SUNY/PPAA & NYAPPA 2019 Summer Conference
Striving for Synergies

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Calculating the carbon content of commercial construction

Carbon Counts!

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Abstract

With the advent of industry-wide Environmental Product Declarations (EPDs) for most conventional construction materials, it's now easy to calculate the approximate tons of CO2eq emitted from the construction of our buildings. From there we can look at some alternative material choices that can reduce this "carbon bloom." We'll review the methodology and information sources, introduce a "carbon pallet" spreadsheet, and go through a couple of examples to develop a feel for high and low values of carbon emissions per square foot of building construction, with the goal of increasing awareness of this important new design parameter.

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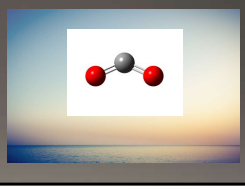
Agenda

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



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Carbon Counts!
Calculating the carbon content of commercial construction

The Big Picture

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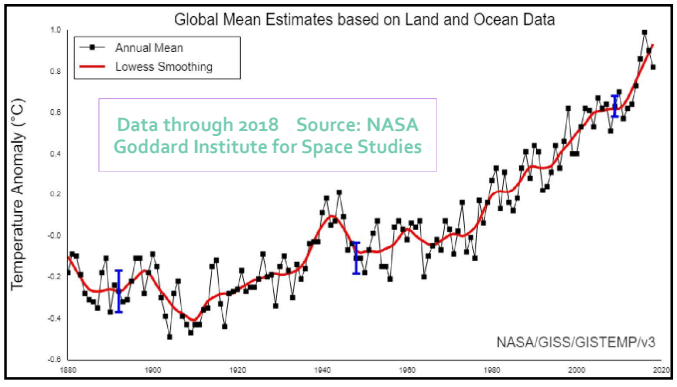

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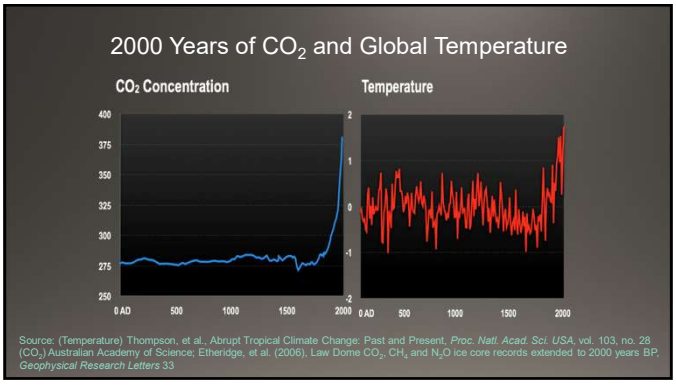

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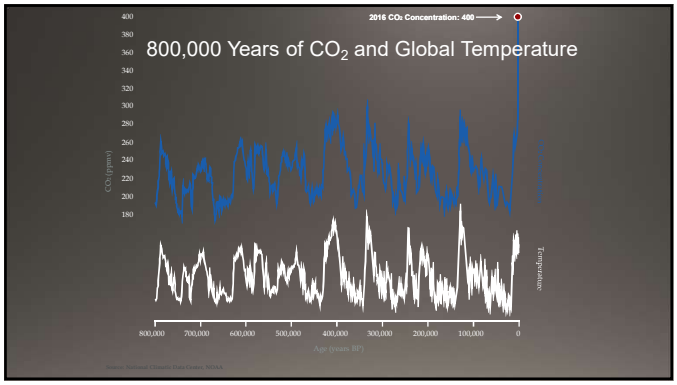

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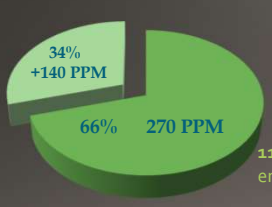
CO2 Increase Since 1800's



Prior to 1800's

Added 1800's-2019

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

270 ppm to 410 ppm = 52% increase in CO_2

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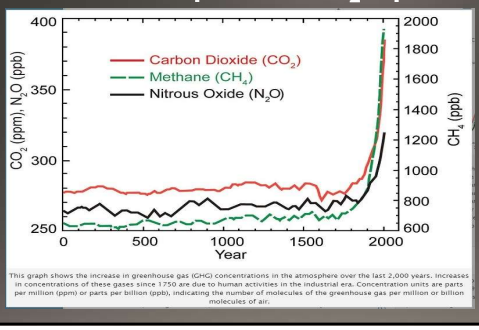
Atmospheric CO_2eq



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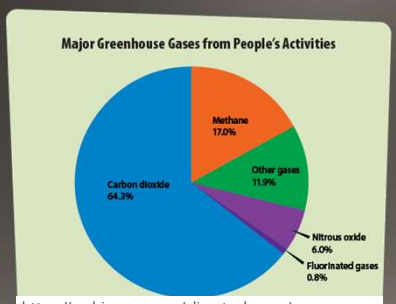
US - GWP Gas Emissions 2014



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

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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/

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Carbon Counts!
Calculating the carbon content of commercial construction

LCAs, PCRs, EPDs

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Confusing Terms

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

- Embodied Energy
- Embodied Carbon
- Carbon Sequestration

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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

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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
Raw materials supply	Transport	Manufacturing	Transport	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	De-construction	Transport	Waste processing	Disposal	Reuse, recovery, recycling potential
EXCLUDED FROM THIS STUDY														

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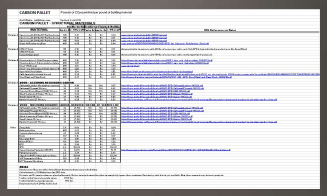

Carbon Counts!
Calculating the carbon content of commercial construction

Structural Carbon Pallet

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Gasoline

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

- Weighs 6.30 lbs./gallon
- Combustion of 1 gallon produces 20 lbs. 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 → 20 lbs. CO_2
- "Well to wheel" 1 gallon → **25 lbs. CO_2** **4X its weight**

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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

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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 ºF

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

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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.

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Carbon Pallet – Steel

www.asce.org/epd

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

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

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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

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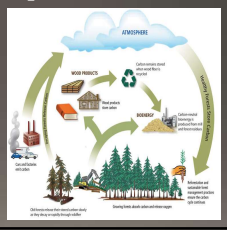
Carbon Pallet - Wood

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



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

www.realoutdoorliving.org

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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.
- **Example**

  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.**

1 lb. wood stores about 1.5 lbs. of atmospheric CO_2

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

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CARBON PALLET - STRUCTURAL MATERIALS

MATERIAL	lbs./c.f.	Cradle-to-Gate lbs. CO_2eq/lb.	Cradle-to-Finished-Building 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
Grade 60 Reinforcing Bars	495	0.85	5%	5%	0.94
CMU: 8" thick	55	0.10	5%	5%	0.11
CMU: 10" thick	65	0.10	5%	5%	0.11
Cementitious grout	145	0.16	5%	5%	0.18
Structural steel - Wide Flange sections	495	1.16	5%	5%	1.28
Structural steel - Fabricated steel plate	495	1.47	5%	5%	1.62
Steel - HSS (avg)	495	1.76	5%	5%	1.94
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

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CARBON PALLET - STRUCTURAL MATERIALS

MATERIAL	lbs./c.f.	Cradle-to-Gate lbs. CO_2eq/lb.	Cradle-to-Finished-Building 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					
Softwood Lumber 19% moisture content	32	(0.94)	10%	10%	(0.77)
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)

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CO2eq'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

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Insulation Material	R-value R/inch	Density lb/ft³	Emb. E MJ/kg	Emb. Carbon $kgCO_2$/kg	Emb. Carbon $kgCO_2$/ ft²•R	Blowing Agent (GWP)	Bl. Agent kg/kg foam	Blowing Agent GWP/ bd-ft	Lifetime GWP/ ft²•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

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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.

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Carbon Counts!
Calculating the carbon content of commercial construction

Example Building

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20,000 sf, 2-Story Academic Building
Conventional Construction – structure only

- 20 ga. steel roof deck
- Open-web steel roof joists
- Structural steel framing
- 2nd floor composite steel deck
- Cold-formed steel wall studs
- 5" conc. 1st. floor slab on grade
- Strip footings + foundation walls
- Interior spread footings

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20,000 sf, 2-Story Academic 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	2.5	psf	25,000	lbs.	1.52	38,000
Structural steel framing	20,000	sf	7.5	psf	150,000	lbs.	1.38	207,000
Composite steel floor decking	10,000	sf	2.3	psf	23,000	lbs.	2.61	60,030
Cold-formed steel wall studs	30,000	sf	0.4	psf	12,000	lbs.	2.53	30,360
2nd floor conc - 3.5" eff. t, 4000 psi	10,000	sf	108	cy	421,200	lbs.	0.14	58,968
1st floor conc slab - 5" 3000 psi	10,000	sf	155	cy	604,500	lbs.	0.10	60,450
Strip footings + fd'n walls 3500 psi			110	cy	429,000	lbs.	0.12	51,480
Int. ft'gs, 12 x 6x6, 3500 psi			24	cy	93,600	lbs.	0.12	11,232
Steel rebar, assume 0.5% conc vol.	2.0	cy	54	cf	26,958	lbs.	0.94	25,341
								600,281

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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

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20,000 sf, 2-Story Academic 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

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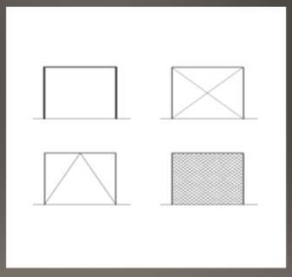
Steel Lateral Bracing Systems

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.



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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

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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

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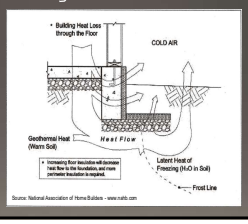
Frost-Protected Shallow Foundations

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



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Frost-Protected Shallow Foundations

LEFT:

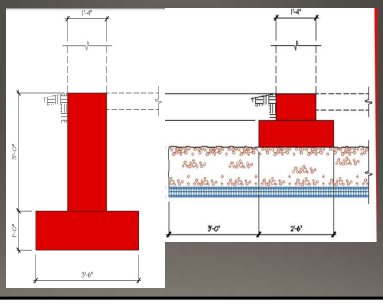
Conv. Ftg/fdn wall

Aconc = 7.5 sf/ft.

RIGHT: FPSF

Aconc = 2.6 sf/ft.

65% redux of conc!



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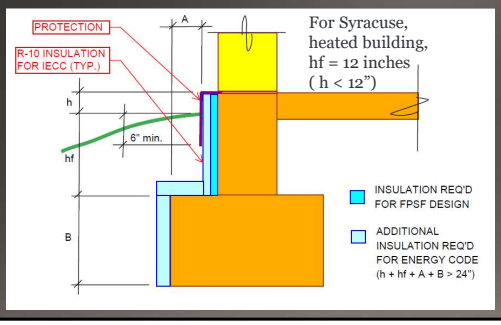
FPSF and Energy Code Thermal Design



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20,000 sf, 2-Story Academic 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	2.5	psf	25,000	lbs.	1.52	38,000
Structural steel framing - optimized	20,000	sf	6.8	psf	136,000	lbs.	1.38	187,680
Composite steel floor decking	10,000	sf	2.3	psf	23,000	lbs.	2.61	60,030
2x4 / 2x6 wall studs - 22% framing factor	30,000	sf	3.2	psf	96,800	lbs.	-0.77	(74,536)
2nd fl. conc - 3.5" eff. t, 3000 psi, 20% SCM	10,000	sf	108	cy	421,200	lbs.	0.09	37,908
1st floor conc slab - 4" 3000 psi, 20% SCM	10,000	sf	155	cy	604,500	lbs.	0.09	54,405
FPSF + fd'n walls 3000 psi, 20% SCM			55	cy	214,500	lbs.	0.09	19,305
Int. ft'gs, 12 x 6x6, 3000 psi, 20% SCM			24	cy	93,600	lbs.	0.09	8,424
Steel rebar, assume 0.5% conc vol.	1.7	cy	46	cf	23,224	lbs.	0.94	21,830
								400,026

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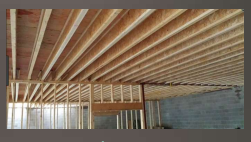
Transformative Improvements

- Wood framing
  - Glulam and microllam
  - 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
- Wood wall studs



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Concrete Optimization

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

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20,000 sf, 2-Story Academic Building

Transformative Improvements – structure only

- 20 ga. steel roof deck → OSB roof sheathing
- Open-web steel roof joists → TGI wood floor & roof joists
- Structural steel framing → Glulam floor & roof beams
- 2nd floor composite steel deck → Plywood floor sheathing
- 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, 30% SCM, cem. redux
- Interior spread footings → 30% SCM, cem. redux, opt.

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20,000 sf, 2-Story Academic Building

Transformative – structure only

MATERIAL							lbs. CO2eq/lb.	lbs. CO2eq
OSB wood roof decking	10,000	sf	3.2	psf	32,083	lbs.	-0.55	(17,646)
TGI wood roof floor and roof joists	20,000	sf	4.2	psf	84,000	lbs.	-0.53	(44,520)
Glulam beams and columns	20,000	sf	5	psf	100,000	lbs.	-0.37	(37,000)
Steel wood connectors	20,000	sf	0.5	psf	10,000	lbs.	2.61	26,100
2x4 / 2x6 wall studs	30,000	sf	3.2	psf	96,800	lbs.	-0.77	(74,536)
Plywood floor decking	10,000	sf	2.6	psf	26,250	lbs.	-0.6	(15,750)
1st floor conc slab - 4" 2500 psi, 20% SCM	10,000	sf	124	cy	483,600	lbs.	0.07	33,852
Optim. FPSF + fdn. walls 3000 psi, 30% SCM			44	cy	171,600	lbs.	0.08	13,728
Optim. int. ftgs, 12 x 6x6, 3000 psi, 30% SCM			19	cy	74,880	lbs.	0.08	5,990
Steel rebar, assume 0.4% conc vol.	0.8	cy	21	cf	10,312	lbs.	0.94	9,693
								(100,088)

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Example Building Summary

- Conventional 600,281 lbs. CO2eq 30 lbs./sf
- Incremental 400,026 lbs. CO2eq 20 lbs./sf
- Transformative (-100,088) lbs. CO2eq -5 lbs./sf

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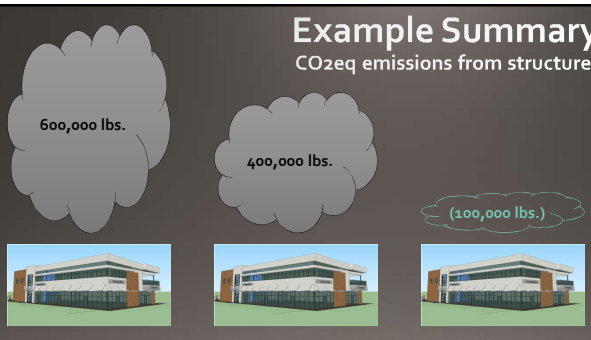
Example Summary

CO2eq emissions from structure



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Carbon Counts!
Calculating the carbon content of commercial construction

Advanced Ideas

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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

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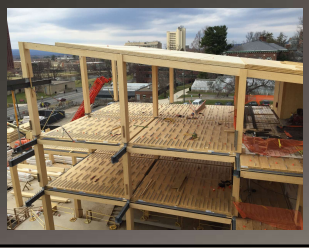
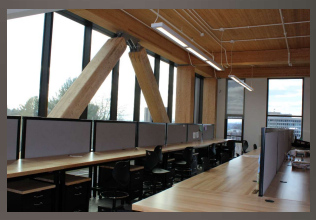
Cross-Laminated Timber

University of Massachusetts Design Building, Amherst, MA

Structural Engineer: Simpson Gumpertz & Heger
Architect: Leers Weinzapfel





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The Near Future (2022): CLT in CNY!

IBC 2021

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!**

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Tall Wood Buildings – Portland, OR

Carbon12 – 8-story glulam and CLT building completed in '17

(Courtesy treesource.org)

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Tall Wood Buildings – BC Canada

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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?**

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

Typical Concrete Slab Strength: 3000 psi

3000 lbs./in^2 X (12 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! ***

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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)

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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

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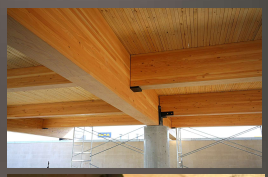
Dowel-Laminated Timber



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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/

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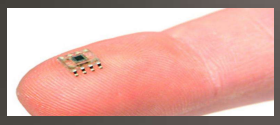
The Role of the Engineer



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Thank you!

Carbon Counts!
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Questions?

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