Low-Carbon Buildings

Dr John Straube, P.Eng.

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UNIVERSITY OF WATERLOO | Department of Civil and Environmental Engineering
Architectural Engineering

Engineering/Architecture/Construction

Building Science for Building Enclosures

This text is intended for the building professions: the engineer, architect or technical specialist involved in the design, construction, operation, maintenance, repair, and renovation of buildings.
The focus is on the building enclosure, i.e., walls, windows, roofs, below-grade construction, and the relevant building science. The control of heat, air, and moisture is emphasized because of their critical importance.

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Building Science for Building Enclosures

Straube
Burnett

Building Science for Building Enclosures

Second Edition

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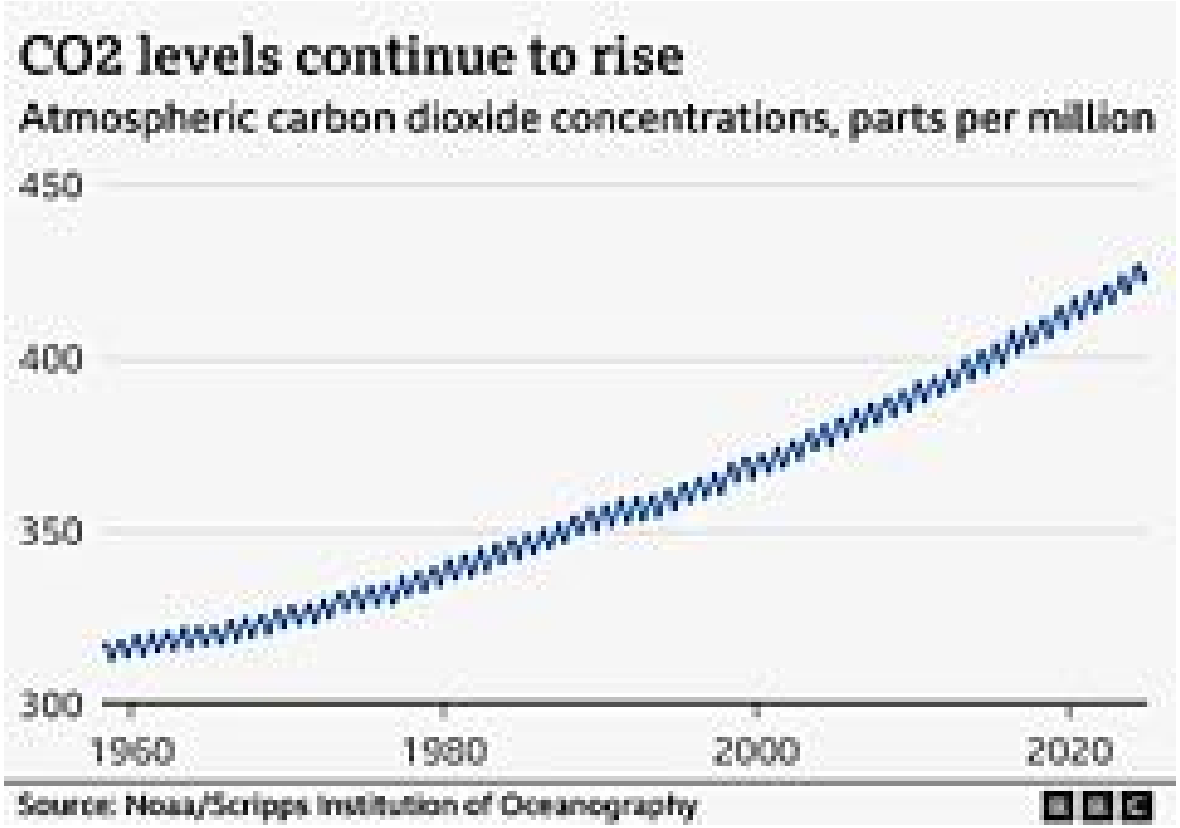
This presentation

- Question: How much focus should we put on low-embodied carbon building materials?
- Outline:
  - Why care about carbon
  - How are we doing in the building industry
  - Electrify Everything
  - Materials and Carbon
  - Integrating Renewables

Why care about carbon?

Carbon in atmosphere is rising

- Risen by 100 ppm since I was born
- This can screw things up, like the climate



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Resiliency and Sustainability

- **Sustainability**
  .. how we impact the world, e.g., CO_2
- **Resilience**
  … how the world impacts us, e.g., floods

Sustainability

- Building construction and operation impacts the environment
- Habitat destruction, ecological disruption, resource depletion are some consequences

- **Climate Change** is widely accepted as the biggest threat

- Climate change is driven by anthropogenic **carbon emissions** (and other GHG of course)

The story until now …

- Energy consumption *used to* = environmental damage
  - Response: reduce energy use in buildings
- Recent Past
  - Energy efficiency, PV on buildings
- Future:
  - Energy produced by low carbon / renewable sources
  - So, **Carbon emissions, not energy** become the focus

Operational Carbon

- Result of operational energy use
- Emissions from energy use
  - How much energy does the building use?
  - Where does the energy come from?

Global construction expected to exceed 230 billion square meters by 2060.
That's another New York City every month for the next 40 years.

Source: Architecture 2030

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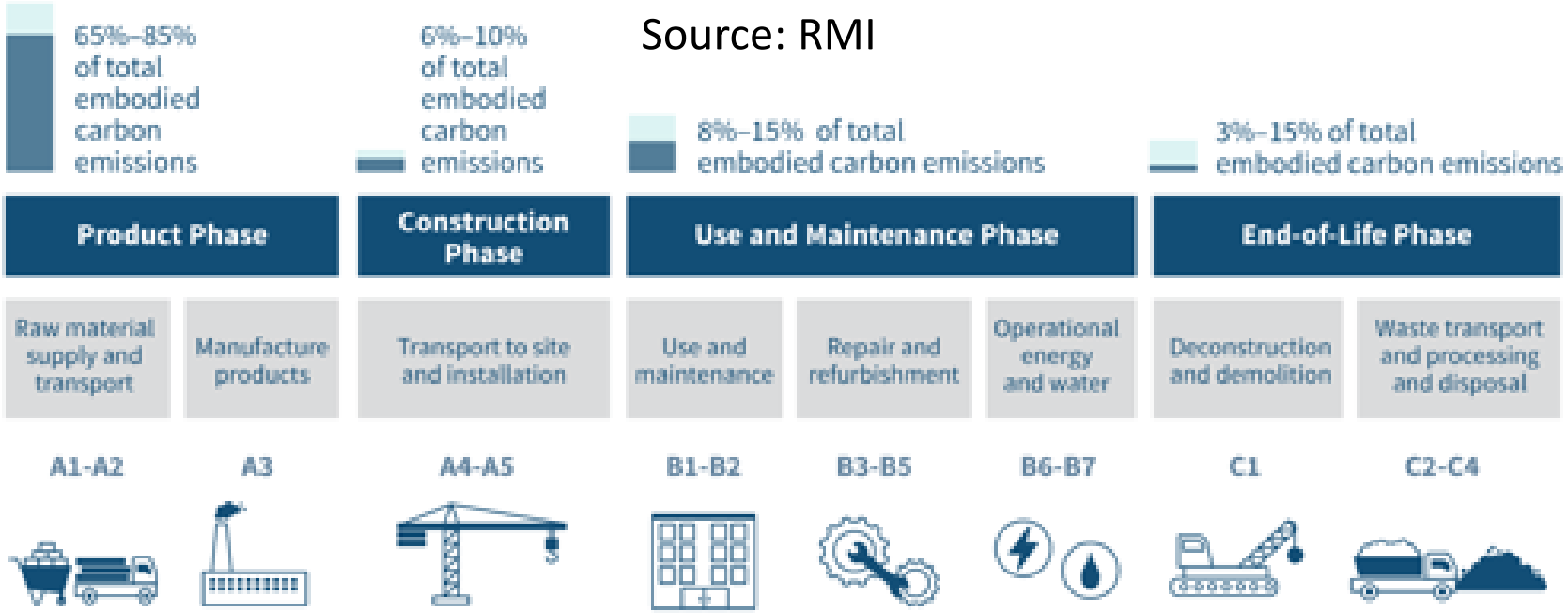
What is embodied carbon?

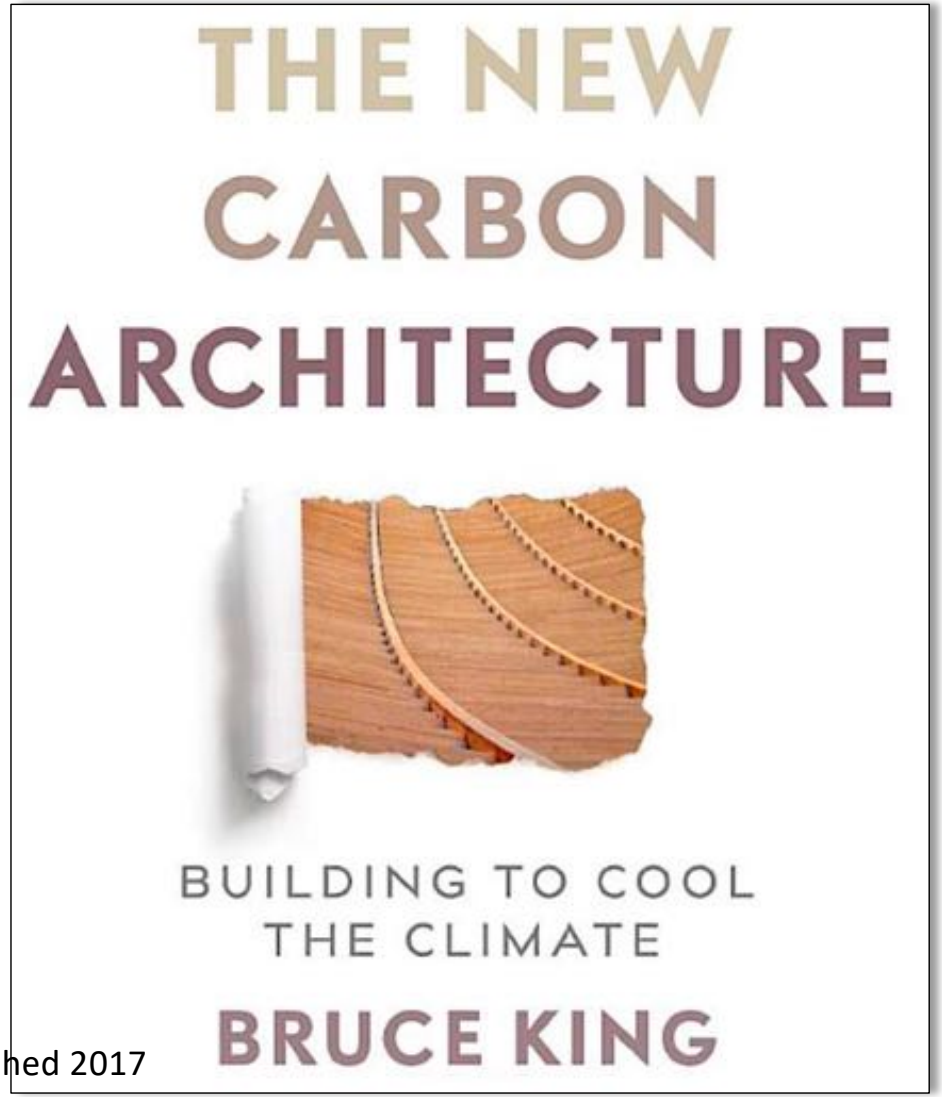
- Carbon (GHG) emitted by manufacture, transport, maintenance of materials



Source: RMI

Embodied

- New attention to Carbon embodied within materials and their production



Published 2017

Sequestered Carbon

- Carbon removed from atmosphere and stored in building materials
- Wood
  - Removes CO_2 from air via photosynthesis during “production”
  - About 180% CO_2 of the mass of wood
- Concrete releases 50-70% of cement mass during production
  - removes CO_2 from air via carbonation during service
  - about 25% CO_2 of the mass of cement used

The promised future

1. Buildings will consume very little operational energy
2. We will transition to low-carbon energy

   and, the electric grid will be zero carbon source

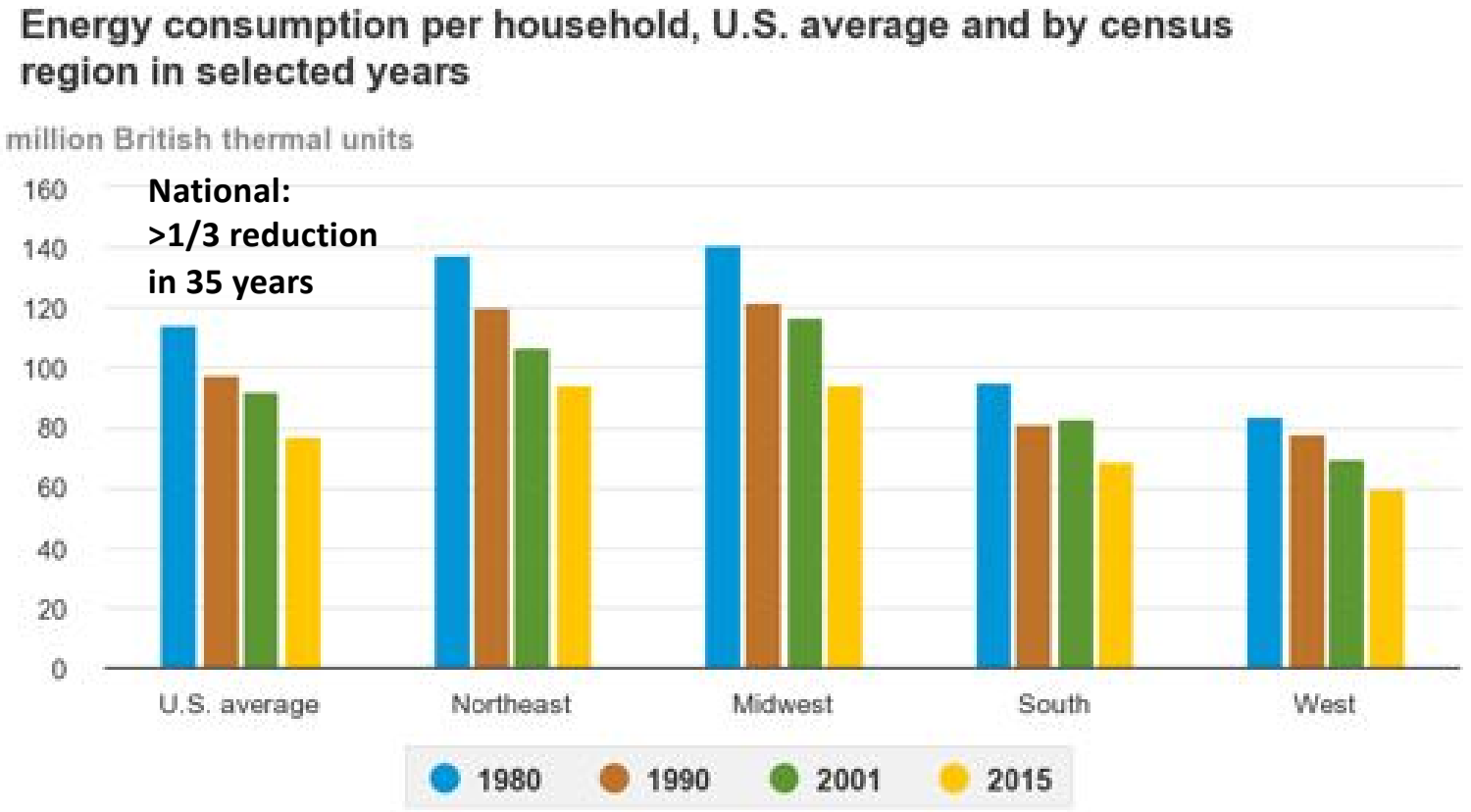
Therefore….

- Carbon embodied in materials should become our focus

Are we there yet?

Do we have a low-carbon grid?
Are we building low energy use buildings?

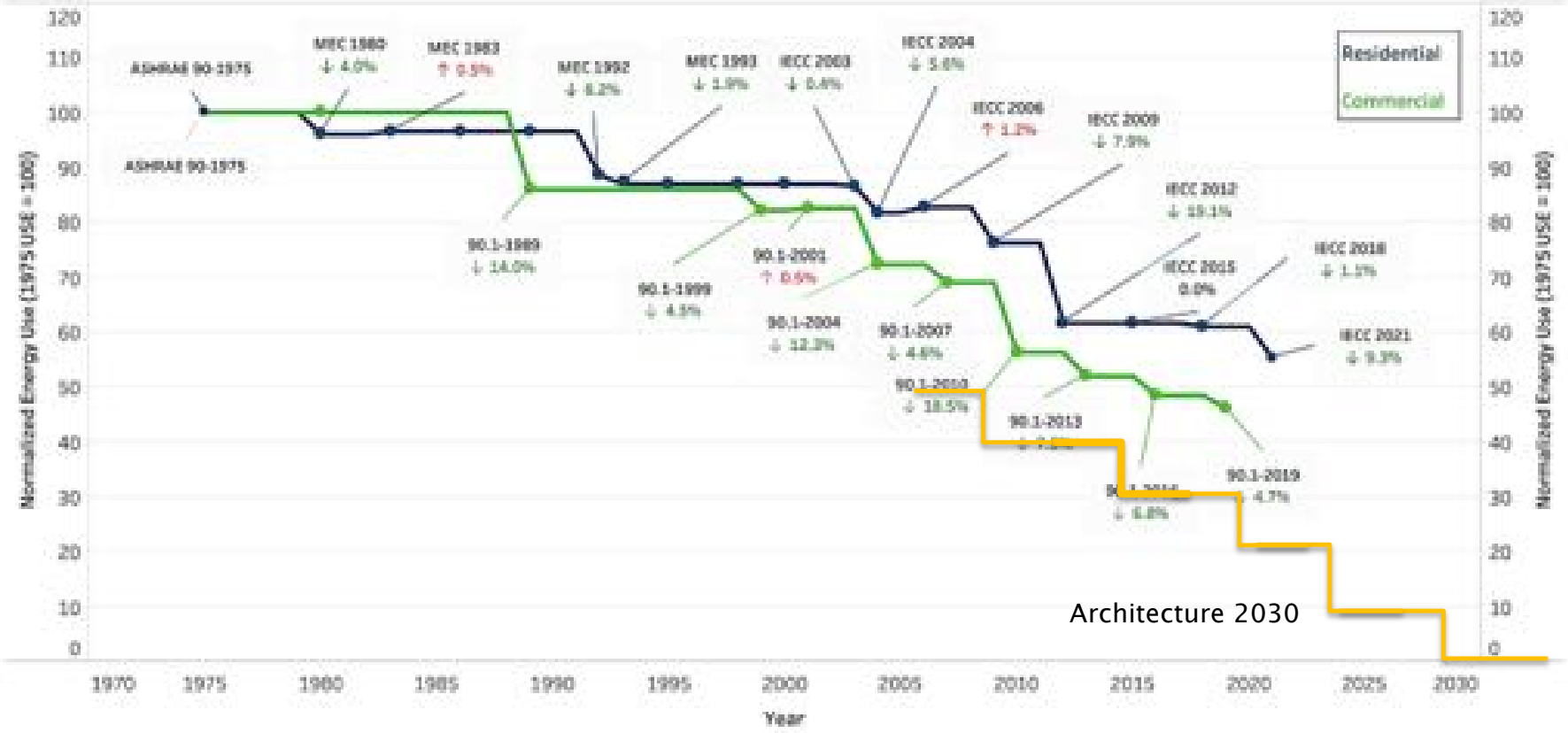
Energy Use per Household



Data source: U.S. Energy Information Administration, *Residential Energy Consumption Survey* for indicated years

Note: Excludes losses in electricity generation and delivery, and consumption of wood fuels.

Energy Codes over time



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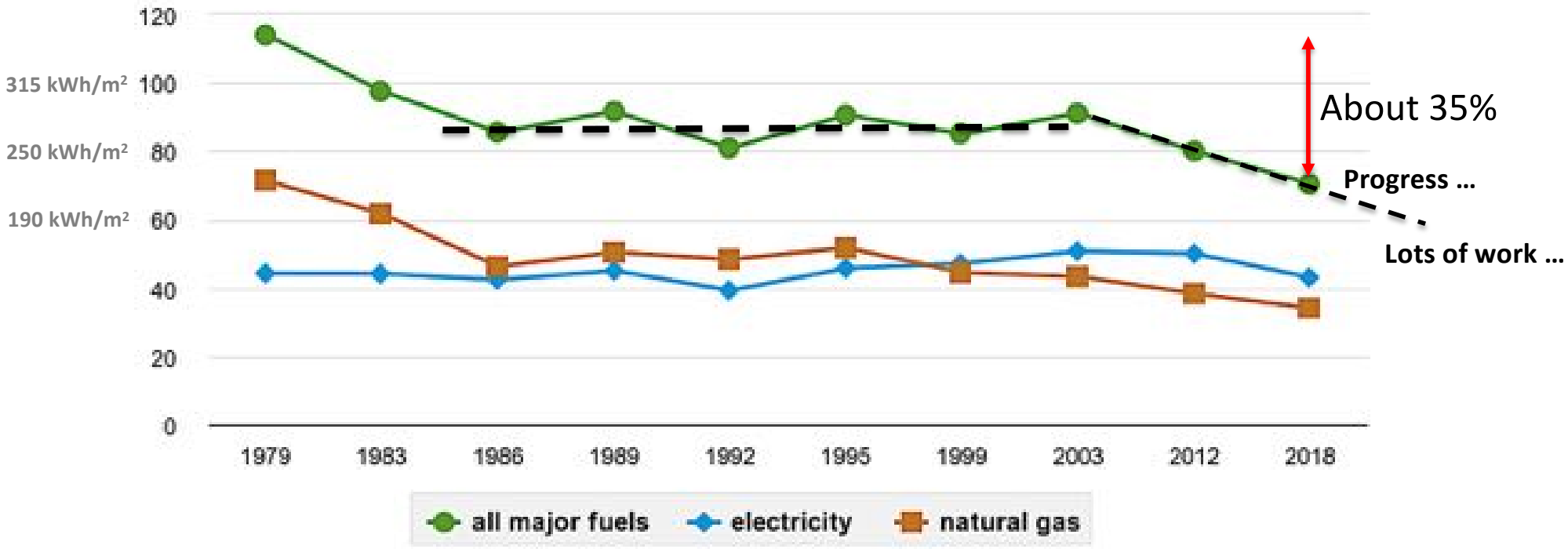
Energy intensity of major fuels in U.S. commercial buildings in selected years

thousand British thermal units per square foot of floorspace



Data source: U.S. Energy Information Administration, Commercial Buildings Energy Consumption Survey
Note: Major fuels include electricity, natural gas, fuel oil, and district heat.

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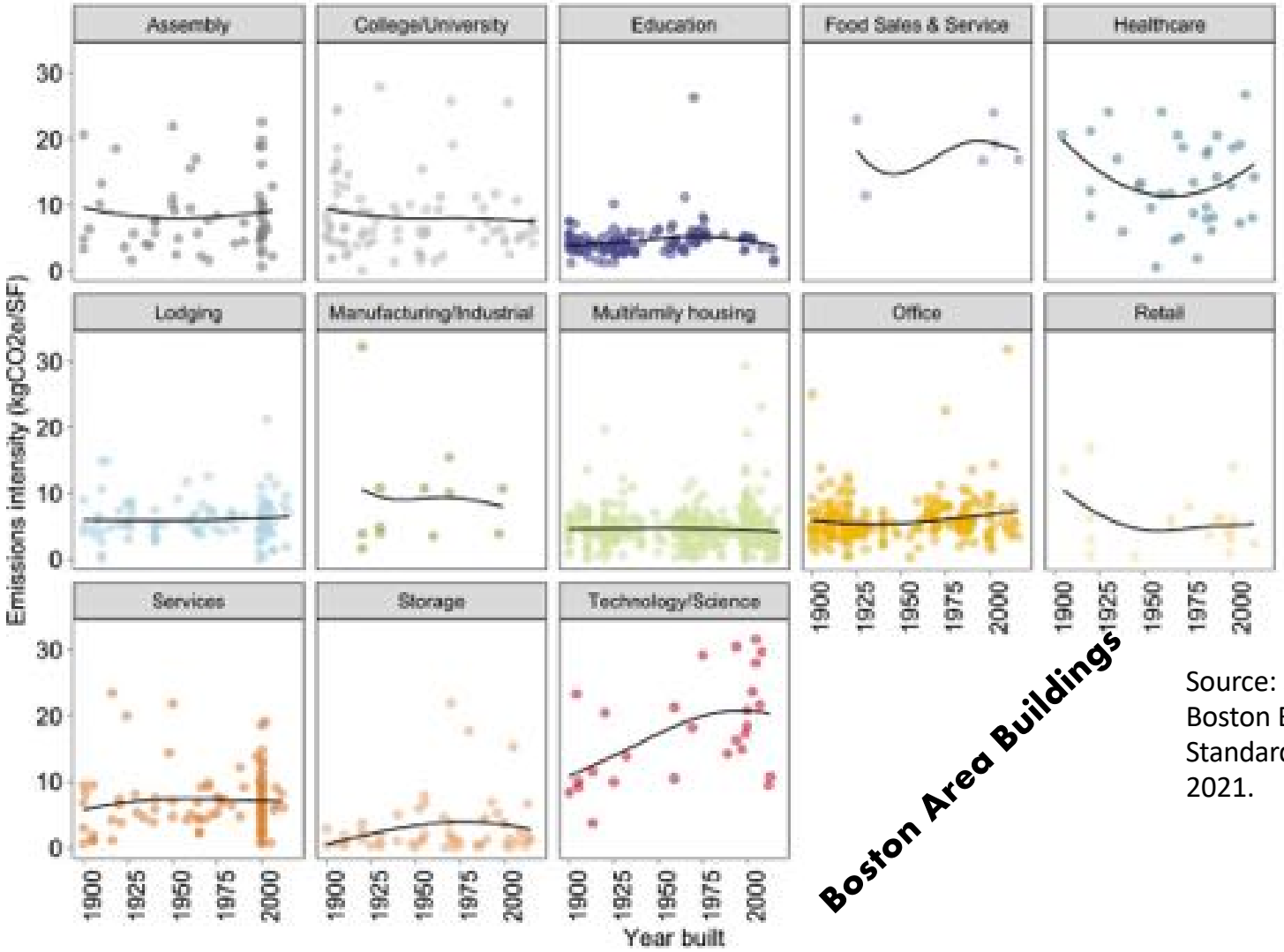
Figure 4. Emissions intensity in BERDO buildings by year built, 2018 data



Boston Area Buildings

Can you see a clear reduction in carbon reduction?

Source: Synapse Energy Economics. Boston Building Emissions Performance Standard Technical Methods Overview. 2021.

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Beware Simple Solutions

-

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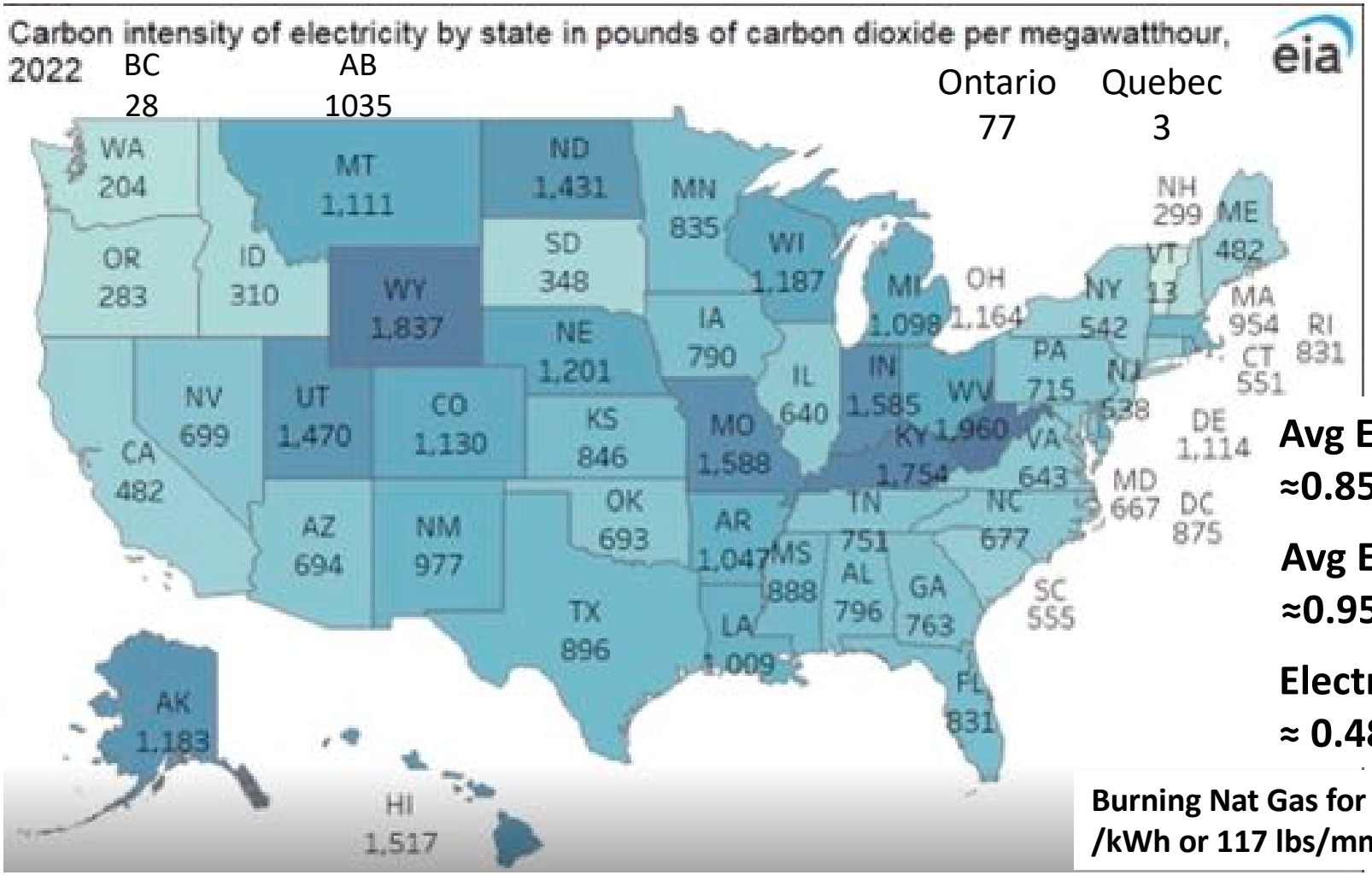
"Electrify Everything"

- Electricity use still results in significant carbon emissions
- Household, municipal, broader grids cant handle instant electrification
  - 100A panel in house, now add heat pump and electric car to every house on the street

How is your electricity made?



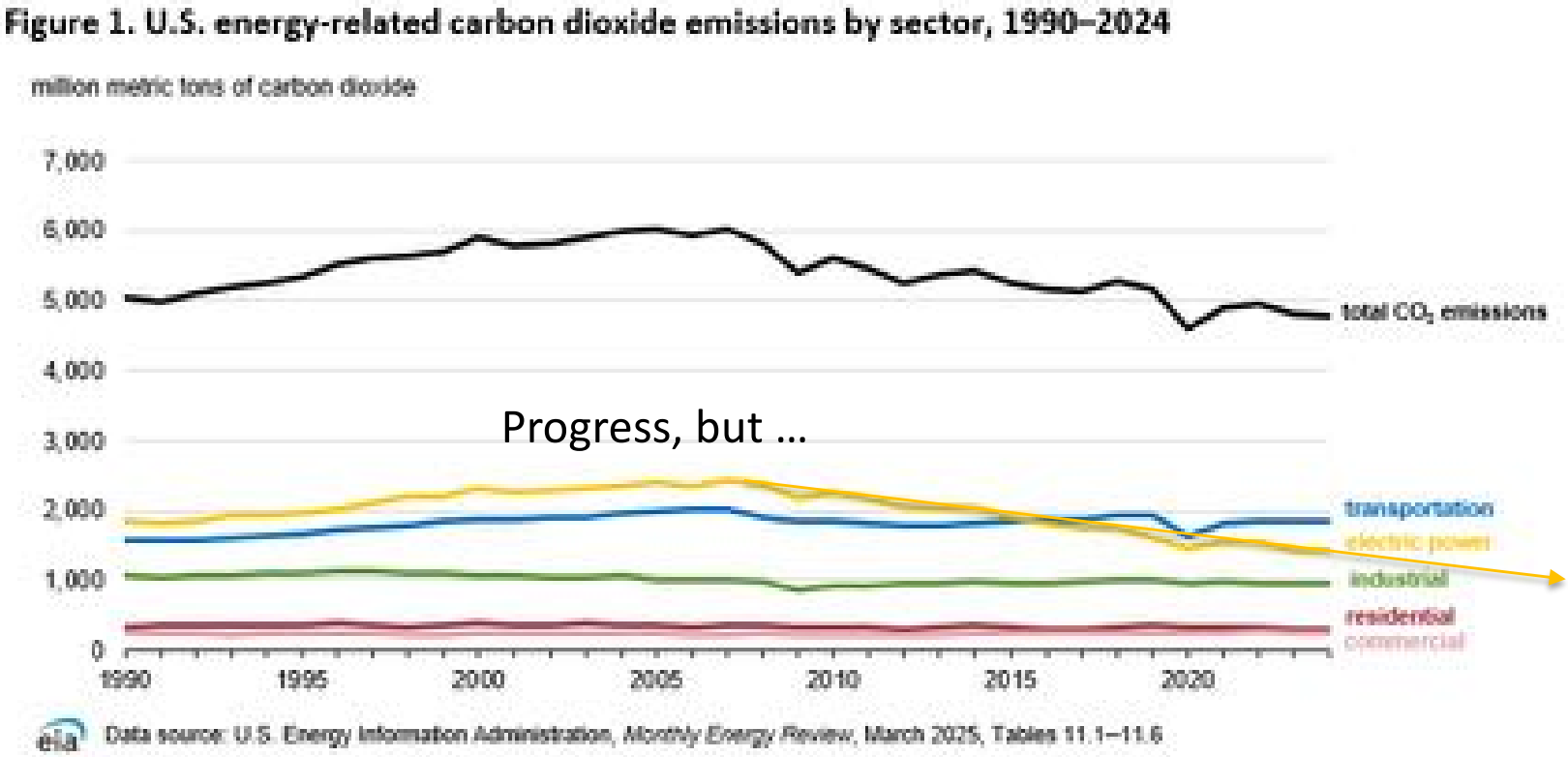
Avg Electricity in USA:
≈0.85 lbs CO_2e / kWh

Avg Electricity in MA:
≈0.95 lbs CO_2e / kWh

Electricity in CA:
≈ 0.48 lbs CO_2e / kWh

Burning Nat Gas for heating is about 0.44 lb /kWh or 117 lbs/mmBTU, 0.12/CF

De-carbonization of the Grid



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Conclusions

- Our buildings are not low-energy
- Our grid is not low-carbon

- Trends are positive, but much work to be done

Building Life-cycle Carbon

Life-cycle Carbon

=

operational carbon

+

embodied carbon

- *Operational* depends on the amount and kind of energy
- *Embodied* depends on the amount and kind of materials

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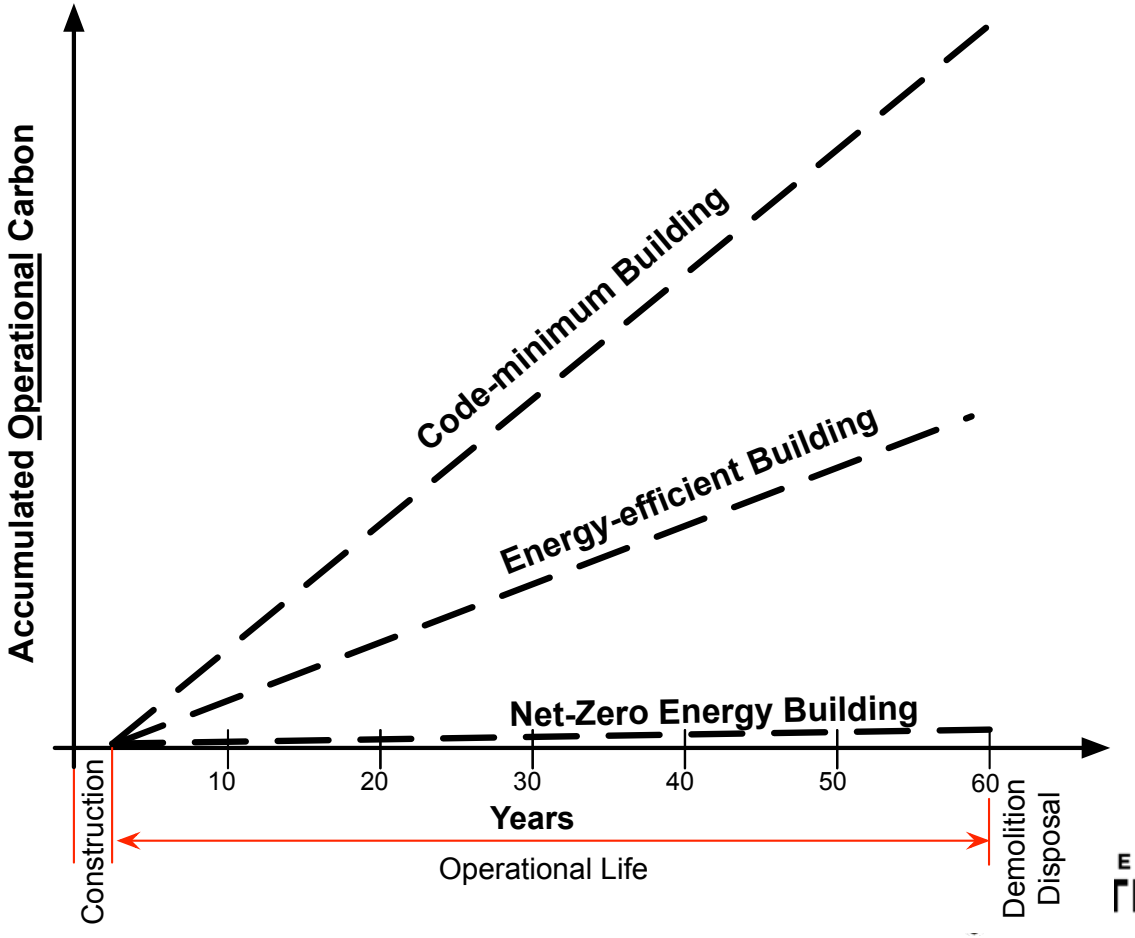
Operational Energy Still Matters



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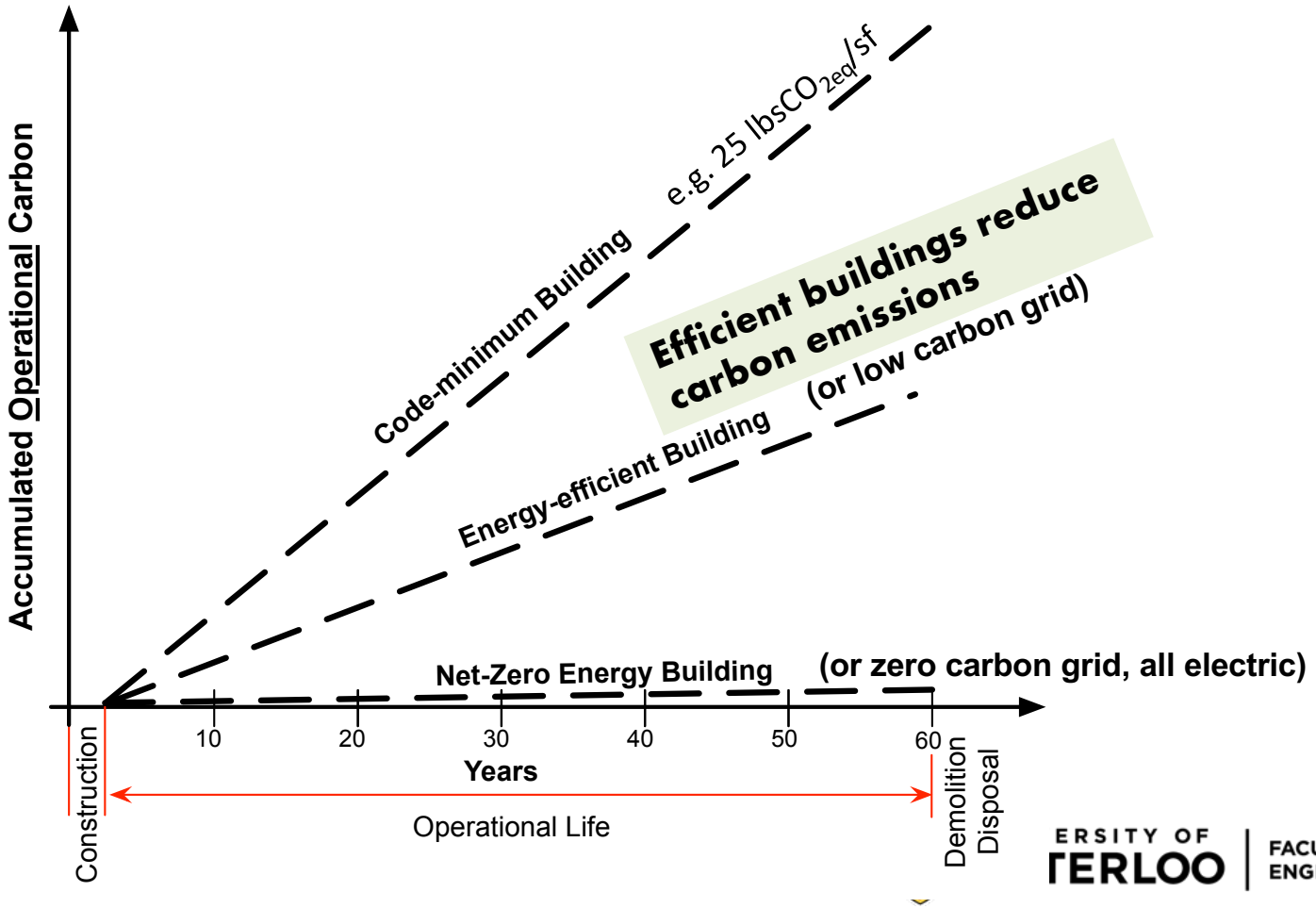
Operational Carbon



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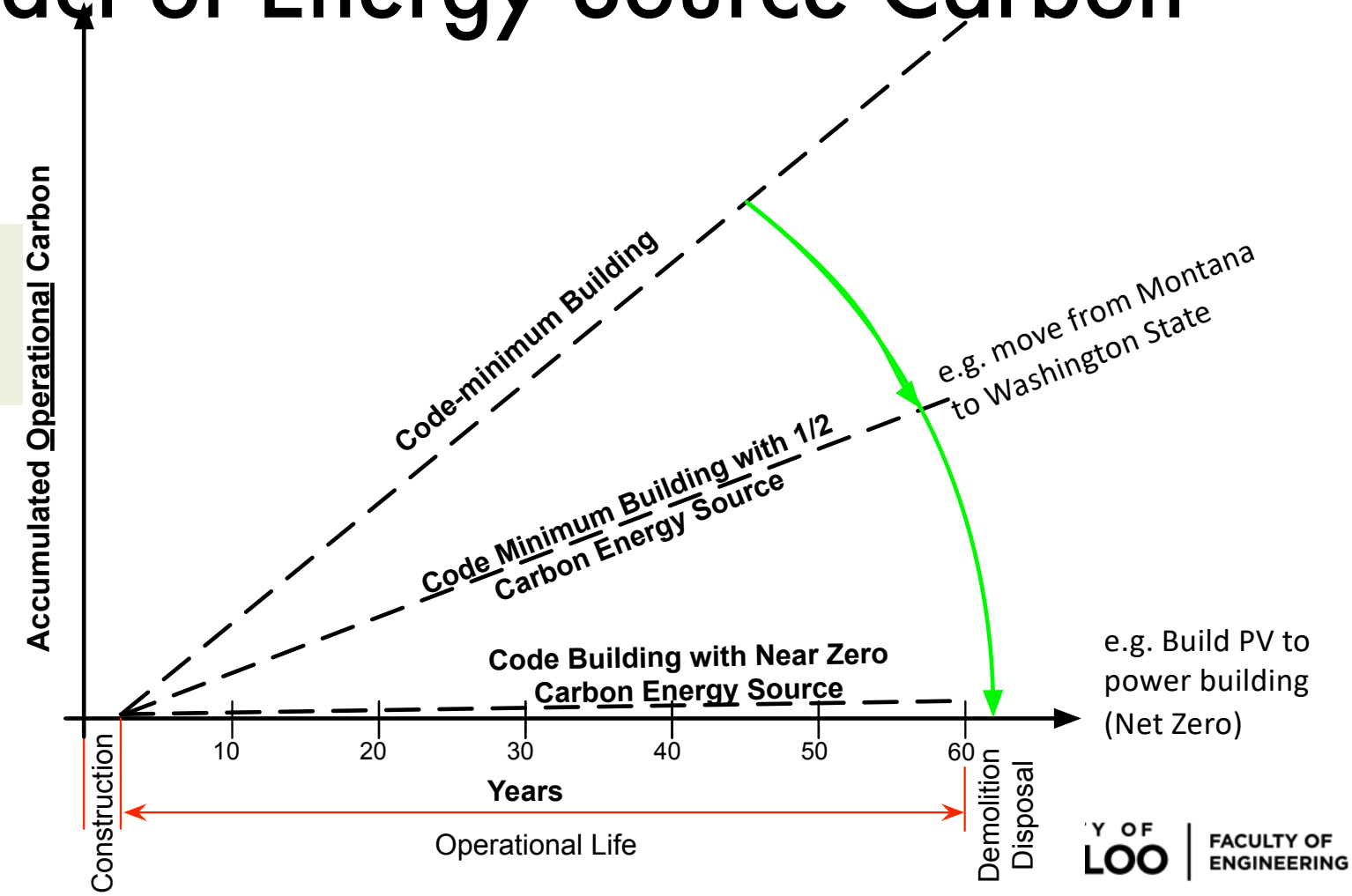
Impact of Energy Source Carbon

The source of energy has a profound effect on carbon emissions. Can swamp efficiency.



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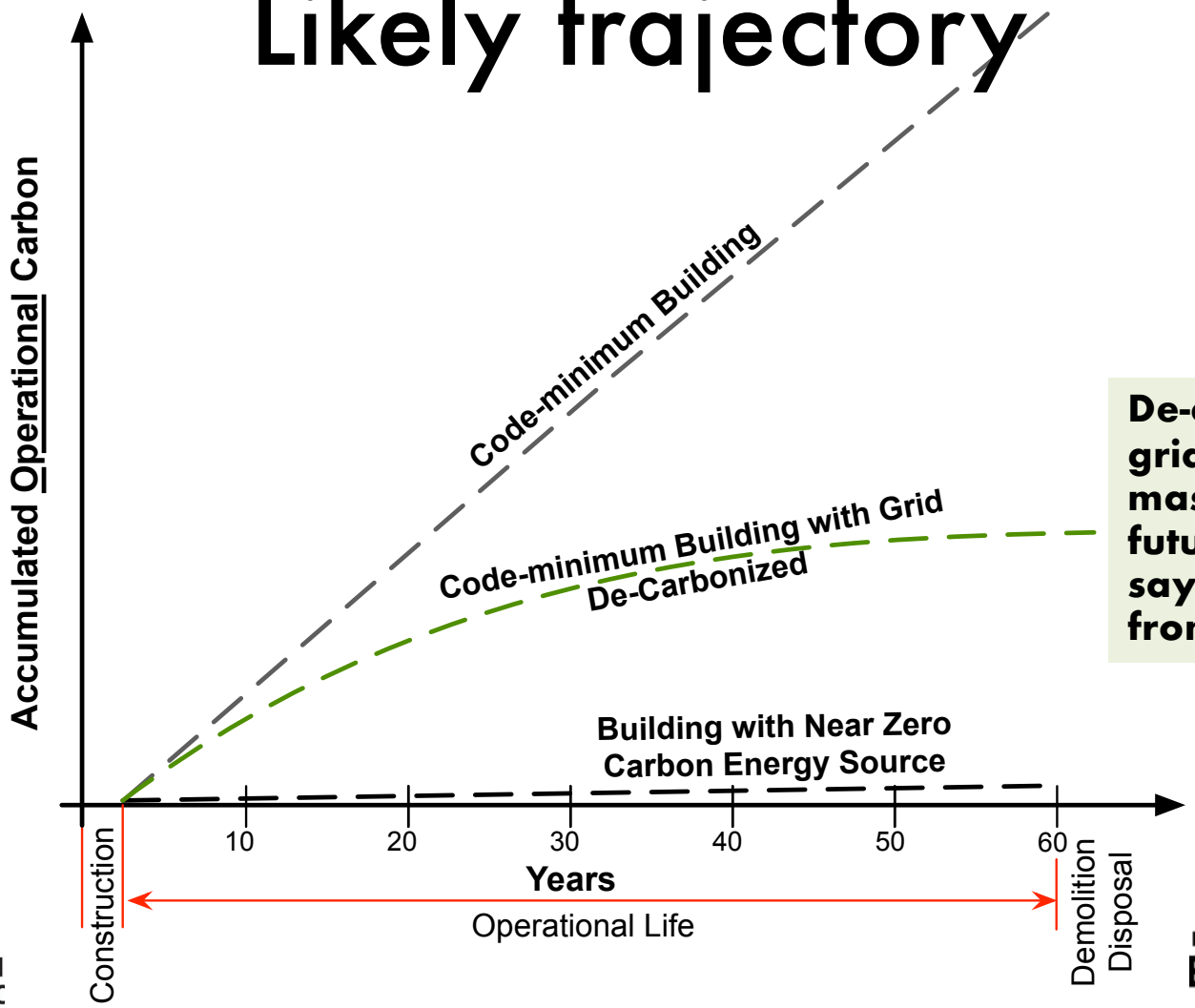
Likely trajectory



De-carbonized grid/energy has a massive impact on future emissions, say 25-50 years from now

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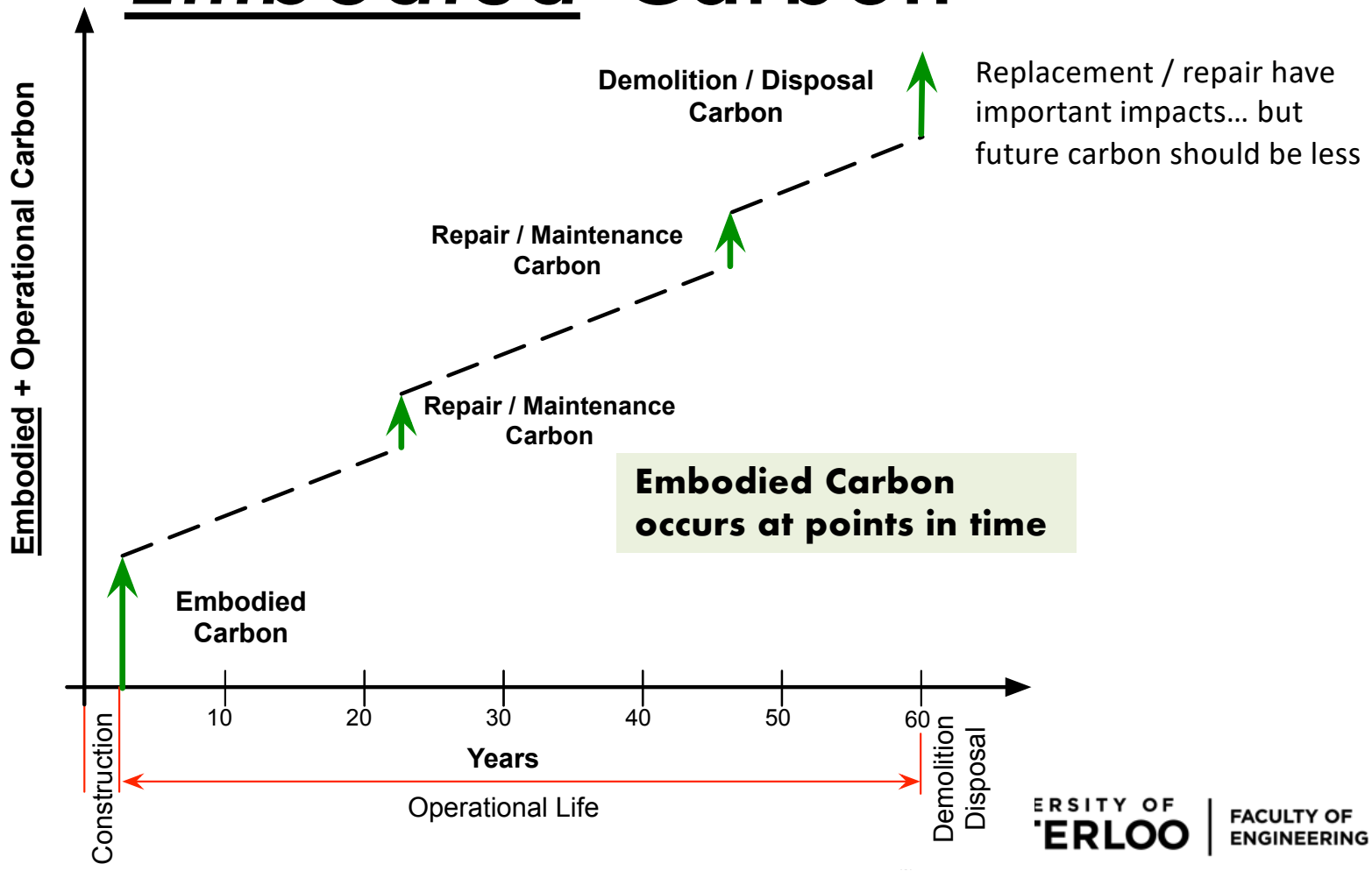
Embodied Carbon



Replacement / repair have important impacts… but future carbon should be less

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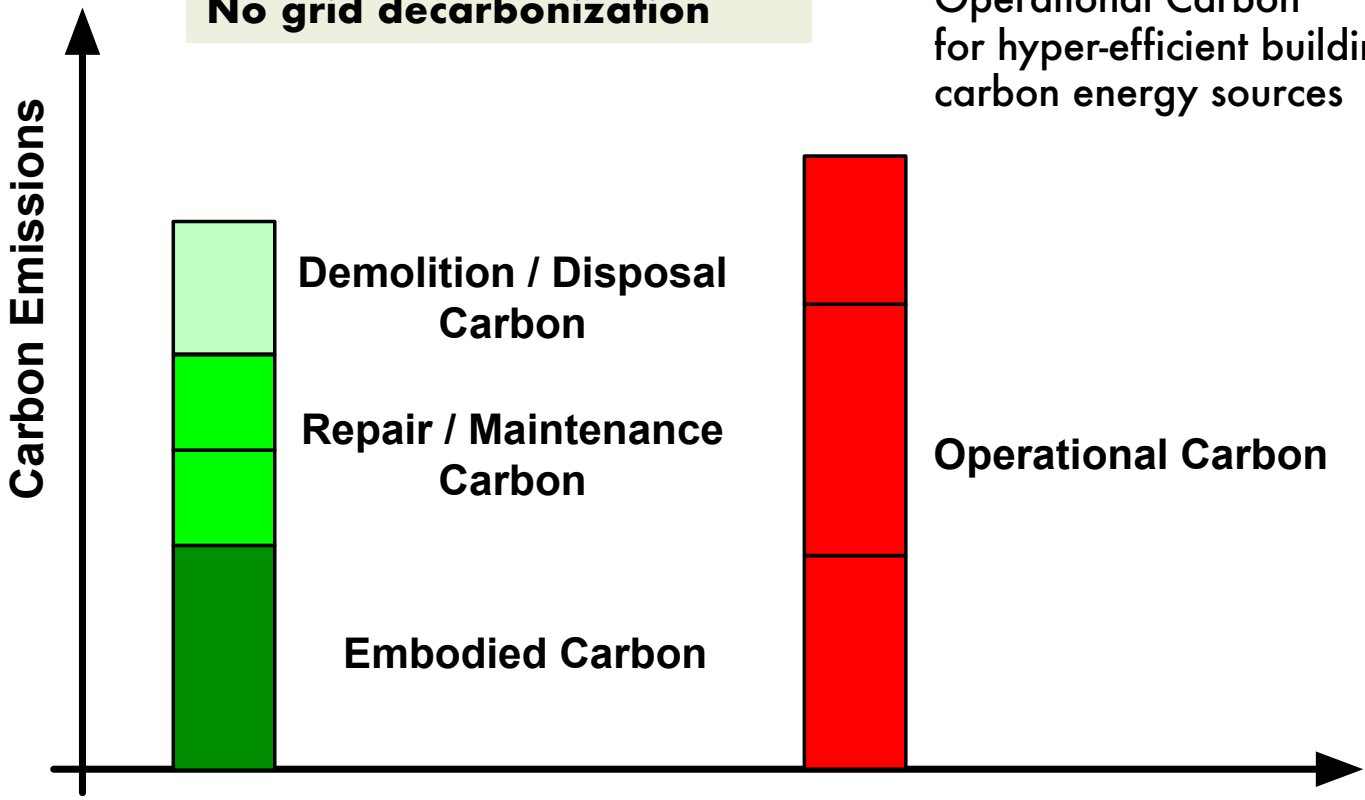
Life-cycle Carbon Emissions

Example 60 year life-cycle
No grid decarbonization

Embodied Carbon may approach Operational Carbon for hyper-efficient building and/or low-carbon energy sources



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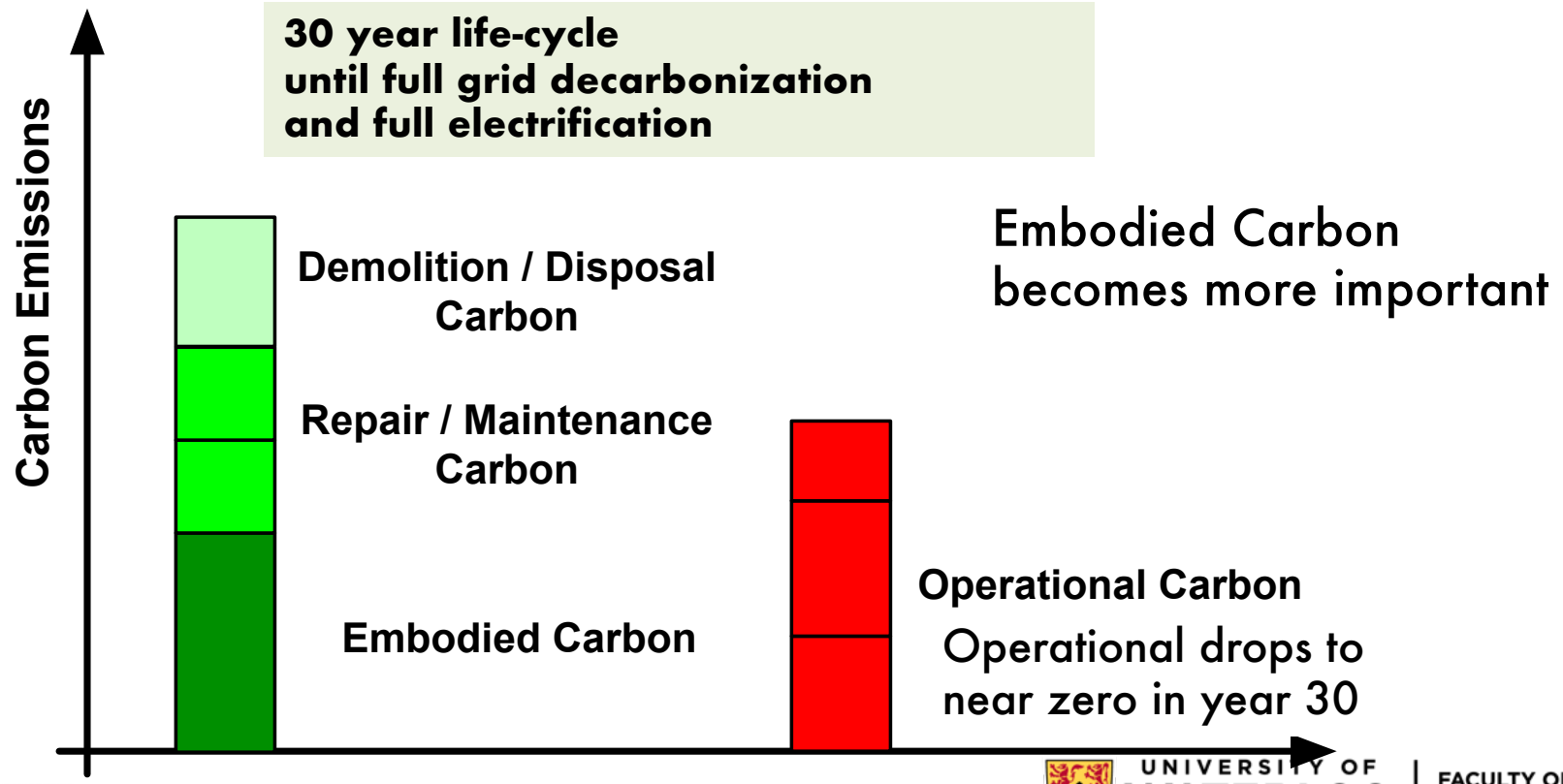
30 years to Grid Decarbonization



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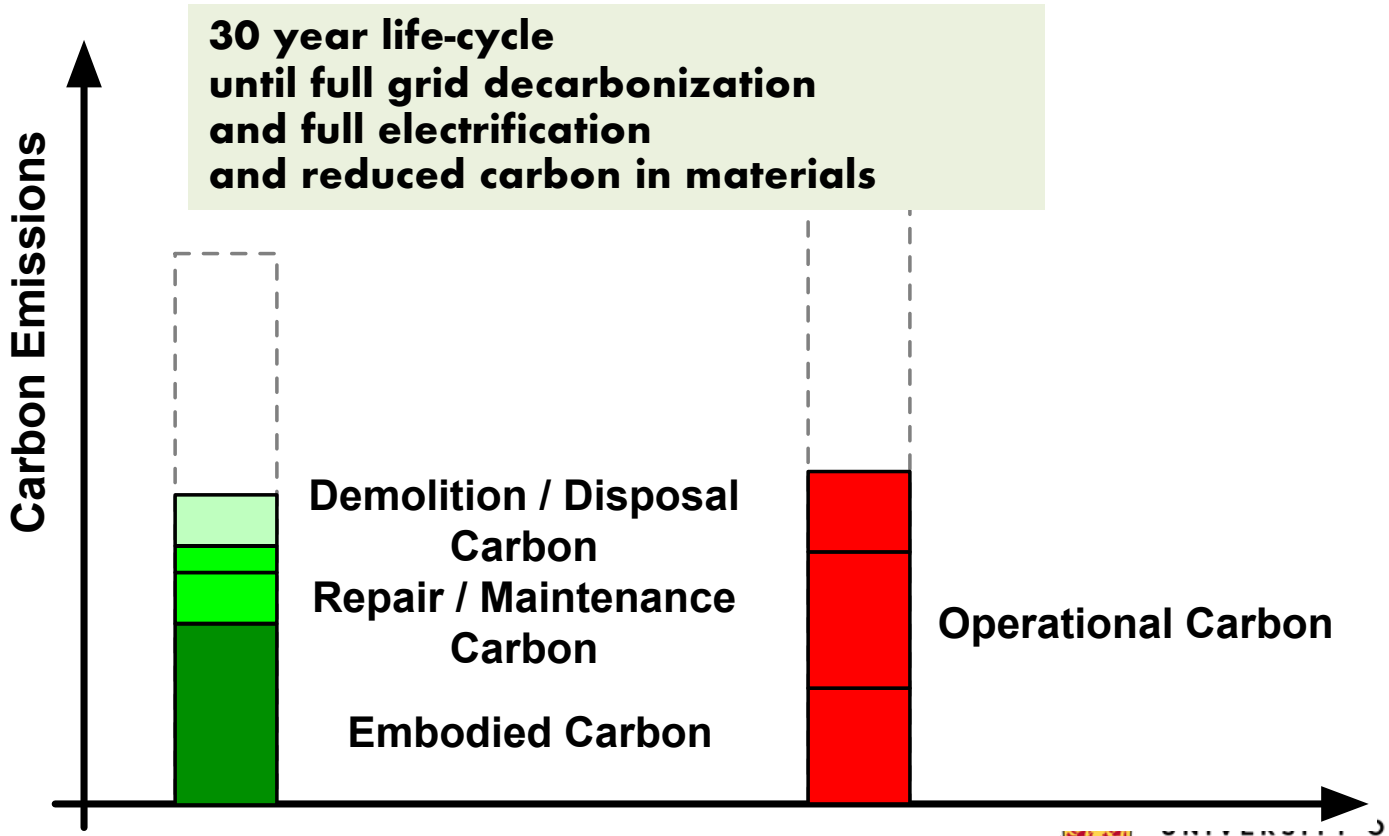
30 years to Economy Decarbonization



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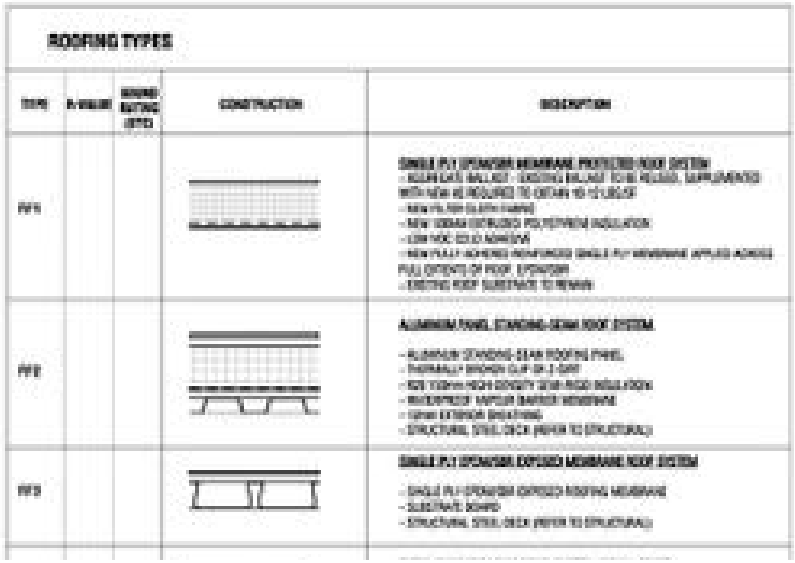
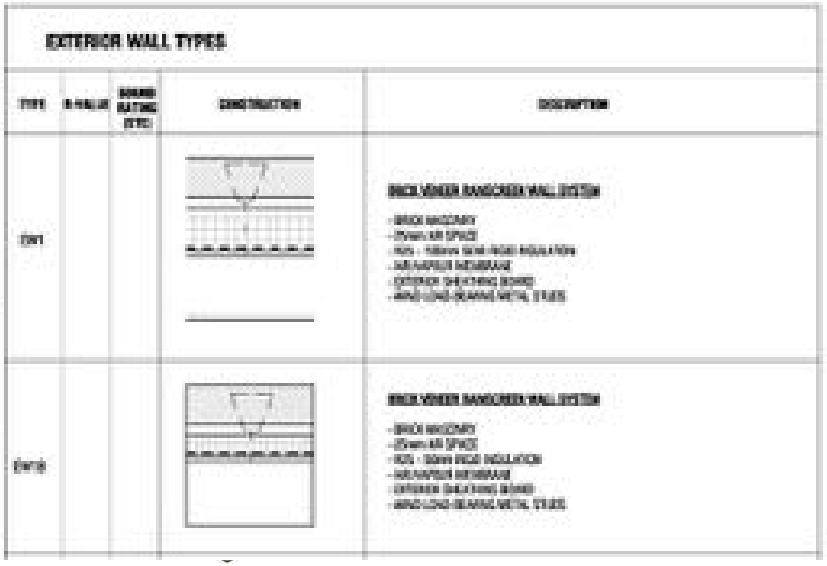
How much embodied carbon is in your building?

Estimating Embodied Carbon

- Materials are not products, components, or systems
- Designers need to develop project-specific assemblies
- Recommendation: use the enclosure schedule to start





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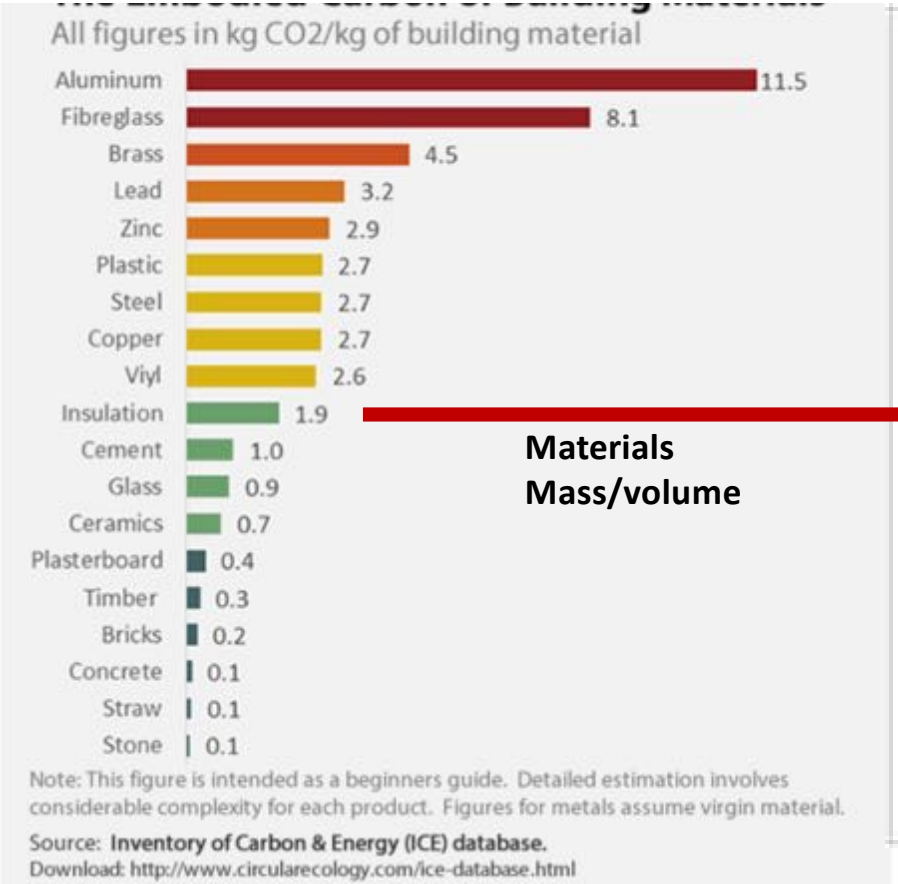
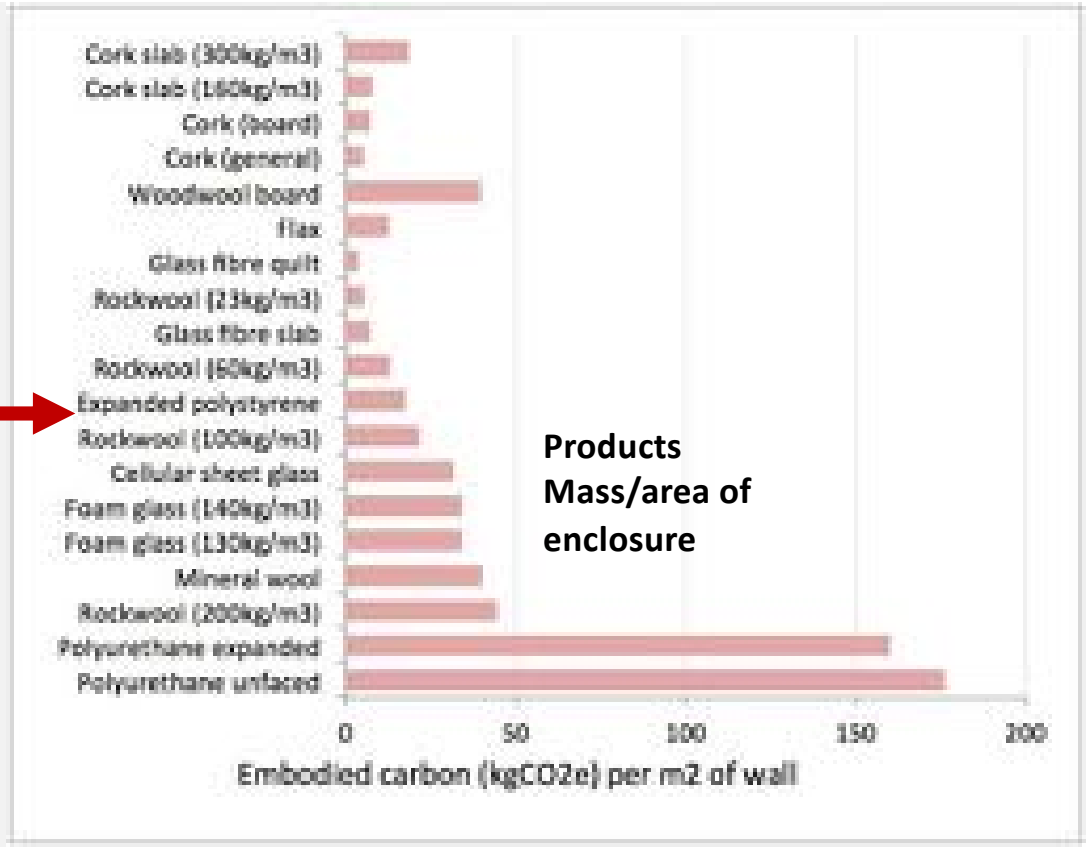
Weight of Materials vs Products



Materials
Mass/volume



Products
Mass/area of enclosure

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Source: Inventory of Carbon & Energy (ICE) database

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Environmental Product Declarations

- Most common, reliable, and consistent source of data
- Becoming more widely available….
  Keep “googling” ..they change!
- Not “gospel”
- Vary with time, assumptions

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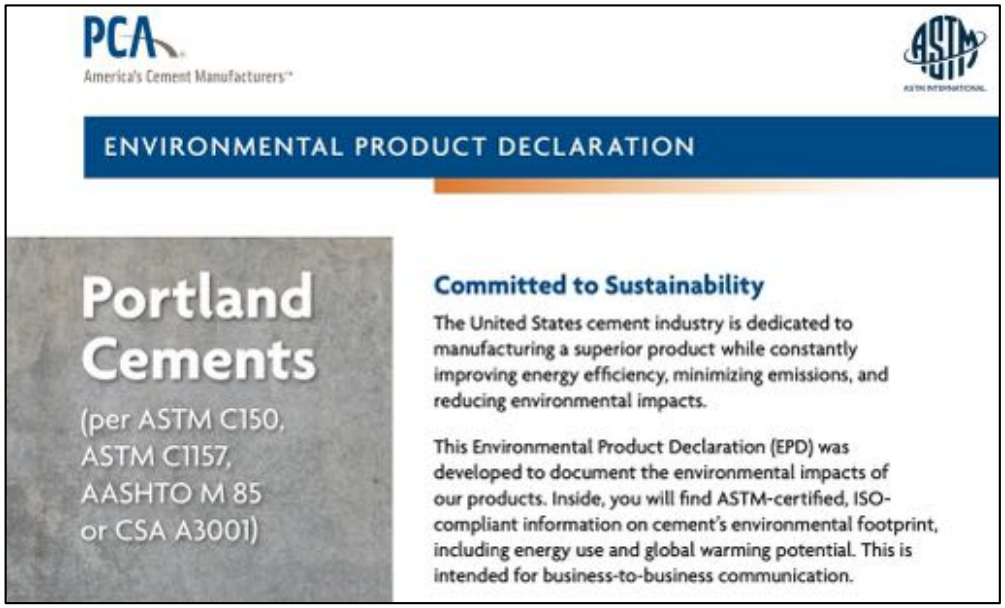
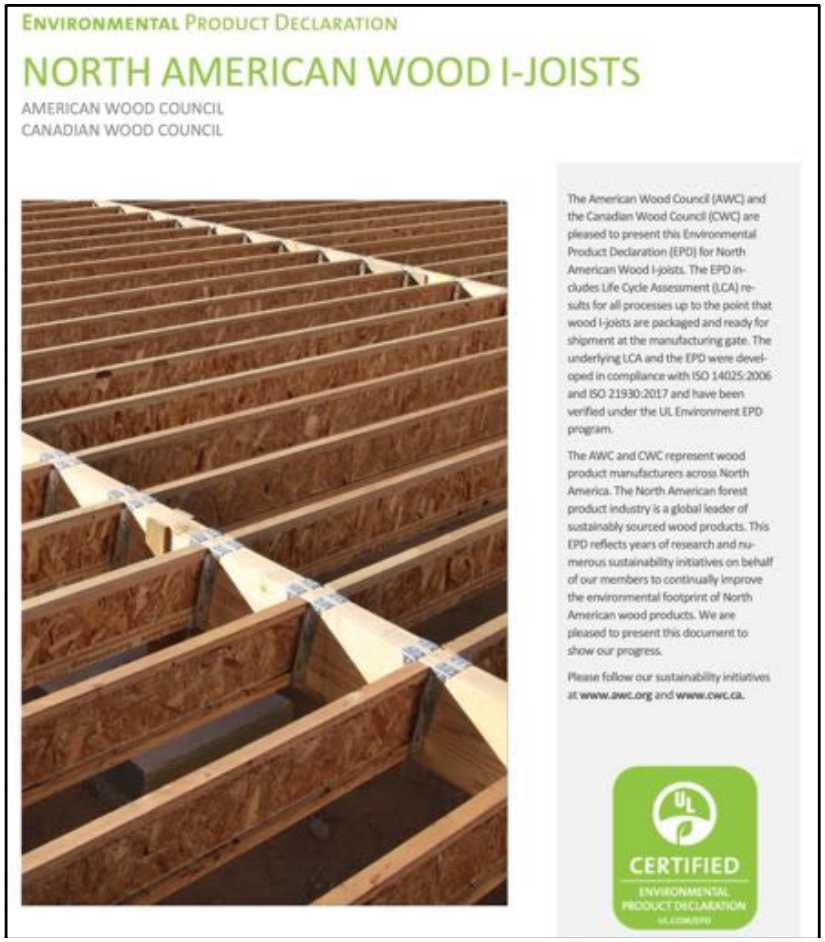
Specific Materials





ENVIRONMENTAL PRODUCT DECLAR

According to /ISO 14025/ and /EN 15804/

Declaration owner	Rieder Sales GmbH
Issuer	*Institut Bauen und Umwelt e.V. (IBU)*
Programme holder	*Institut Bauen und Umwelt e.V. (IBU)*
Declaration number	EPD-RSE-20180069-IAD1-DE
Date of issue	29.10.2018
Valid until	28.10.2023

concrete skin' and 'öko skin' –
Glass-fibre-reinforced concrete
Rieder Sales GmbH

www.ibu-epd.com / https://epd-online.com

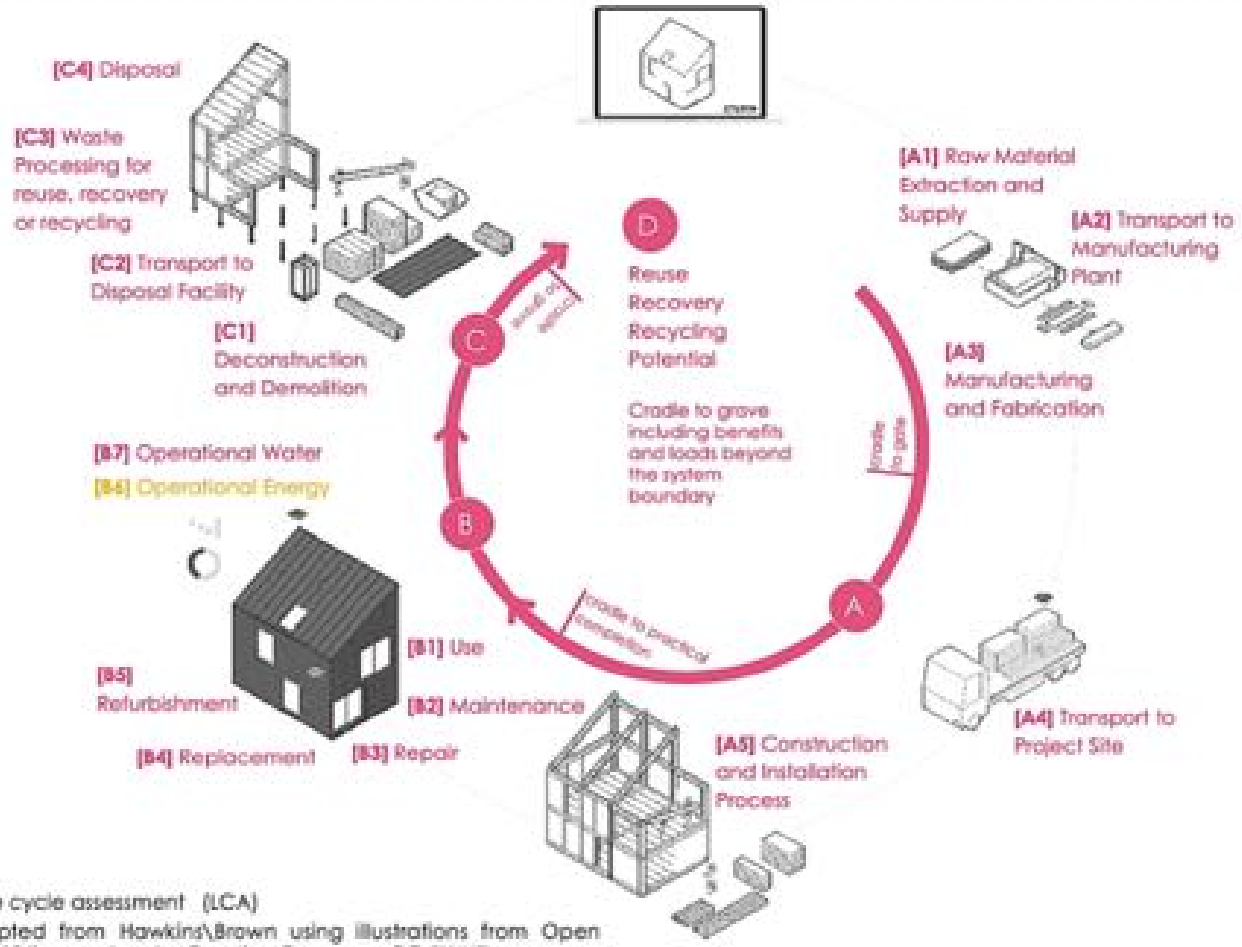


Figure 2.1 - Life cycle assessment (LCA)
Diagram adapted from Hawkins\Brown using illustrations from Open Systems Lab 2018 licensed under Creative Commons CC-BY-ND

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Mass timber for commercial

- don’t get myopic
- Consider full life-cycle

Hybrids .. Good engineering

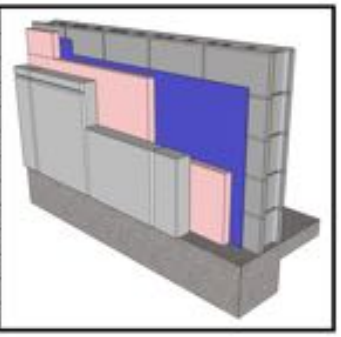
Novel Hybrids

Investigating Alternate Systems

Concrete Masonry Unit Wall #3 (CMU-W3)

Building Component Description:

Category:	Exterior Walls		**Assembly Layers**
Brief Description:	Concrete masonry unit wall with typical exterior rigid insulation and pre-cast concrete cladding		***Outside***
			125mm concrete pre-cast cladding
			25mm air gap
			50mm extruded polystyrene rigid insulation
			Self-adhesive membrane with primer (AB, VB, WB)
Quick Numbers:			200mm standard weight concrete block
			(includes #15M bars @ 400mm o/c with grout)
ASHRAE Standard 90.1:	R-Value: 11.9	RSI-Value: 2.1	Latex paint
THERM 5.2:	R-Value: 13.3	RSI-Value: 2.3	***Inside***
Wall Thickness:	390 mm		
Total Embodied Energy:	1,553 MJ/m^2		
Total Embodied GWP:	110 kg of CO_2 eq./m^2		



Life-Cycle Assessment Results:

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)												[3] Total GWP	[4] Total GWP per m^2
	Manufacturing			Construction			Maintenance			End of Life				
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	5,523	2	5,525	48	4	51	0	0	0	0	0	0	5,576	110
50	5,523	2	5,525	48	4	51	44	0	44	5	2	7	5,626	110

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m^2 (Length x Height = 7.6m x 6.7m = 50.9m^2)

Spreadsheet analysis
Data from EPDs

22.5 lb/ft^2

From: Kevin Van Ooteghem (2010). The Life-Cycle Assessment of a Single-Storey Retail Building in Canada. M.A.Sc. Thesis, Civil & Environmental Engineering Department University of Waterloo

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Investigating alternate systems

Building Component Description:

Category:	Exterior Walls	**Assembly Layers**	
Brief Description:	Wood stud wall (400mm o/c) with typical exterior rigid insulation and standard clay brick cladding	*Outside*	
		Ontario (standard) clay brick cladding	
		25mm air gap	
		50mm extruded polystyrene rigid insulation	
		Self-adhesive membrane with primer (AB, VB, WB)	
Quick Numbers:		16mm non paper-faced gypsum sheathing	
		38mm x 140mm wood studs @ 400mm o/c	
ASHRAE Standard 90.1:	R-Value:	*(wood studs are kiln-dried to a MC of at least 19%)*	
THERM 5.2:	R-Value:	*(also includes 110g/m² steel nails @ 400mm o/c)*	
Wall Thickness:	337 mm	*(also includes double top plate and one sill plate)*	
Total Embodied Energy:	948 MJ/m²	Regular 16mm gypsum board	
Total Embodied GWP:	56 kg of CO_2 eq./m²	Latex paint	
		Inside	

Global Warming Potential (kg of CO_2 eq.)

Lifespan (Years)	Embodied Global Warming Potential (GWP)													
	Manufacturing			Construction			Maintenance			End of Life			[3] Total GWP	[4] Total GWP per m²
	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total	Material	[2] Trans.	Total		
[1] Initial	2,797	1	2,798	13	3	16	0	0	0	0	0	0	2,814	55
50	2,797	1	2,798	13	3	16	44	0	44	0	1	1	2,859	56

Embodied energy (and GWP) numbers are based on an area of wall = 50.9 m² (Length x Height = 7.6m x 6.7m = 50.9m²)

11.4 lb/ft²

From: Kevin Van Ooteghem (2010). The Life-Cycle Assessment of a Single-Storey Retail Building in Canada. M.A.Sc. Thesis, Civil & Environmental Engineering Department University of Waterloo

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Danger: Improper Substitution

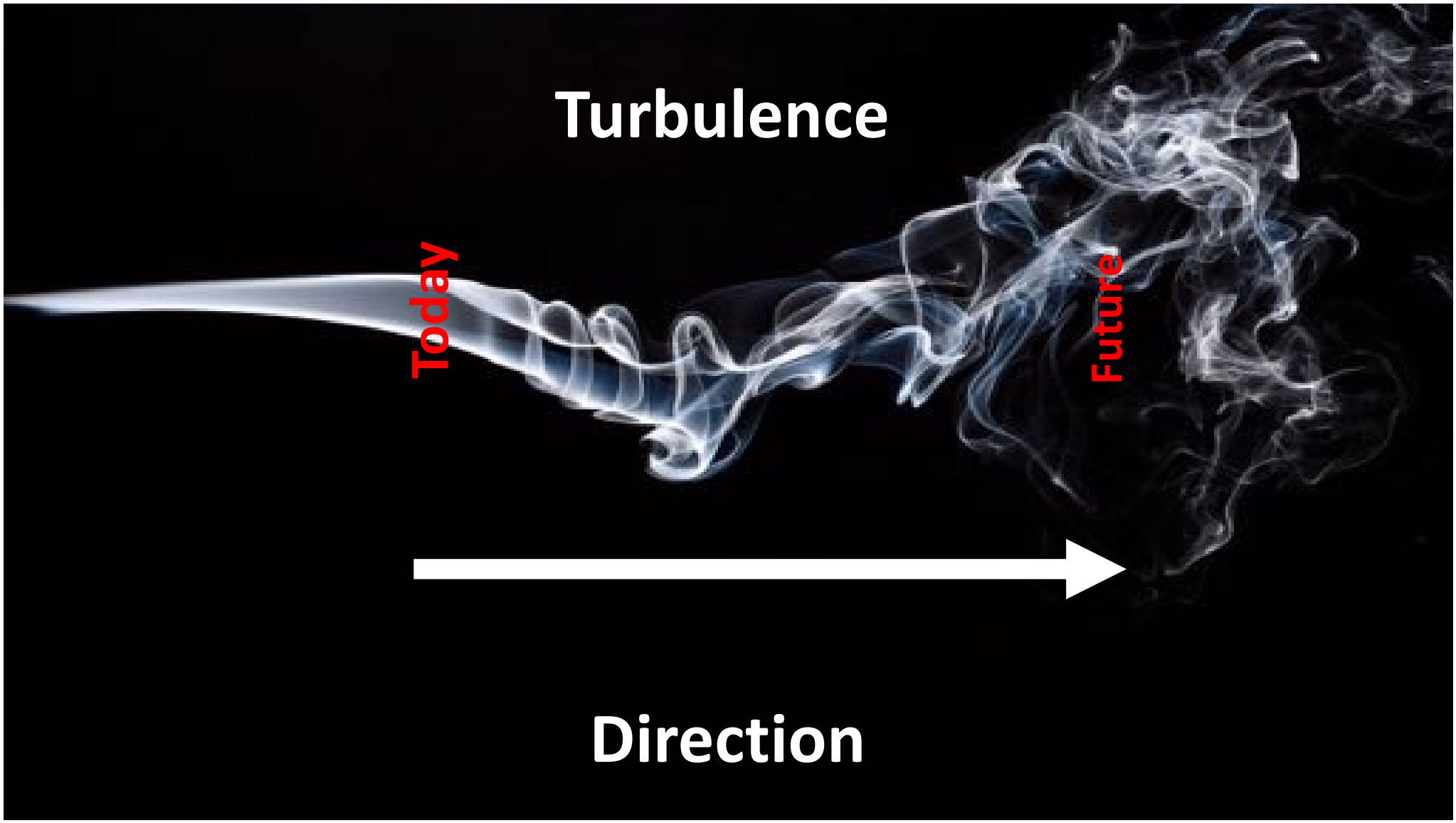
- Systems may have very different performance characteristics (resilience, durability, etc)
- Be sure to ensure alternates have similar or better important attributes
  - Especially: durability, fire resistance, etc

Decarbonizing Materials

- As the grid de-carbonizes, the embodied carbon of products is also reducing
- Industries are changing to lower carbon methods…
  - So steel, cement, aluminum etc will all be lower carbon

Current Building Industry Response

For North America


Turbulence
Today
Future
Direction

Industry Response

- Energy codes have become tighter
  - Account for thermal bridging, air leakage = actual performance
  - ASHRAE 90.1, IECC
- Regulations to limit actual operating carbon emissions
  - NYC Local Law 97, Boston BERDO, Seattle &Toronto BEPS
  - Essentially the ultimate **performance** path
- Expect this approach to grow

BERDO: Building Emissions Reduction and Disclosure Ordinance

“The future is already here – it’s just not very evenly distributed.”
William Gibson

NYC Law 97 and BERDO are small % of buildings

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Whole-Building Carbon Targets

- Having metrics and targets is critical for achieving better performance
- Example, for energy, MMBTU/ft^2, or kWh/m^2
  - E.g. Passive House 120 kWh/m^2 for primary
- Embodied Carbon metric
  - kg $CO_{2\ eq}/m^2$
  - lb $CO_{2\ eq}/ft^2$

Low-rise wood frame Housing

- Many embodied carbon studies, wide variation…
- about 50 $lbCO_2/ft^2$ (250 $kgCO_2/m^2$)

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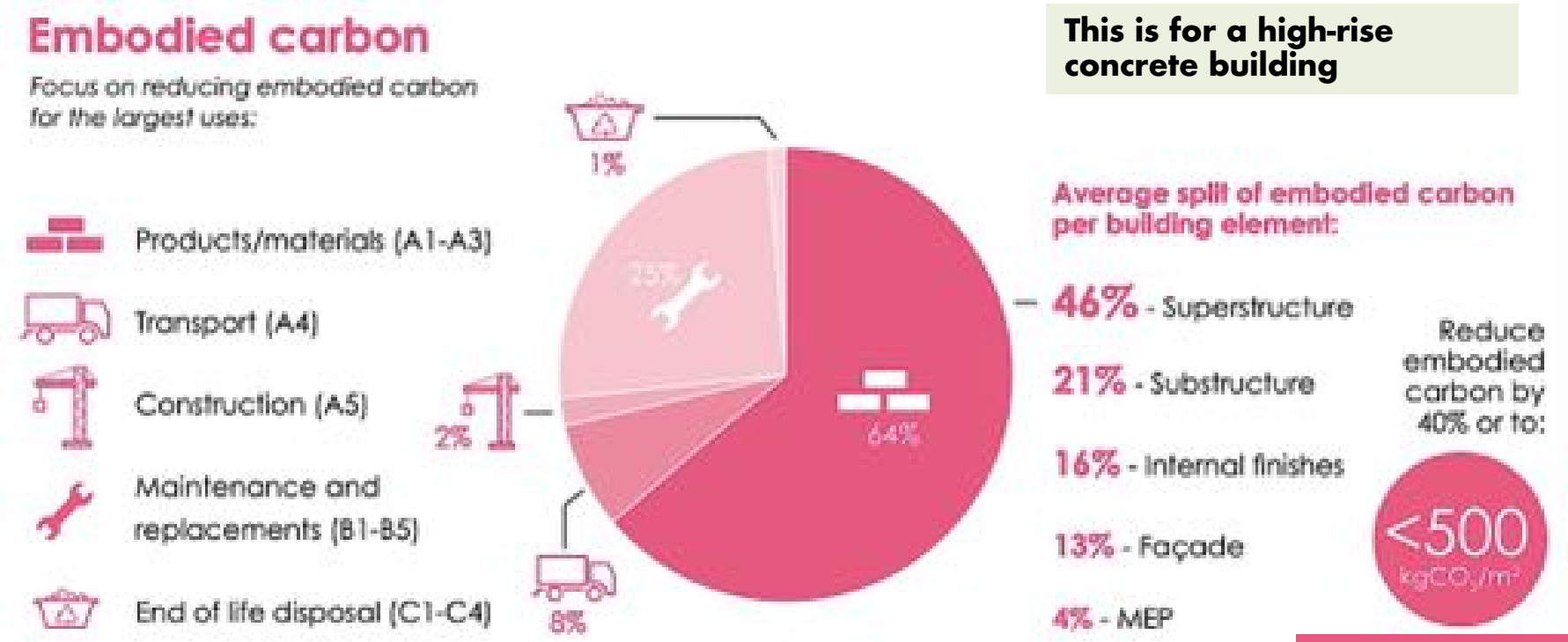
Targets being developed …

Baseline	Best practice 2020	Best practice 2030
800 $kgCO_2/m^2$	<500 $kgCO_2/m^2$	<300 $kgCO_2/m^2$
165 $lbCO_2/ft^2$	**100 $lbCO_2/ft^2$**	**60 $lbCO_2/ft^2$**
Baselines will vary by building type and features. The inclusion of a parkade, for example, would expand the baseline significantly.	Equivalent to **40% reduction** over baseline. **30%** of materials from re-used sources. **50%** of materials can be re-used at end of life.	Equivalent to **65% reduction** over baseline. **50%** of materials from re-used sources. **80%** of materials can be re-used at end of life.

Source: LETI Embodied Carbon Primer & City of Vancouver Zero Emissions Building Plan

Multi-family Embodied CO_2 Example



100 lbCO_2/ft^2

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LETI Climate Emergency Design Guide, leti.com

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Firm, Measurable Operational Targets

- Ambitious BERDO (Boston)
- NYC carbon fines ($268/ton)

BERDO: Building Emissions Reduction and Disclosure Ordinance

BERDO Limits, from the ordinance

Building use	Emissions standard ($kgCO_2e/SF/yr.$)					
	2025 - 2029	2030-2034	2035-2039	2040-2044	2045-2049	2050-
Assembly	7.8	4.6	3.3	2.1	1.1	0
College/ University	10.2	5.3	3.8	2.5	1.2	0
Education	3.9	2.4	1.8	1.2	0.6	0
Food Sales & Service	17.4	10.9	8.0	5.4	2.7	0
Healthcare	15.4	10.0	7.4	4.9	2.4	0
Lodging	5.8	3.7	2.7	1.8	0.9	0
Manufacturing/	23.9	15.3	10.9	6.7	3.2	0
Multifamily housing	4.1	2.4	1.8	1.1	0.6	0
Office	5.3	3.2	2.4	1.6	0.8	0
Retail	7.1	3.4	2.4	1.5	0.7	0
Services	7.5	4.5	3.3	2.2	1.1	0
Storage	5.4	2.8	1.8	1.0	0.4	0
Technology/Science	19.2	11.1	7.8	5.1	2.5	0

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Changing Design Landscape

- A real “step” change… deliver specific performance and confirm it during use
- This requires new design and build process
  - Set quantifiable performance targets (e.g., OPR)
    - True U-value, airtightness, energy use, carbon emissions, embodied carbon
  - Iterate design to achieve target
  - Measure & confirm performance (commissioning)
  - Measure and report (operation)

How does renewable energy fit in?

On-site Generation

- Solar PV Generates electricity with no carbon
  - But … modest embodied carbon & chemicals
- Alas, only power when the sun is shining
  - Need Grid or Batteries, best is both
  - Batteries have significant environmental/economic costs

Ratio of Collector to Floor Area

- ASHRAE "max *technical* potential" energy use
- *Economic* optimum is often lower ratio

	PACIFIC COAST	WARM AND DRY	HOT AND HUMID	WARM AND HUMID	COLD AND DRY	COLD AND HUMID	ARCTIC
Warehouses	0.08	0.08	0.07	0.09	0.10	0.13	0.19
Offices	0.11	0.14	0.15	0.15	0.15	0.18	0.30
Retail	0.18	0.24	0.25	0.25	0.26	0.32	0.67
Schools	0.22	0.28	0.32	0.32	0.31	0.38	0.66
Apartments	0.33	0.40	0.41	0.44	0.47	0.57	0.90

Evolve Building, Waterloo (Net Positive)

- **Entire roof coverage is common in NZE**
- **Sometime more coverage is needed**
- **Consider service access, fire fighter access paths, etc.**

Parking structure

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Cover it all

- Parking structure can feed a “campus”

Source: DOE/NREL

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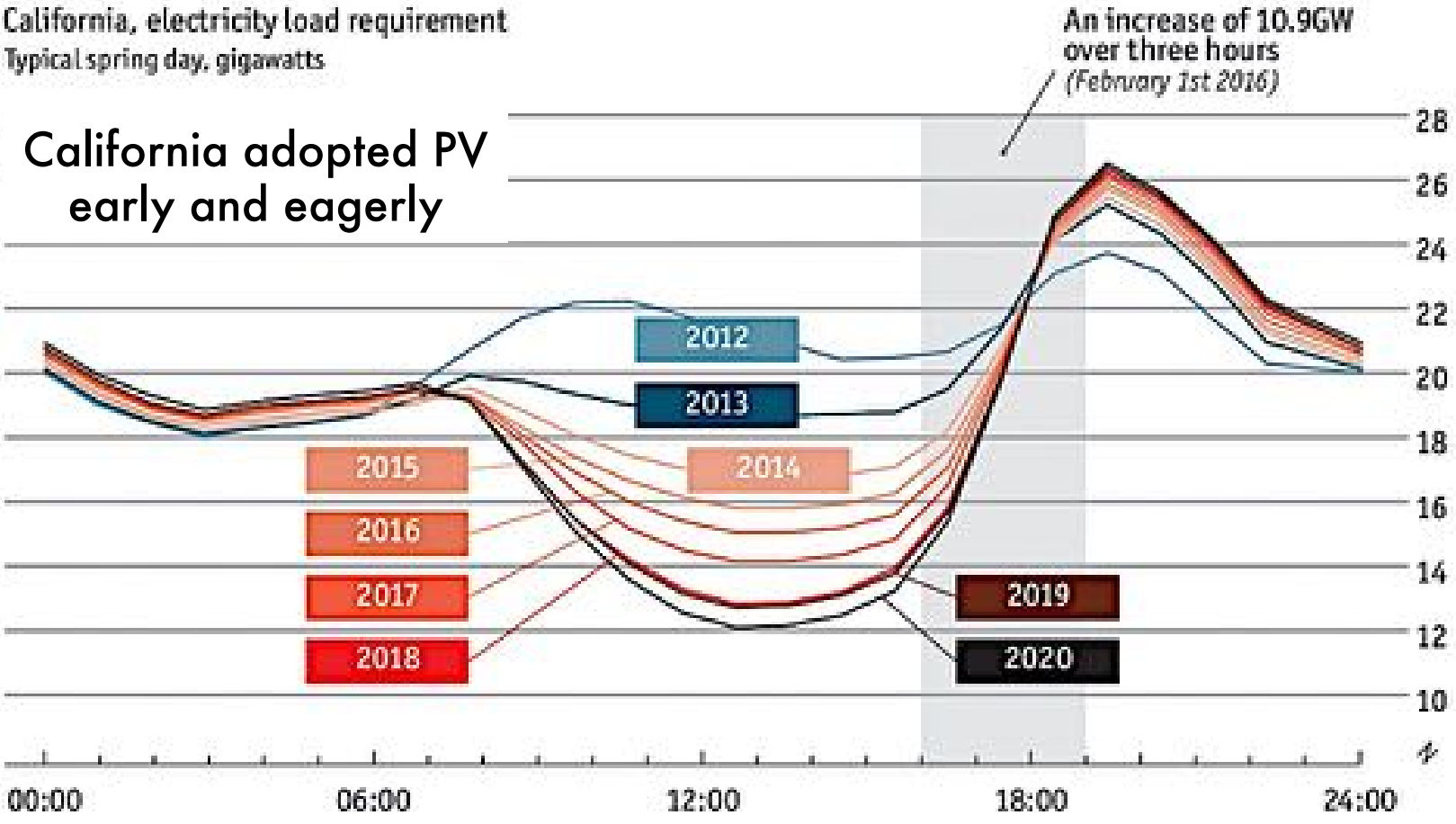
Utilities are increasingly buying in

- 

Who gets the bill?

California, electricity load requirement

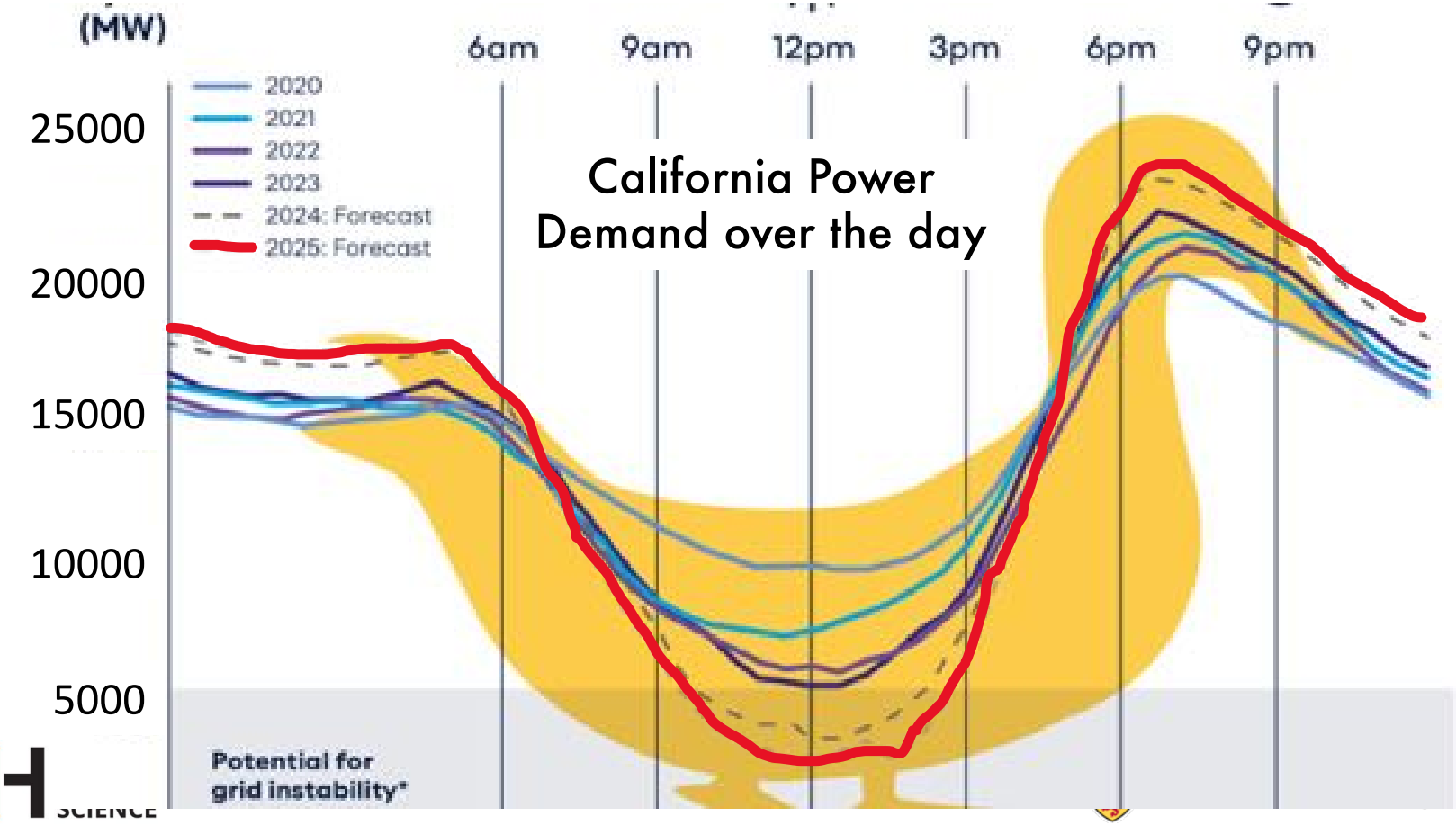
Typical spring day, gigawatts



Source: California ISO

Economist.com

The "Duck" Curve



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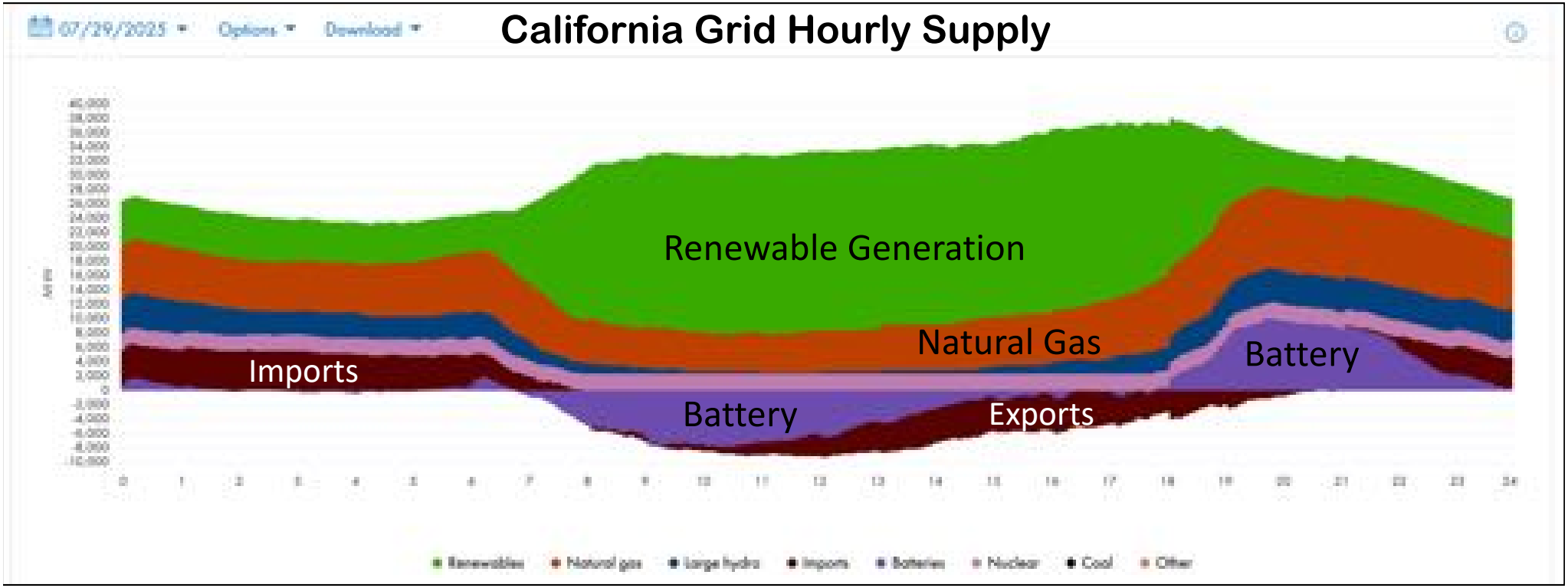
Ducks and Batteries



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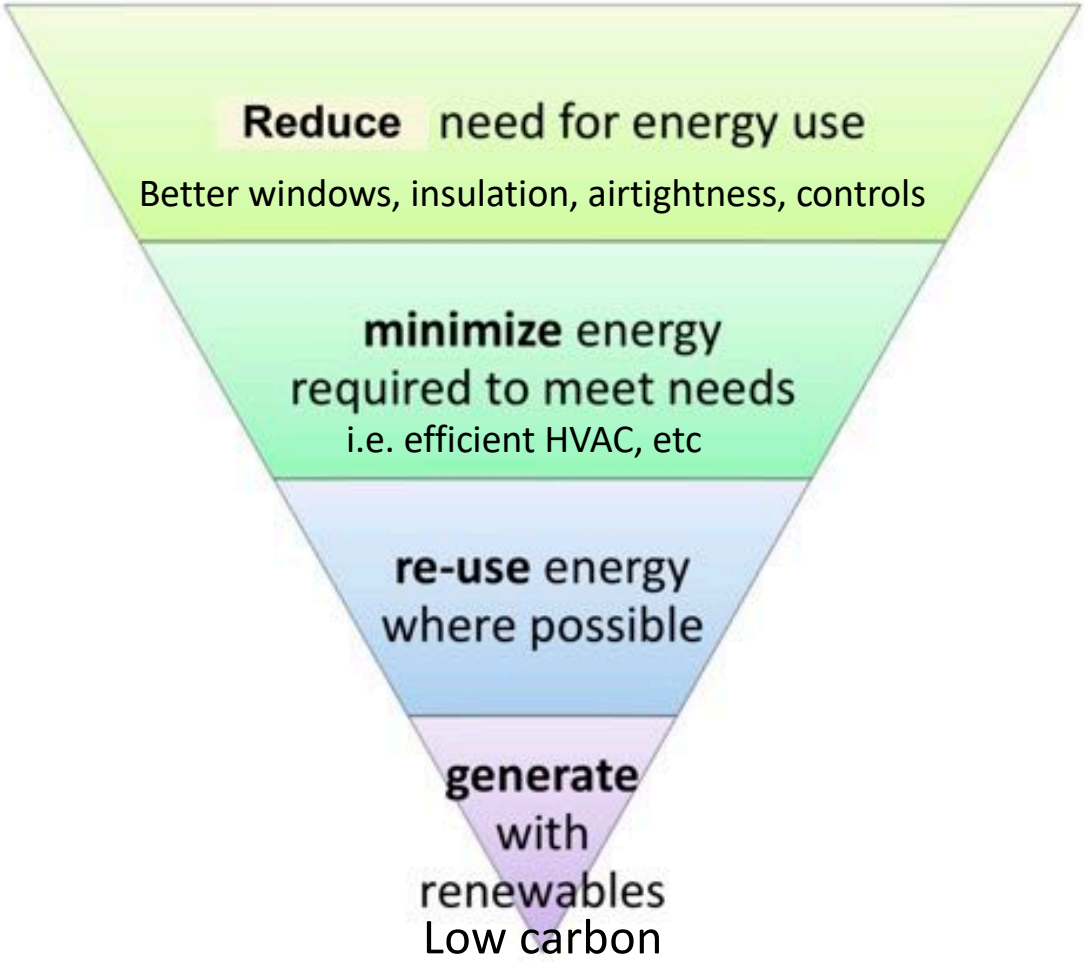
How will this change our industry?

Operational Energy Saving vs Building

New Build



Retrofit

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How to reduce embodied carbon

1. Don't build ☺
   - Renovate, plan smarter
2. Build smaller
3. Build simpler
4. Use materials and products efficiently
5. Use materials and products with lower carbon

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Summary

- Low embodied-carbon buildings are the future of the industry – but this may take along time
- Much work remains to reduce energy consumption, decarbonize the grid

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