NESEA BuildingEnergy NYC

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Calculating the carbon content of commercial construction

Carbon Counts!

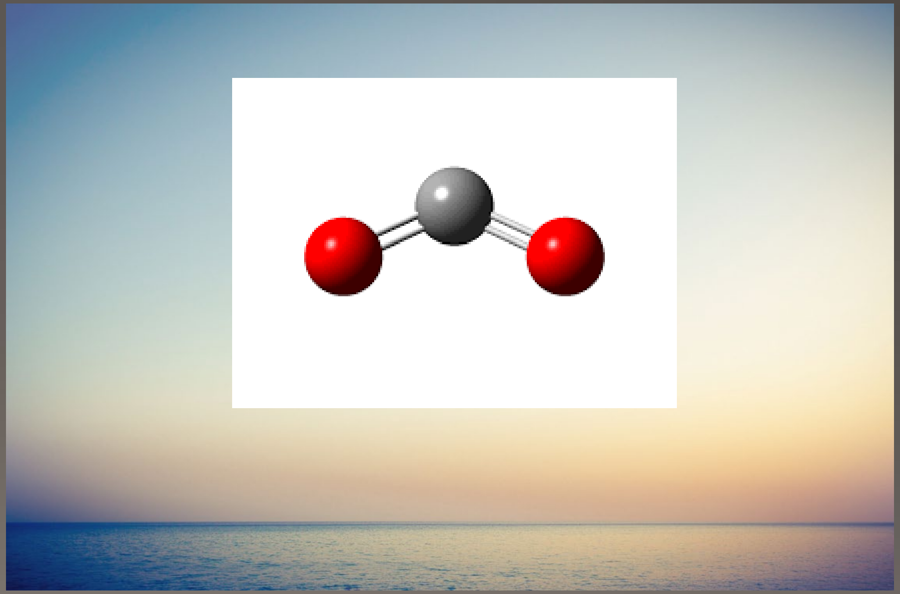
Abstract

- How much carbon dioxide is released into the atmosphere as a result of your new construction project?
- Is it more or less than the emissions from an average project?
- What can you do, at little or no cost to your project, to reduce this carbon bloom?

With the advent of Environmental Product Declarations (EPD’s) for most conventional construction materials, it’s now possible to calculate the approximate tons of CO_2e emitted from the construction of our buildings. This is done using a "carbon pallet" tool developed by the presenter, which will be demonstrated and shared with attendees. We'll see how design changes impact the carbon tally and examine how "biogenic carbon" can reduce net carbon emissions – or even make a building carbon negative.

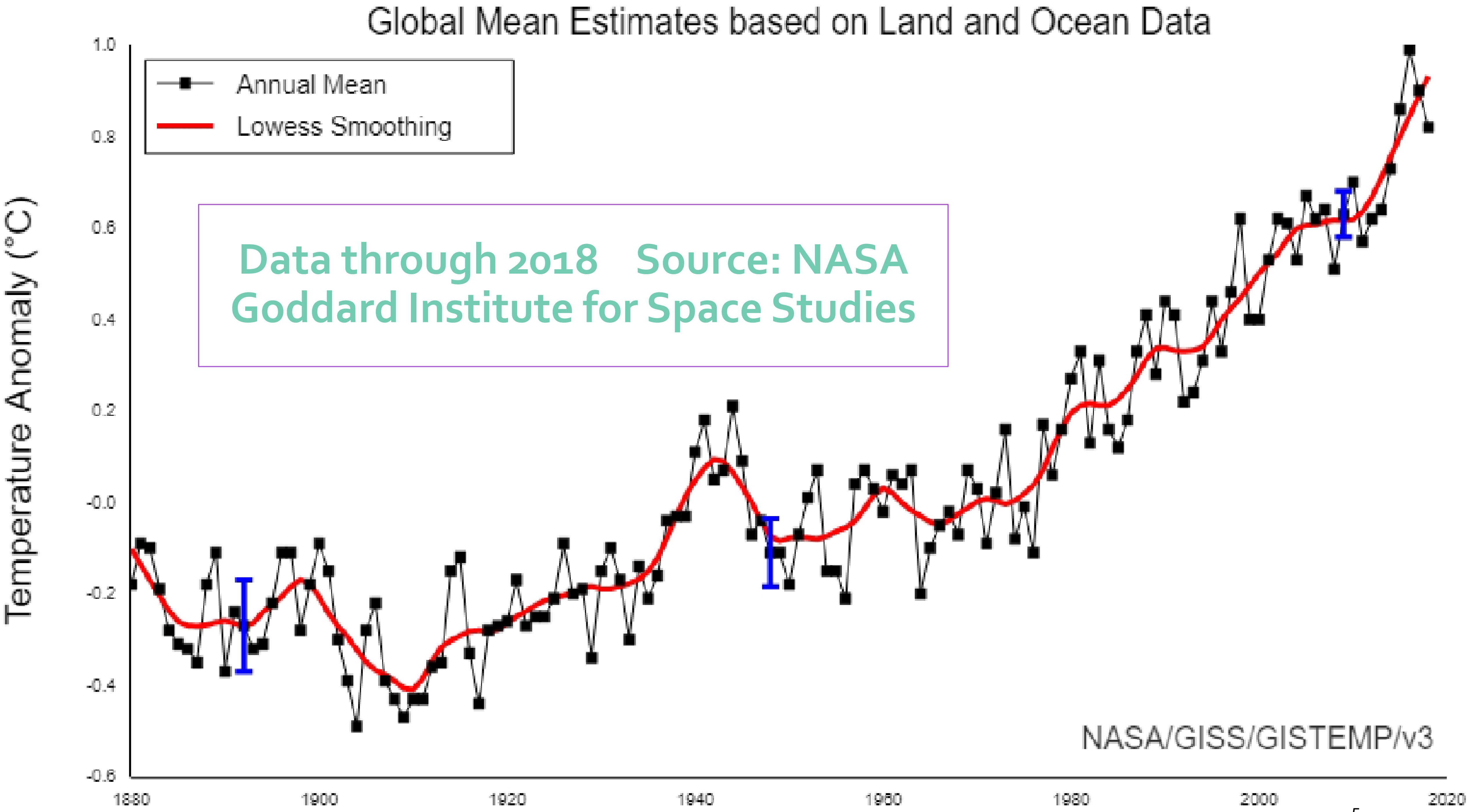
Agenda

- The Big Picture
- LCAs, PCRs and EPDs
- Structural Carbon Pallet
- Example Building
- Advanced Ideas
- Questions



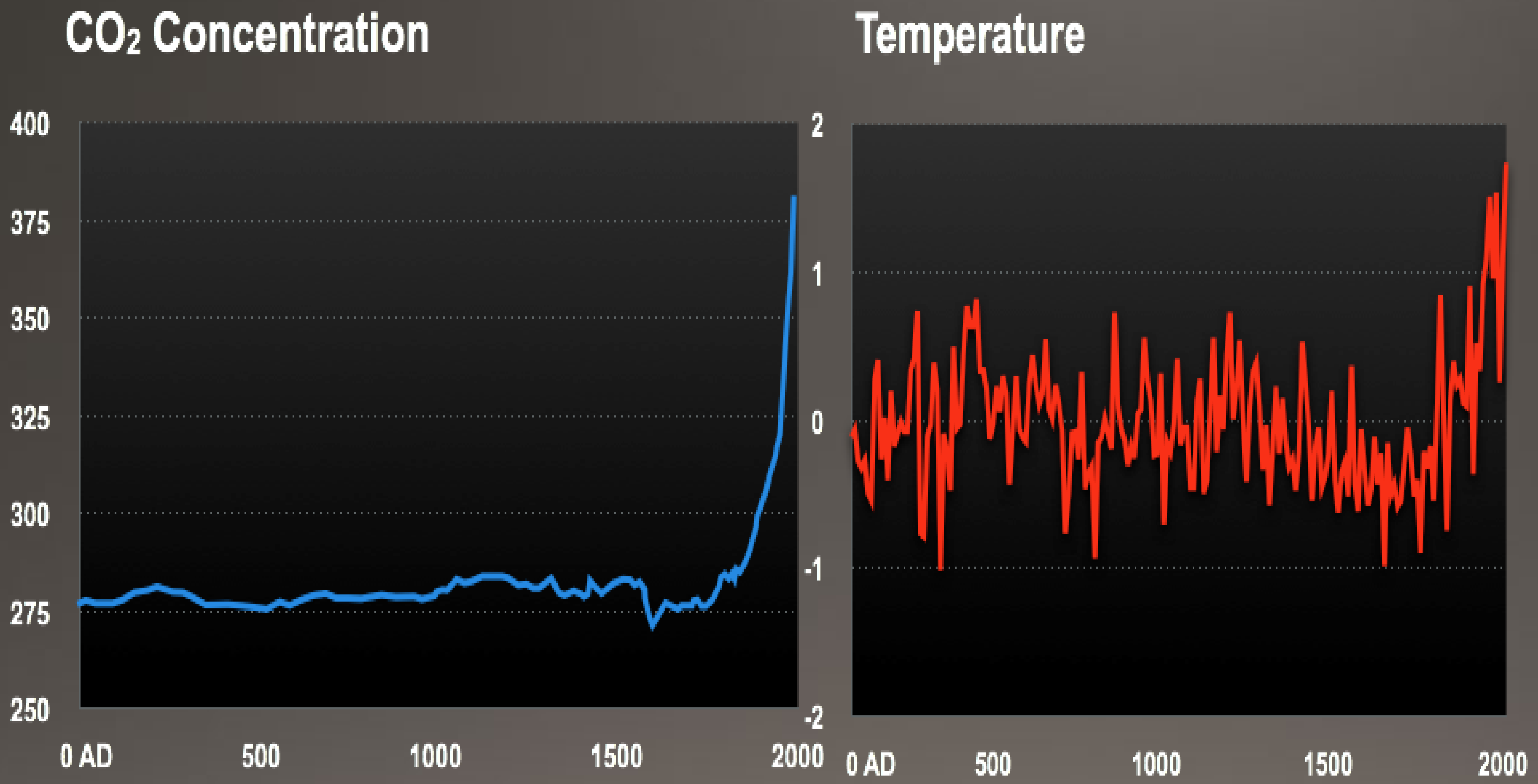
Carbon Counts!
Calculating the carbon content of commercial construction

The Big Picture



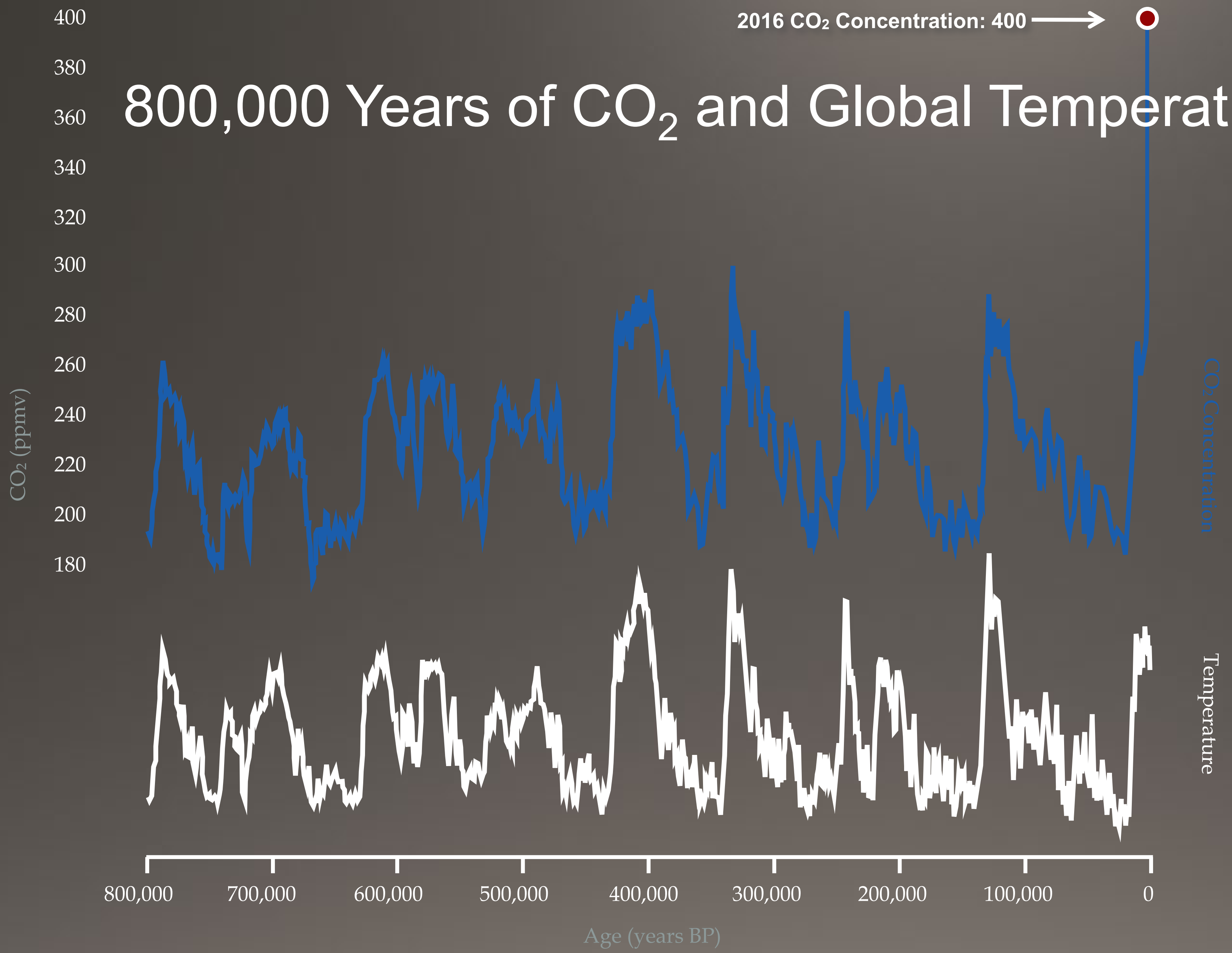
Global Mean Estimates based on Land and Ocean Data
Annual Mean
Lowess Smoothing
Data through 2018 Source: NASA Goddard Institute for Space Studies
Temperature Anomaly (°C)
1.0
0.8
0.6
0.4
0.2
-0.0
-0.2
-0.4
-0.6
1880
1900
1920
1940
1960
1980
2000
2020
NASA/GISS/GISTEMP/v3

2000 Years of CO_2 and Global Temperature



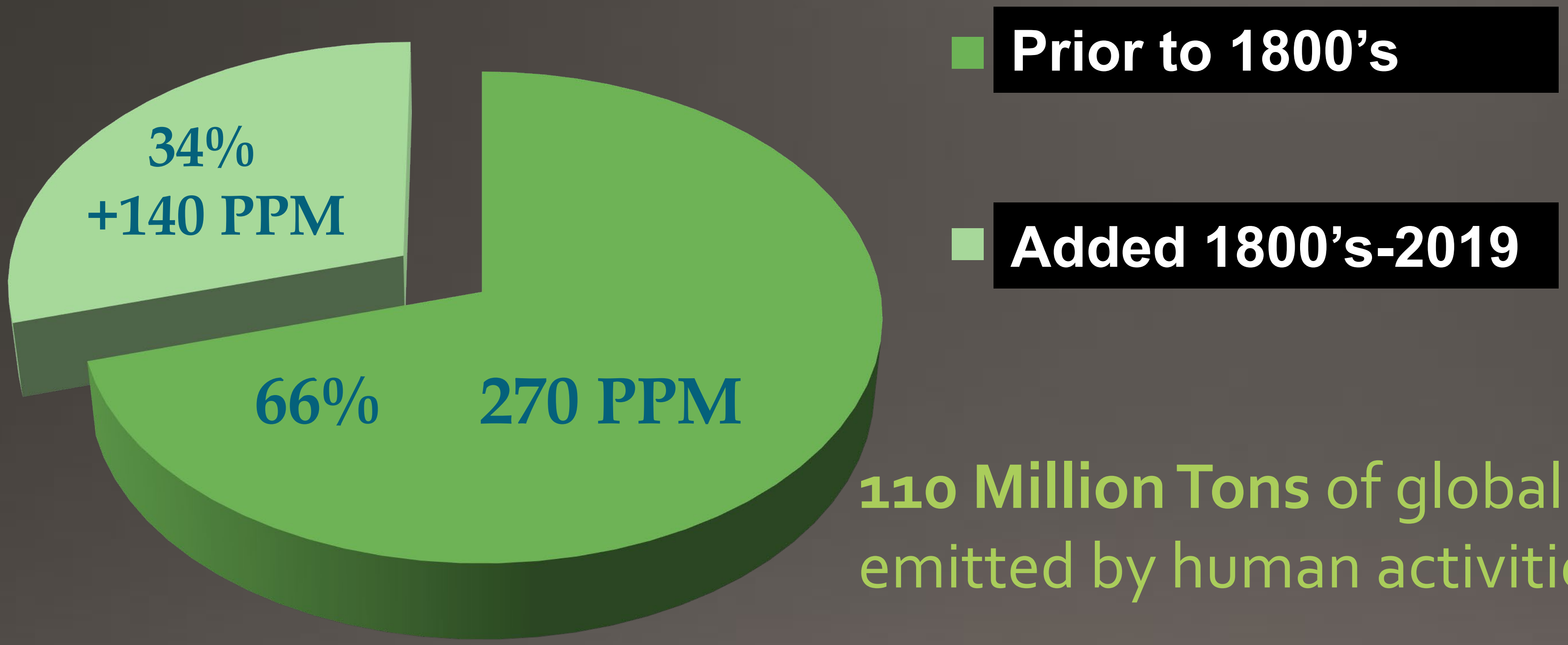
Source: (Temperature) Thompson, et al., Abrupt Tropical Climate Change: Past and Present, *Proc. Natl. Acad. Sci. USA,* vol. 103, no. 28 (CO_2) Australian Academy of Science; Etheridge, et al. (2006), Law Dome CO_2, CH_4 and N_2O ice core records extended to 2000 years BP, *Geophysical Research Letters* 33

800,000 Years of CO_2 and Global Temperature



Source: National Climatic Data Center, NOAA

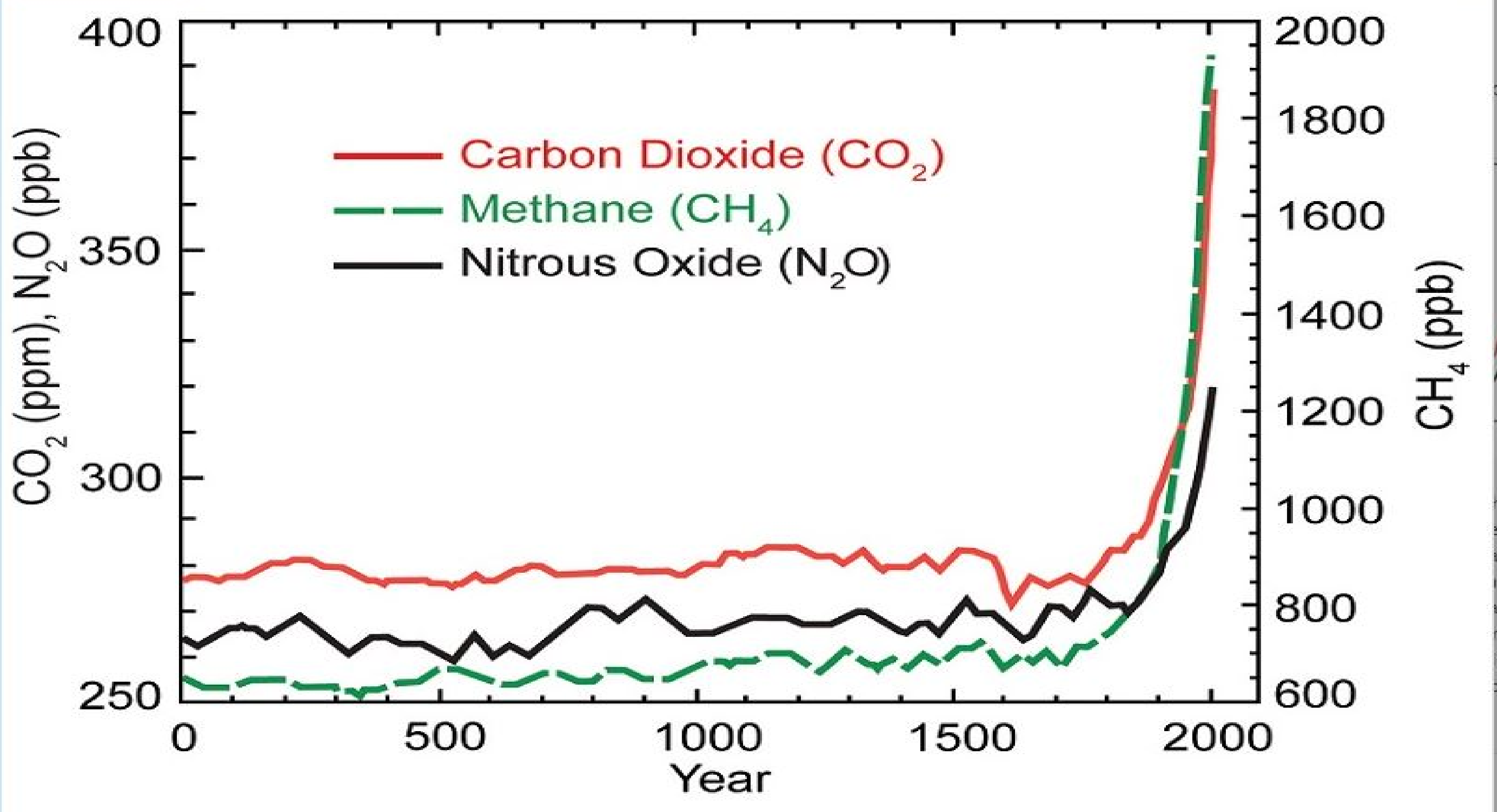
CO_2 Increase Since 1800's



110 Million Tons of global warming gases emitted by human activities every day

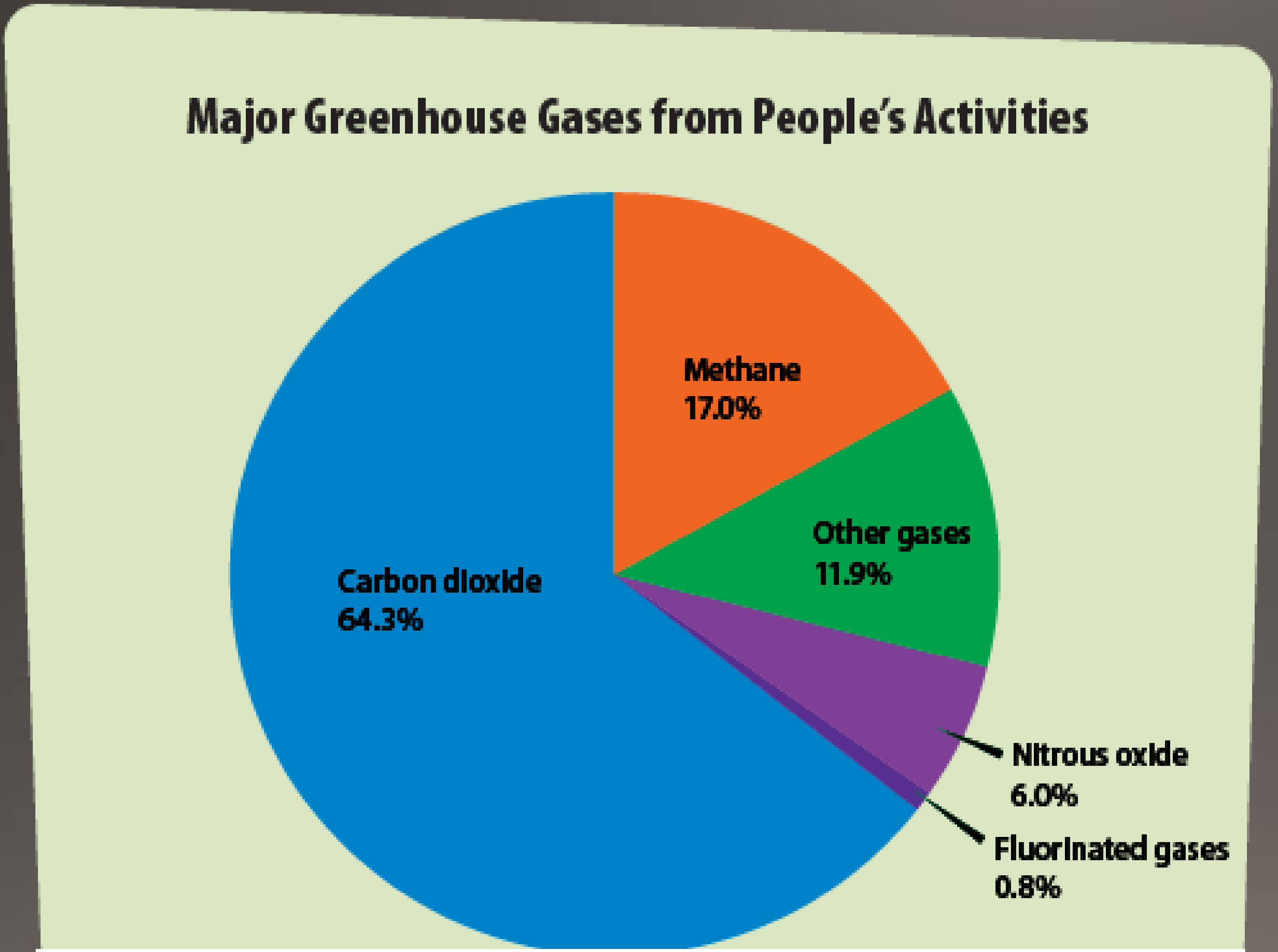
270 ppm to 410 ppm = 52% increase in CO_2

Atmospheric CO_2eq



This graph shows the increase in greenhouse gas (GHG) concentrations in the atmosphere over the last 2,000 years. Increases in concentrations of these gases since 1750 are due to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion molecules of air.

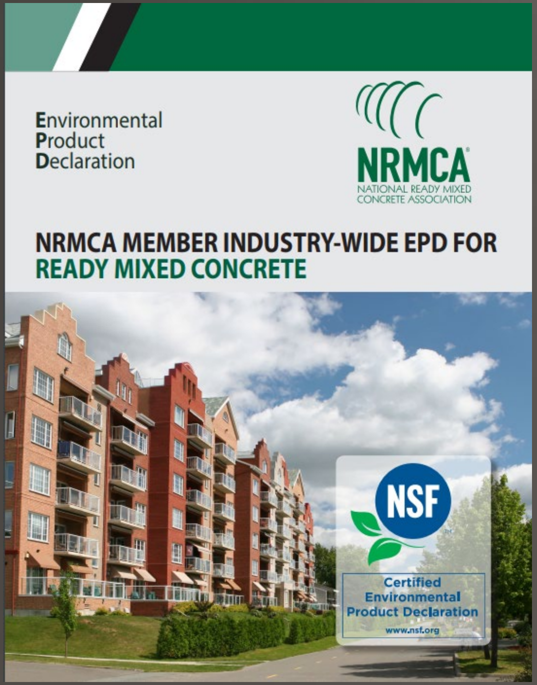
US - GWP Gas Emissions 2014



https://archive.epa.gov/climatechange/kids/basics/today/greenhouse-gases.html

Climate Leadership and Community Protection Act

- Requires the state to cut **60%** of its statewide carbon emissions (from 1990 levels) by **2030** (or a 40% reduction) and **15%** by **2050** (or an 85% reduction) with that remaining 15% from carbon credits.
- NYS is required to produce **70%** of its electricity production from renewable sources by **2030**.
- Carbon emissions in the electricity sector are to be eliminated by **2040**.
- A 22-member climate council made of state agency representatives is charged with ensuring it happens.
- At least **35%** of funds from the state's clean energy program are to go toward disadvantaged communities which will be identified by the Department of Environmental Conservation.
- See www.nyrenews.org/what-we-do/



Carbon Counts!
Calculating the carbon content of commercial construction

LCAs, PCRs, EPDs

Confusing Terms

- Embodied Energy
- Embodied Carbon
- Carbon Sequestration

- **Carbon Footprint**
- **CO_2eq or CO_2eq_{100}**
- **Biogenic Carbon**
- **LCAs, PCRs, EPDs**

Definitions

- LCA – Life Cycle Assessment
- PCR – Product Category Rules
- EPD – Environmental Product Declaration

- CO_2eq_{100}

The global warming potential (GWP) of different greenhouse gases over a 100-year period, a.k.a. CDE100

Life Cycle Assessment (LCA) Ranges

- Cradle-to-Gate (fab shop, lumber yard, batch plant)
- Cradle-to-Service (incl. shipping, constr., waste)
- Cradle-to-Grave
- Cradle-to-Cradle

Product Stage			Construction Stage		Use Stage					End-of-Life Stage				Benefits & Loads
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
			EXCLUDED FROM THIS STUDY											
Raw materials supply	Transport	Manufacturing	Transport	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	De-construction	Transport	Waste processing	Disposal	Reuse, recovery, recycling potential

	CARBON PALLET	Pounds of CO_2eq emitted per pound of building material					
	Jim D'Alaisia jad@khhpc.com	Updated	6-Jul-2019				
	CARBON PALLET - STRUCTURAL MATERIALS						
			Cradle-to-Ga	Cradle-to-Finished-Buildin			
	MATERIAL	lbs./c.f	lbs. CO_2eq/lb	aste Es	nstr. Es	lbs. CO_2eq/lb	URL Reference, or Notes
Division 3	Concrete with 500 lbs/CY Portland ceme	145	0.13	5%	5%	0.14	www.nrmca.org/sustainability/EPDProgram/
	Concrete with 400 lbs/CY Portland ceme	145	0.10	5%	5%	0.11	www.nrmca.org/sustainability/EPDProgram/
	Concrete with 300 lbs/CY Portland ceme	145	0.08	5%	5%	0.09	www.nrmca.org/sustainability/EPDProgram/
	Grade 60 Reinforcing Bars	495	0.85	5%	5%	0.94	www.astm.org/CERTIFICATION/DOCS/253.EPD_for_Concrete_Reinforcing_Steel.pdf
Division 4	CMU: 8" thick	55	0.10	5%	5%	0.11	Assumed similar to concrete with 400 lbs. of cement per cubic yard. Only EPD is from individual manufacturers like Angel Block
	CMU: 10" thick	65	0.10	5%	5%	0.11	
	Cementitious grout	145	0.16	5%	5%	0.18	Assumed similar to concrete with 650 lbs. of cement per cubic yard (proportion-based spec)
Division 5	Structural steel - Wide Flange sections	495	1.16	5%	5%	1.28	https://www.aisc.org/globalassets/why-steel/102.1_aisc_epd_-fab-sections_20160331.pdf
	Structural steel - Fabricated steel plate	495	1.47	5%	5%	1.62	https://www.aisc.org/globalassets/why-steel/101.1_aisc_epd_-fab-plate-20160331.pdf
	Steel - HSS (avg)	495	1.76	5%	5%	1.94	www.aisc.org/epd
	Steel - avg. bldg project (from above 3 li	495	1.25	5%	5%	1.38	
	Open-Web Steel Joists	495	1.38	5%	5%	1.52	https://steeljoist.org/resources/environmental-product-declarations/
	Cold-formed steel studs & track	495	2.30	5%	5%	2.53	https://www.steelsustainability.org/-/media/files/steelsustainability/scs-epd-03838_sri_cfs-stud-track_011916-print-version.ashx?la=en&hash=DB01394EC64AB05C27278F1742457D6D8843C25A
	Steel Roof and Floor Deck	495	2.37	5%	5%	2.61	https://www.sdi.org/wp-content/uploads/2016/10/101.1_SDI_-EPD_Steel-Roof-and-Floor-Deck_20151215.pdf
Division 6	WOOD - ASSUMING NO BIOGENIC CARBON						
	Softwood Lumber 19% moisture content	32	0.14	10%	10%	0.17	https://awc.org/pdf/greenbuilding/epd/AWC-EPD-SoftwoodLumber-190328.pdf
	Softwood Plywood 19% m.c.	36	0.23	10%	10%	0.28	https://awc.org/pdf/greenbuilding/epd/AWC-EPD-SoftwoodPlywood-190328.pdf
	Oriented Strand Board (OSB) 19% m.c.	44	0.35	10%	10%	0.42	https://awc.org/pdf/greenbuilding/epd/AWC-EPD-OSB-190328.pdf
	Glued-Laminated Timber 19% m.c.	39	0.32	10%	5%	0.37	https://awc.org/pdf/greenbuilding/epd/AWC-EPD-Glulam-190328.pdf
	Wood I-Joists 19% m.c.	38	0.48	5%	5%	0.53	https://awc.org/pdf/greenbuilding/epd/AWC-EPD-IJoists-190328.pdf
	Nordic X-Lam CLT 19% m.c.	31	0.25	5%	5%	0.28	https://fpinnovations.ca/ResearchProgram/environment-sustainability/epd-program/Documents/environmental-product-declaration-nordic-x-lam.pdf
Division 6	WOOD - INCLUDING BIOGENIC CARBON, REDUCED FOR END-OF-SERVICE LIFE						
	Softwood Lumber 19% moisture content	32	(0.94)	10%	10%	(0.77)	https://awc.org/pdf/greenbuilding/epd/AWC-EPD-SoftwoodLumber-190328.pdf
	Softwood Plywood 19% m.c.	36	(0.88)	10%	10%	(0.60)	https://awc.org/pdf/greenbuilding/epd/AWC-EPD-SoftwoodPlywood-190328.pdf
	Oriented Strand Board (OSB) 19% m.c.	44	(0.97)	10%	10%	(0.55)	https://awc.org/pdf/greenbuilding/epd/AWC-EPD-OSB-190328.pdf
	Glued-Laminated Timber 19% m.c.	39	(1.09)	10%	5%	(0.72)	https://awc.org/pdf/greenbuilding/epd/AWC-EPD-Glulam-190328.pdf
	Wood I-Joists 19% m.c.	38	(1.06)	5%	5%	(0.53)	https://awc.org/pdf/greenbuilding/epd/AWC-EPD-IJoists-190328.pdf
	Nordic X-Lam CLT 19% m.c.	31	(0.94)	5%	5%	(0.67)	https://fpinnovations.ca/ResearchProgram/environment-sustainability/epd-program/Documents/environmental-product-declaration-nordic-x-lam.pdf
Other	Straw bale	7.0	0.01	5%	5%	0.01	
	Baling wire/ties	495	2.83	5%	5%	3.11	
	Cement plaster stucco	60	0.25	5%	5%	0.28	
	Brick	137	0.16	5%	5%	0.17	
	Fiberglass Batt	1.0	1.40	5%	5%	1.54	
	Mineral Fiber	4.0	1.20	5%	5%	1.32	
	EPS	1.0	2.90	5%	5%	3.19	
	XPS	2.0	120.00	5%	5%	132.00	
	Owens Corning Foamular 250 XPS	1.6	84.70	5%	5%	93.17	http://www.owenscorning.com/NetworkShare/EIS/10018927%20EPD%20-%20FOAMULAR%20Insulation.pdf
	Polyisocyanurate	2.2	3.30	5%	5%	3.63	
	Closed-Cell HFC-blown polyurethane	2.0	120.00	5%	5%	132.00	
	3/4" Composite Siding	120	0.85	5%	5%	0.94	
	5/8" Gypsum Sheathing	42	0.12	5%	5%	0.13	

NOTES

Unreferenced lines are older data without documented sources or calculations

Calculations by J. D'Alaisia based on EPD data.

5% waste and 5% construction are placeholders only. Better to include something than to completely ignore these emissions. No industry-wide data is yet available. Also, these amounts vary between projects.

1 cubic yard of concrete weighs aprox.	3900	lbs.
1 cubic foot of steel weighs approx.	503	lbs.
Density of steel is 0.291 lbs./cubic inch		

Carbon Counts!
Calculating the carbon content of commercial construction

Structural Carbon Pallet

Gasoline a.k.a. Petrol a.k.a. Motor Spirit

- Weighs 6.30 lbs./gallon
- Combustion of 1 gallon produces about 20 lbs. of CO_2 !

  $2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$ (octane)

  $C + O_2 \rightarrow CO_2$

  $12 + (2)(16) = 44$

- "Cradle-to-gate" 1 gallon → 5 lbs. CO_2
- Combustion 1 gallon → <u>20 lbs. CO_2</u>
- "Well to wheel" 1 gallon → **25 lbs. CO_2** **<u>4X its weight</u>**

Jobsite Emissions

Gasoline – 25 lbs. CO_2 /gallon ("well to wheel")

Hypothetical Labor Situation

12 workers, driving
12 trucks that get
12 mpg,
12 miles to and from jobsite, for
12 weeks….

12 · 25 lbs. CO_2/g/12 mi./g · 12 mi. · 12 · 5 =

18,000 lbs. CO_2

CO_2e of Portland Cement

Production of Portland cement accounts for 6 to 8%* of the worldwide **anthropogenic** CO_2

- About half is a byproduct of the chemical reaction
- About half is produced by heating - 2,700 ⁰F

1 ton of Portland cement produces just under 1 ton of CO_2

Global production of Portland cement is 5% per year

200,000 metric tonnes of CO_2 emitted by producers every hour

Portland cement plant in Alpena, MI

* - the actual percentage is subject to debate

Carbon Pallet - Concrete

- NRMCA EPD's updated Oct. 2016 cradle-to-gate
  - http://www.nrmca.org/sustainability/EPDProgram/
  - Approximations
    - 1.0 lb. CO_2 for every 1 lb. of Portland cement in mix *
    - 0.1 lb. CO_2 for every 1 lb. of concrete placed *
  - Varies from about 350 to 800 lbs. per cubic yard *

* - Not including delivery to jobsite, placement, forms, waste, end-of-life impacts.

Carbon Pallet – Steel

www.asce.org/epd

- AISC EPD's – May 2016 – Cradle to Gate
  - Hot rolled sections – 1.16 lbs./lb. *
  - Hollow structural sections– 1.76 lbs./lb. *
  - Steel plate – 1.47 lbs./lb. *
- **Estimate 1.5 lbs./lb. structural steel**
- Sheet metal – 2.37 lbs./lb. *

* - Not including delivery to jobsite, erection, scaffolding, waste, and end-of-life impacts.

Wood – Greenhouse Gas Emissions

- Sourcing is highly variable
  - Transportation of forest products
  - Management of forest
- Complexity of natural carbon cycle
- Include footprint of construction waste?
- Value of wood's sequestration of carbon in a long-lived and durable building?

http://owic.oregonstate.edu

Carbon Pallet - Wood

- AWC EPD’s – Apr 2013 – Cradle to Gate
  - http://awc.org/greenbuilding/epd
  - Softwood Lumber – 0.15 lbs. CO_2e/lb. wood *

* - Not including delivery to jobsite, erection, scaffolding, waste, sequestration, end-of-life impacts.

CARBON PALLET - STRUCTURAL MATERIALS					
		Cradle-to-Gate	Cradle-to-Finished-Building		
MATERIAL	**lbs./c.f.**	**lbs. CO_2eq/lb.**	**Waste Est.**	**Constr. Est.**	**lbs. CO_2eq/lb.**
Concrete with 500 lbs/CY Portland cement	145	0.13	5%	5%	0.14
Concrete with 400 lbs/CY Portland cement	145	0.10	5%	5%	0.11
Concrete with 300 lbs/CY Portland cement	145	0.08	5%	5%	0.09
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Steel - avg. bldg project (from above 3 lines)	495	1.25	5%	5%	1.38
Open-Web Steel Joists	495	1.38	5%	5%	1.52
Cold-formed steel framing	495	2.30	5%	5%	2.53
Steel Roof and Floor Deck	495	2.37	5%	5%	2.61

CARBON PALLET - STRUCTURAL MATERIALS					
		Cradle-to-Gate	Cradle-to-Finished-Building		
MATERIAL	lbs./c.f.	lbs. CO_2eq/lb.	Waste Est.	Constr. Est.	lbs. CO_2eq/lb.
WOOD - ASSUMING NO BIOGENIC CARBON					
Softwood Lumber 19% moisture content	32	0.14	10%	10%	0.17
Softwood Plywood 19% m.c.	36	0.23	10%	10%	0.28
Oriented Strand Board (OSB) 19% m.c.	44	0.35	10%	10%	0.42
Glued-Laminated Timber 19% m.c.	39	0.32	10%	5%	0.37
Wood I-Joists 19% m.c.	38	0.48	5%	5%	0.53
Nordic X-Lam CLT 19% m.c.	31	0.25	5%	5%	0.28
WOOD - INCLUDING BIOGENIC CARBON, REDUCED FOR END-OF-SERVICE LIFE					
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Softwood Plywood 19% m.c.	36	(0.88)	10%	10%	(0.60)
Oriented Strand Board (OSB) 19% m.c.	44	(0.97)	10%	10%	(0.55)
Glued-Laminated Timber 19% m.c.	39	(1.09)	10%	5%	(0.72)
Wood I-Joists 19% m.c.	38	(1.06)	5%	5%	(0.53)
Nordic X-Lam CLT 19% m.c.	31	(0.94)	5%	5%	(0.67)

CO_2eq's of Other Materials & Systems

- Exteriors: bricks, rainscreen panels
- Interiors: finishes and furnishings
- Fenestration
- Insulation
- MEP, FP equipment, elevators, process equipment, etc.
- Sitework: asphalt, concrete, grading
- Construction equipment & services
- Design-phase emissions
- ....and Operations

Insulation Material	R-value R/inch	Density lb/ft³	Emb. E MJ/kg	Emb. Carbon $kgCO_2/kg$	Emb. Carbon $kgCO_2/ft^2 \cdot R$	Blowing Agent (GWP)	Bl. Agent kg/kg foam	Blowing Agent GWP/ bd-ft	Lifetime GWP/ $ft^2 \cdot R$
Cellulose (dense-pack)	3.7	3.0	2.1	0.106	0.0033	None	0	N/A	0.0033
Fiberglass batt	3.3	1.0	28	1.44	0.0165	None	0	N/A	0.0165
Rigid mineral wool	4.0	4.0	17	1.2	0.0455	None	0	N/A	0.0455
Polyisocyanurate	6.0	1.5	72	3.0	0.0284	Pentane (GWP=7)	0.05	0.02	0.0317
Spray polyurethane foam (SPF) – closed-cell (HFC-blown)	6.0	2.0	72	3.0	0.0379	HFC-245fa (GWP=1,030)	0.11	8.68	1.48
SPF – closed-cell (water-blown)	5.0	2.0	72	3.0	0.0455	Water (CO_2) (GWP=1)	0	0	0.0455
SPF – open-cell (water-blown)	3.7	0.5	72	3.0	0.0154	Water (CO_2) (GWP=1)	0	0	0.0154
Expanded polystyrene (EPS)	3.9	1.0	89	2.5	0.0307	Pentane (GWP=7)	0.06	0.02	0.036
Extruded polystyrene (XPS)	5.0	2.0	89	2.5	0.0379	HFC-134a[1] (GWP=1,430)	0.08	8.67	1.77

1. XPS manufacturers have not divulged their post-HCFC blowing agent, and MSDS data have not been updated. The blowing agent is assumed here to be HFC-134a.

GWP of Insulation Types

New options: GPS rigid insulation and rigid-board phenolic foam!

Source: BuildingGreen

XPS and Global Warming

As of 2018 most Extruded Polystyrene (**XPS**) produced in the U.S. uses HFC 134a as a blowing agent. This gas has a GWP rating (over 100 years) of **1,430** - it has 1,430 times more global warming potency than CO_2. The gas never breaks down, remaining active in the atmosphere for thousands of years.

The EPA has drafted a policy curtailing its use, but its adoption is on hold. Alternates to this blowing agent are available, and used in the EU, but they are more expensive.

Carbon Counts!
Calculating the carbon content of commercial construction

Example Building

100,000 sf, 10-Story Mixed-Use Building
Conventional Construction – structure only

- 20 ga. steel roof deck
- Open-web steel roof joists
- Structural steel framing w/concrete shear walls
- Composite steel deck floors
- Cold-formed steel wall studs
- 5″ conc. 1st floor slab on grade
- Strip footings + foundation walls
- Interior spread footings

100,000 sf, 10-Story Mixed-Use Building

Conventional Construction – structure only`

MATERIAL							lbs. CO2eq/lb.	lbs. CO2eq	
20 ga. steel roof decking	10,000	sf	2.2	psf	22,000	lbs.	2.61	57,420	
Open-web steel roof joists	10,000	sf	2.7	psf	27,000	lbs.	1.52	41,040	
Structural steel framing (incl. shear conn's)	100,000	sf	8.7	psf	870,000	lbs.	1.38	1,200,600	
Composite steel floor decking	90,000	sf	2.3	psf	207,000	lbs.	2.61	540,270	
Cold-formed steel wall studs	150,000	sf	0.4	psf	60,000	lbs.	2.53	151,800	
Shear walls, 80 lf, 12"t, 4000 psi	9,600	sf	356	cy	1,386,667	lbs.	0.14	194,133	
2-10th fl. conc - 3.5" eff. t, 4000 psi	90,000	sf	972	cy	3,791,667	lbs.	0.14	530,833	
1st floor conc slab - 5" 4000 psi	10,000	sf	154	cy	601,852	lbs.	0.14	84,259	
Strip ftgs, fd'n walls, 4000 psi	2,704	sf	160	cy	623,362	lbs.	0.14	87,271	
Int. ft'gs, piers 12 x 8'x8'x18", 4000 psi	768		51	cy	199,680	lbs.	0.14	27,955	
Steel rebar, assume 0.7% conc vol.	2.6	cy	69	cf	34,733	lbs.	0.94	32,649	
								2,948,231	lbs. CO2
								29.48	psf

Incremental Improvements

- Reduction of steel roof deck gage
- Optimized structural steel framing
- Supplemental Cementitious Materials (SCM) – cement redux
- Reduced concrete strength – Portland cement redux
- Frost-protected shallow foundations (FPSF)
- Wood wall studs

100,000 sf, 10-Story Mixed-Use Building

Incremental Improvements – structure only

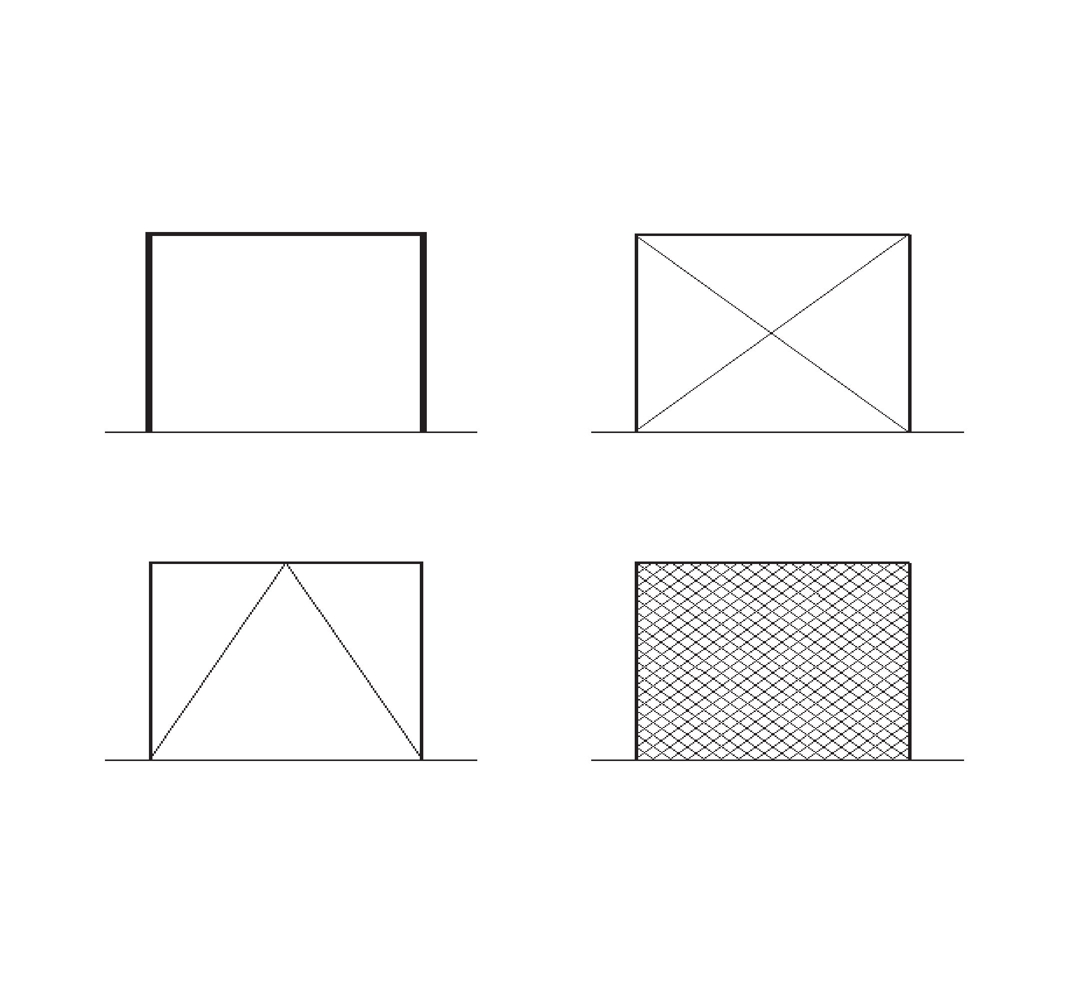
- 20 ga. steel roof deck → 22 ga. steel roof deck
- Open-web steel roof joists
- Structural steel framing → 10% material optimized
- 2nd floor composite steel deck → 20% SCM, cement redux
- Cold-formed steel wall studs → Wood wall studs
- 5″ conc. 1st. floor slab on grade → 4″, 20% SCM, cement redux
- Strip footings + foundation walls → FPSF, 20% SCM, cem. redux
- Interior spread footings → 20% SCM, cement redux

Steel Lateral Bracing Systems

Steel Moment Frames require more steel material per service unit than braced frames.

Braced frames can be designed in a variety of configurations.

Consider Hybrid Masonry/Steel Frames.



Supplementary Cementitious Materials (SCMs)

- Fly Ash
  - Byproduct of coal-fired electric and steam generating plants
  - Type C and Type F - both used for concrete
  - 15 - 25% cement replacement, typical
- Ground Granulated Blast-Furnace Slag (GGBFS)
  - Co-generated during the refinement of iron from iron ore
  - Must be ground to cement-grain fineness
  - Effect on concrete is similar to Fly Ash
  - 25 - 50% cement replacement, typical

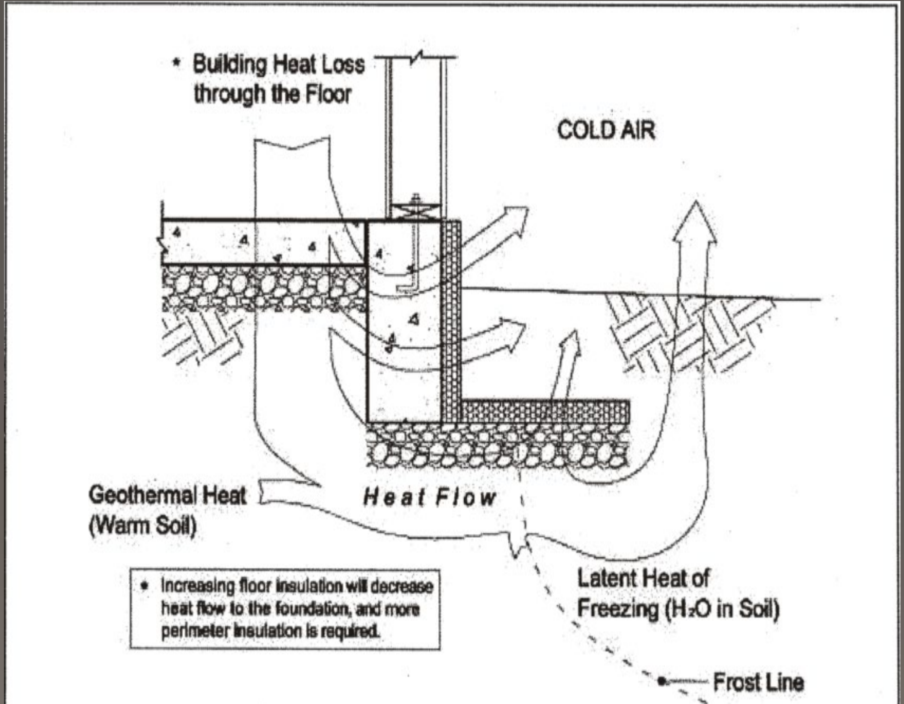
Others
- Silica Fume
- Rice Hull
- Ground Glass
- More

Fly Ash Types C or F

- The use of fly ash in concrete:
  - Reduces permeability
  - Slightly delays strength gain
  - Slightly reduces shrinkage
  - Reduces heat of hydration
  - Increases workability
  - Increases resistance to ASR
  - Slightly higher ultimate strength
  - Reduces and delays bleeding
- Other Effects
  - Reduces the amount of CO_2 generated
  - Reduces the amount of waste disposed in landfills
  - May reduce cost

Frost-Protected Shallow Foundations

- Strategically placed rigid insulation and drainage fill
- Reduces depth of excavation, backfill, foundation material
- Schemes for both heated and unheated buildings and elements



Source: National Association of Home Builders - www.nahb.com

Frost-Protected Shallow Foundations

LEFT:

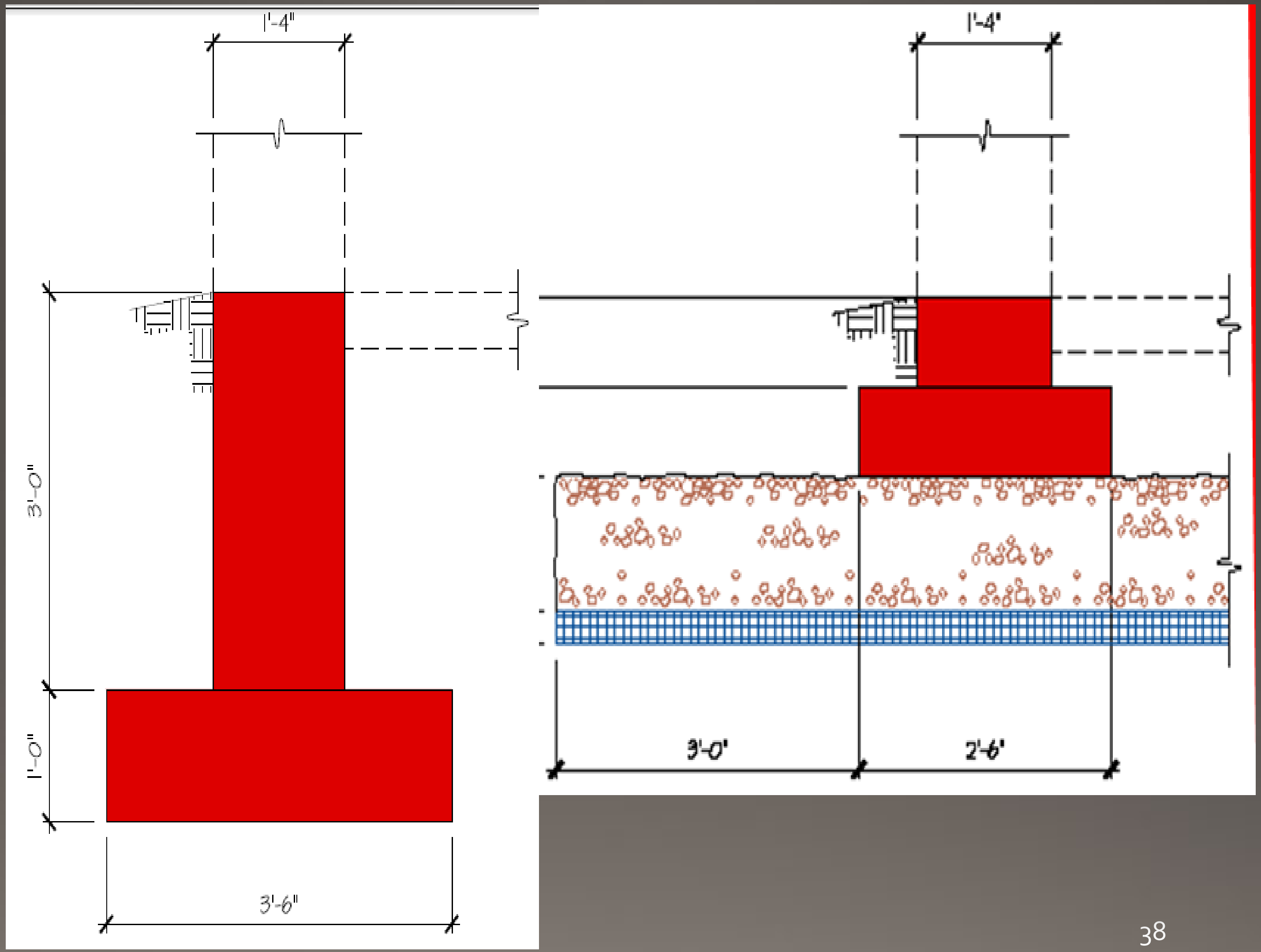
Conv. Ftg/fdn wall

Aconc = 7.5 sf/ft.

RIGHT: FPSF

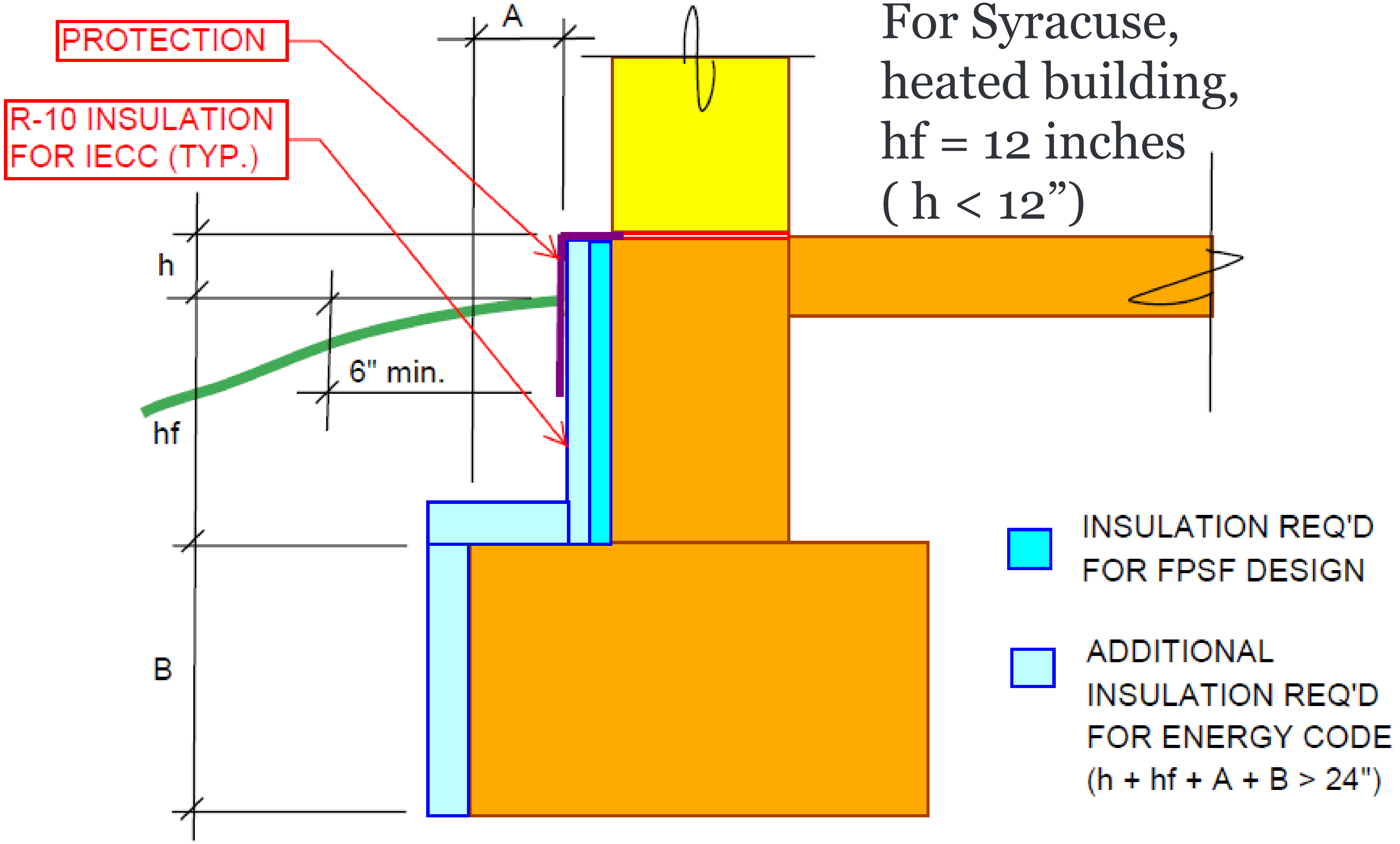
Aconc = 2.6 sf/ft.

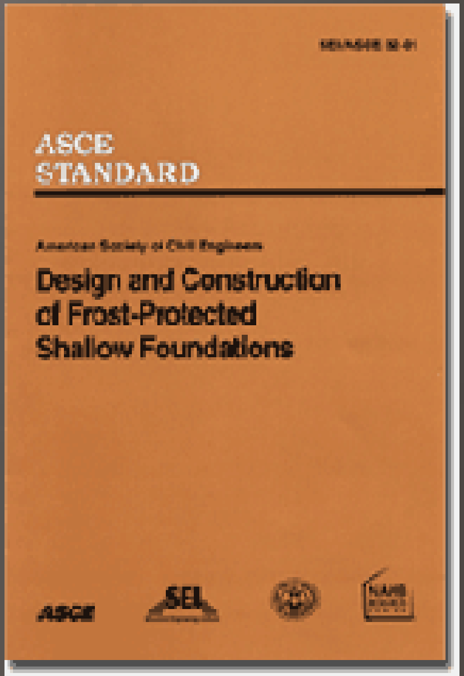
65% redux of conc!

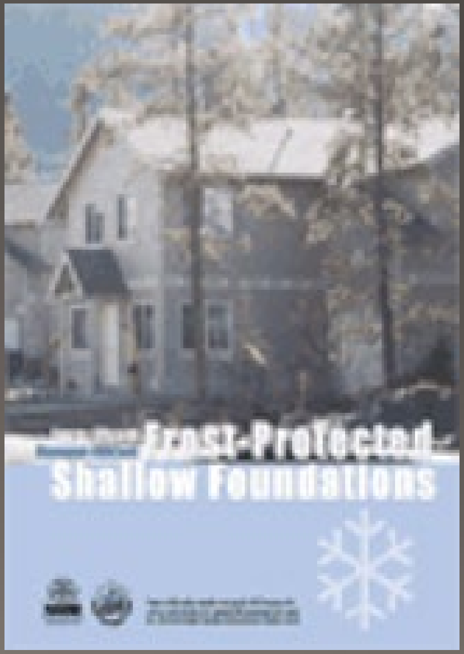


FPSF and Energy Code Thermal Design

For Syracuse,
heated building,
hf = 12 inches
(h < 12”)





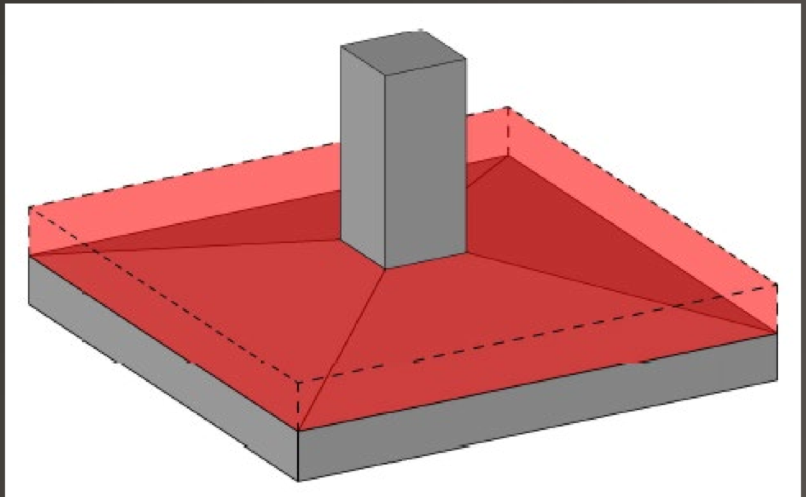


100,000 sf, 10-Story Mixed-Use Building

EZPZ Incremental – structure only

MATERIAL							lbs. CO2eq/lb.	lbs. CO2eq	
22 ga. steel roof decking	10,000	sf	1.8	psf	18,000	lbs.	2.61	46,980	
Open-web steel roof joists	10,000	sf	2.6	psf	26,000	lbs.	1.52	39,520	
Structural steel framing (19% optimized)	100,000	sf	7.9	psf	790,000	lbs.	1.38	1,090,200	
Composite steel floor decking	90,000	sf	2.3	psf	207,000	lbs.	2.61	540,270	
2x4 / 2x6 wall studs - 22% framing factor	150,000	sf	3.2	psf	484,000	lbs.	0.17	82,280	
Shear walls, 80 lf, 12"t, 4000 psi, 20% SCM	9,600	sf	356	cy	1,386,667	lbs.	0.11	152,533	
2-10th fl. conc - 3.5" eff. t, 3000 psi, 20% SCM	90,000	sf	972	cy	3,791,667	lbs.	0.09	341,250	
1st floor conc slab - 4" 3000 psi, 20% SCM	10,000	sf	123	cy	481,481	lbs.	0.09	43,333	
Strip ftgs, FPSF fd'n walls, 3500 psi, 20% SCM	1,664	sf	82	cy	319,673	lbs.	0.1	31,967	
Int. ft'gs, 12 x 8'x8'x18", 3500 psi, 20% SCM	768	sf	43	cy	166,400	lbs.	0.1	16,640	
Steel rebar, assume 0.7% conc vol.	8.5	cy	231	cf	116,012	lbs.	0.94	109,051	
								2,494,025	lbs. CO2
								24.94	psf

Concrete Optimization



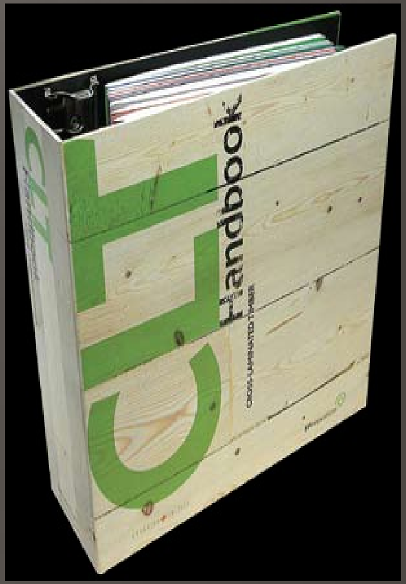
Conventional spread footings require full depth at face of piers only. Top surfaces can be thinner at edges. 20% concrete redux.

Transformative Improvements

- Wood framing
  - Glulam, microlam, CLT
  - TGI floor and roof joists
  - Plywood / OSB floor and roof decking
- Higher percentage of SCM – greater cement redux
- Frost-protected shallow foundations (FPSF)
- Optimized foundation design

Cross-Laminated Timber

- Pre-manufactured laminated panels for walls, floors, roofs
- Solid wood resists heat flow, contributes to thermal mass
- Fire tests are encouraging
- Hybrid podium systems – lower levels of concrete or steel
- Other wood-based structural systems exist, including Woodcube, Massivtre



Cross-Laminated Timber

University of Massachusetts Design Building, Amherst, MA

Structural Engineer: Simpson Gumpertz & Heger
Architect: Leers Weinzapfel

The Near Future (2022): CLT in the NE!

<u>IBC 2021</u>

Approved Dec 2019

- Type IV-A – Wood buildings up to 18 stories tall
- Type IV-B – Wood buildings up to 12 stories tall
- Type IV-C – Wood buildings up to 9 stories tall

- **CLT Plant Opening in Maine**

100,000 sf, 10-Story Mixed-Use Building

Transformative Improvements – structure only

- 20 ga. steel roof deck → **CLT decking**
- Open-web steel roof joists → **Glulam roof beams**
- Structural steel framing → **Glulam beams and columns**
- 2nd floor composite steel deck → **CLT decking w/conc. topping**
- Cold-formed steel wall studs → **CLT exterior walls**
- 5″ conc. 1st. floor slab on grade → **4″, 30% SCM, cement redux**
- Strip footings + foundation walls → **FPSF, 30% SCM, cem. redux**
- Interior spread footings → **30% SCM, cem. redux, opt.**

100,000 sf, 10-Story Mixed-Use Building

Transformative – structure only

MATERIAL							lbs. CO2eq/lb.	lbs. CO2eq	
5-ply CLT (6 7/8") roof and floor decking	100,000	sf	17.8	psf	1,776,042	lbs.	0.28	497,292	
7-ply CLT (9 5/8) wall panels 20% WWR	39,936	sf	24.9	psf	992,992	lbs.	0.28	278,038	
Glulam roof and floor beams - 5 1/2" x 14"	12,000	lf	20.9	plf	250,250	lbs.	0.37	92,593	
Glulam columns - est. 12 int, avg. 5 1/2" X 16"	1,440	lf	22.2	plf	31,964		0.37	11,827	
Steel composite floor ties	90,000	sf	1.2	psf	108,000		2.53	273,240	
Steel conn hardware for glulam, 10 lbs. ea.	1,680	pcs	10	lbs.	16,800		1.62	27,216	
2-10th fl. conc - 2" t, 3000 psi, 30% SCM	90,000	sf	556	cy	2,166,667	lbs.	0.08	173,333	
Shear walls, 80 lf, 12"t, 4000 psi, 30% SCM	9,600	sf	356	cy	1,386,667	lbs.	0.1	138,667	
1st floor conc slab - 4” 2500 psi, 30% SCM	10,000	sf	123	cy	481,481	lbs.	0.07	31,296	
Strip ftgs, FPSF fd'n walls, 3500 psi, 30% SCM	2,704	sf	133	cy	519,468	lbs.	0.08	41,557	
Int. ft'gs, optimized 3500 psi, 30% SCM	768	sf	34	cy	133,120	lbs.	0.09	11,981	
Steel rebar, assume 0.7% conc vol.	8.4	cy	227	cf	114,261	lbs.	0.94	107,405	
								1,684,445	lbs. CO2
								16.84	psf

Biogenic Carbon

- Carbon comprises about 50% of the mass of dry wood fiber.
- 1 lbs. Carbon in wood represents about 3.67 lbs. of CO_2 removed from the atmosphere.
- <u>**Example**</u>

100 lbs. of 19% moisture content wood

Dry wood fiber = (100 lbs.)(1/1.19) = 84 lbs.

Sequestered CO_2 = (84 lbs.)(.5)(3.67) = **154 lbs.**

<u>**1 lb. wood stores about 1.5 lbs. of atmospheric CO_2**</u>

… Not including emissions at the end of the product's life.

100,000 sf, 10-Story Mixed-Use Building

Transformative – structure only

INCLUDING BIOGENIC CARBON and END-OF-LIFE IMPACTS

MATERIAL							lbs. CO2eq/lb.	lbs. CO2eq	
5-ply CLT (6 7/8") roof and floor decking	100,000	sf	17.8	psf	1,776,042	lbs.	-0.67	(1,189,948)	
7-ply CLT (9 5/8) wall panels 20% WWR	39,936	sf	24.9	psf	992,992	lbs.	-0.67	(665,305)	
Glulam roof and floor beams - 5 1/2" x 14"	12,000	lf	20.9	plf	250,250	lbs.	-0.72	(180,180)	
Glulam columns - est. 12 int, avg. 5 1/2" X 16"	1,440	lf	22.2	plf	31,964		-0.72	(23,014)	
Steel composite floor ties	90,000	sf	1.2	psf	108,000		2.53	273,240	
Steel conn hardware for glulam, 10 lbs. ea.	1,680	pcs	10	lbs.	16,800		1.62	27,216	
2-10th fl. conc - 2" t, 3000 psi, 30% SCM	90,000	sf	556	cy	2,166,667	lbs.	0.08	173,333	
Shear walls, 80 lf, 12"t, 4000 psi, 30% SCM	9,600	sf	356	cy	1,386,667	lbs.	0.1	138,667	
1st floor conc slab - 4" 2500 psi, 30% SCM	10,000	sf	123	cy	481,481	lbs.	0.07	31,296	
Strip ftgs, FPSF fd'n walls, 3500 psi, 30% SCM	2,704	sf	133	cy	519,468	lbs.	0.08	41,557	
Int. ft'gs, optimized 3500 psi, 30% SCM	768	sf	34	cy	133,120	lbs.	0.09	11,981	
Steel rebar, assume 0.7% conc vol.	8.4	cy	227	cf	114,261	lbs.	0.94	107,405	
								(1,253,751)	lbs. CO2
								(12.54)	psf

Example Building Summary

• Conventional	2,950,000 lbs. CO2eq	29.5 lbs./sf
• Incremental	2,490,000 lbs. CO2eq	24.9 lbs./sf
• Transformative	1,680,000 lbs. CO2eq	16.8 lbs./sf
• Transformative * Including Biogenic Carbon *	(-1,250,000) lbs. CO2eq	-12.5 lbs./sf

2,950,000 lbs.

2,490,000 lbs.

(1,250,000 lbs.)

Conventional

Incremental

Transformative

Bloomage vs. Leakage - BLOOMAGE

Calculate UA TOTAL (Heat only)	AREA	R	U	UA
ROOF	10000	30	0.033	333
OPAQUE WALLS	40000	20	0.050	2000
FENESTRATION	10000	2.8	0.357	3571
TOP OF FOUNDATION	400	10	0.100	40
SHELF ANGLES	3690		0.390	1439
CONVECTIVE LOSSES				2500
TOTAL				9884

Bloomage vs. Leakage: Total Annual Heating Energy

$E_{annual} = U_{total}$ X 24 hrs/day X HDD / efficiency

HDD - Heating degree-days are the number of degrees that the daily average temperature falls below 65° F - 4777° F days in NYC

<u>Base Building</u>

Assume 90% heating system efficiency

9884 Btu-hr/° F X 24 hrs/day X 4777° F days / 0.9

= 1,260 MMBtu per year required for heating

1,260 / 100,000 sf floor area = 12,600 Btu/sf

Bloomage vs. Leakage: Quantify CO2eq Emitted from Heating

Natural Gas creates 117 lbs. CO_2e per MMBtu

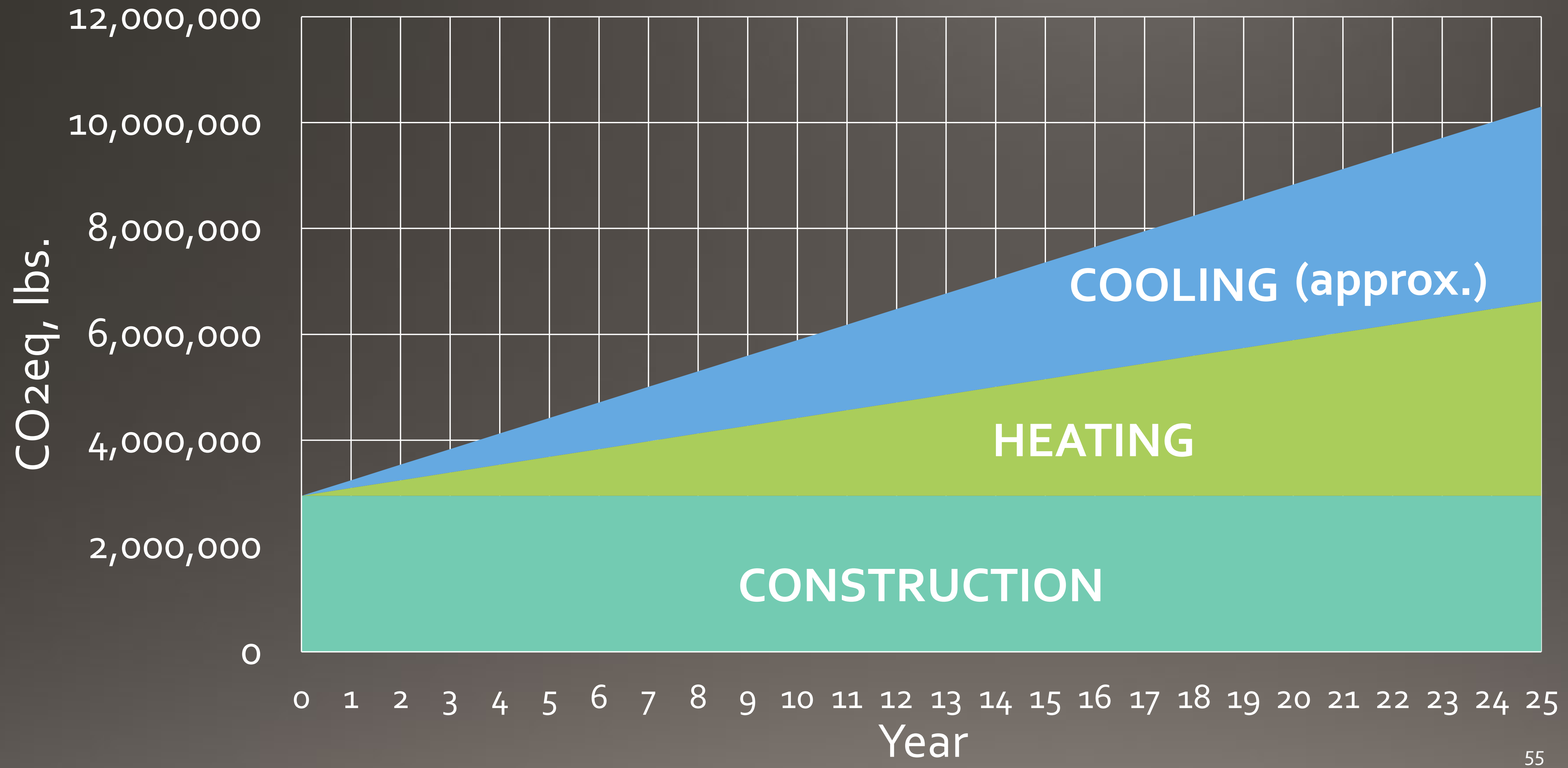
(http://www.eia.gov/tools/faqs/faq.cfm?id=73&t=11)

1260 MMBtu / year X 117 lbs. CO_2eq /MMBtu

= 147,000 lbs. CO_2eq /year for heating

50,800 / 100,000 sf floor area = 1.47 lbs./sf

Bloomage vs. Leakage



Carbon Counts!
Calculating the carbon content of commercial construction

Advanced Ideas

Tall Wood Buildings – Portland, OR

Carbon12 – 8-story glulam and CLT building completed in 2017

(Courtesy treesource.org)

Tall Wood Buildings – BC Canada

Concrete Exposure Classes ACI 318

- Freeze-Thaw Exposure Class F1 (moderate)
  - Concrete exposed to freezing and thawing cycles and occasional exposure to moisture and no deicing salts are used.
  - Min $f'c$ = 4500 psi
- Corrosion Protection Exposure Class C2 (severe)
  - Concrete exposed to moisture and an external source of chlorides in service – from deicing chemicals, salt, brackish water, seawater or spray from these sources.
  - Min $f'c$ = 5000 psi
- **Crystalline waterproofing admixtures and topical applications – do they change exposure class?**

Concrete Slabs on Grade: How Strong Must the Concrete Be?

Typical Concrete Slab Strength: 3000 psi

$3000 \text{ lbs./in}^2 \times (12 \text{ in./ft.})^2 =$ 432,000 psf

Typical Floor Live Loading: 100 psf

432,000 psf / 100 psf = 4,320 use a 2.0 FoS....

*** Most concrete slabs on grade are at least 2,000 times stronger than their required strength! ***

Concrete Slabs on Grade: Alternatives to the Conventional

STANDARD

5” standard concrete on compacted subbase

Concrete Type, Cement Amount	CO_2-e per SF (cradle-to-gate)
4000 psi, 450 lbs./CY	6.9
3000 psi, 350 lbs./CY	5.4 (22% redux)
3000 psi, 20% SCM, 280 lbs./CY	4.3 (38% redux)

ALTERNATIVE

4” low-strength concrete with superplasticizer on compacted subbase w/ 3/8” underlayment topping

Concrete Type, Cement Amount	CO_2-e per SF (cradle-to-gate)
2000 psi, 50% SCM, 150 lbs./CY	1.8 (70% redux)
500 psi, 50% SCM, 50 lbs./CY	0.62 (91% redux)

Alternative Cements

- Hybrid cement
- Alkali cements
  - Alkali-Activated Cements (AAC)
  - Aluminosilicate-based alkaline cements
- **Geopolymer cements**
- Sulfur cement
- Fly ash cement
- Calcium sulfoaluminate-based cements
- Gypsum cements

Dowel-Laminated Timber

Energy Innovation and Carbon Dividend Act – H.R. 763

- EFFECTIVE – will reduce CO_2 emissions by 40% in first 12 years
- GOOD FOR PEOPLE – increased health, more $ for lower income
- GOOD FOR THE ECONOMY – 2.1 million new jobs, increased GDP
- BIPARTISAN – Cosponsored by Republicans and Democrats
- REVENUE NEUTRAL – No $ kept or spent by the government

https://citizensclimatelobby.org/energy-innovation-and-carbon-dividend-act/

Questions?

Carbon Counts!
Calculating the carbon content of commercial construction

Thank you!

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The Role of the Engineer