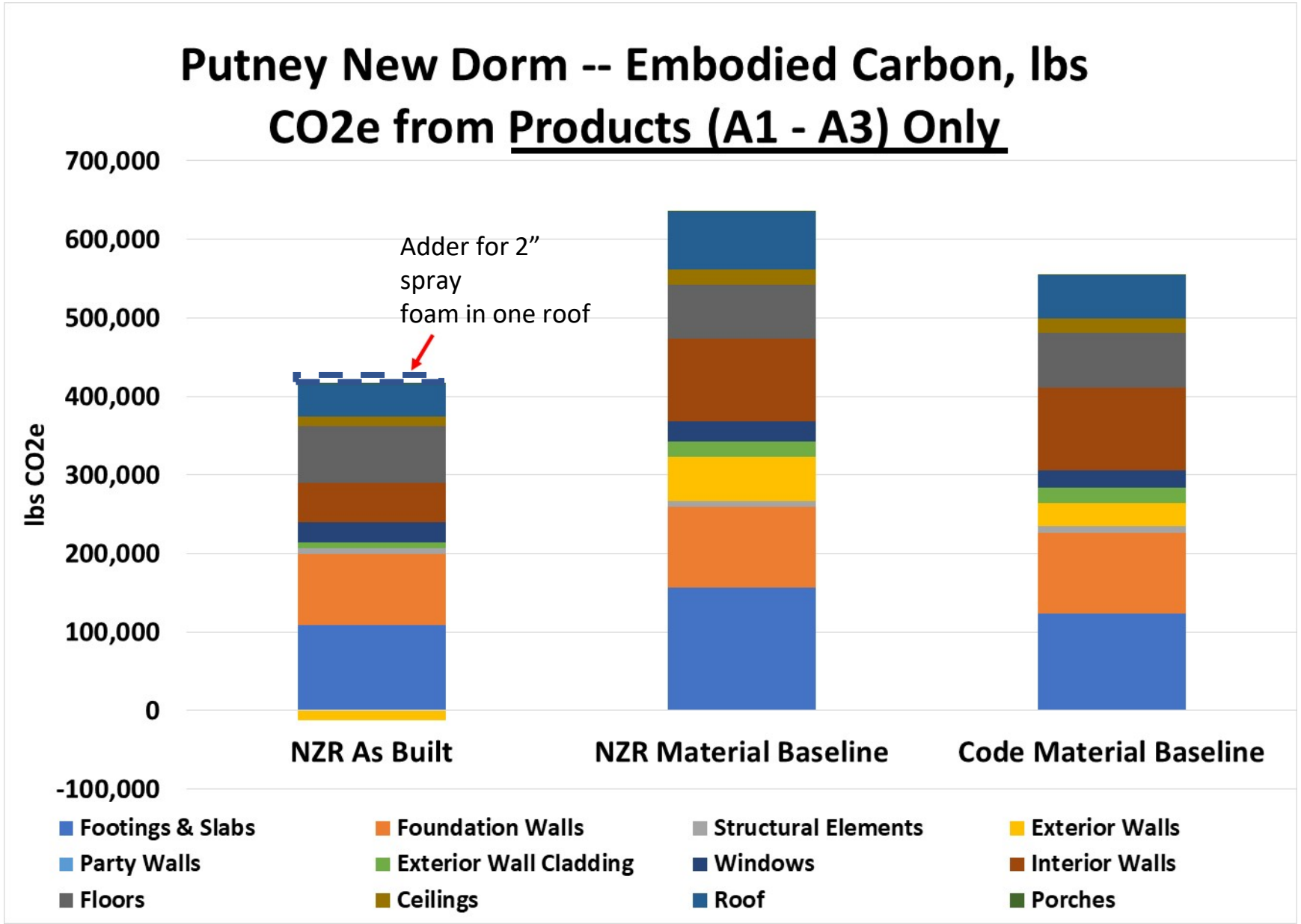
The Putney School New Dorms –

Operational Energy CO2e Emissions



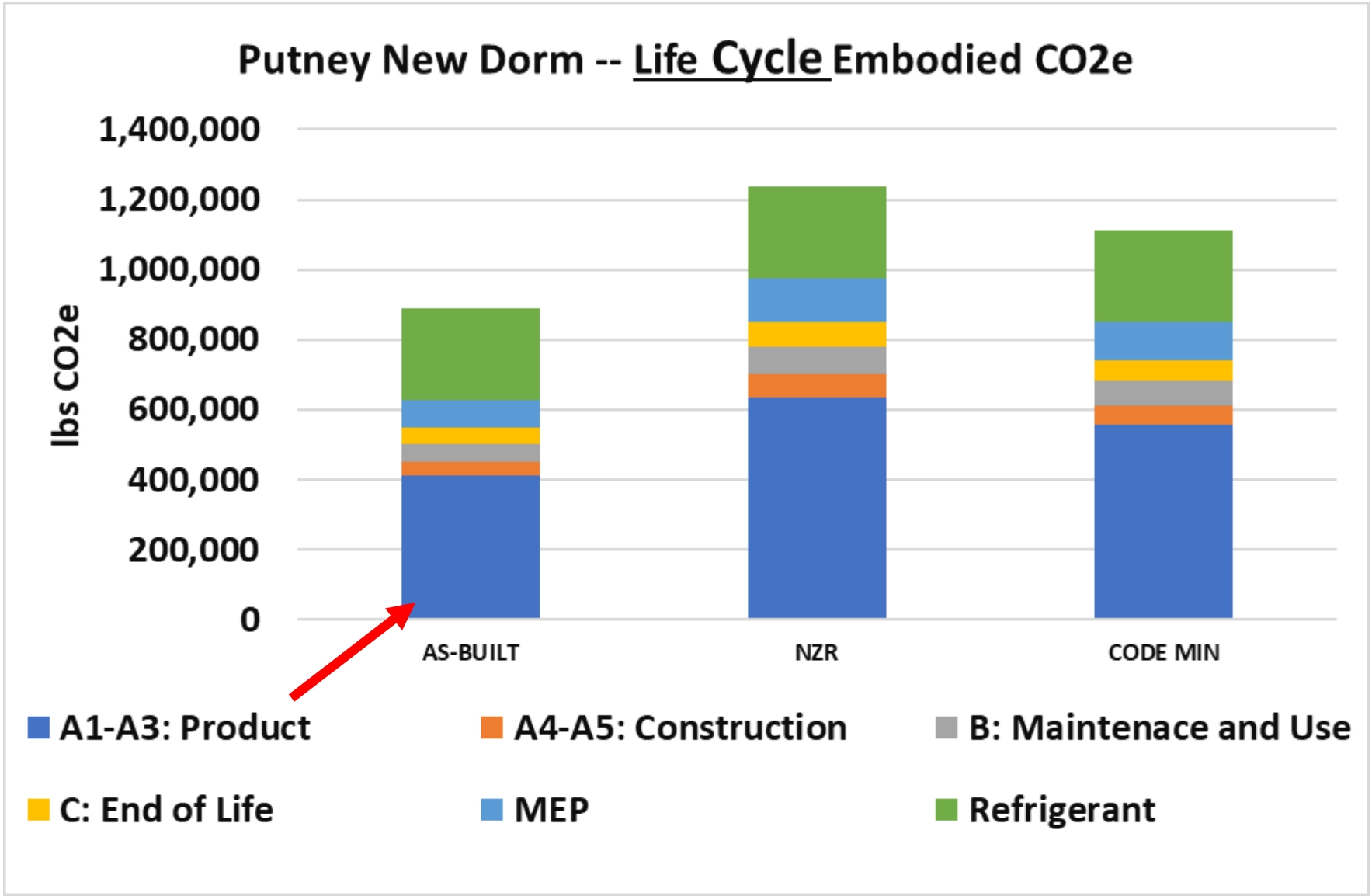


The Putney School New Dorm – Embodied CO2e Emissions - BEAM



The Putney School New Dorms –

Embodied Energy CO2e Emissions --- Life Cycle Assessment



The Putney School New Dorms –

The BIG PICTURE
What is the atmospheric CO2e over time?

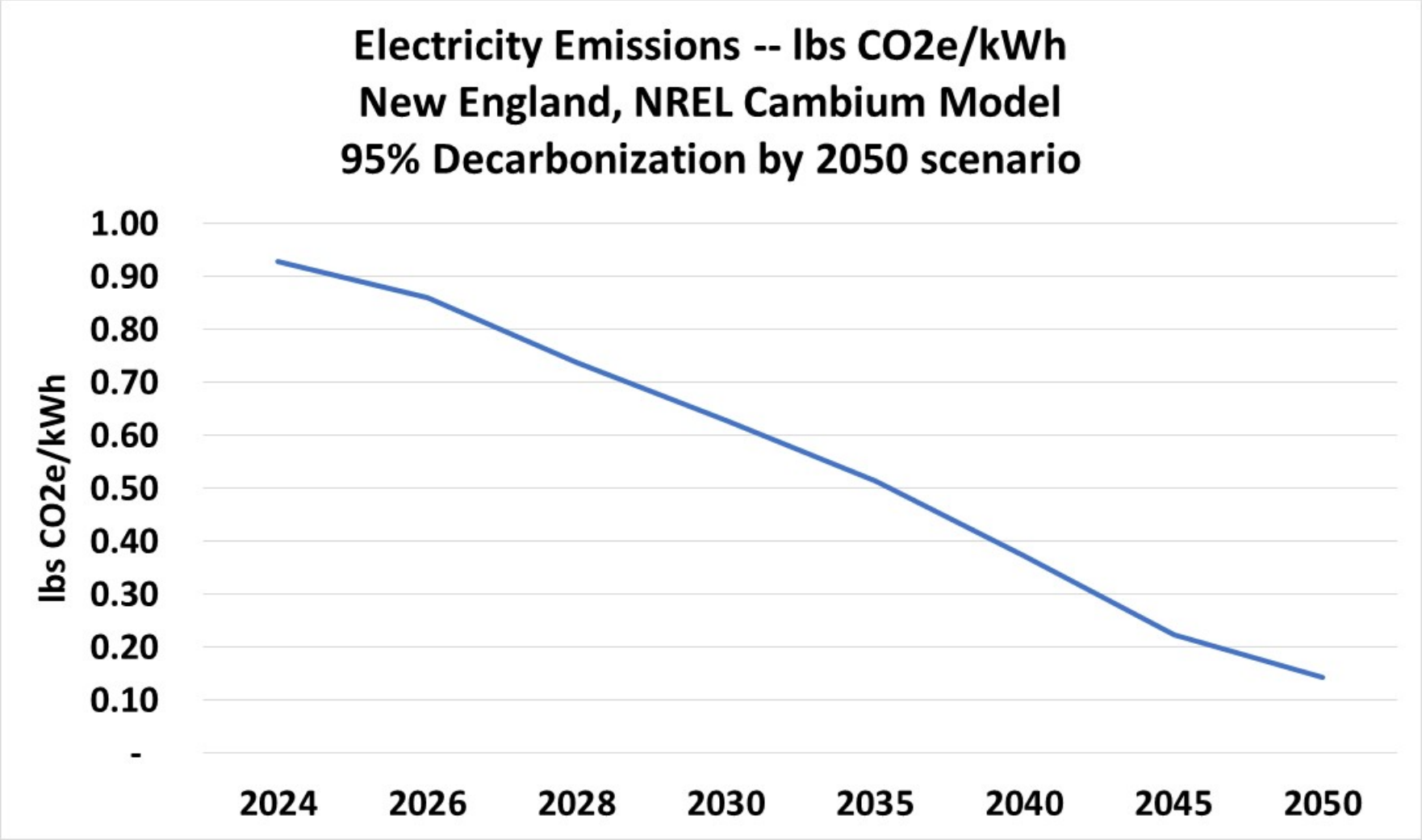
Electric Grid Emissions Expected to Reduce Over Time

and

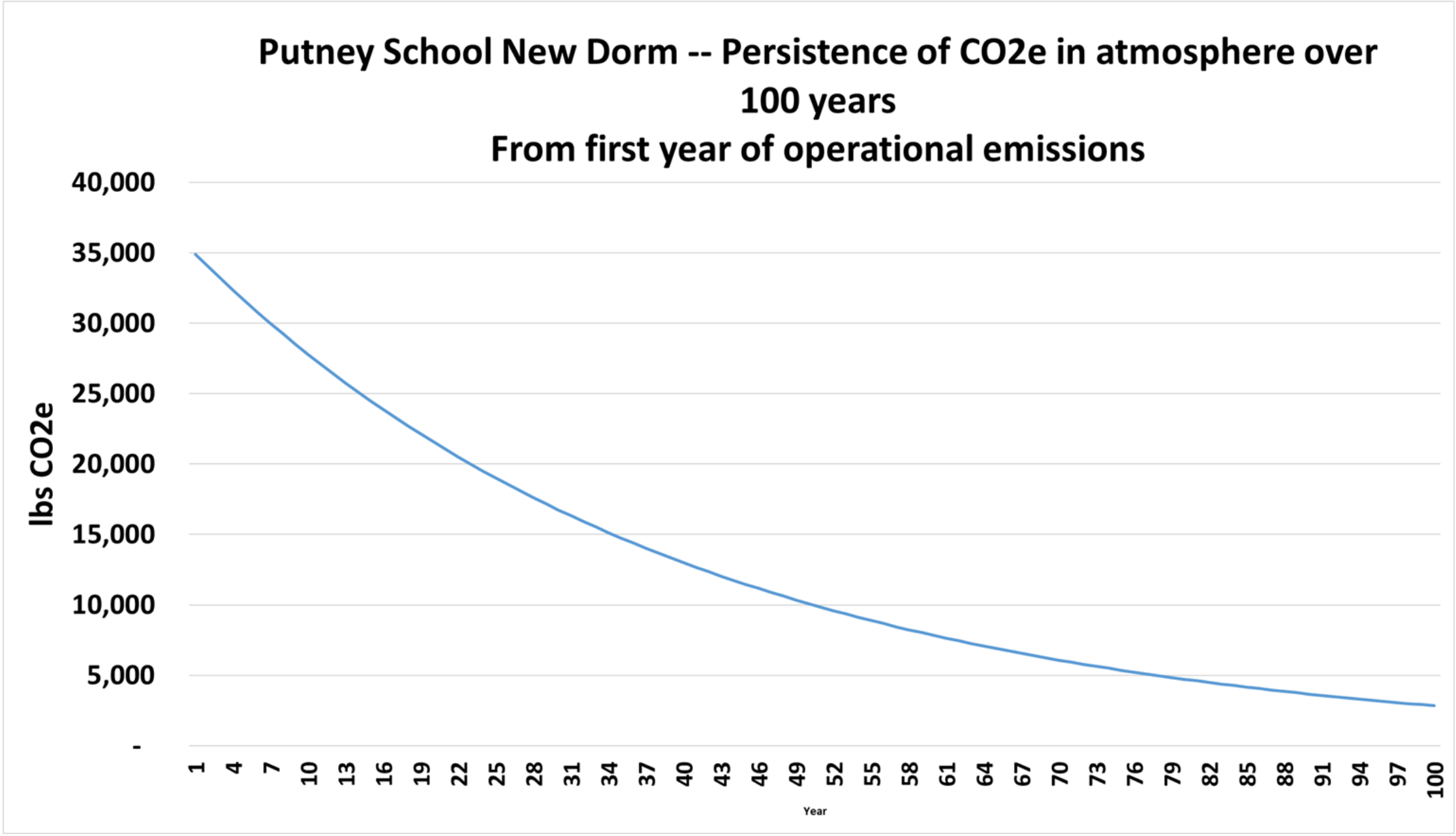
Persistence of CO2 in the atmosphere

The Putney School New Dorms –

Grid Electricity CO2e Emissions Over Time – NREL Cambium Model

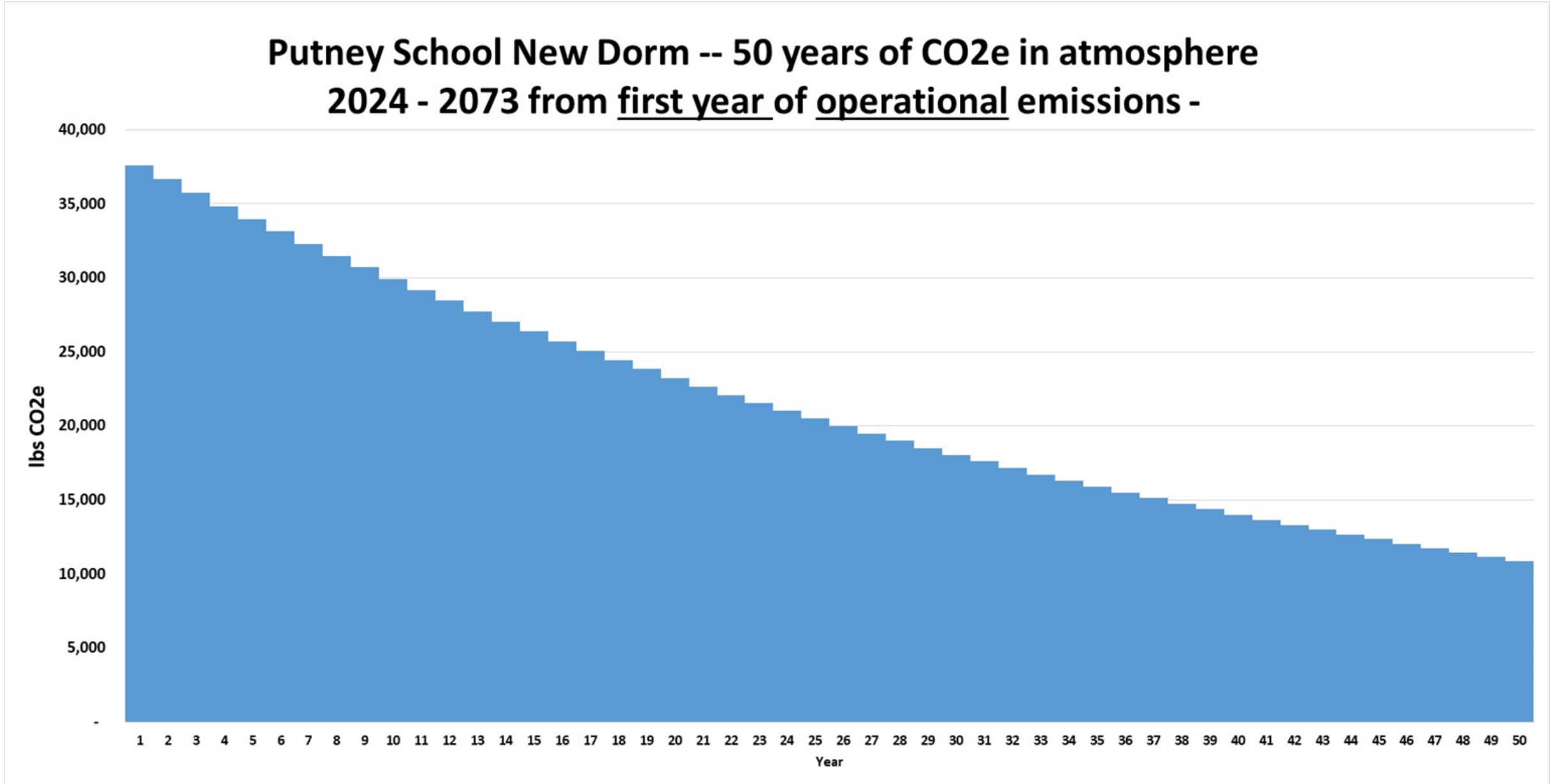


The Putney School New Dorm – CO2e Emissions --- Persistence in Atmosphere

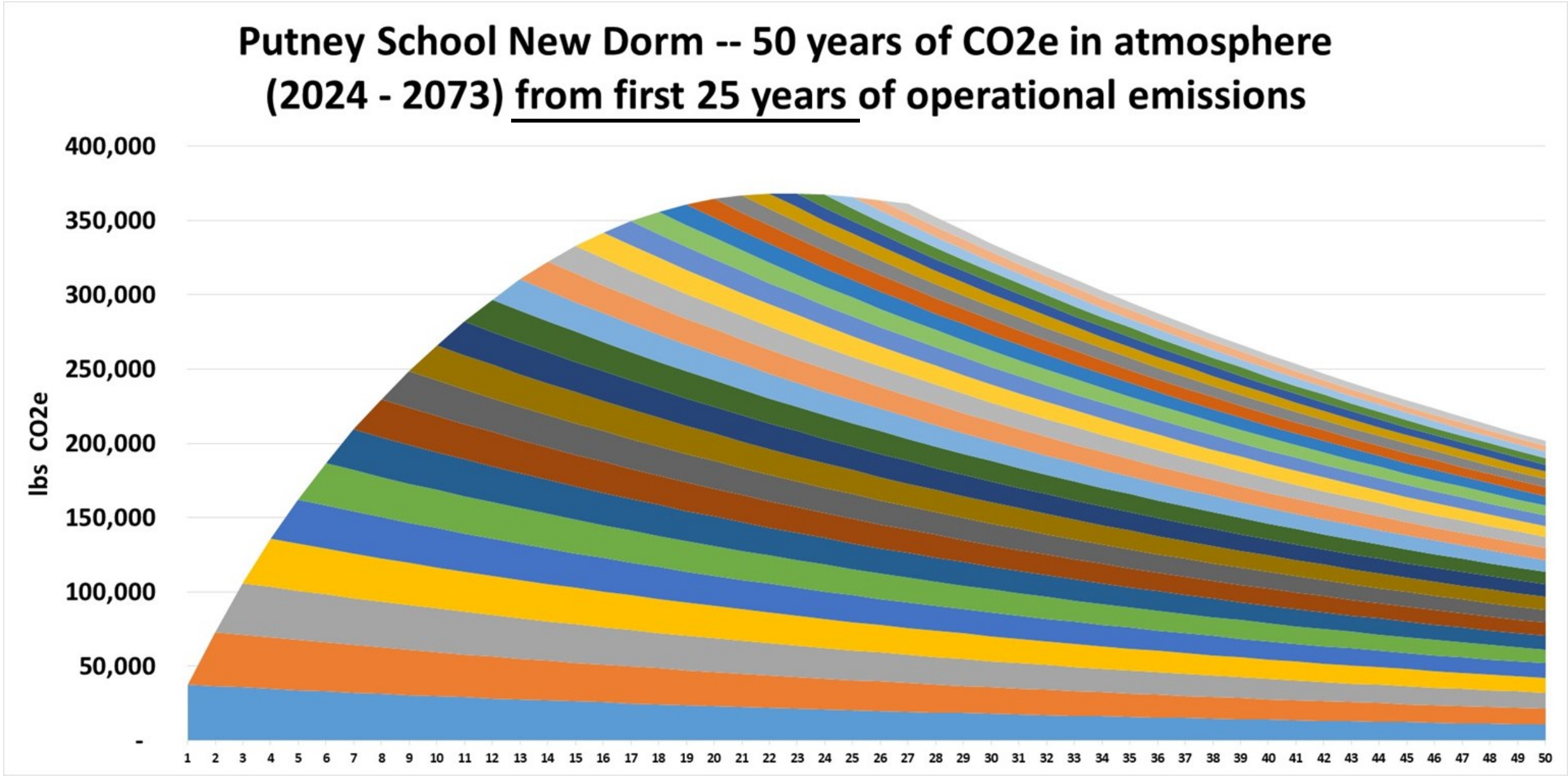


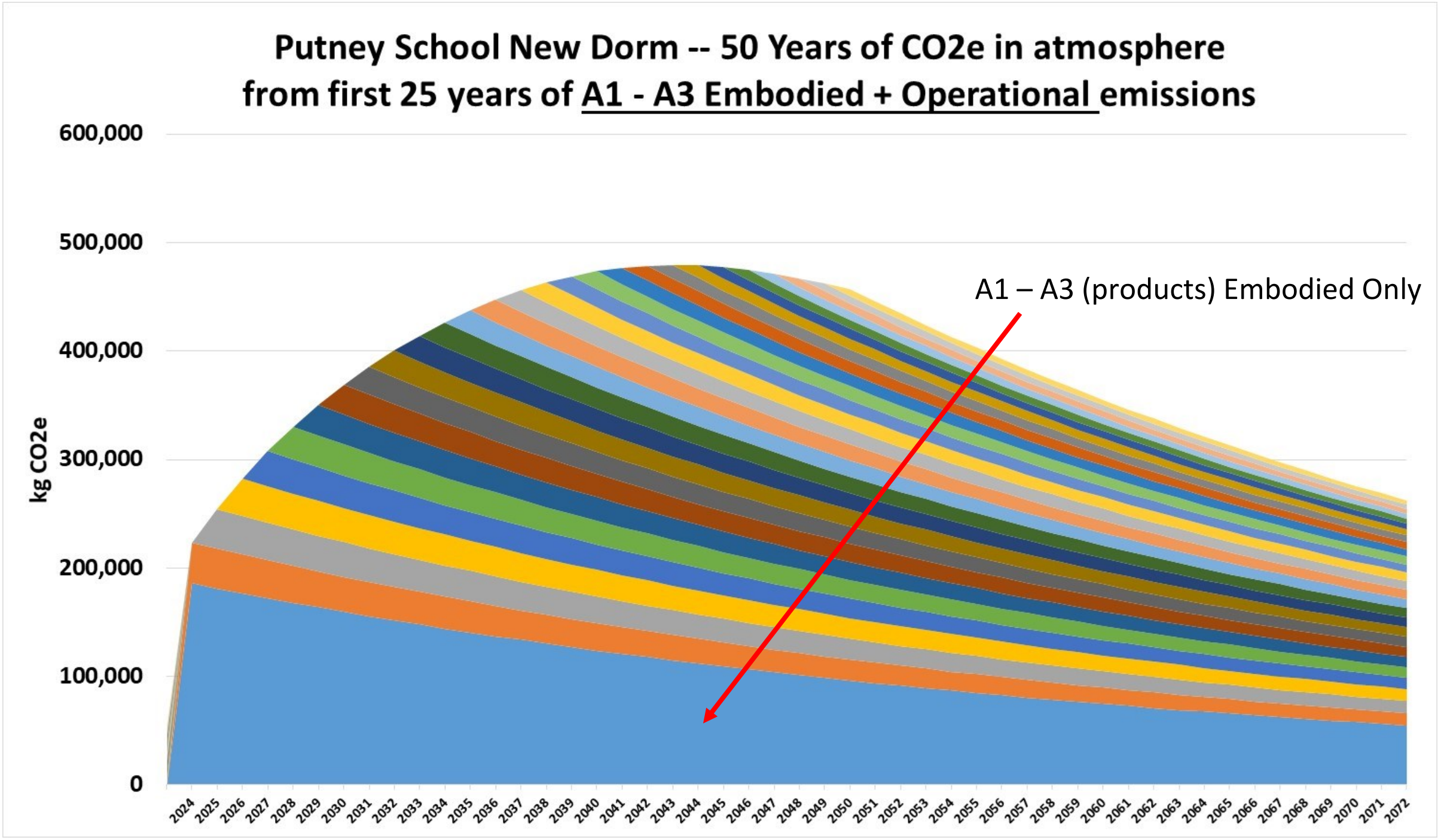
The Putney School New Dorms –

CO2e Emissions --- Persistence in Atmosphere

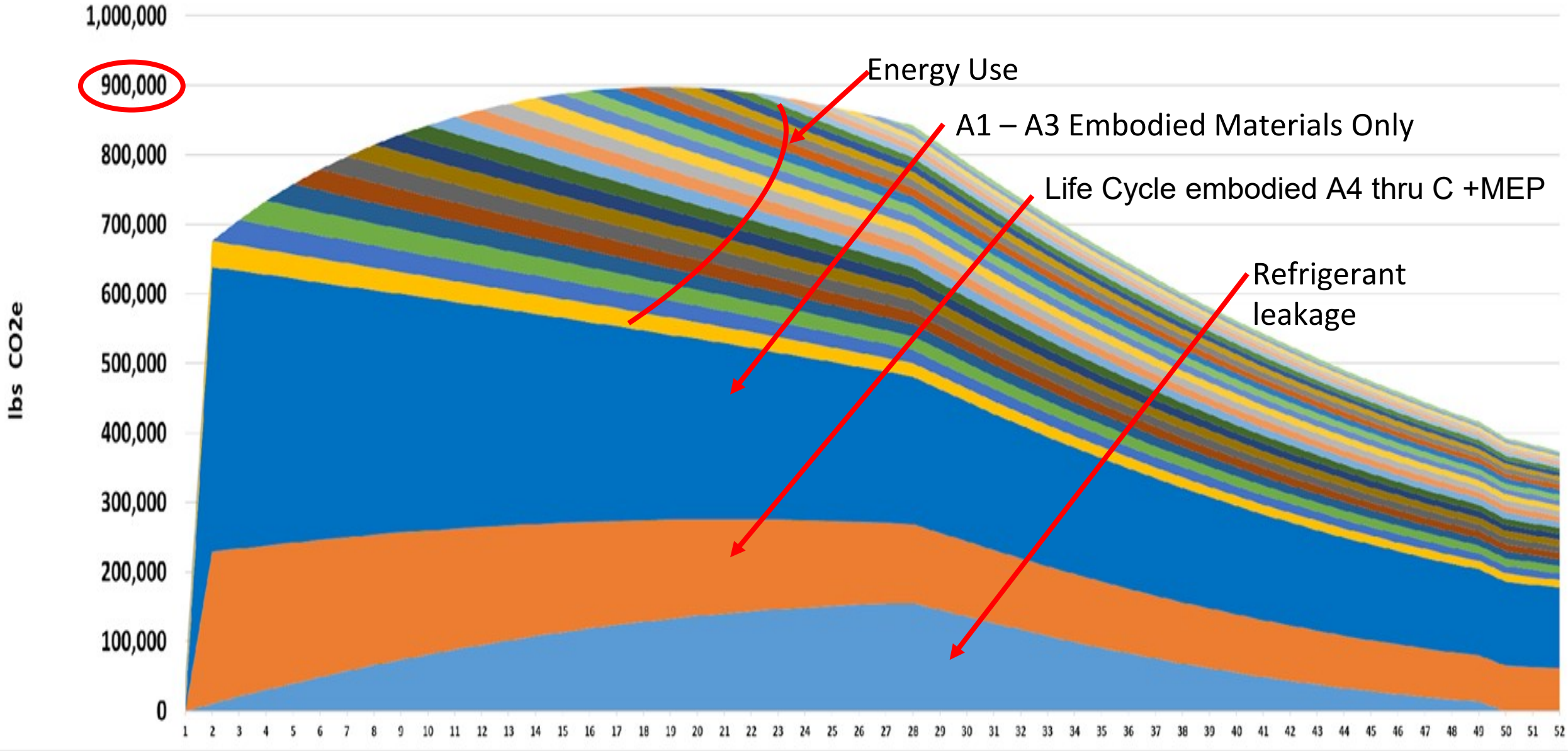


The Putney School New Dorm – CO2e Emissions --- Persistence in Atmosphere

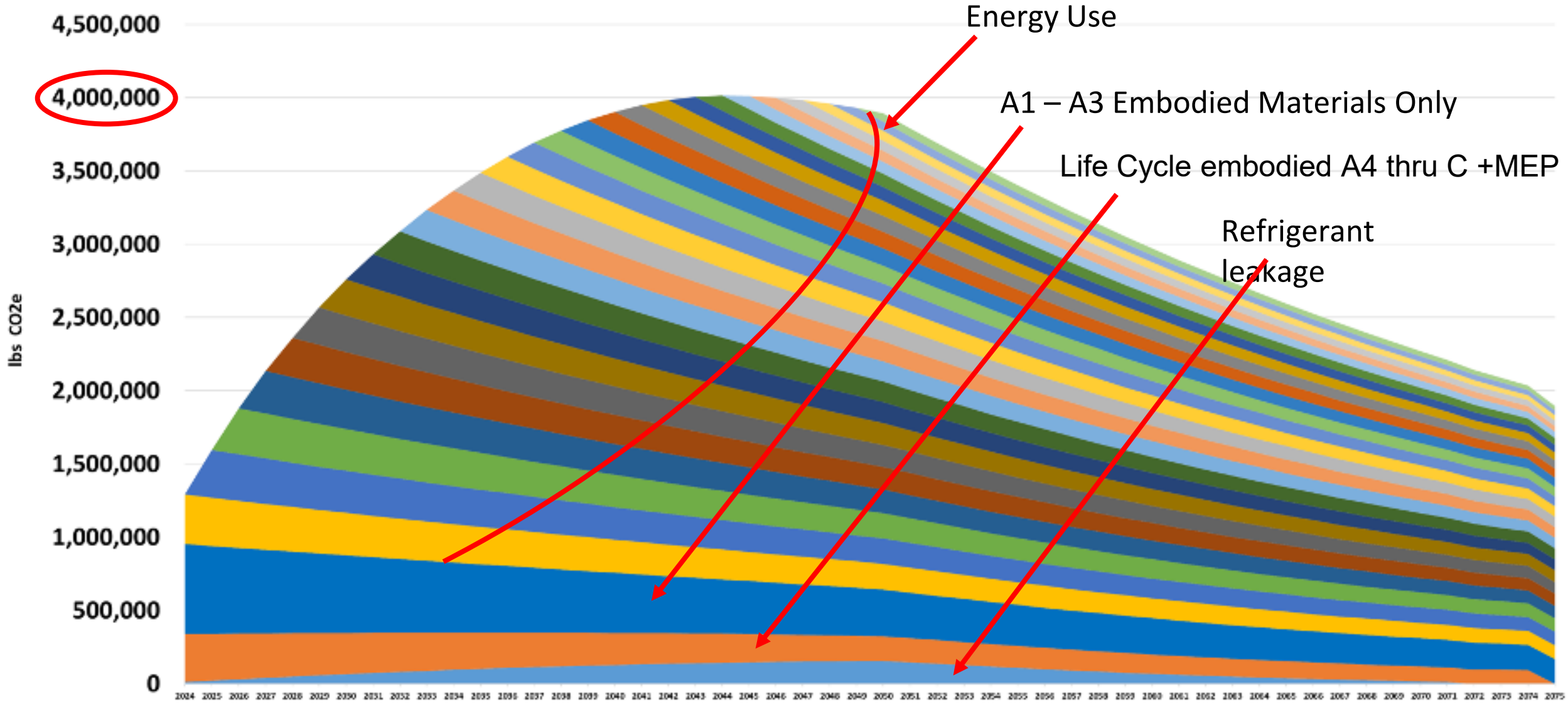



Putney School New Dorm -- 50 Years of CO2e in atmosphere
from first 25 years of A1 - A3 Embodied + Operational emissions
600,000
500,000
400,000
300,000
200,000
100,000
0
kg CO2e
A1 – A3 (products) Embodied Only
2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045 2046 2047 2048 2049 2050 2051 2052 2053 2054 2055 2056 2057 2058 2059 2060 2061 2062 2063 2064 2065 2066 2067 2068 2069 2070 2071 2072

Putney School New Dorm -- 50 years of CO2e in atmosphere from first 25 years of ALL emissions



CODE VERSION OF Putney School New Dorm -- 50 years of CO2e in atmosphere from first 25 years of ALL emissions



The Putney School New Dorms –

Lessons Learned -- Critical Items

- Active commitment of owner, design team and builder
- Early engagement allows strategy to turn into design, specs and details
- Lots of corners and roofs make it much more difficult to achieve a good enclosure

The Putney School New Dorms –

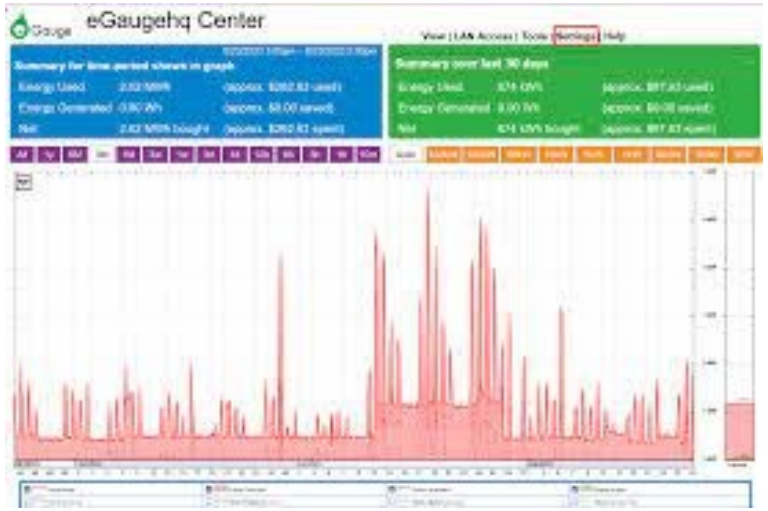
Lessons Learned -- Critical Items

- Cement substitutes in concrete difficult to achieve and can have uncertainty in supply
- Building enclosure commissioning – including periodic testing of enclosure
- Show up more often! Preconstruction meeting needs to be followed by same for each sub just before they begin their piece of the work
- Moisture management during construction!

The Putney School New Dorms –

Lessons Learned -- Critical Items

- ReArch CM attention to detail AND problem solving was excellent
- Skilled, can-do air sealing and insulation subcontractor (Murphy's CellTech)
- Building enclosure commissioning and MEP commissioning (BECx and Cx) with EGauge monitoring system

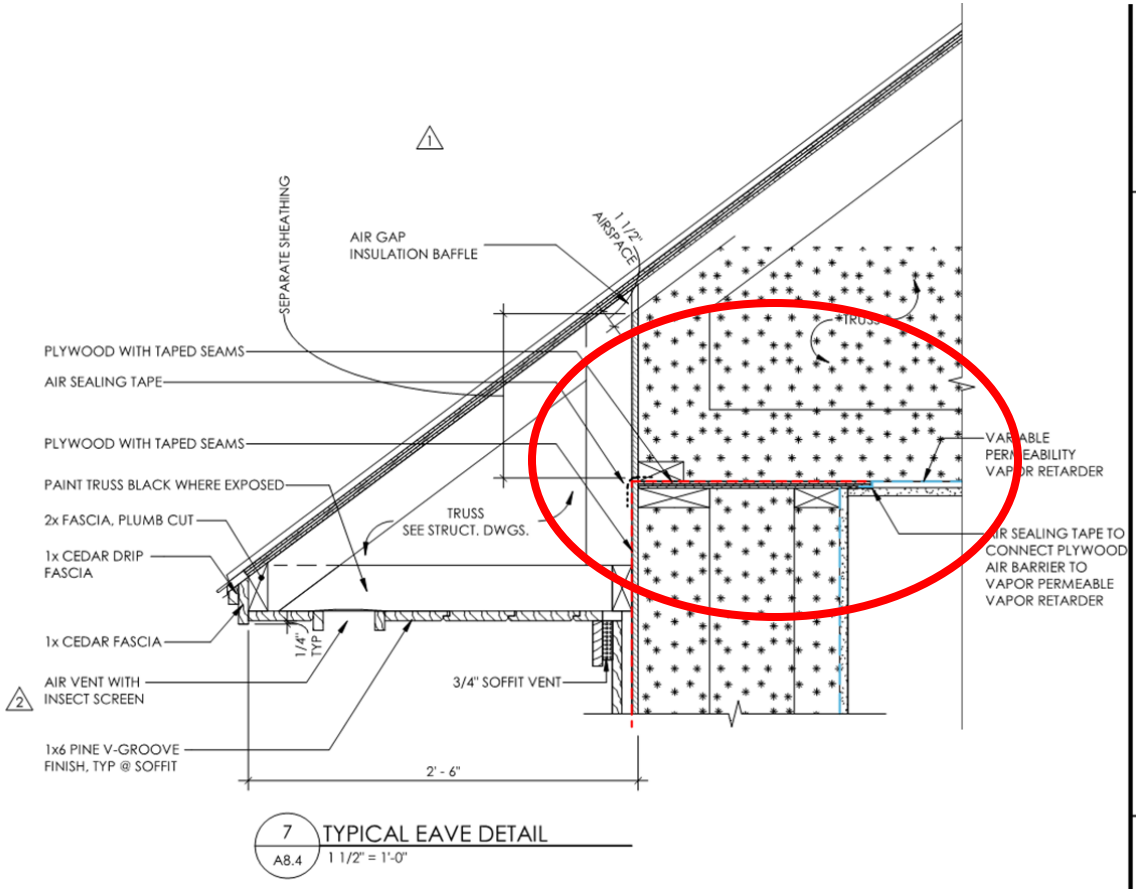


The Putney School New Dorms –

Lessons Learned – Pinch Points in the Process

- Complex enclosure areas required on-site head-scratching sessions with CM, framers, insulation and and air sealing contractor, enclosure commissioner

- Cement substitutes availability hard to predict – hold the line: Pre-plan, schedule. SCM landscape is shifting; e.g. ground glass

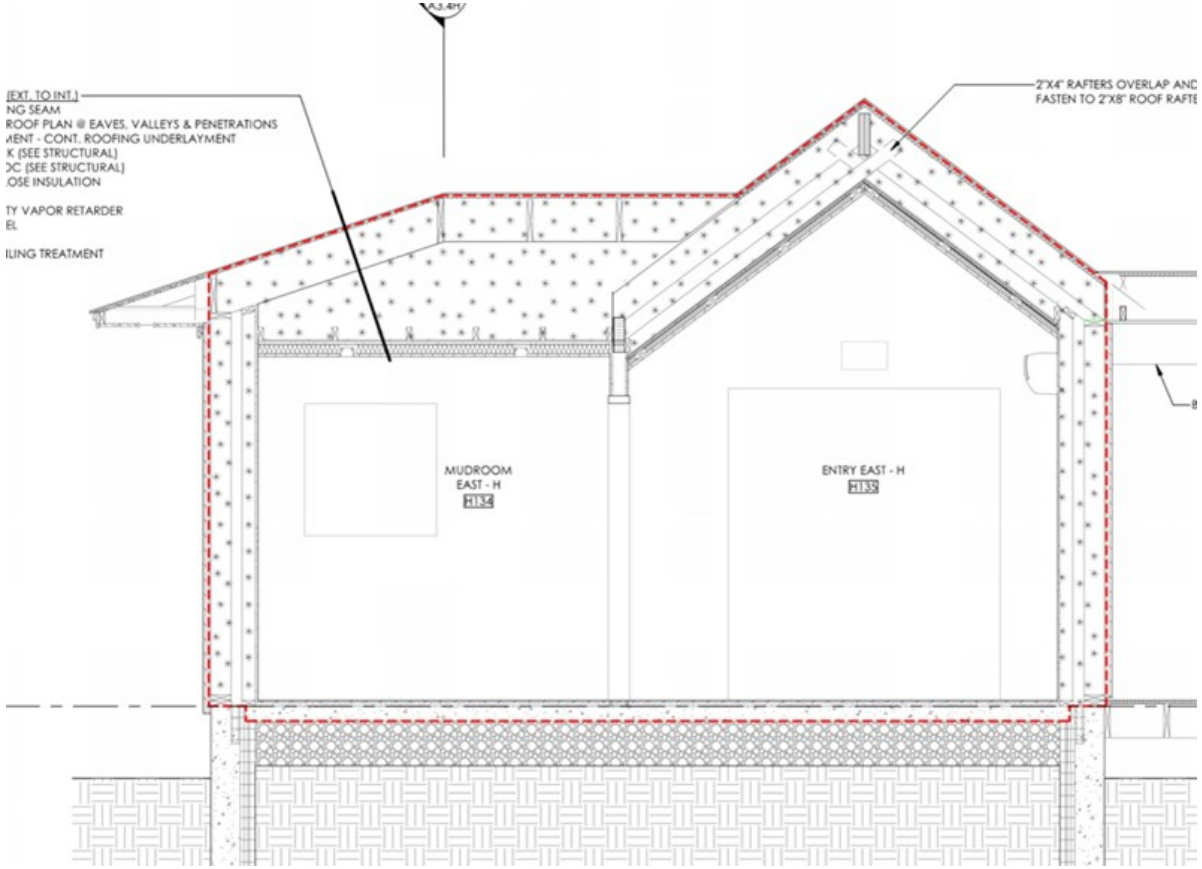


The Putney School New Dorms –

Lessons Learned – Pinch Points in the Process

- An eagle eye on submittals is critical. For example, low embodied gypsum board not in submittal but was easy: same cost, lighter weight and half the embodied energy. But not available for fire rated gypsum board

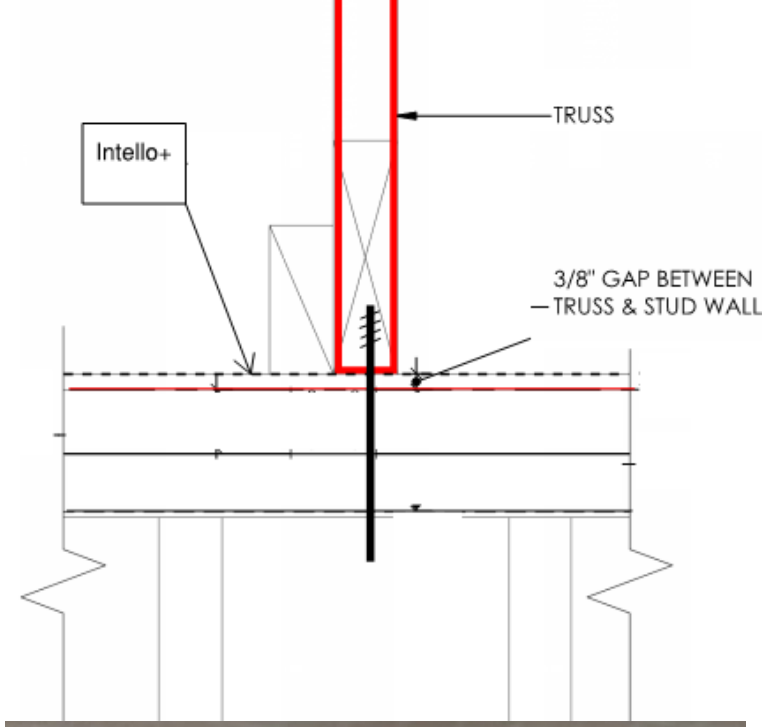
- Incomplete design prior to construction increases stress on process



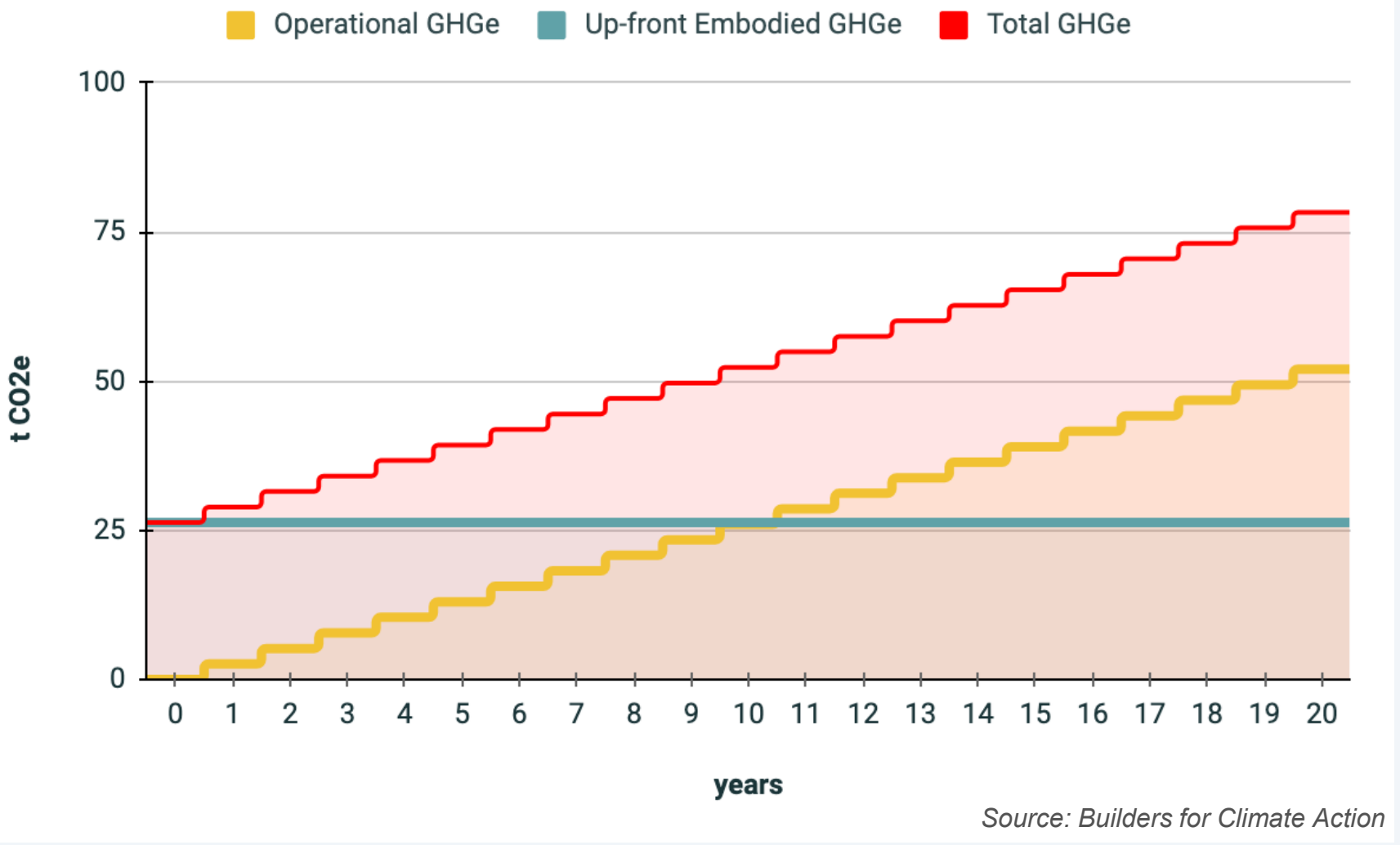
The Putney School New Dorms – Lessons Learned – Pinch Points

- Top of exterior wall detail -- Attic air-sealing detail

- Truss uplift/partition wall/air barrier problem solving



Cumulative Embodied and Operational Emissions - 20 years



Source: Builders for Climate Action

Total GHGe @ 20 years =

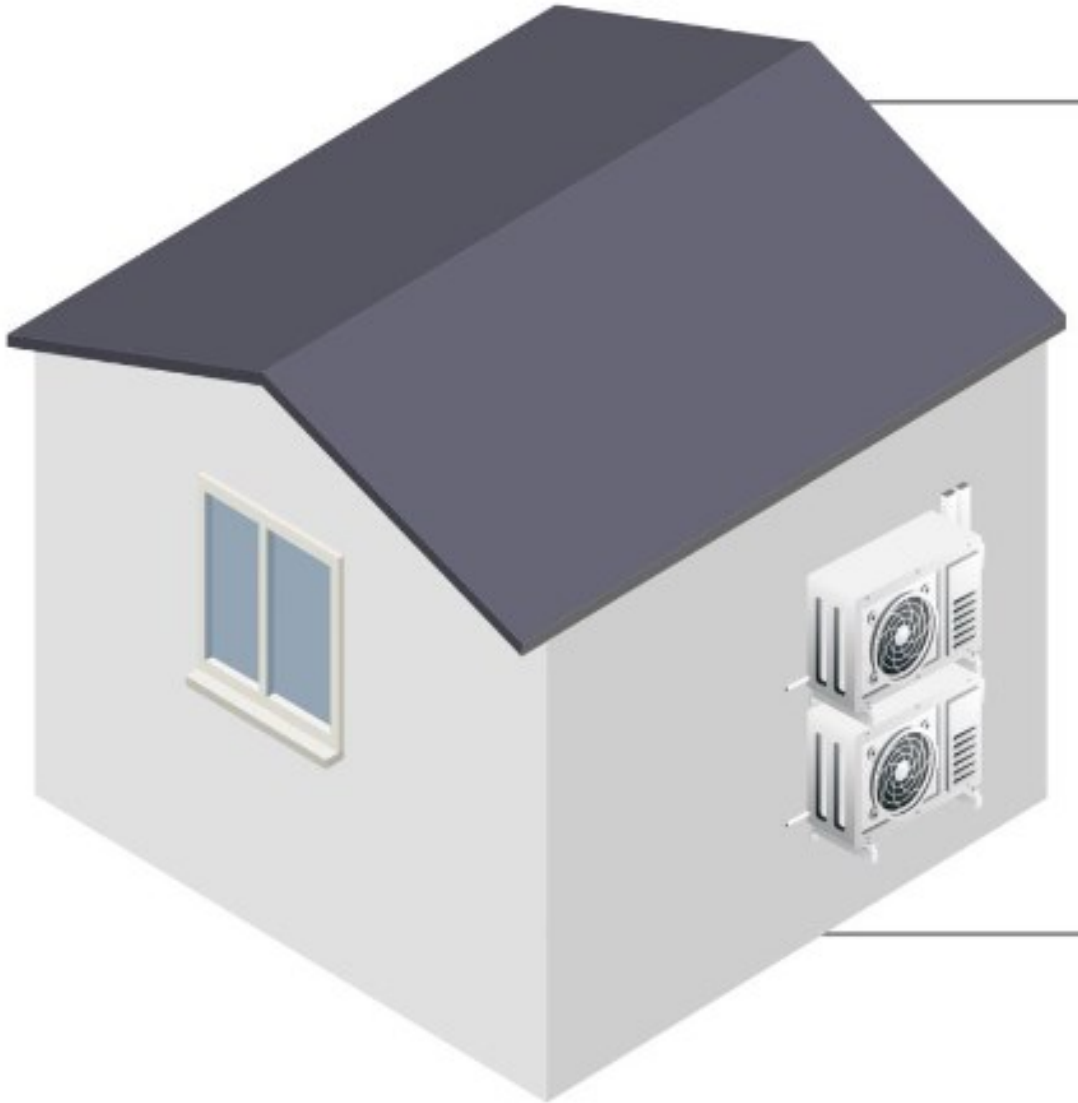
78 t CO_2e

Tackle Embodied & Operational Together

Performance Improvement	Reduce Operation GHGe	Possible to Achieve with Equivalent or Reduced Embodied GHGe
Reduced building size and/or surface area	✓	✓
Increased quantity of insulation	✓	✓
High performance windows	✓	✓
Improved air tightness	✓	✓
Improved equipment efficiency	✓	✓
Fuel switching	✓	✓
Passive solar/ventilation design	✓	✓

Source: Builders for Climate Action

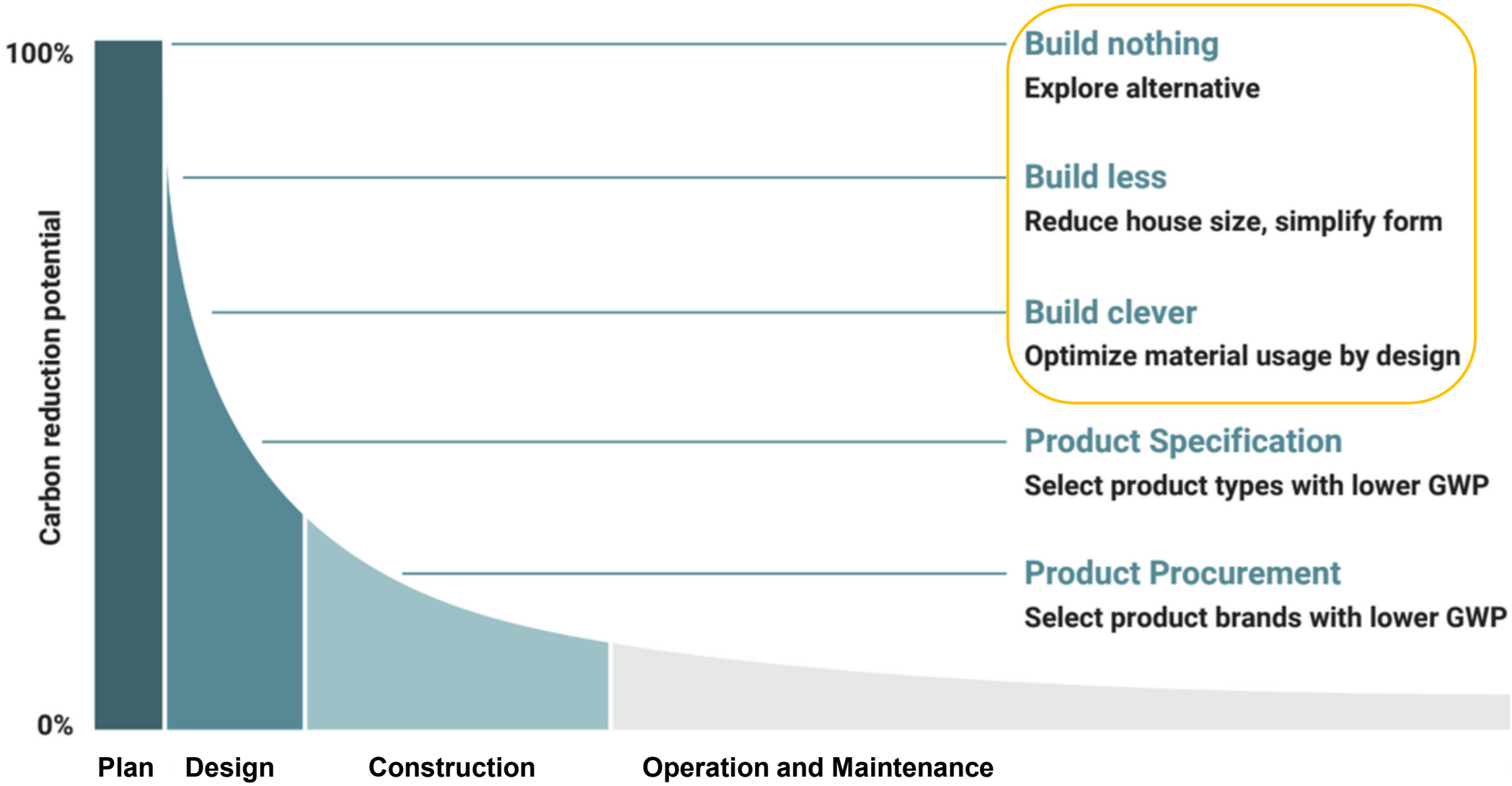
System Size and Life Cycle Emissions



Oversized Equipment Means

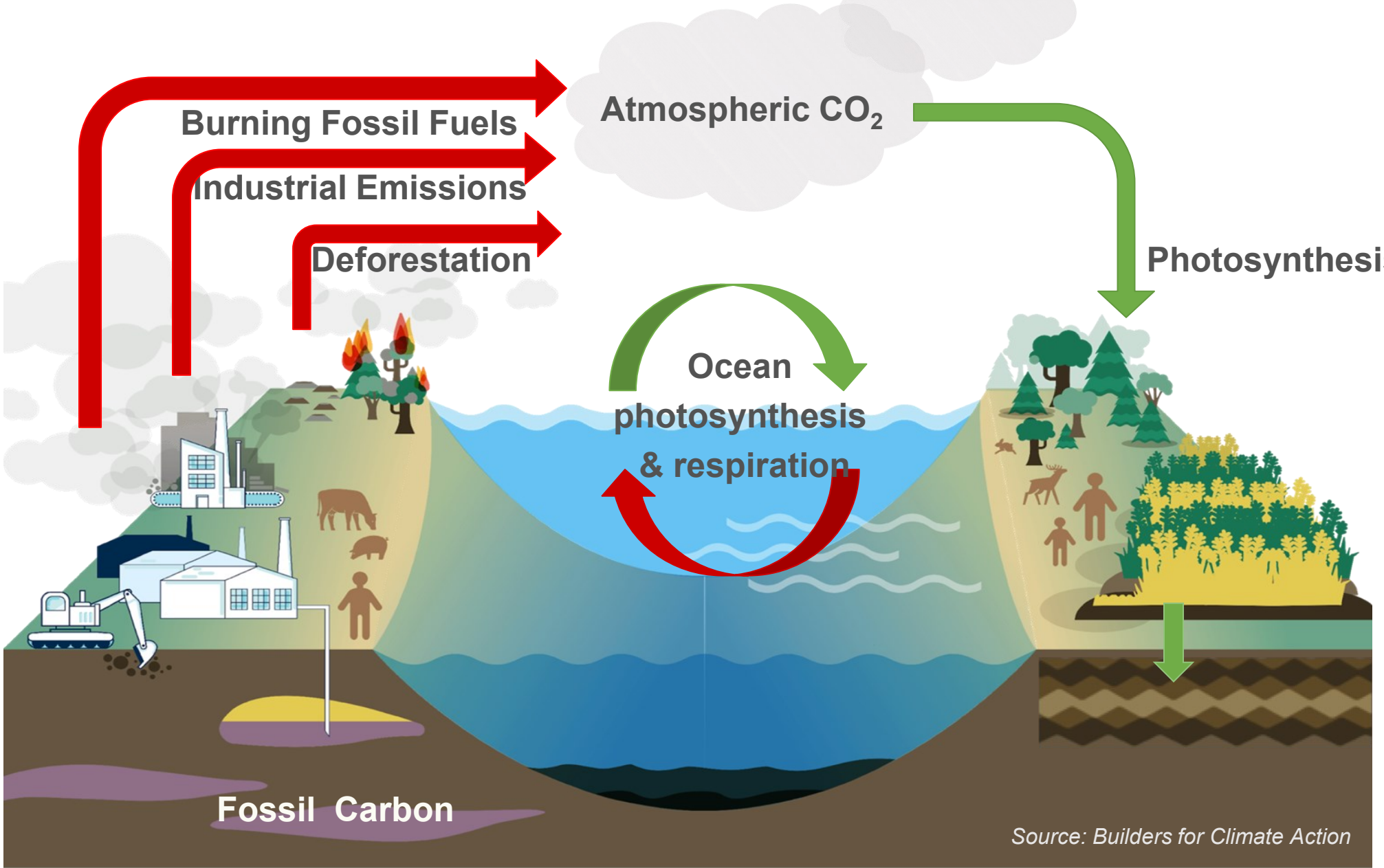
- more embodied emissions
- more refrigerant leakage
- shorter service life
- more replacements
- occupant discomfort

Carbon Reduction Potential Over Project Stages



Graphic: Builders for Climate Action

Carbon cycle: more going up than coming down



Carbon storage

> **Bio-based materials may represent our best hope for radical decarbonisation** through the responsible management of carbon cycles. The shift towards properly managed bio-based materials could lead to compounded **emission savings in the sector of up to 40 per cent by 2050** in many regions.

Citation: United Nations Environment Programme & Yale Center for Ecosystems + Architecture. (2023). *Building materials and the climate: Constructing a new future*. United Nations Environment Programme.

REGIONAL CRITERIA FOR SUSTAINABLE WOOD SOURCING: NORTH AMERICAN MASS TIMBER BUILDINGS

Q1 2025

Commissioned by Amazon

Coordinated by ZGF Architects

Contributors: Blackbriar | NEFF | Skanska | Sustainable Northwest

Carbon storage categories

Varieties of carbon-storing products:

1. Waste stream materials
2. Agricultural & forestry residue
3. Purpose grown crops
4. Lab-grown materials
5. Virgin forest products

Carbon Storage Short Cycle

Carbon Storage Long Cycle

Source: Builders for Climate Action

Short Cycle Carbon Storage

Short cycle **carbon storage** comes from feedstocks that are:

- At the end of their typical lifecycle
  (will not continue to grow and absorb CO2)
- Are about to become GHG emissions
  (from decay, decomposition and/or fire)

Source: Builders for Climate Action

Short Cycle Carbon Storage

CO2
(stored this year)

CO2
(released this year)

Shrink

Increase

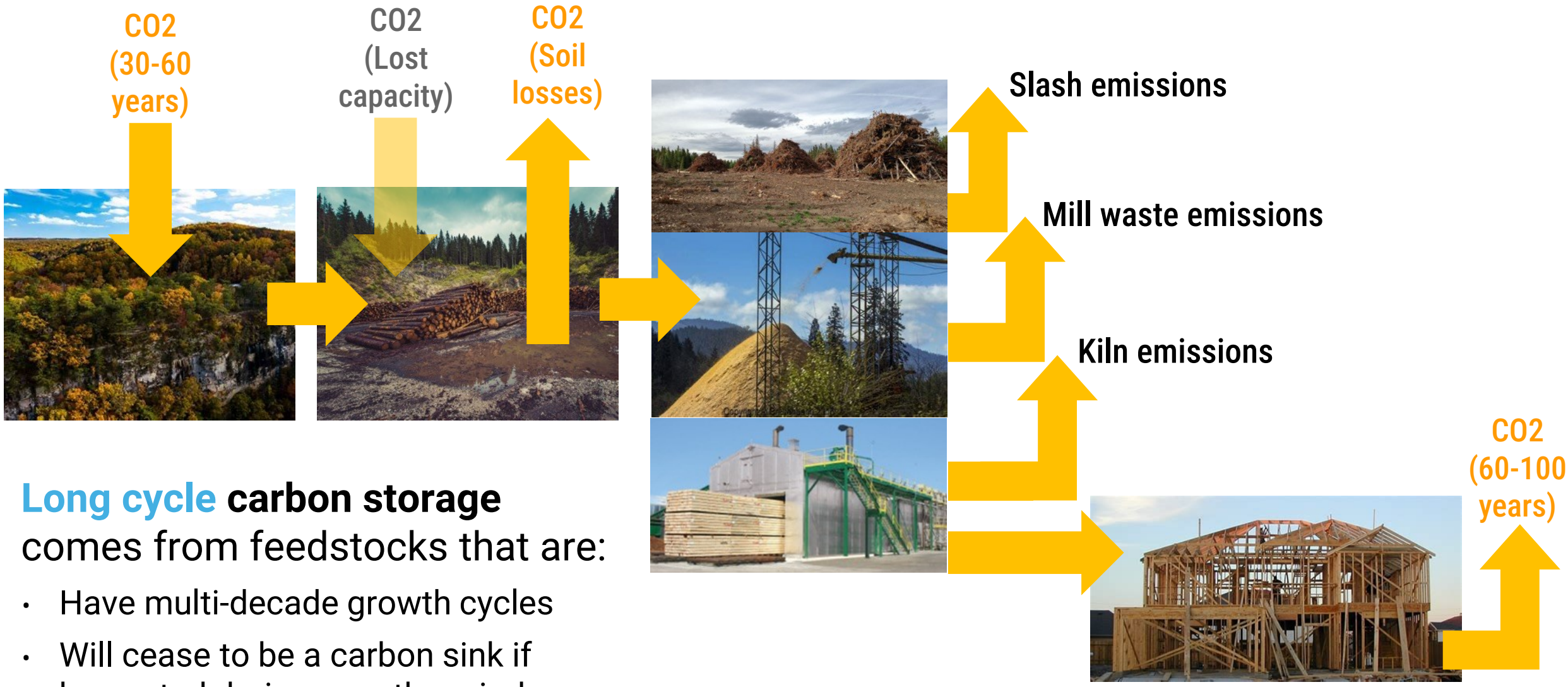
CO2
(released
60-100 years)

Short cycle carbon storage comes from feedstocks that are:

- At the end of their typical lifecycle
  (will not continue to grow and absorb CO2)
- Are about to become GHG emissions
  (from decay, decomposition and/or fire)

Source: Builders for Climate Action

Long cycle carbon storage



Long cycle carbon storage comes from feedstocks that are:

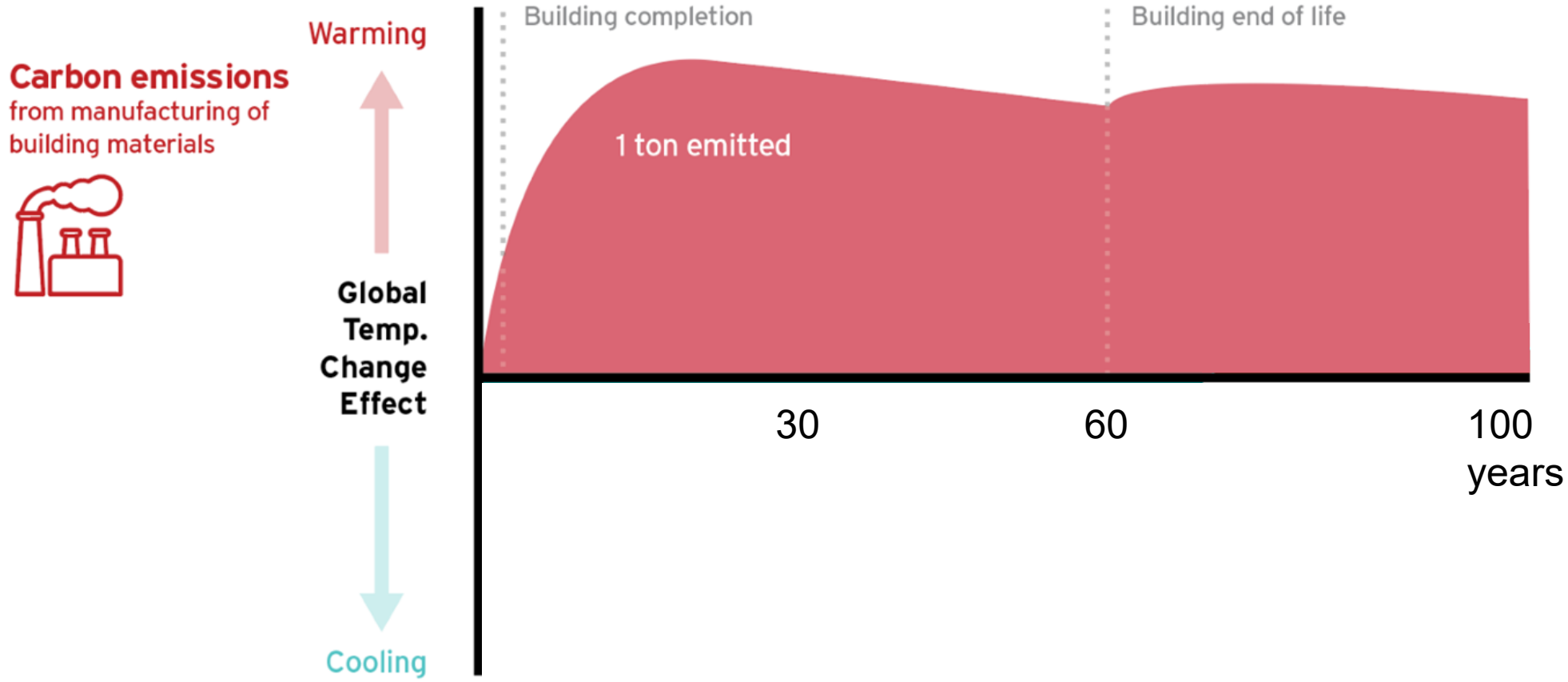
- Have multi-decade growth cycles
- Will cease to be a carbon sink if harvested during growth period

Source: Builders for Climate Action

Carbon Storage Accounting in Static LCA

Graphic : Builders for Climate Action

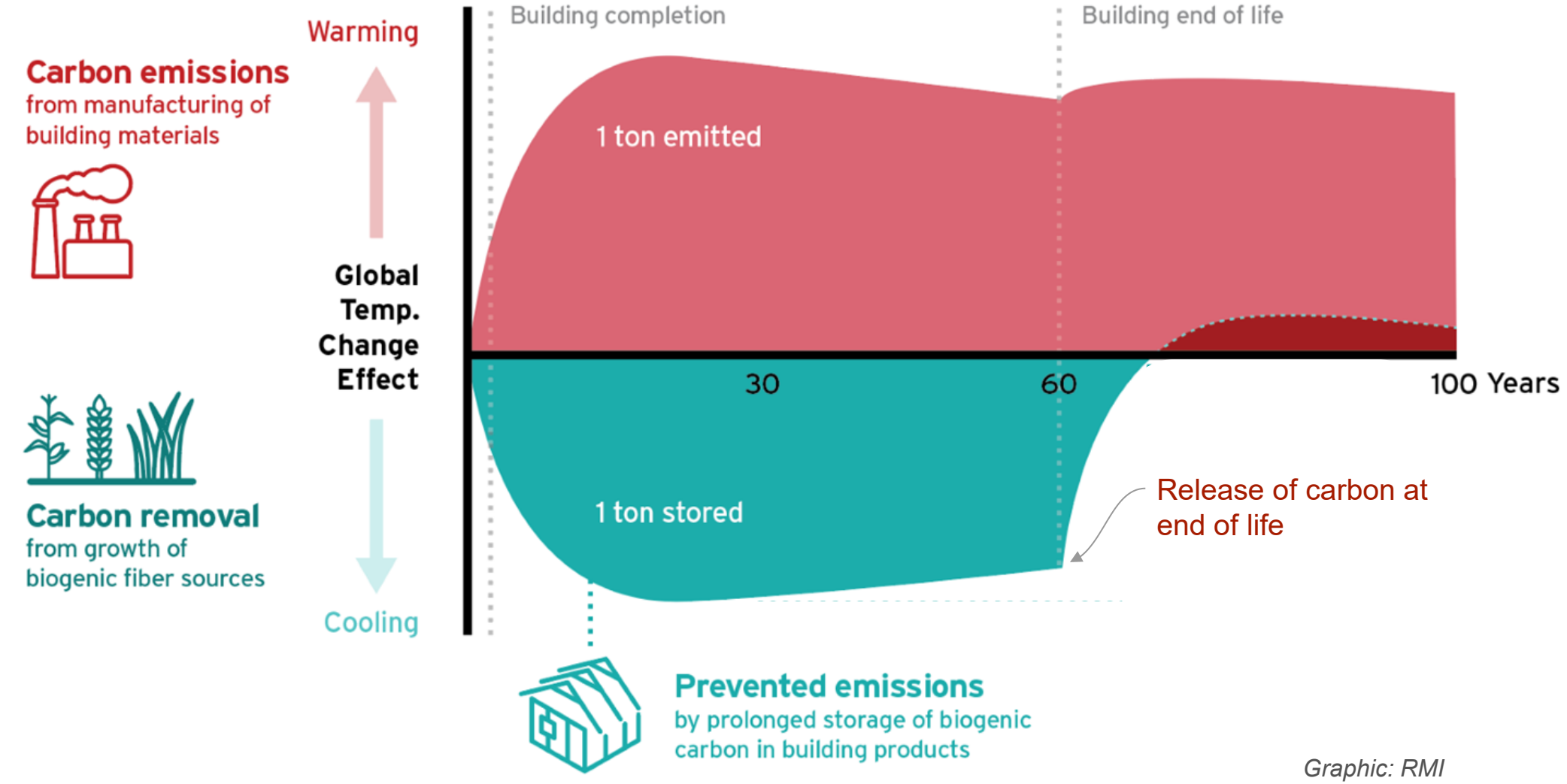
Cumulative Emissions and the Time Value of CO_2



Graphic: RMI

Note: This graph is generated by modeling 1 ton of carbon emitted and 1 ton of carbon removed using the Temporal Climate Impacts tool developed by the University of Bath.

Cumulative Emissions and the Time Value of CO_2



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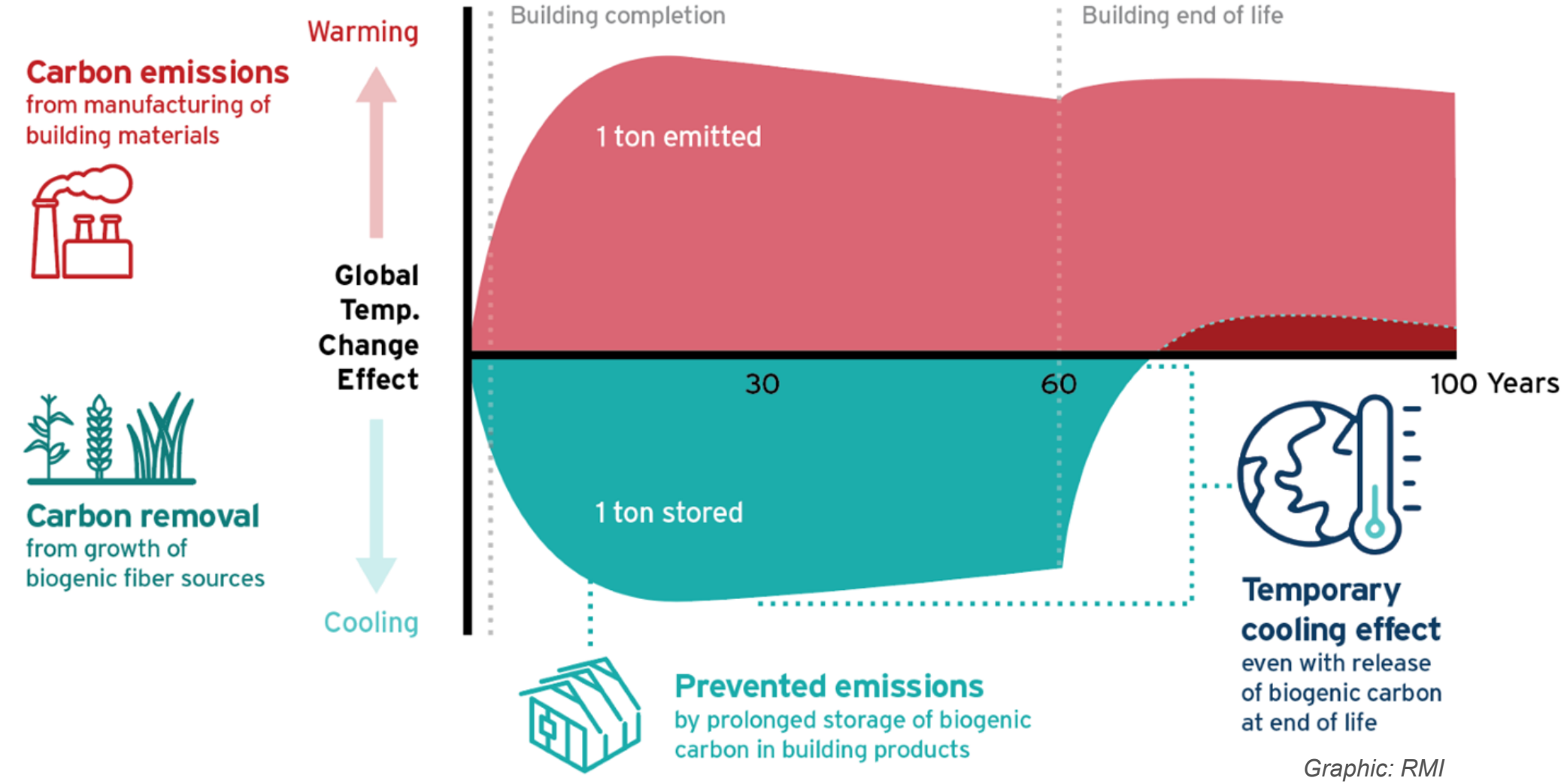
Cumulative Emissions and the Time Value of CO_2



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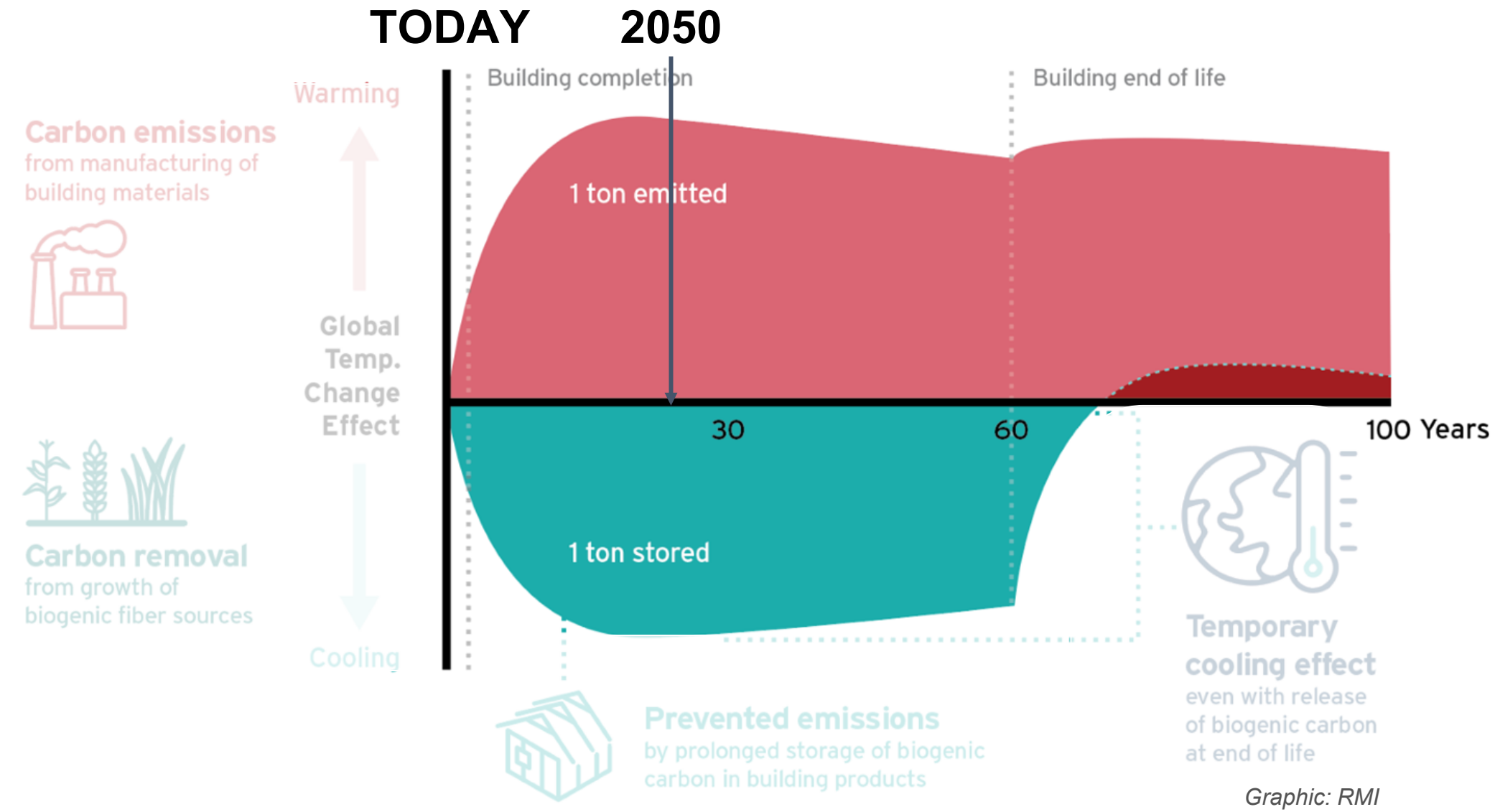
Cumulative Emissions and the Time Value of CO_2



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Two accounting methods:

COUNTING
CARBON STORAGE

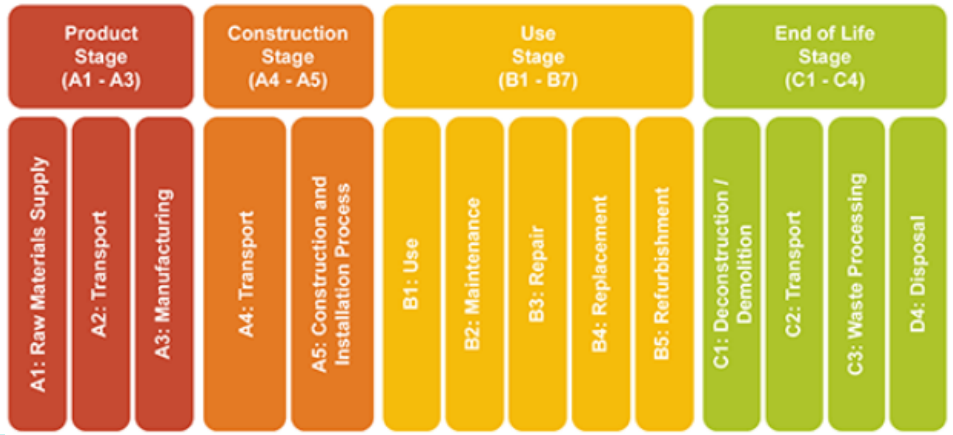
VALUING
CARBON STORAGE

Source: Chris Magwood - RMI

Two accounting methods:

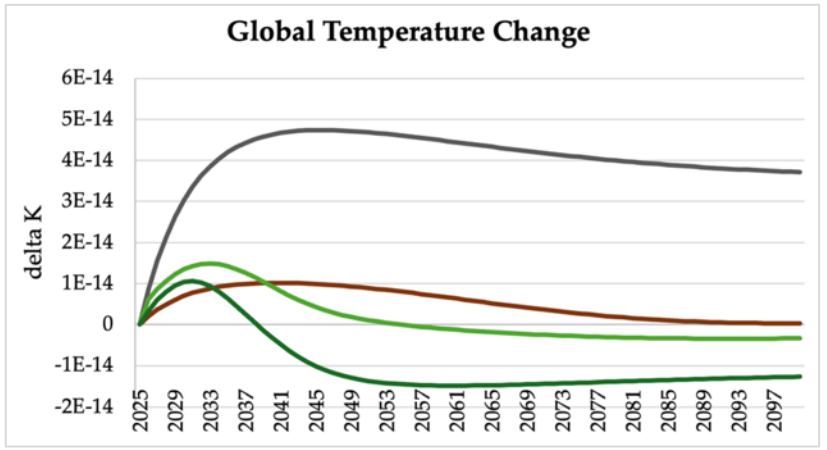
COUNTING
CARBON STORAGE

STATIC LCA



VALUING
CARBON STORAGE

DYNAMIC LCA



Source: Chris Magwood - RMI

Two accounting methods:

COUNTING
CARBON STORAGE

STATIC LCA

± $

Ledger of debits
& credits

VALUING
CARBON STORAGE

DYNAMIC LCA

Value of interest
earned & paid

Source: Chris Magwood - RMI

Two different insights:

HOW DOES CARBON MOVE WITHIN A SYSTEM?

COUNTING

CARBON STORAGE

STATIC LCA

HOW DOES CLIMATE RESPOND TO CARBON FLOWS?

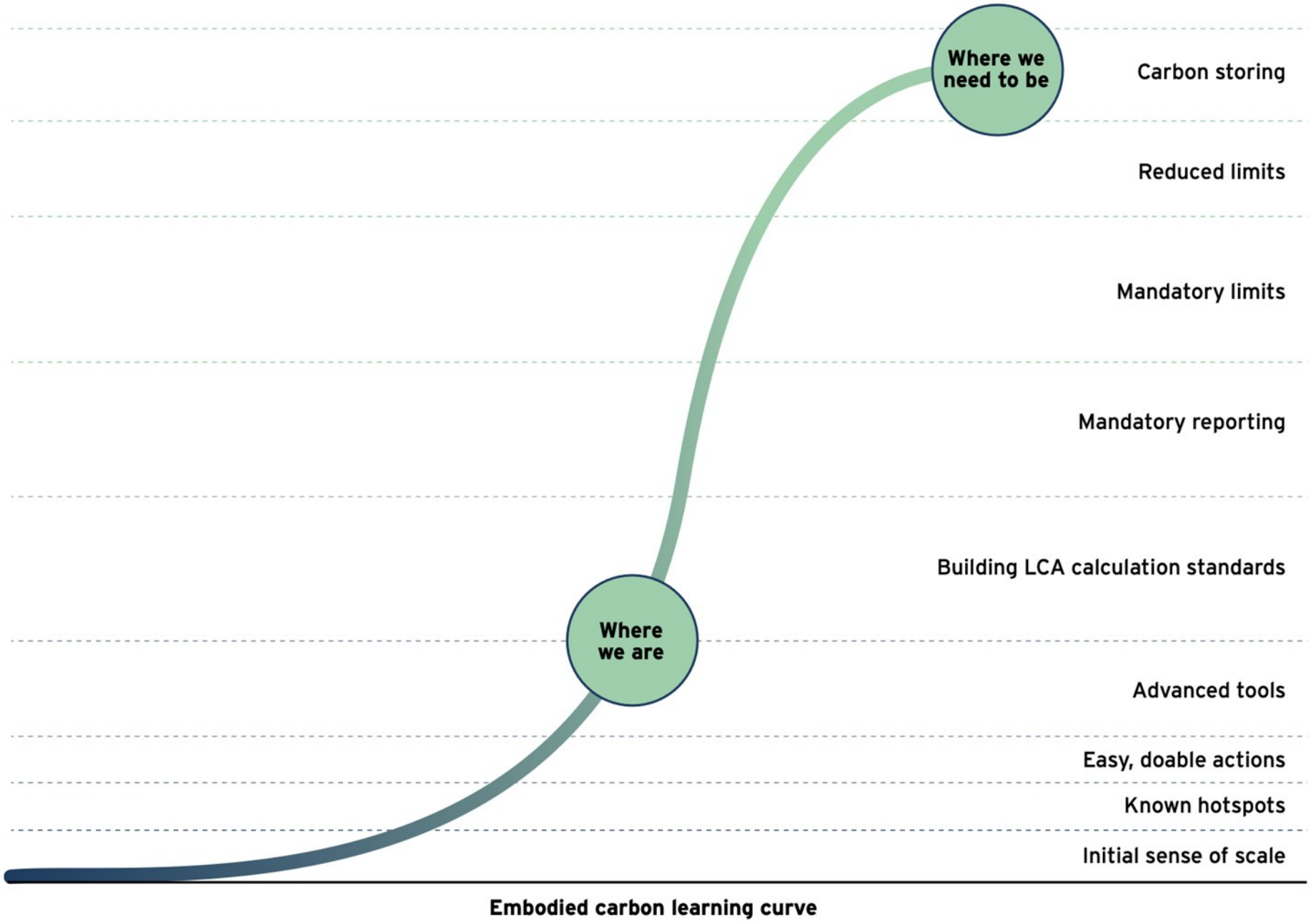
VALUING

CARBON STORAGE

DYNAMIC LCA

Source: Chris Magwood - RMI

We must accelerate our position on this curve to meet climate thresholds



interconnected thinking

RESNET Leading the Path to Net Zero Energy Homes

Standard 1550 Embodied Carbon Task Group

Source: RMI

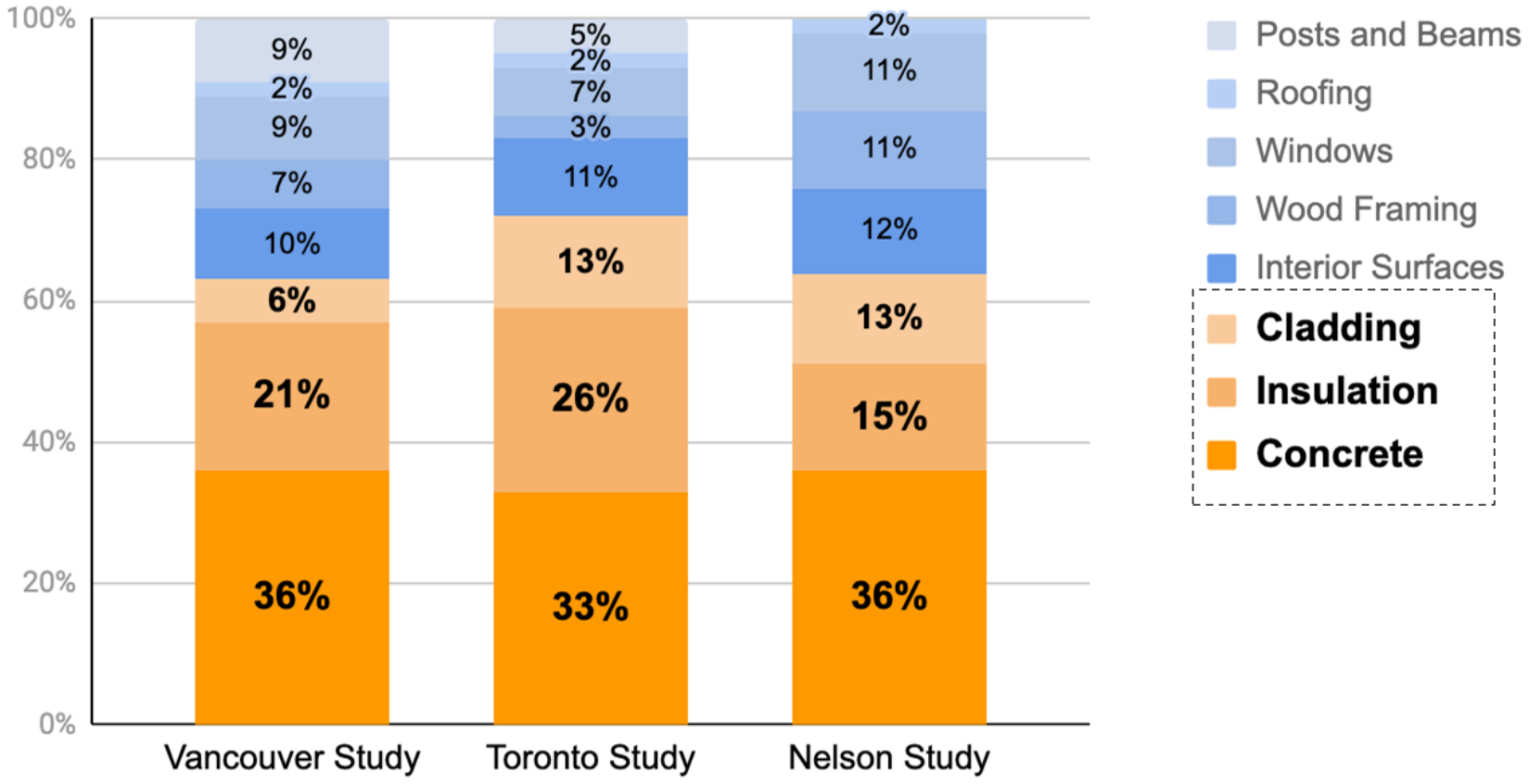
Impact of Material

Over 60% of embodied GHGe

of a new home come from **3 product categories,**

and

insulation being the second highest contributor.



Embodied Carbon Emissions from New Homes by Material Category, BfCA studies.

Why a RESNET standard?

Source: RMI

Why a RESNET standard?

LEVERAGE EXISTING MODELING DATA

EMBODIED CARBON

Source: RMI

Pilot Program – It's Happening!

100 Homes Benchmarking Study in MA (2024-25):

- Create regional benchmark for policy and program development
- Pilot RESNET Standard 1550 to inform improvements
- Prepare industry: rater training, workflow, QA/QC
- Integrate energy modeling and embodied carbon assessment software

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NORTHEAST HOME ENERGY RATING SYSTEM ALLIANCE

NMR Group, Inc.

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EVERSOURCE

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Source: https://www.reddit.com/r/NatureIsFuckingLit/comments/hf0dm1/winding_river_in_the_adirondacks/

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