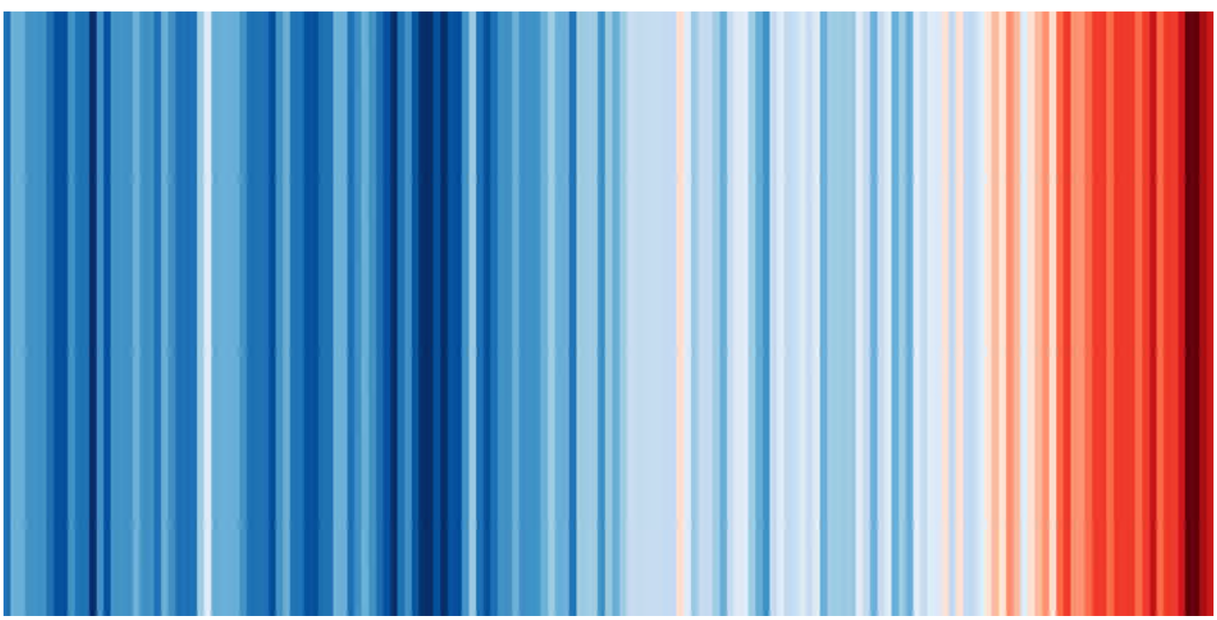
Embodied Carbon: Strategies to Zero

Tony Saracino – Sustainability Engagement Manager, Autodesk
Heath Blount – Principal, Brightworks Sustainability

AUTODESK

BRIGHTWORKS SUSTAINABILITY

1



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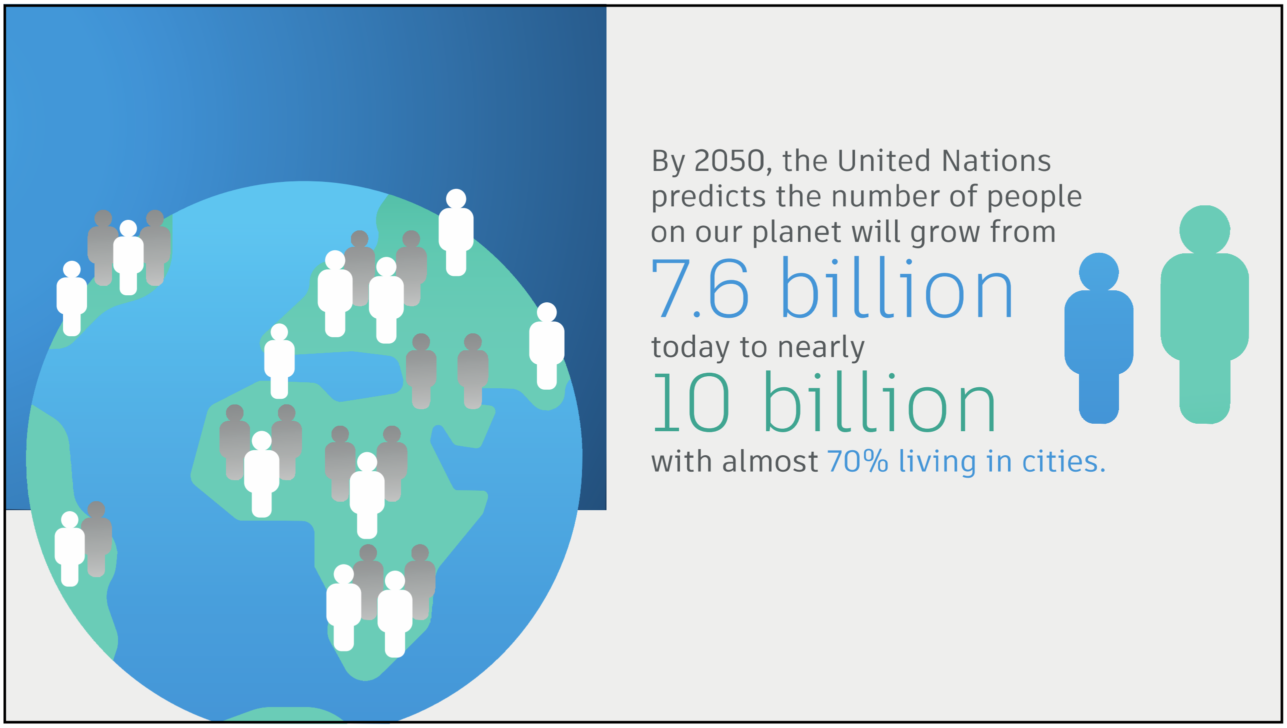
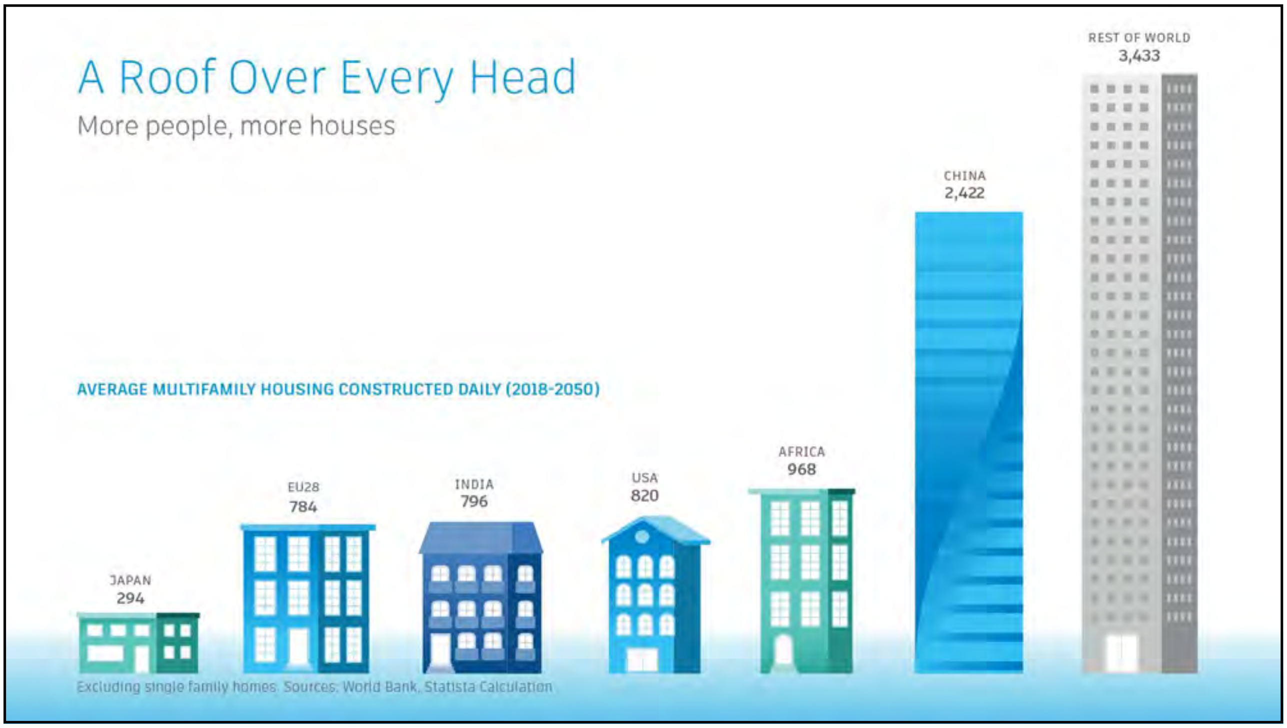

By 2050, the United Nations
predicts the number of people
on our planet will grow from
7.6 billion
today to nearly
10 billion
with almost 70% living in cities.

3


EVERY DAY, AT LEAST 200,000 PEOPLE PACK
THEIR BAGS AND MOVE TO THE BIG CITY.
BY 2050 ALMOST 70% OF THE WORLD'S
POPULATION WILL LIVE IN CITIES—
THAT'S ABOUT 7 BILLION PEOPLE.

4



A Roof Over Every Head
More people, more houses
AVERAGE MULTIFAMILY HOUSING CONSTRUCTED DAILY (2018-2050)
JAPAN 294
EU28 784
INDIA 796
USA 820
AFRICA 968
CHINA 2,422
REST OF WORLD 3,433
Excluding single family homes. Sources: World Bank, Statista Calculation

5

With Every Opportunity Comes Responsibility
BUILDING CONSTRUCTION PROJECTS CONTRIBUTE
40%
of the waste in landfills
TODAY'S BUILDINGS PRODUCE
1/3
of the world's greenhouse gas emissions
THEY ALSO USE
25%
of global water
40%
of global energy

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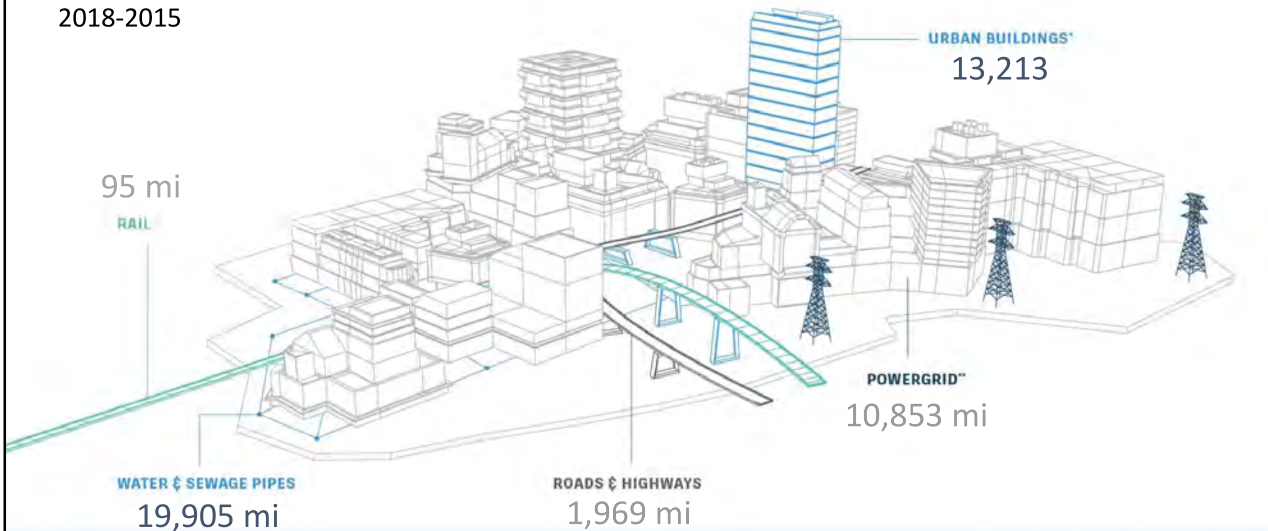
Global Average Daily Construction

2018-2015



* Commercial and residential, excl single family homes

** Including high voltage transmission lines and distribution lines

Source: Statista Calculation

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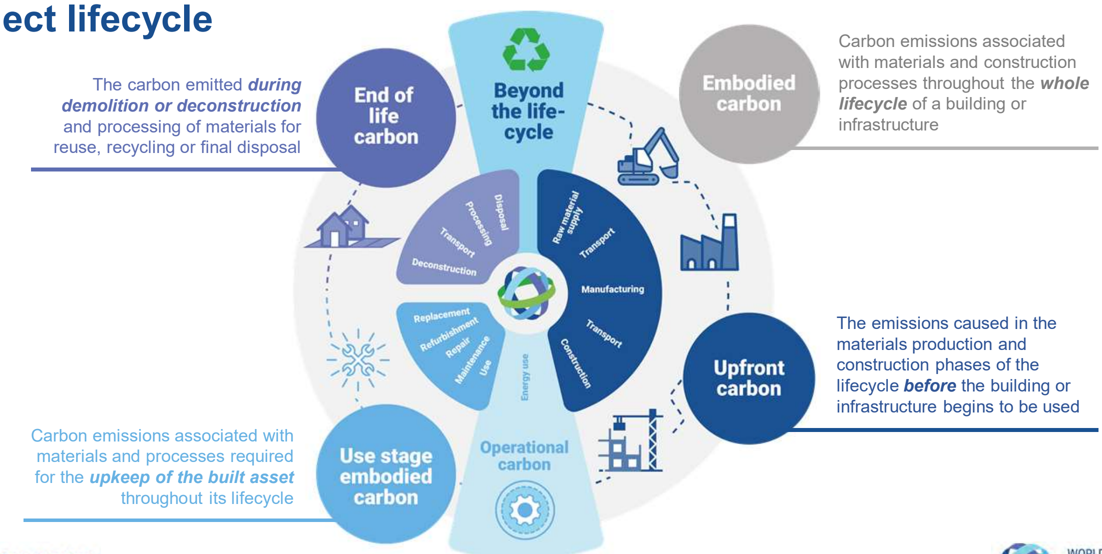
Project lifecycle



ADVANCING NET ZERO

WORLD GREEN BUILDING COUNCIL

Source: World Green Building Council: *Bringing Embodied Carbon Upfront, 2019*

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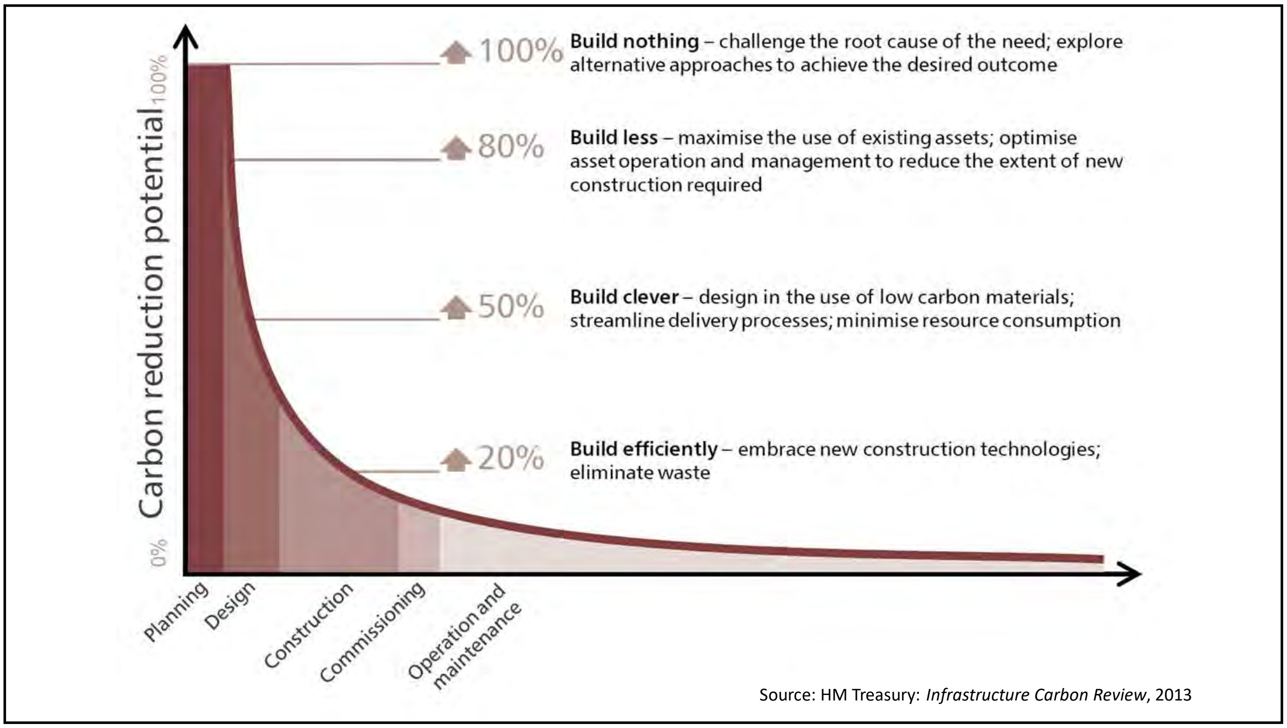
Carbon reduction potential
100%
0%
100% Build nothing – challenge the root cause of the need; explore alternative approaches to achieve the desired outcome
80% Build less – maximise the use of existing assets; optimise asset operation and management to reduce the extent of new construction required
50% Build clever – design in the use of low carbon materials; streamline delivery processes; minimise resource consumption
20% Build efficiently – embrace new construction technologies; eliminate waste
Planning
Design
Construction
Commissioning
Operation and maintenance
Source: HM Treasury: Infrastructure Carbon Review, 2013

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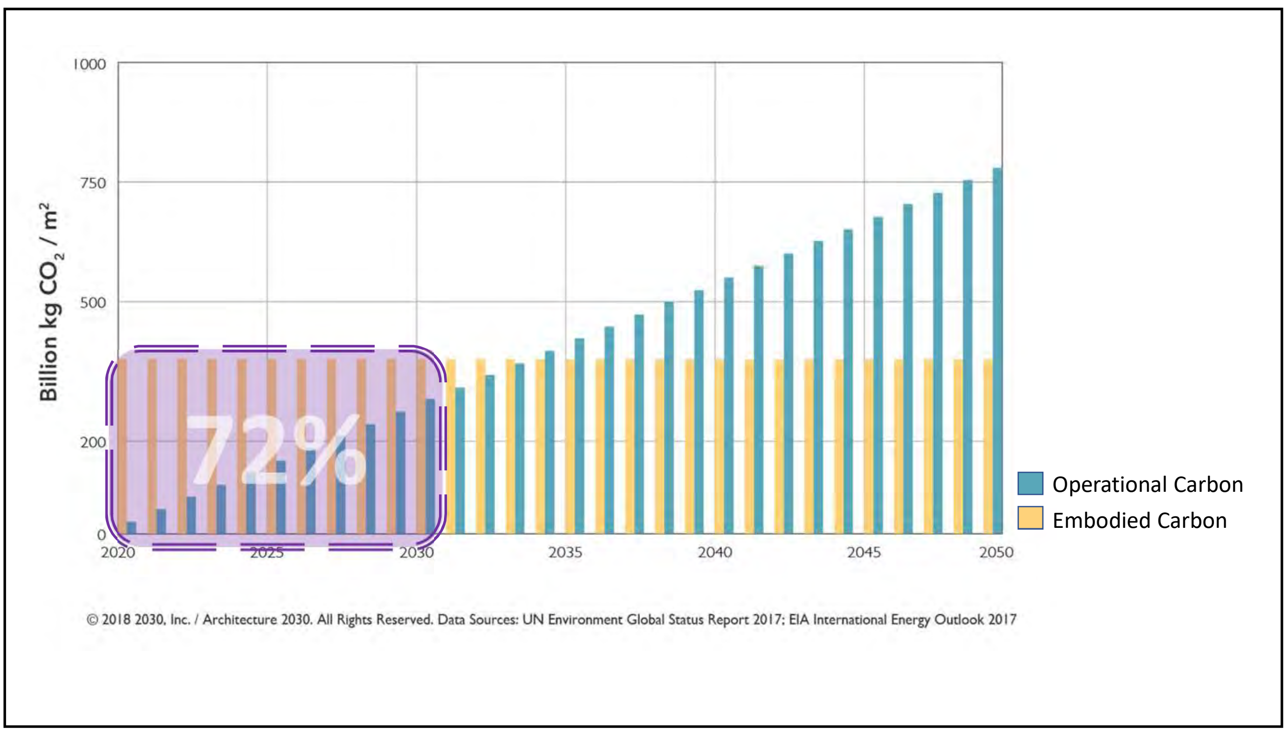
Billion kg CO2 / m2
1000
750
500
200
0
2020
2025
2030
2035
2040
2045
2050
72%
Operational Carbon
Embodied Carbon
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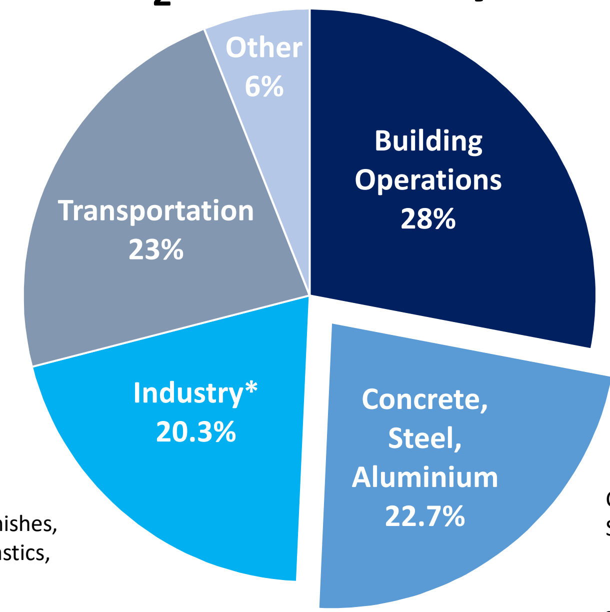
Global CO_2 Emissions by Sector



*includes building finishes, glass, equipment, plastics, rubber, paper, other

Concrete 11.1%
Steel 10.1%, Aluminum 1.5%

Source: 2018 Global ABC Report; IEA

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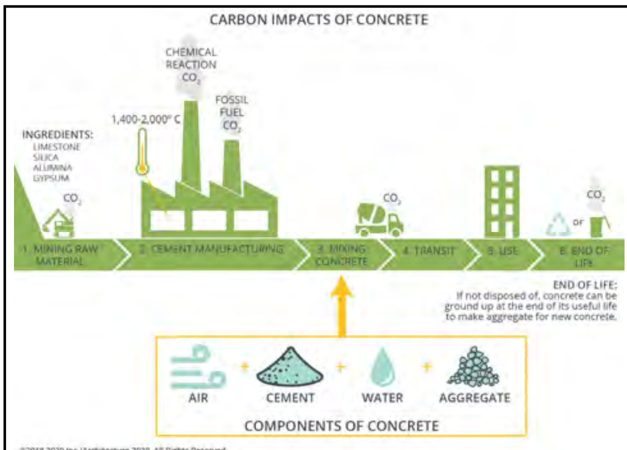

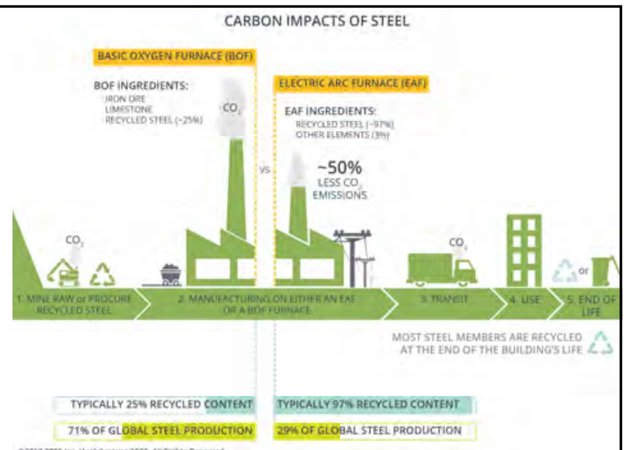

- Concrete is the most widely used construction material in the world, and is responsible for 6-10% of global anthropogenic carbon dioxide (CO_2) emissions
- CO_2 is released at two points during cement production: 40% from the burning of fossil fuels in the manufacturing process, and 60% is from naturally occurring chemical reactions during processing
- **Using less cement is the most impactful way to reduce the carbon footprint of concrete.**

- Basic Oxygen Furnaces (BOFs) use coal or gas vs Electric Arc Furnaces (EAFs) which run on electricity
- BOFs have maximum recycled content of 25-37% vs. EAFs with recycled content up to 100%
- **Using steel from electric arc furnaces is the best way to reduce embodied emissions in steel, because EAFs uses high levels of recycled material and can be powered by renewable energy sources.**

Source: Carbon Smart Materials Palette, Architecture 2030

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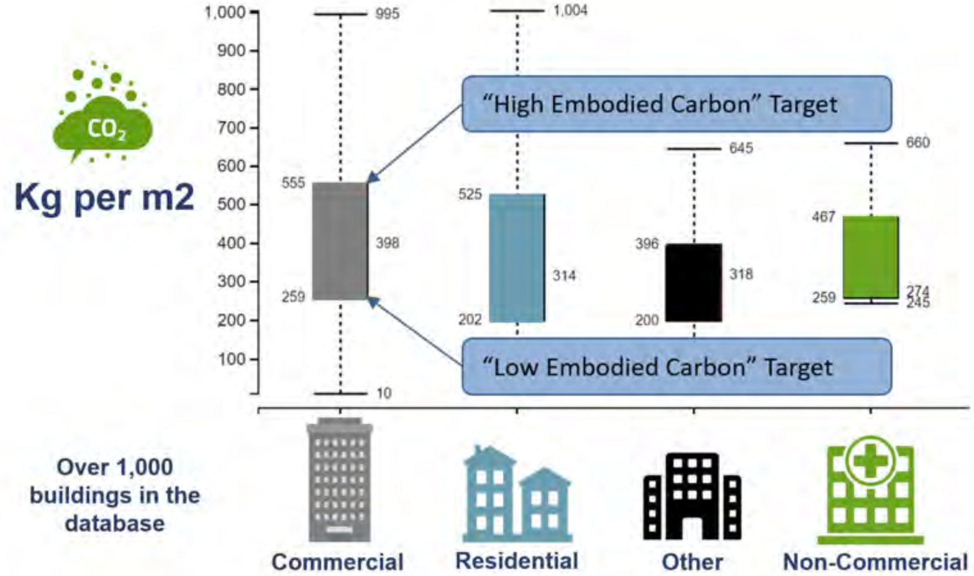
Benchmarking Embodied Carbon



Source: Carbon Leadership Forum – Embodied Carbon Benchmark Study

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Measuring Embodied Carbon

Life Cycle Assessments / EPDs / WBLCA

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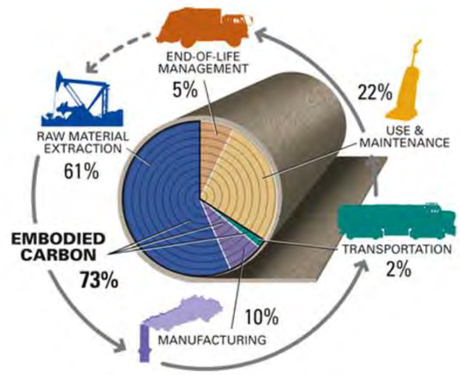
LCA Impact Categories

Embodied carbon

- Global warming potential (greenhouse gases), in kg CO_2e;
- Depletion of the stratospheric ozone layer, in kg CFC-11e;
- Acidification of land and water sources, in moles H+ or kg SO_2e;
- Eutrophication, in kg nitrogen eq or kg phosphate eq;
- Formation of tropospheric ozone (smog), in kg NOx, kg O3 eq, or kg ethene; and
- Depletion of nonrenewable energy resources, in MJ using CML / depletion of fossil fuels in TRACI.



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Life-Cycle Stages

defined by EN 15978 and EN 15804 standards, which can be included in LCAs.

The following table lists all life cycle stages according to EN standards:

Product Stage			Construction Process Stage		Use Stage							End-of-Life Stage				Benefits and loads beyond the system boundary		
Raw material supply	Transport	Manufacturing	Transport to building site	Installation into building	Use/application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D

Life-cycle stages according to EN standards.

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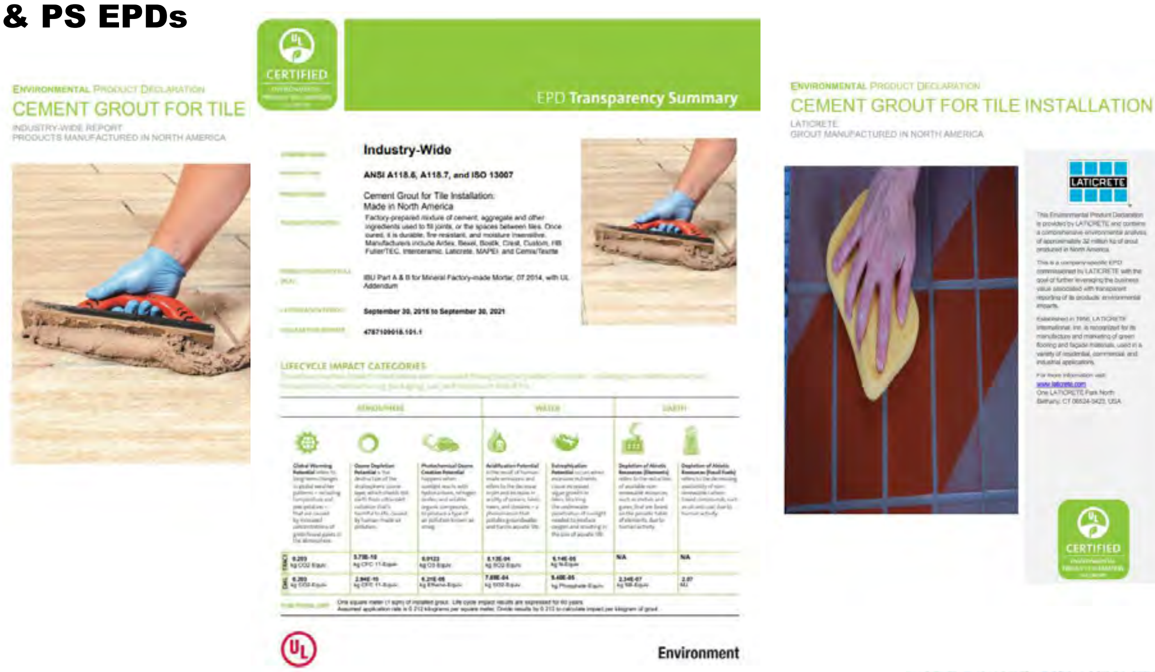
IW & PS EPDs



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LEED V4.1 - MRc1 Building Life-Cycle Impact Reduction (BD+C only)

**Reference the LEED Credit for more documentation requirement details*

- Option 1: Historic Reuse
- Option 2: Renovation of Abandoned or Blighted Building
- Option 3: Building and Material Reuse (Salvage)
- Option 4: Whole Building LCA (WBLCA)
  - WBLCA covers structure and enclosure only.
  - Path 1 – Complete a WBLCA of design building (1pt)
  - Path 2 – Complete WBLCA of design building AND baseline. Show 5% reduction in 3+ impact categories (2pts)
    - Baseline and proposed buildings must:
      - Be of comparable size, function, orientation, and operating energy performance.
      - Same service life, 60+ years
      - Use same software and parameters to evaluate. Data sets compliant with ISO 14044
  - Path 3 – Same as Path 2, but with a 10% reduction. (3pts)
  - Path 4 – Same as Path 2, but with salvaged/reused materials use AND a 20% reduction. (4pts)

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ILFI Zero Carbon Certification

INTERNATIONAL LIVING FUTURE INSTITUTE

Operational carbon:

- Demonstrate actual net zero based on 12 mo. performance period.
- Requires 25% below ASHRAE 90.1-2010.
- No combustion allowed for new buildings.
- Offsetting renewables may either be on- or off-site

Embodied carbon:

- WBLCA using 50 year lifespan for foundation, structure, enclosure and interior.
- Reduce 10% compared to baseline
- Purchase carbon offsets one time.

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Tools

Product EC / Procurement

EC3

EPD®

CERTIFIED ENVIRONMENTAL PRODUCT DECLARATION

THIRD-PARTY VERIFIED EPD ISO 14025 and EN 15804 Institut Bauen und Umwelt e.V.

Whole Building LCA

One Click LCA

tally ENVIRONMENTAL IMPACT TOOL

Athena Impact Estimator for Buildings

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Measuring Embodied Carbon

Project Process

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EMBODIED CARBON TOOLS AND PROCESS

Embodied Carbon Tools and Project Schedule

- Introduce team to intent and design strategies to reduce project's Embodied Carbon

SD

- Use a WBLCA tool (One Click Carbon Designer, Tally, Athena) to compare structural options at high level

DD

- If possible, work with energy modeler to find the balance between operational and embodied carbon to minimize "total carbon" (EC + OC), especially if exploring alternative insulation

CD

- Use EC3, Carbon Smart Materials Palette to inform product selections and include EC requirements in specs
- OneClick LCA, Tally, Athena – use BIM model and/or buyout information to complete full WBLCA

CA

- Take lessons learned from this project and apply it to the next project.

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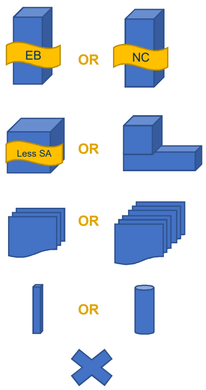
EMBODIED CARBON TOOLS AND PROCESS

Project Schedule

SD
DD
CD
CA

Design strategies to reduce project's Embodied Carbon:

- Project need
- Massing
- Fewer materials
- Reducing concrete
- Eliminating parking



Compare Structural options using OneClick Carbon Designer

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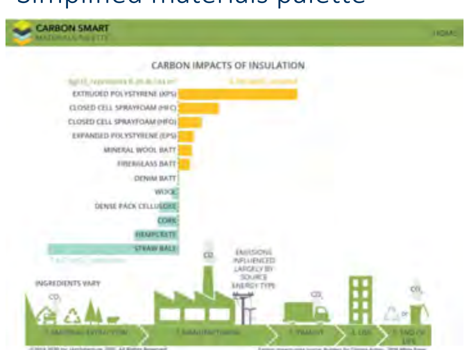
EMBODIED CARBON TOOLS AND PROCESS

Project Schedule

SD
DD
CD
CA

Refine:

- Structure
- Simplified materials palette



Work with energy modeler to find the balance between OC & EC

What's the trade off in energy performance for lower R-values (lower EC) or alternative insulations?

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EMBODIED CARBON TOOLS AND PROCESS

Project Schedule

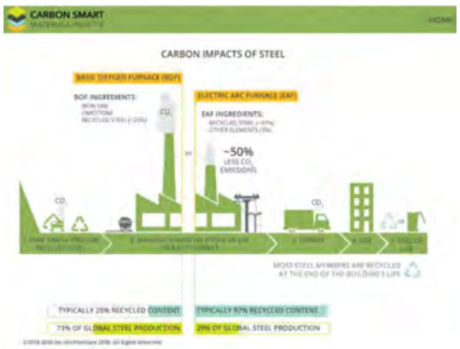
SD

DD

CD

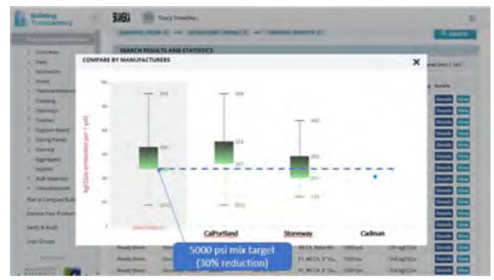
CA

Use EC3, Carbon Smart Materials Palette to inform product selections



…and set EC requirements in specs

- Require products with PS EPD
  (for product types where this is available)
- Require products to be below EC3-set GWP target



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EMBODIED CARBON TOOLS AND PROCESS

Project Schedule

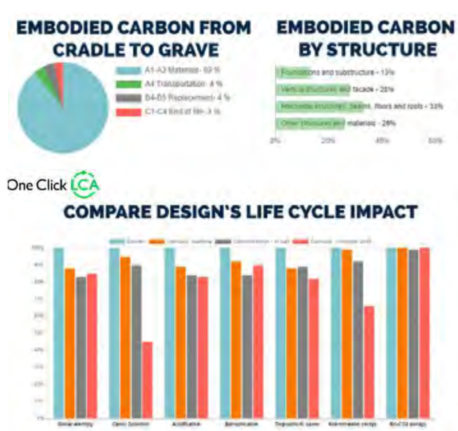
SD

DD

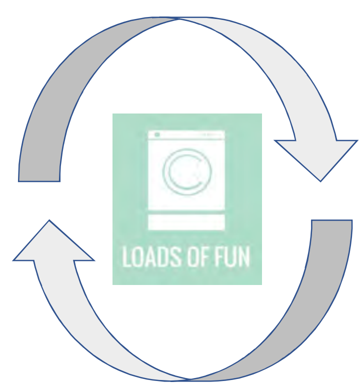
CD

CA

OneClick LCA, Tally, Athena – use BIM model and/ or buyout information to complete full WBLCA



Take lessons learned from this project and apply it to the next project.



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Resources

Embodied Carbon Construction Calculator (EC3)
www.buildingtransparency.org

Carbon Smart Materials Palette
https://materialspalette.org/

OneClick LCA – Cloud-based Whole Building LCA
https://www.oneclicklca.com/

Tally – Revit Plug-in for Whole Building LCA
http://choosetally.com/

Athena's Impact Estimator
http://www.athenasmi.org/our-software-data/impact-estimator/

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Commitments, Policy, and Industry Leadership

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Emerging Policies and Codes – California

Buy Clean California Act 2017

- Applies to all publicly funded projects
- Sets a maximum lifecycle global warming potential
- Structural steel,rebar, flat glass, and mineral wool board insulation

January 1, 2019 – Awarding authorities will request submission of Environmental Product Disclosures (EPDs)
January 1, 2020 – Awarding authorities will require submission of EPDs
January 1, 2021 – DGS will publish the maximum acceptable GWP for eligible materials.
July 1, 2021 – Awarding authorities will gauge GWP compliance of eligible materials with EPDs.

https://www.dgs.ca.gov/PD/Resources/Page-Content/Procurement-Division-Resources-List-Folder/Buy-Clean-California-Act

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Emerging Policies and Codes – Washington

- Buy Clean Washington – HB2412
  - Did not move forward for 2018
  - Based on CA's Act. But includes concrete (all), unit masonry, metal (all), and wood (all).
- Universities completed Buy Clean Washington Study >>>

Study Resources	Description	Access
Report Summary	High-level overview of key study information and findings	Download
Briefing to WA State representatives	Kate Simonen's (CLF Director/Project Lead) presentation to the House Capital Budget Committee (2/22/19)	Watch Video
Full Report	Compilation of work generated in developing embodied carbon policy options and recommendations for the State of Washington	Download
Chapter 1: Introduction	Summarizes the history of the Buy Clean Washington bill, and describes the directions for the study	Download
Chapter 2: Policy Review	Summarizes international policies, programs and initiatives with embodied carbon components and distills common themes	Download
Chapter 3: Technical Review	Analyzes the major construction materials in-depth with regards to their embodied carbon impacts, and provides recommendations on how to further the development of supply chain environmental data, such as EPDs, in Washington	Download
Chapter 4: Pilot Study	Presents the pilot projects used for this study and proposes a method for collecting data in the pilot study	Download
Chapter 5: Policy Evaluation	Provides a comprehensive analysis of Buy Clean policy as enacted in California, a framework for developing Buy Clean policy for Washington State, and a list of recommended investments that Washington State could undertake to facilitate consideration of embodied carbon in public procurement	Download
Appendix A: Buy Clean WA Legislation	Official state documentation related to Buy Clean Washington	Download
Appendix B: Pilot Supplementary Materials	Proposed model specifications attachment and structural material quantity reporting template	Download
Appendix C: Resources	Collection of educational information, which the research team collated to provide high-level resources targeted to US-based policy professionals	Download

http://www.carbonleadershipforum.org/resources/buy-clean-washington/

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Emerging Policies and Codes – Oregon

- Exec. Order No. 17-20: *Accelerating Efficiency in Oregon's Built Environment to Reduce Greenhouse Gas Emissions and Address Climate Change*
  - ODOE, DAS, and Oregon Sustainability Board collaborating with DEQ
  - DEQ is working with manufacturers to calculate embodied carbon in concrete
- Oregon code on reusing structural lumber

https://www.oregon.gov/energy/Get-Involved/Documents/BEEWG-Action-Items.pdf

http://embodiedcarbonnetwork.org/wp-content/uploads/sites/13/2018/02/20180216_Webinar-1-Policy_All-Slides.pdf

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Carbon

Carbon Campaigns

INTERNATIONAL LIVING FUTURE INSTITUTE

JOIN THE CAMPAIGN
PARIS SOLUTIONS

MAKING ZERO ENERGY + ZERO CARBON BUILDINGS AND COMMUNITIES THE NORM

WORLD GREEN BUILDING COUNCIL

The Net Zero Carbon Buildings Commitment

ADVANCING NET ZERO

SCIENCE BASED TARGETS
DRIVING AMBITIOUS CORPORATE CLIMATE ACTION

COMPANIES TAKING ACTION

515 COMPANIES TAKING ACTION

CDP WORLD RESOURCES INSTITUTE WWF

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Becoming Part of the Conversation

CRADLE TO CRADLE PRODUCTS INNOVATION INSTITUTE

Built Positive

CARBON LEADERSHIP FORUM
Advancing low carbon construction through research, education and outreach

PLATINUM
ARUP | CENTRAL | MITHŪN | Orca | THE RUSSELL FAMILY FOUNDATION | Thornton Tomasetti | SKANSKA

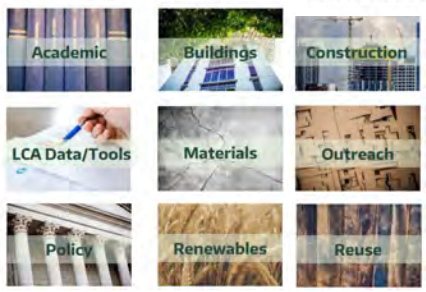
GOLD
climate earth | MAGNUSSON KLEMENCIC | NRMCA | OWENS CORNING | URBAN FABRICK | WALTER P MOORE

SILVER
ADRIAN SMITH + GORDON GILL | ARKIN TILT | KATERRA | LUND OPSAHL | SELLEN | SHKS | SIEGEL AND STRAIN

SUPPORTERS
ARCHITECTURE 2030 | ATHENA SMI | CASBA | COALITION TO PRESERVE LA | CORRIM | ECOLOGICAL BUILDING NETWORK
ENDEAVOUR CENTRE | NET ZERO ENERGY COALITION

Embodied Carbon Network

- Resource sharing, discussion, quick action
- Launched in 2017
- Initiative of the UW Carbon Leadership Forum
- Nine subject-specific Taskforces



BRIGHTWORKS SUSTAINABILITY

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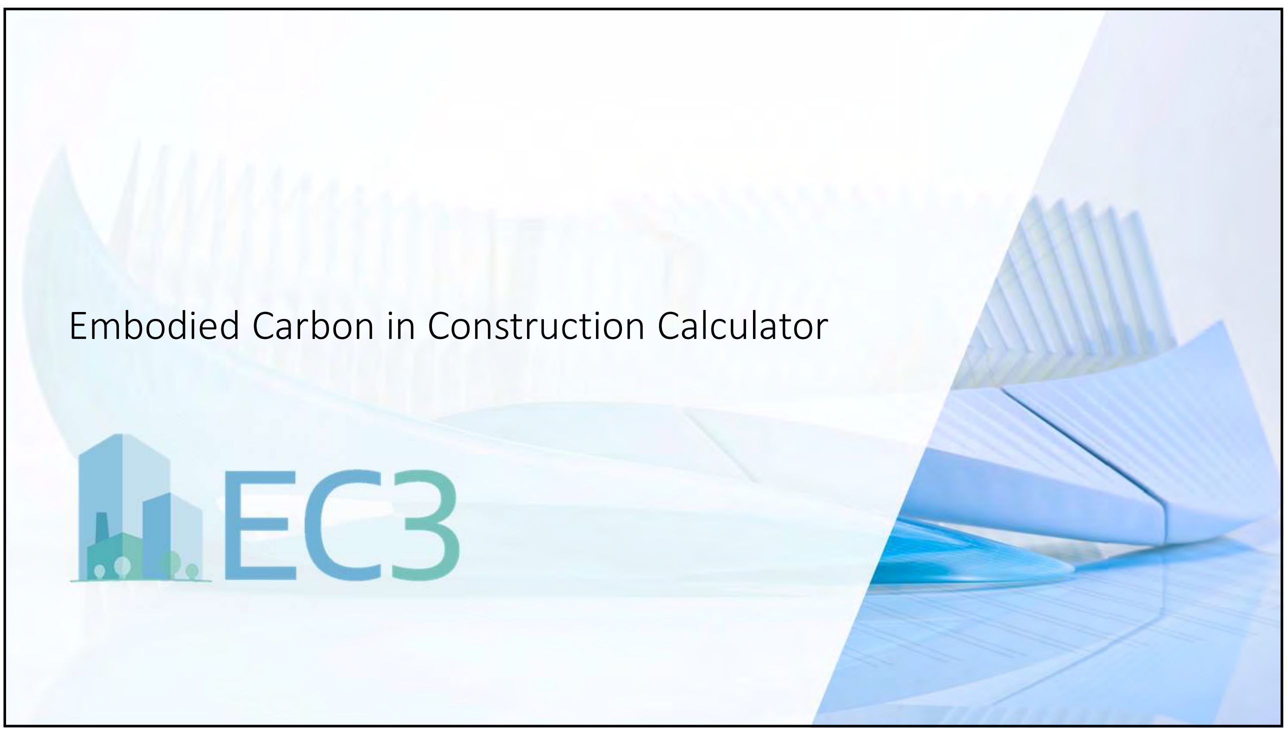

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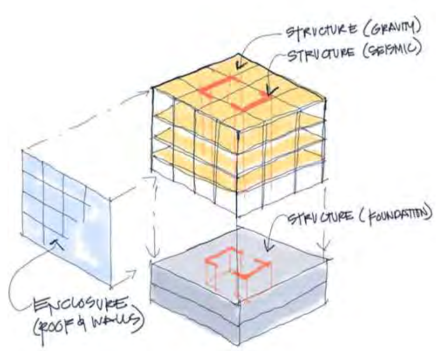
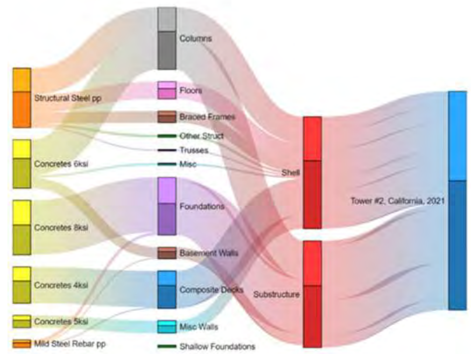
EC3

Carbon Smart Estimating



Life Cycle Impact Results (per m³)
Declared Unit: 1 m³ of 10,000 psi concrete at 28 days

OPERATIONAL IMPACTS	PerformX™ PECC10K
Plant Operating Energy (MJ)	38.6
On-Site Plant Fuel Consumption (MJ)	11.1
Concrete Batch Water (m^3)	1.68E-01
Concrete Wash Water (m^3)	1.91E-02
On-Site Waste Disposal (kg)	0.0
ENVIRONMENTAL IMPACTS	
Total Primary Energy (MJ)	3,017
Climate Change (kg CO_2 eq)	445
Ozone Depletion (kg CFC 11 eq)	1.31E-08
Acidification Air (kg SO_2 eq)	2.96
Eutrophication (kg N eq)	0.09
Photochemical Ozone Creation (kg O_3 eq)	0.61



MATERIAL QUANTITY ESTIMATE × EMBODIED CARBON PER MATERIAL EPDs = BUILDING EMBODIED CARBON (EC) ESTIMATE

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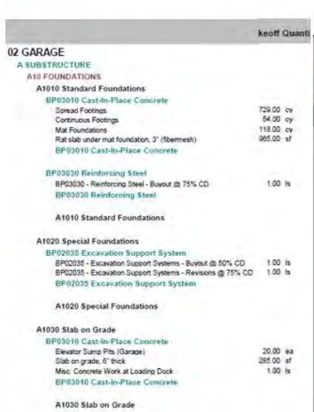
EC3

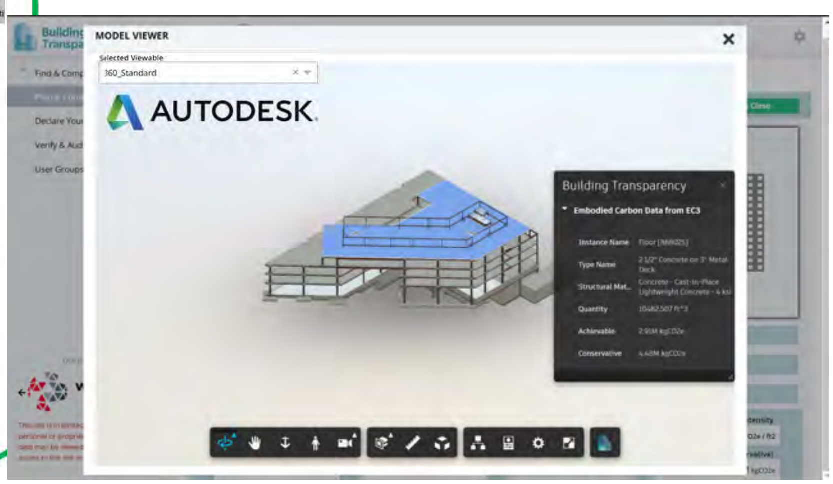
Carbon Smart Estimating

Estimate Quantities



Into EC3

Building Material Quantities from Estimates, BIM, or Tally



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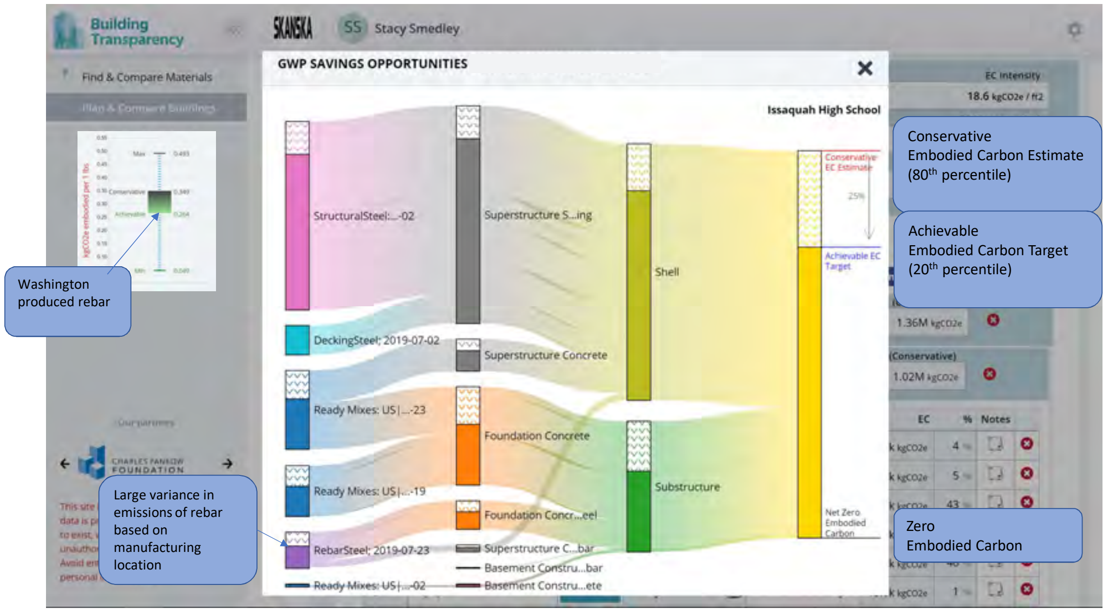
EC3

Carbon Smart Estimating



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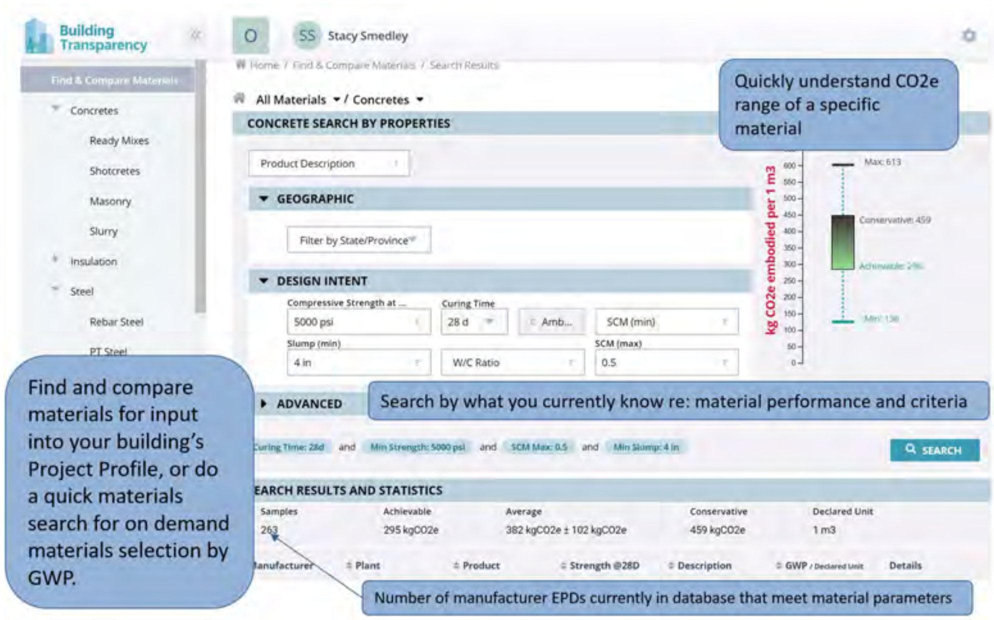
EC3

Carbon Smart Procurement



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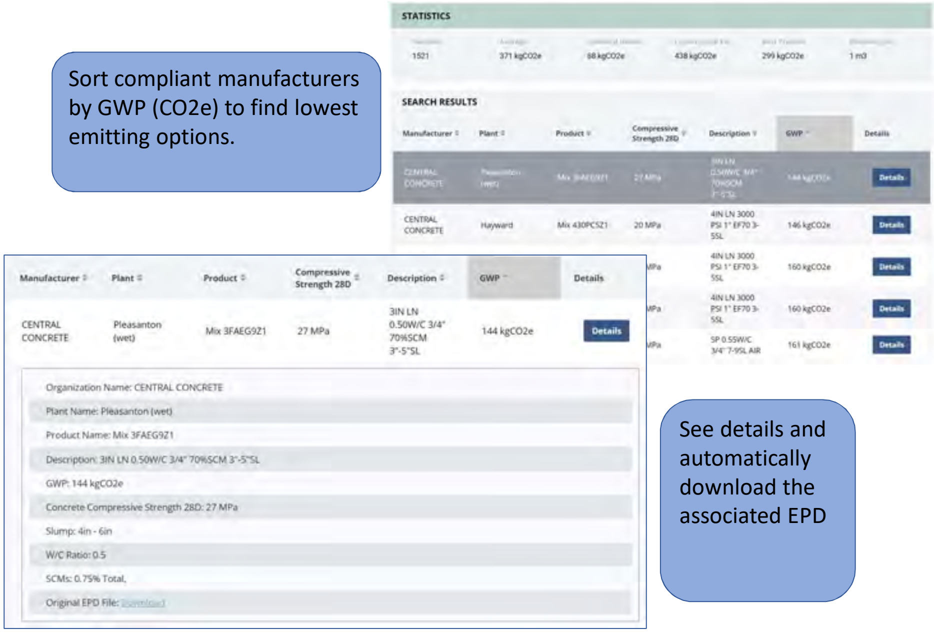
EC3

Carbon Smart **Procurement**

Sort compliant manufacturers by GWP (CO2e) to find lowest emitting options.



See details and automatically download the associated EPD

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EC3

Carbon Smart **Procurement**

Set Targets, Inform Procurement

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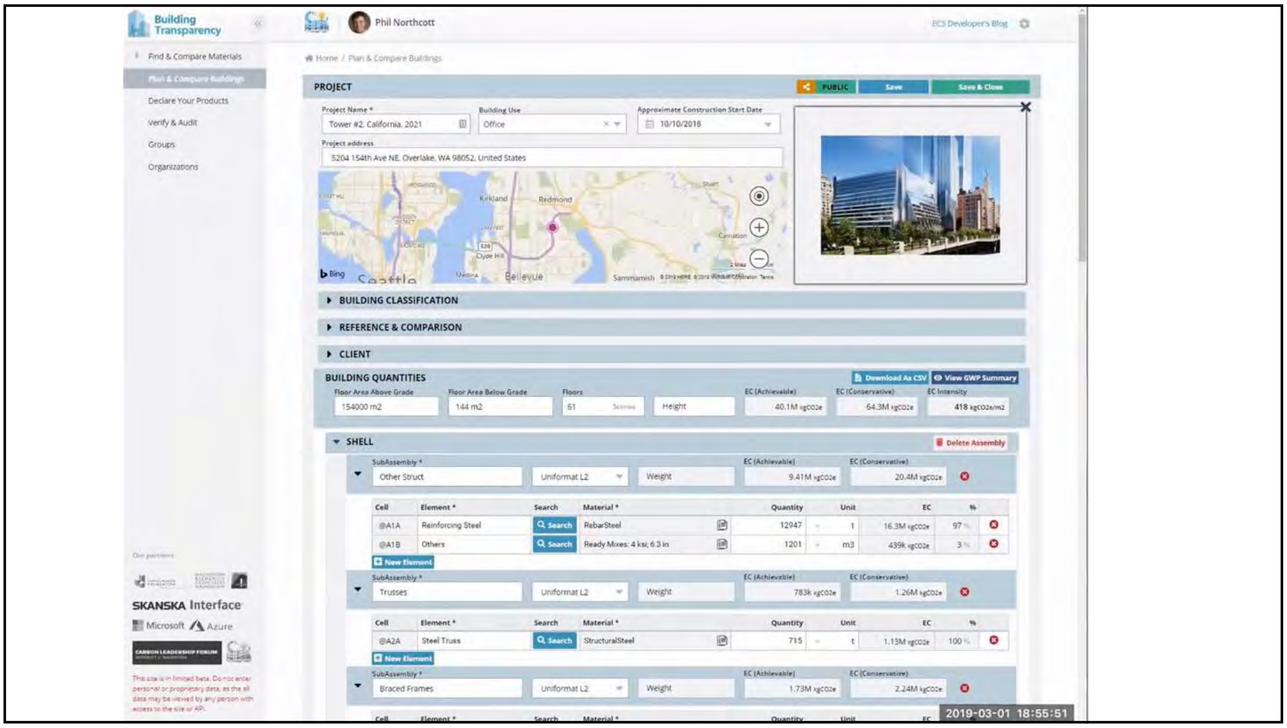

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PROJECT SPONSORS

EC3: Embodied Carbon in Construction Calculator

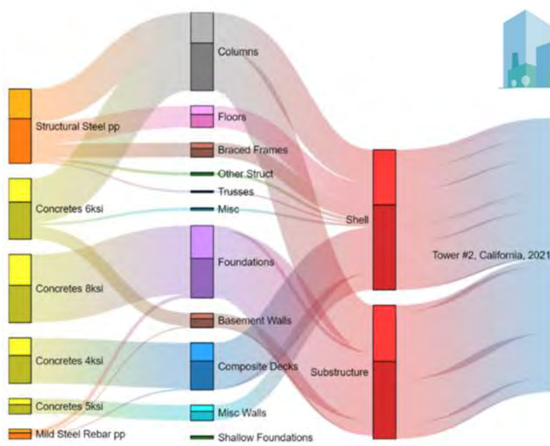
CHARLES PANKOW FOUNDATION
MAGNUSSON KLEMENCIC ASSOCIATES FOUNDATION
SKANSKA
Interface
AISC
AIA
aci Foundation
Microsoft
ALEXANDRIA.
AUTODESK.
WEBCOR
Perkins&Will

NEW PILOT SPONSORS!

walter p moore
BASF We create chemistry
Port of Seattle

PROJECT SUPPORTERS

Armstrong
BLUEGREEN ALLIANCE FOUNDATION
CARBON CURE.
Kingspan.
USG



EC3

PROJECT LEADERSHIP

CLF Carbon Leadership Forum
UNIVERSITY of WASHINGTON
cchange labs

www.buildingtransparency.org
www.carbonleadershipforum.org

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Q&A

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EMBODIED CARBON AND BUILDING MATERIALS:
REDUCTION STRATEGIES

RAPHAEL SPERRY
ASSOCIATE | SUSTAINABILITY
raphael.sperry@arup.com

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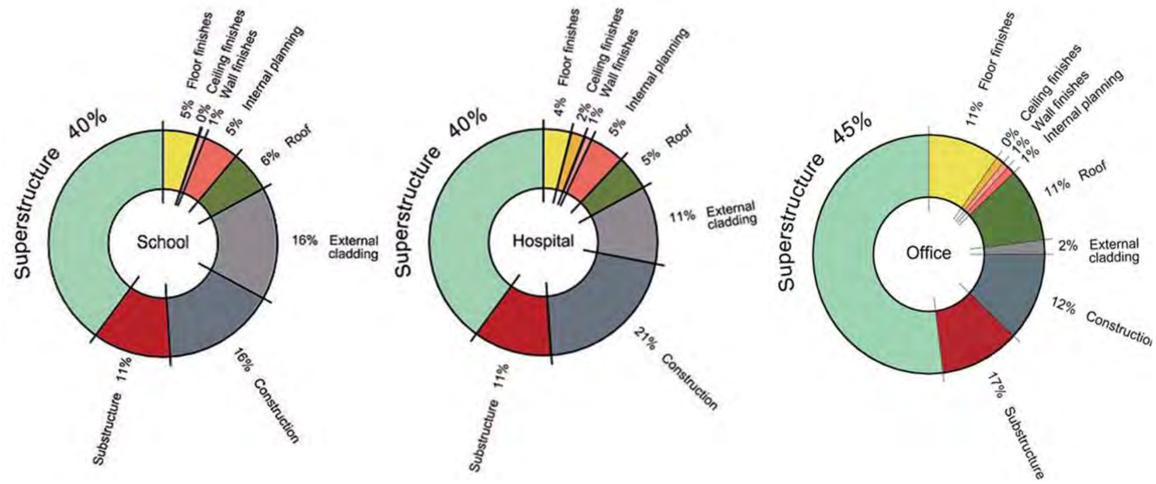
MOST OF THE CARBON IN A BUILDING IS IN THE STRUCTURE



Ref: Arup, *Embodied Carbon Study,* Concrete Centre 2012.

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MOST BUILDING STRUCTURES ARE STEEL, CONCRETE, OR WOOD

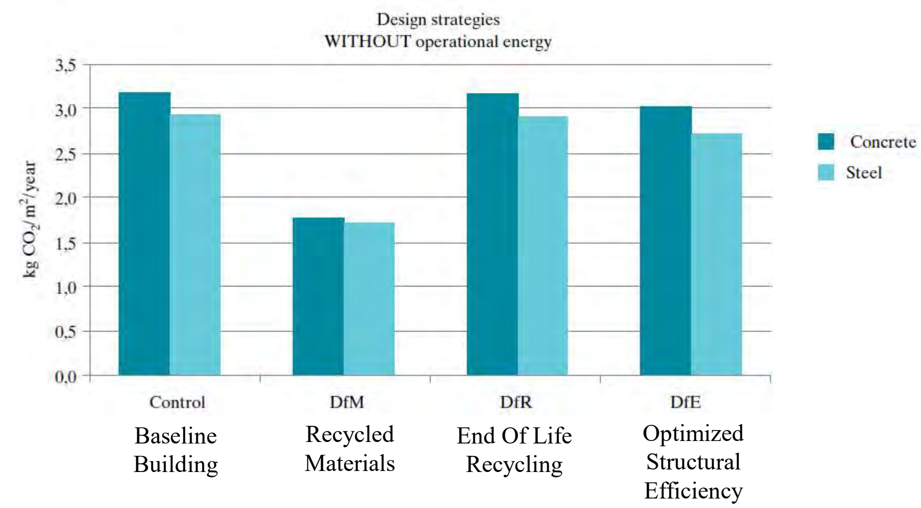
TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (HOURS)

	Concrete		Steel		Masonry		Wood		
BUILDING ELEMENT	**TYPE I**		**TYPE II**		**TYPE III**		**TYPE IV**	**TYPE V**	
	A	**B**	**A**	**B**	**A**	**B**	**HT**	**A**[d]	**B**
Primary structural frame[f] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls Exterior[e, f] Interior	 3 3[a]	 2 2[a]	 1 1	 0 0	 2 1	 2 0	 2 1/HT	 1 1	 0 0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[d]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and associated secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and associated secondary members (see Section 202)	$1^1/_2$[b]	1[b,c]	1[b,c]	0[c]	1[b,c]	0	HT	1[b,c]	0

Ref: California Building Code

46

REDUCING EMBODIED CARBON IN STRUCTURES



Ref: Anderson, John & Silman, Robert. (2009). A Life Cycle Inventory of Structural Engineering Design Strategies for Greenhouse Gas Reduction. Structural Engineering International. 19. 283-288. 10.2749/101686609788957946.

47

REDUCING EMBODIED CARBON IN STRUCTURES: LONG SPAN

- Comparison of airport structures designed by Arup
- Highly project specific
- Space frames can be efficient, have a broad range
- Material optimization is possible

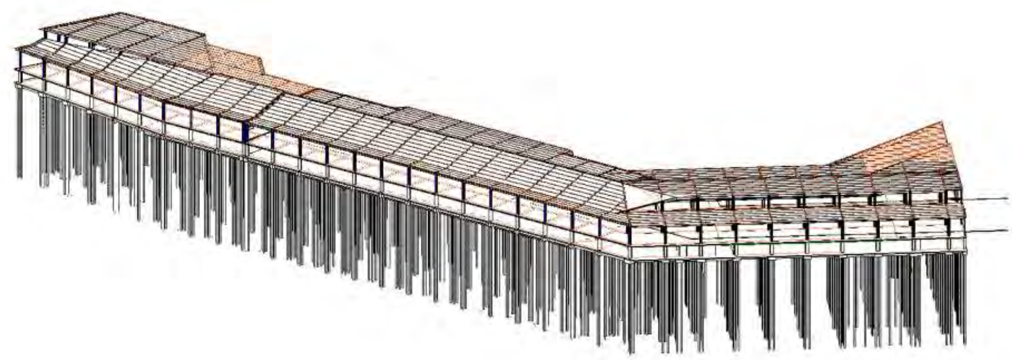
Airport	Structure Type	Space Type	Structural Efficiency	D
NAICM MEX	**Space frame to ground**	**Terminal + Concourse**	**42-54 kg/m²** Sum of Space Frame & Funnels per "Design Basis Roof Quantities Overview.xlsx"	
King Abdulaziz International Airport (KAIA)	Space frame on columns	Terminal -Post-security international hub	106 kg/m²	
Abu Dhabi International Airport (ADIA)	Space frame on columns	Terminal- Passenger Processor	244 kg/m²	
Beijing Capital International Airport Terminal 3	Space frame on columns	Terminal – Passenger Processor (typical bay)	130 kg/m²	
Dublin Airport Terminal 2	Steel post and beam	Terminal – Passenger Processor	285 kg/m²	

Ref:Arup

48

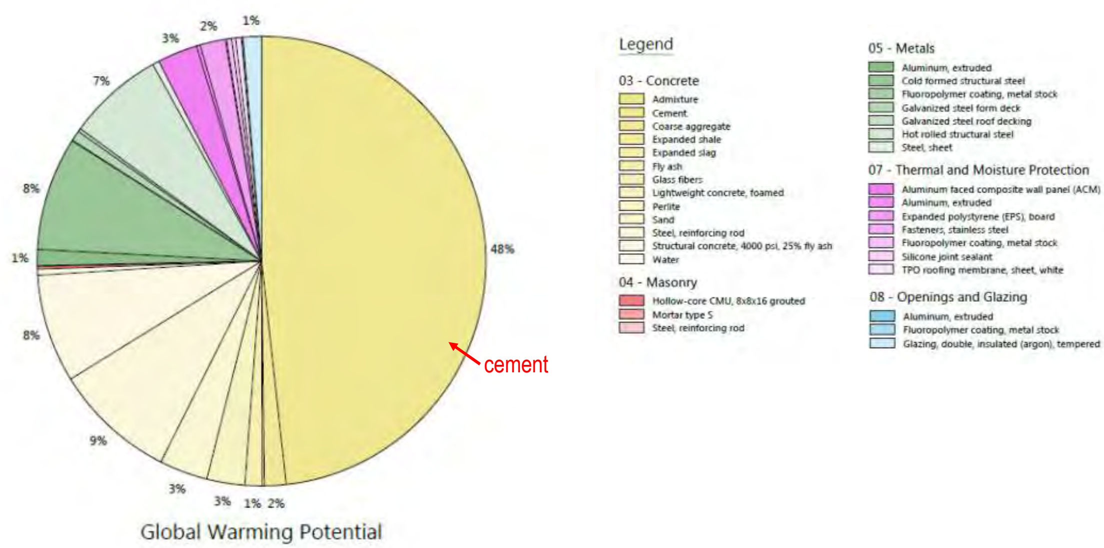
REDUCING EMBODIED CARBON IN STRUCTURES: STEEL STRATEGIES

- Material reuse (e.g. salvaged steel piles, structural sections, open-web joists)
- Low-GWP specification:
  - short-term, switches demand
  - long-term, may shift market



49

REDUCING EMBODIED CARBON IN STRUCTURES: CONCRETE

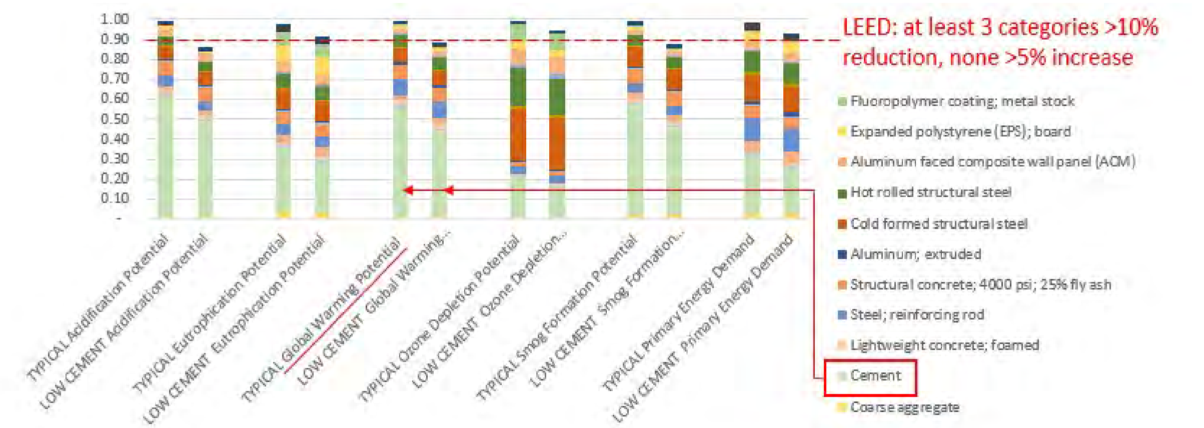


Ref: San Francisco International Airport, Boarding Area B

50

REDUCING EMBODIED CARBON IN STRUCTURES: CONCRETE

Concrete mix designs reduce total project global warming potential impact by more than 10%

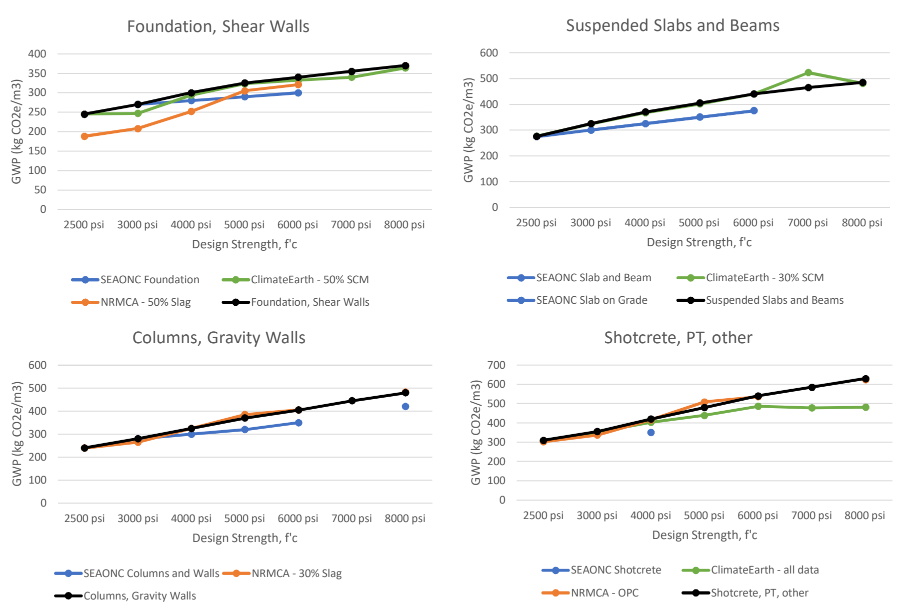


Ref: San Francisco International Airport, Boarding Area B

51

REDUCING EMBODIED CARBON IN STRUCTURES: CONCRETE STRATEGIES

- Select the lowest GWP mix for each element
- Don't overdesign
- Replace cement with SCMs
- Allow for longer strength gain



52

REDUCING EMBODIED CARBON IN STRUCTURES: CONCRETE MODEL SPECIFICATIONS

Bay Area Built Environment Embodied Emissions Project

This project aims to reduce embodied emissions in the built environment by creating local specifications and model policies for low embodied-carbon concrete, developed through a robust regional stakeholder engagement process. The County of Marin leads with project funding from the Bay Area Air Quality Management District, in partnership with StopWaste, Ecological Building Network, Arup, and Carbon Leadership Forum. The project proposal was also supported by City and County of San Francisco, County of Alameda, City of Berkeley, USGBC, and over 30 building industry companies and organizations that work in the Bay Area.

Bay Area stakeholders are encouraged to participate:

Local governments: Participate in the working group to shape the model policy; consider adoption of standards in late 2019.
Developers: Submit a project that will complete by 2022 to be considered for engineering assistance.
Building professionals: Participate in the working group and help shape the specifications.

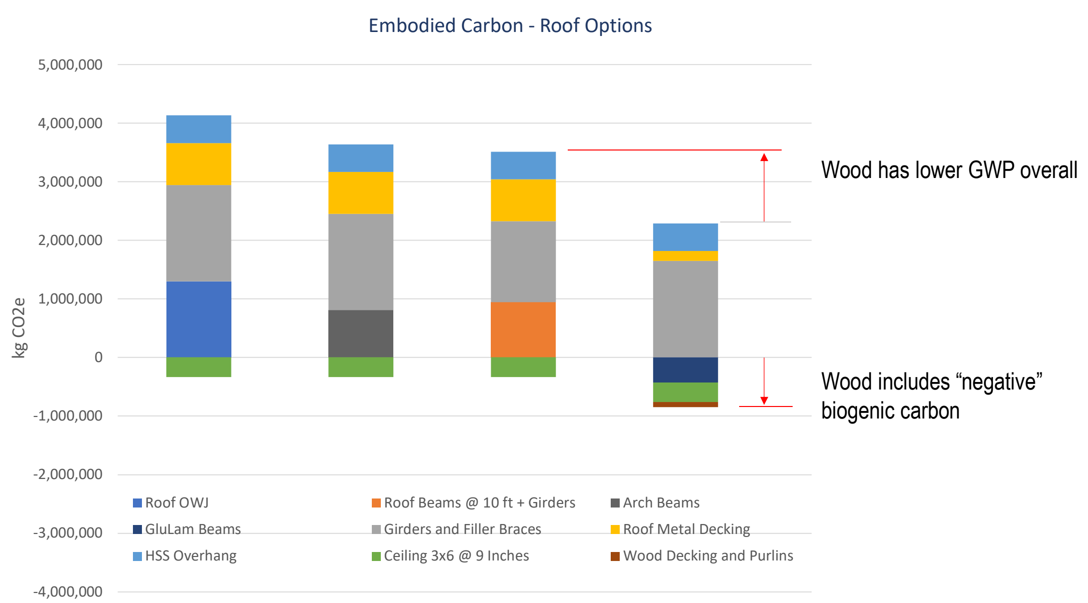
Project Outcomes:

1. **Model code language** for adoption by local governments starting with County of Marin
2. Low embodied-carbon concrete **specifications** for residential and non-residential applications
3. **Four pilot projects** receiving technical assistance to apply the specifications
4. Formation of a **Bay Area Regional Materials Working Group** as an extension of the Embodied Carbon Network

Contact Marin County to learn more:
azanmiller@marincounty.org or
(415) 473-2797

53

REDUCING EMBODIED CARBON IN STRUCTURES: WOOD

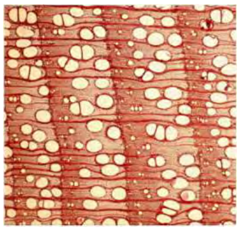


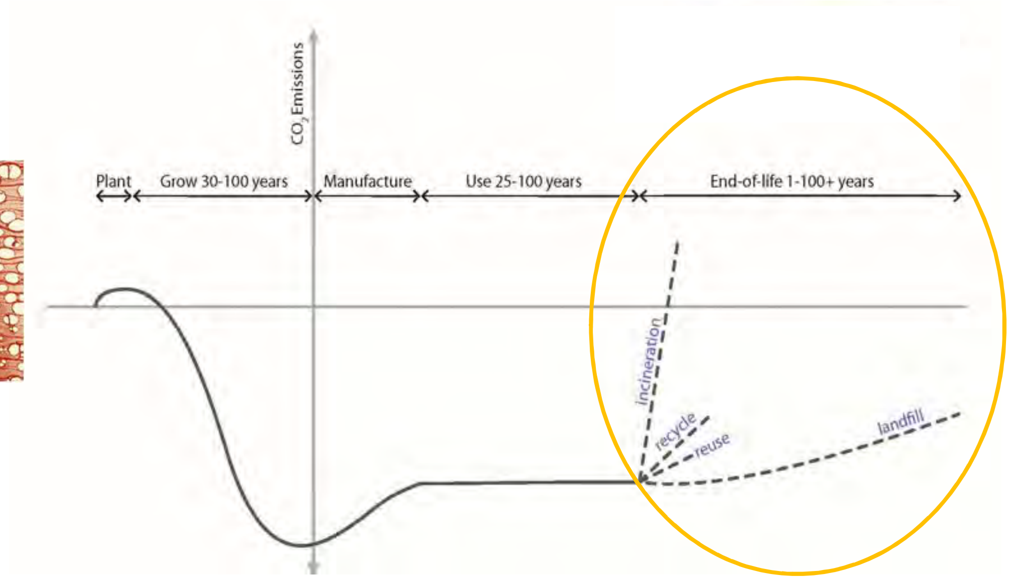
Wood has lower GWP overall

Wood includes "negative" biogenic carbon

54

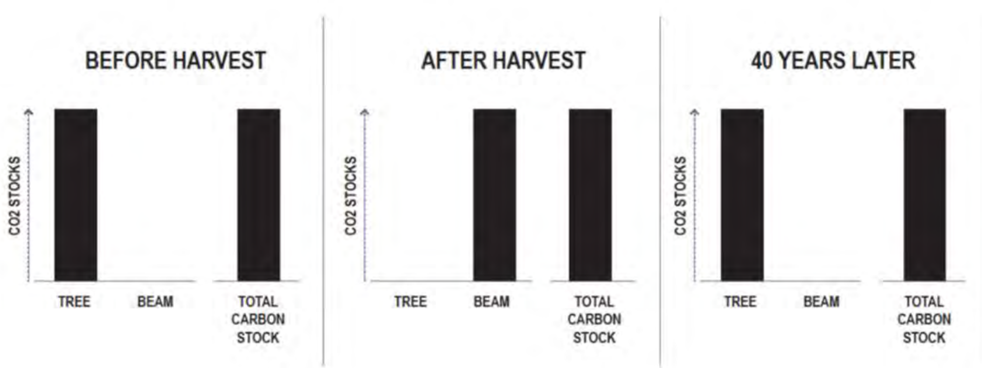
WHAT IS BIOGENIC CARBON?





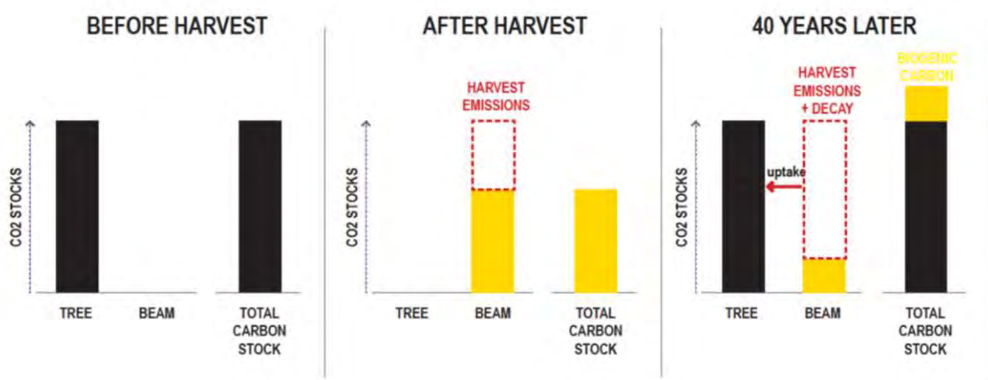
55

BIOGENIC CARBON – INACCURATE SIMPLISTIC VIEW



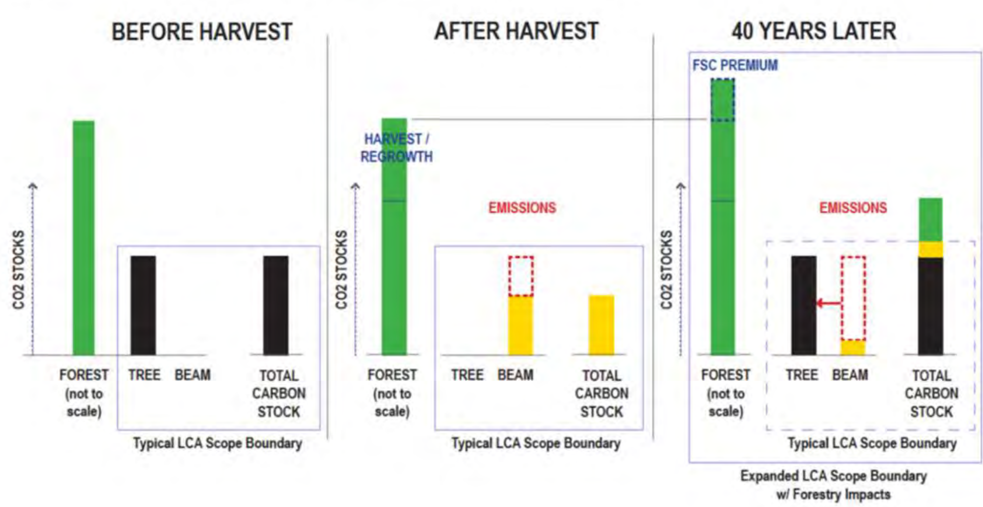
56

BIOGENIC CARBON – MORE ACCURATE SIMPLE VIEW



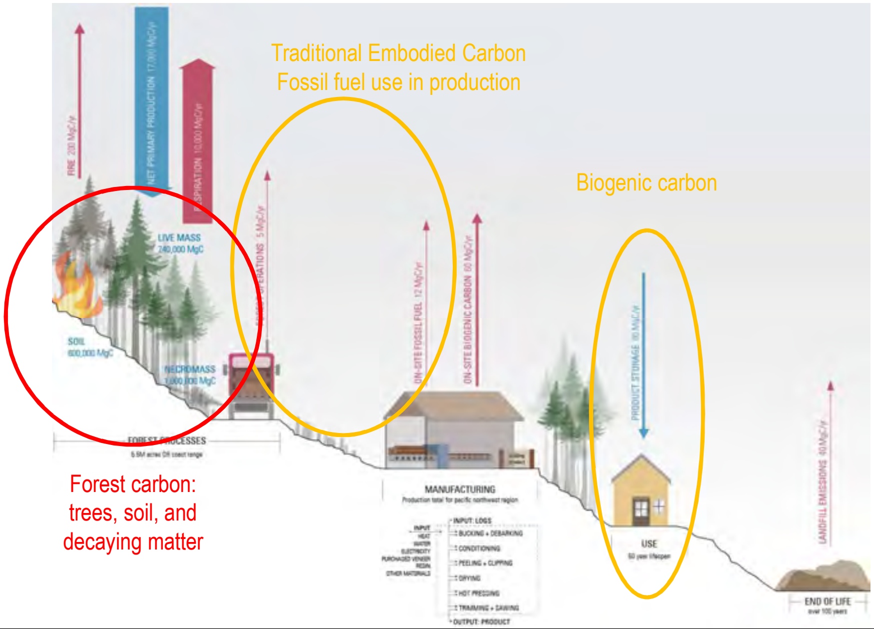
57

BIOGENIC CARBON – ADDING IN FOREST DYNAMICS



58

WHERE IS MOST OF THE CARBON IN FORESTRY?



Fossil fuels: 17 MgC/yr
Biogenic Carbon: 60 MgC/yr
Forest Carbon **2,500,000** MgC

(for 5.5M acres of Oregon Coast Range)

59

WHERE IS MOST OF THE CARBON <u>ACCOUNTED FOR</u> IN WOOD BUILDINGS?

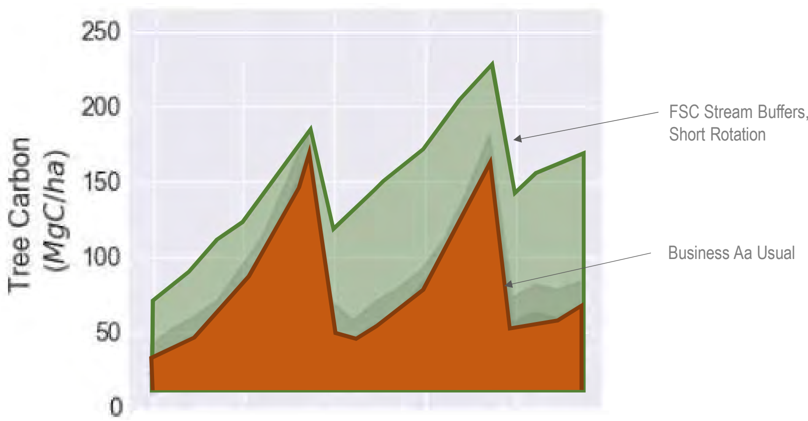
EPD:	Fossil fuels	17 MgC/yr
EPD w/ biogenic carbon:	+ Durable Products	60 MgC/yr
Impact on Forest stocks:	(nowhere)	250,000 Mg/C

a .025% change in forest stocks is a bigger carbon impact than all durable products…

not even considering other benefits to water quality, biodiversity, local economy, etc.

60

POTENTIAL CARBON IMPACT OF IMPROVING FOREST PRACTICES IS LARGE



FSC forestry can store ~36% more carbon per acre just in tree biomass than business as usual in Oregon, or ~1.8 tons CO2e per hectare per year just counting stream buffers

Tradeoffs in Timber, Carbon, and Cash Flow under Alternative Management Systems for Douglas-Fir in the Pacific Northwest

David D. Diaz [1,2,*], Sara Loreno [2], Gregory J. Ettl [1] and Brent Davies [2]

[1] School of Environmental and Forest Sciences, University of Washington, P.O. Box 352100 Seattle, WA 98195-2100, USA; ettl@uw.edu

[2] Ecotrust, 721 NW Ninth Ave, #200. Portland, OR 97209, USA; sloreno@ecotrust.org (S.L.); bdavies@ecotrust.org (B.D.)

61

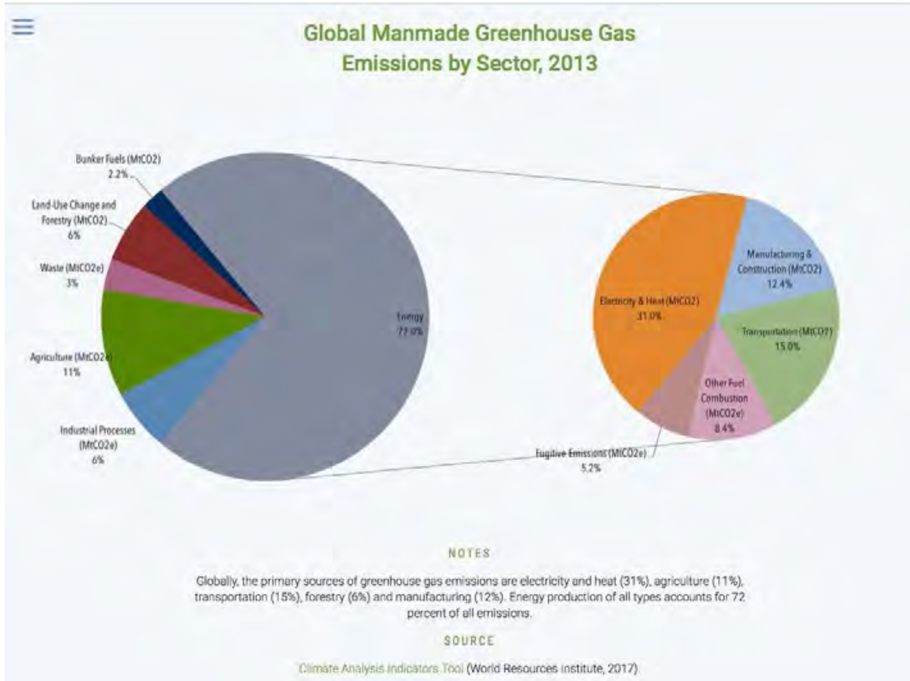
THE REGENERATIVE POTENTIAL OF SUPPLY CHAINS

62

BURNING FOSSIL FUELS ISN'T THE ONLY MAJOR SOURCE OF GREENHOUSE GAS EMISSIONS.

According to the IPCC, the agriculture, forestry, and land use (AFOLU) sector is responsible for about one-quarter of global greenhouse gas emissions.

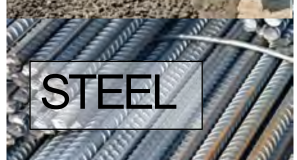
This proportion is slightly smaller in the US (right.)



63

SUPPLY CHAIN TYPES FOR BUILDING MATERIALS

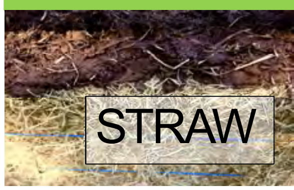
MINERAL-BASED SUPPLY CHAINS

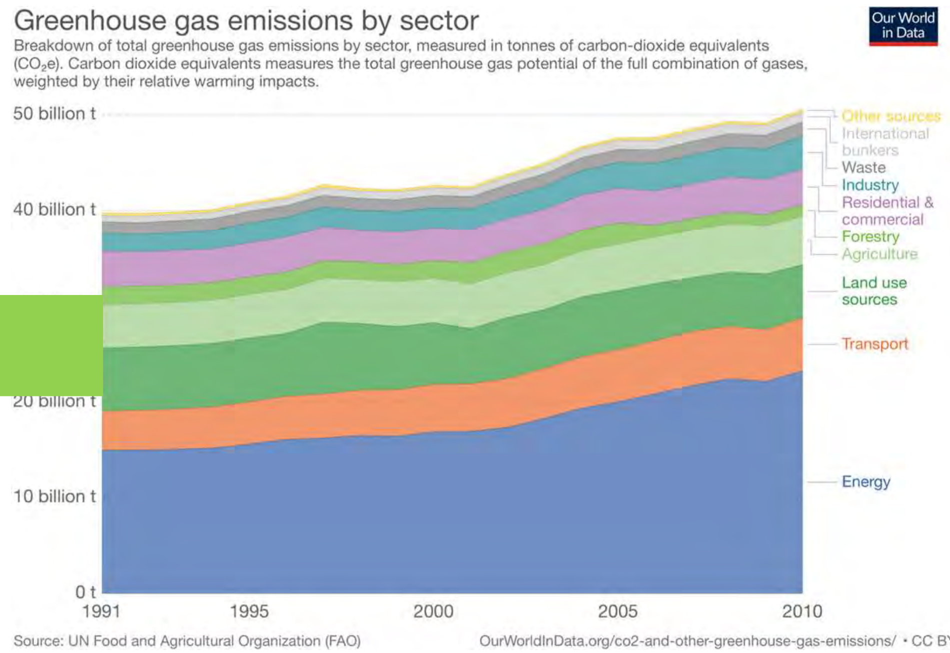


ECOSYSTEM-BASED SUPPLY CHAINS

64

ECOSYSTEM-BASED SUPPLY CHAINS

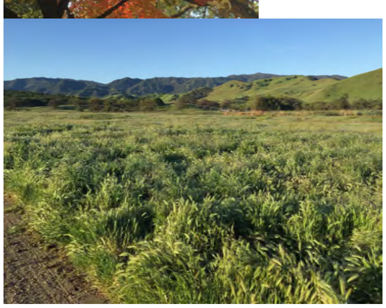




65

THE CURRENT CARBON BASELINE IN ECOSYSTEM SUPPLY CHAINS

FORESTS LOSS OF GLOBAL FOREST COVER • LOSS OF BIODIVERSITY/OLDER, MORE COMPLEX FORESTS • LOSS OF SOIL CARBON IN FORESTS

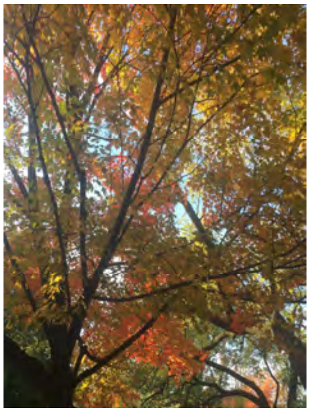


AGRICULTURAL LANDS/GRASSLANDS

SIGNIFICANT LOSS OF ORGANIC SOIL CARBON TO A DEPTH OF SEVERAL FEET OVER THE PAST 200 YEARS AS A RESULT OF INDUSTRIAL AGRICULTURE AND GRAZING

66

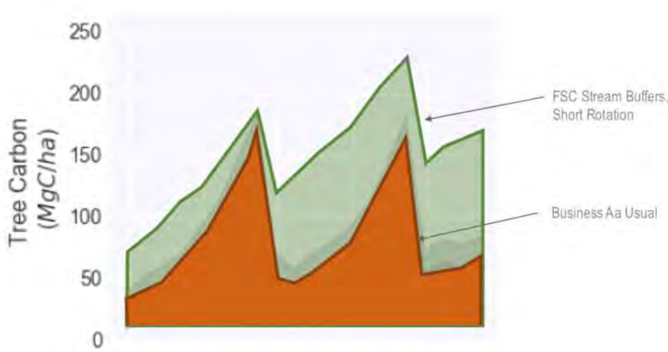
FORESTS: OPPORTUNITIES FOR CARBON SEQUESTRATION



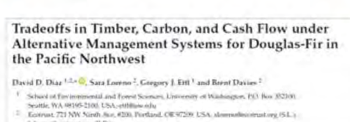
1. MAKING MORE FOREST: REFORESTATION AND AFFORESTATION
2. ADDING AGE TO A FOREST ECOSYSTEM
3. ADDING TO THE ABOVEGROUND CARBON IN A FOREST ECOSYSTEM
4. ADDING TO THE BELOWGROUND CARBON IN A FOREST

67

POTENTIAL IMPACT OF FOREST PRACTICES IS LARGE



FSC forestry can store ~36% more carbon per acre just in tree biomass than business as usual in Oregon, or ~1.8 tons CO2e per hectare per year just counting stream buffers



Tradeoffs in Timber, Carbon, and Cash Flow under Alternative Management Systems for Douglas-Fir in the Pacific Northwest

David D. Diaz [1,2,*], Sara Loreno [2], Gregory J. Ettl [1] and Brent Davies [2]

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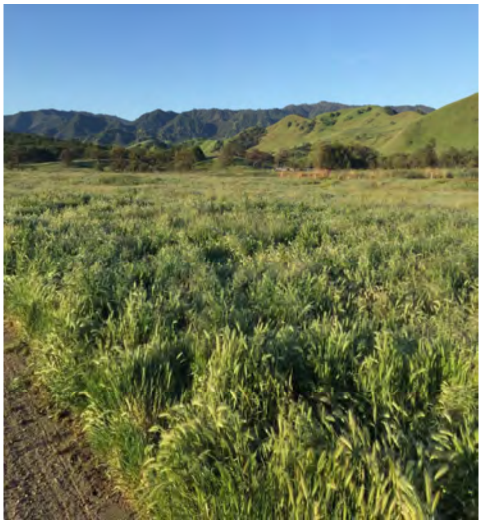
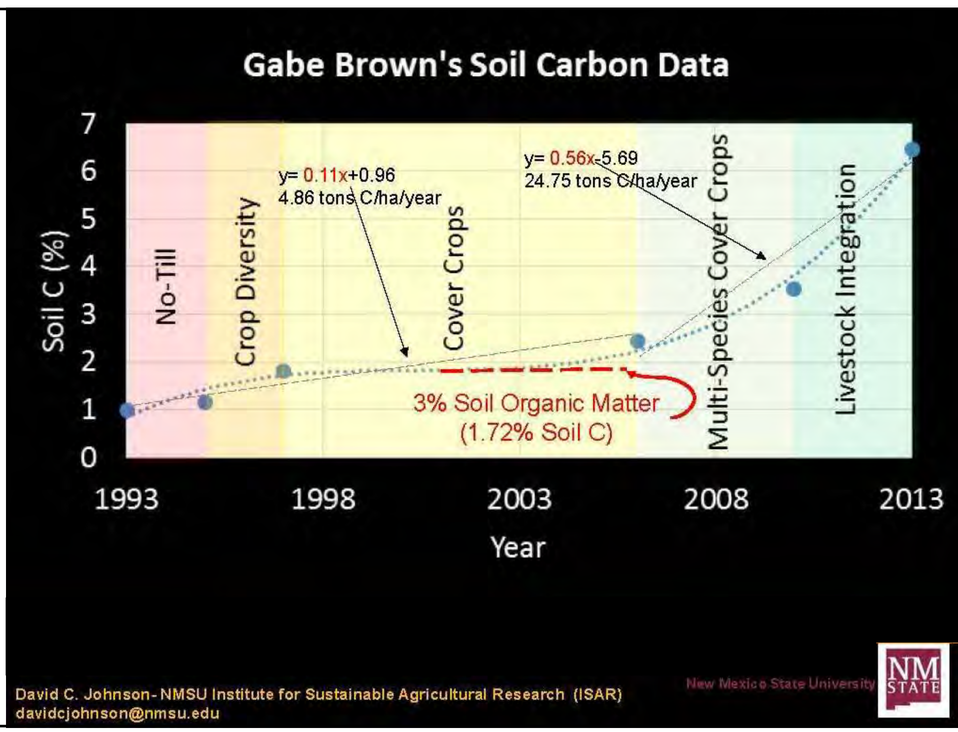
AGRICULTURE AND GRASSLANDS: OPPORTUNITIES FOR CARBON SEQUESTRATION



1. Land management practices that support rebuilding stable soil carbon at depth through the liquid carbon pathway
2. Working with the annual cycles of grassland ecosystems to intensify the rate of soil carbon sequestration
3. Creating agricultural ecosystems with multiple yields above- and belowground, supporting the soil microbiome

69

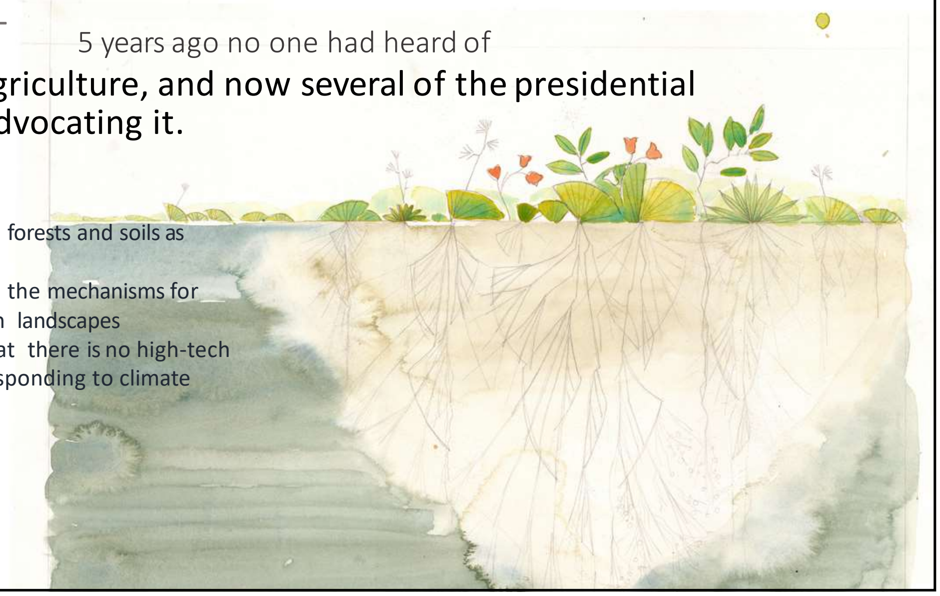


70

THE EXPONENTIAL GROWTH CURVE OF CARBON-SEQUESTERING LAND MANAGEMENT

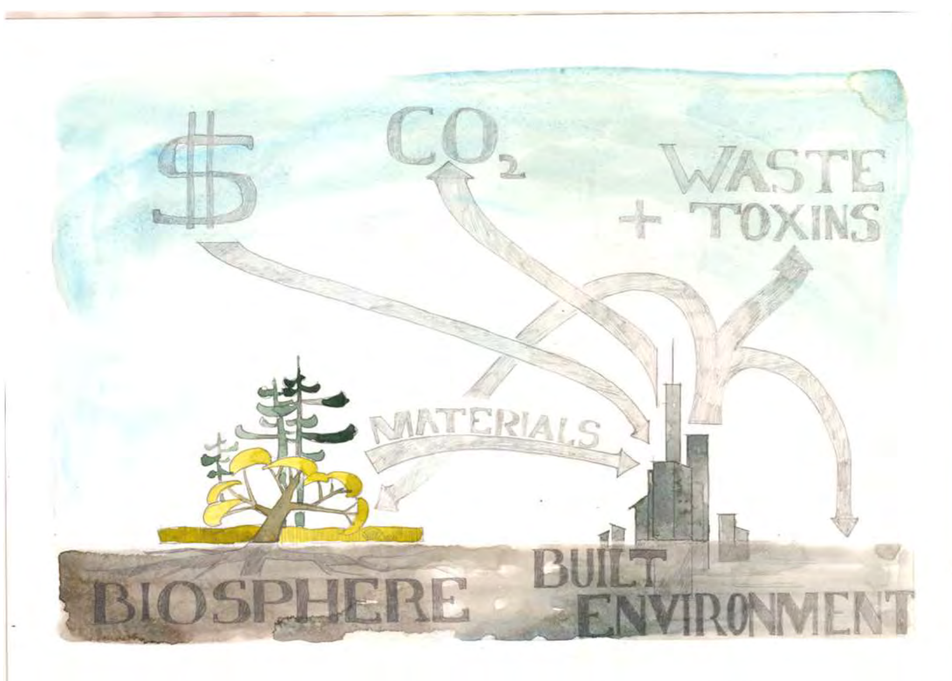
5 years ago no one had heard of

- regenerative agriculture, and now several of the presidential candidates are advocating it.



- Growing awareness of forests and soils as powerful carbon sinks
- Growing awareness of the mechanisms for sequestering carbon in landscapes
- Growing awareness that there is no high-tech
- “silver bullet” for responding to climate change

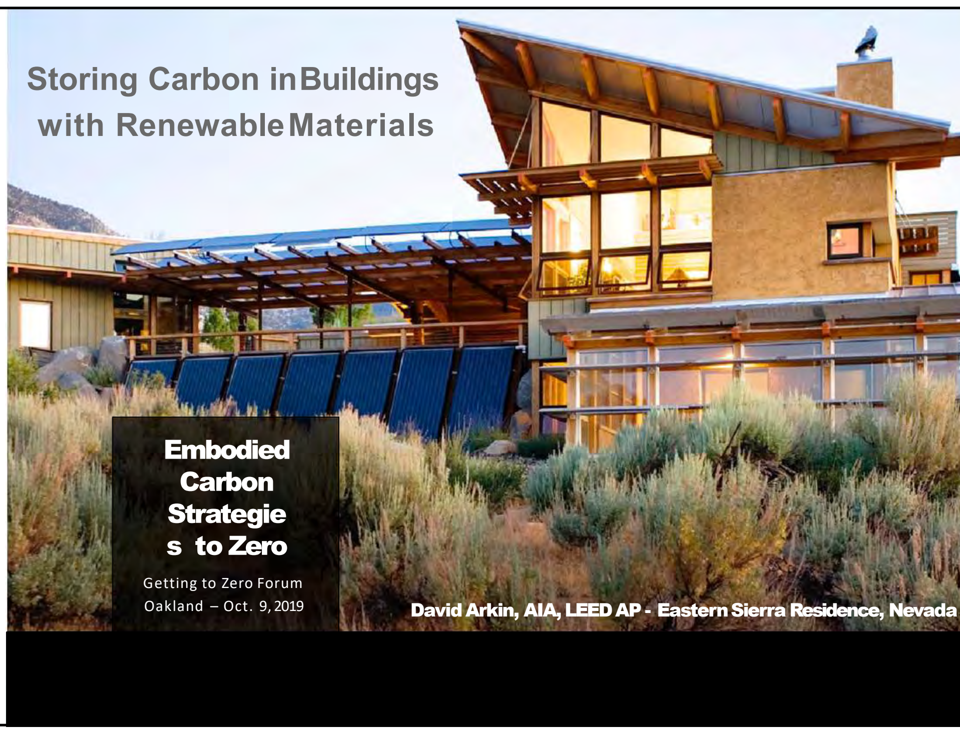
71



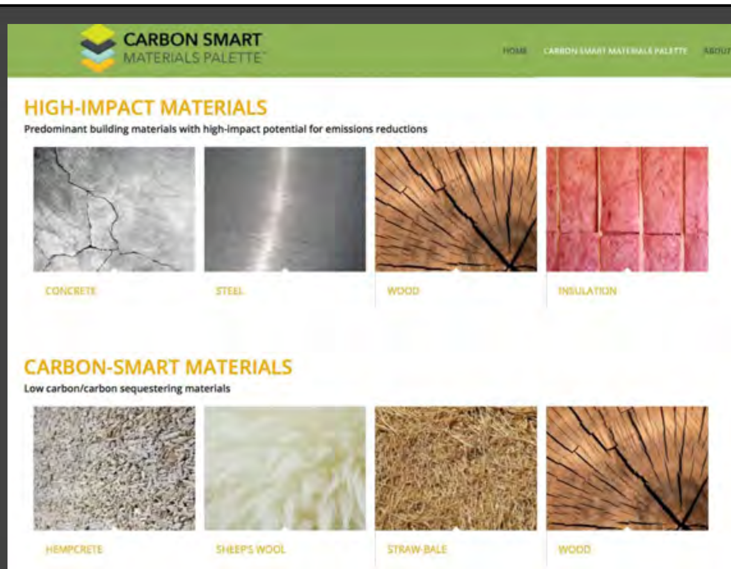
72


CO2
$
WASTE =
MATERIALS
BUILT
ENVIRONMENT
BIOSPHERE

73


Storing Carbon in Buildings
with Renewable Materials
Embodied
Carbon
Strategie
s to Zero
Getting to Zero Forum
Oakland – Oct. 9, 2019
David Arkin, AIA, LEED AP - Eastern Sierra Residence, Nevada

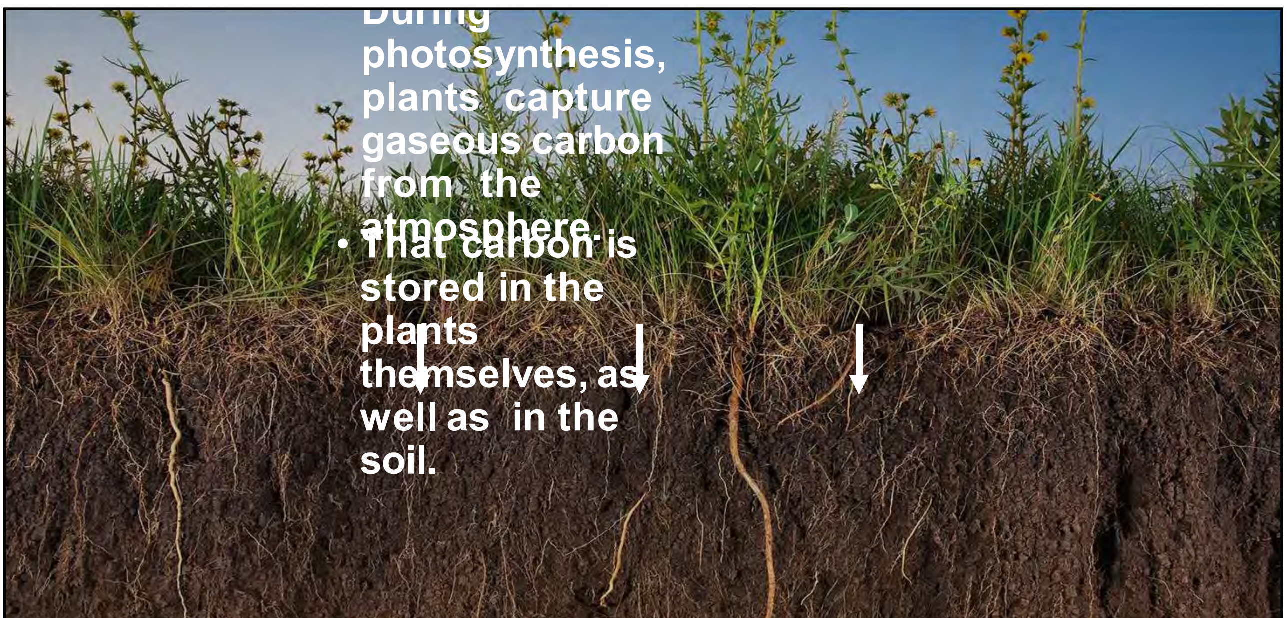
74



www.materialspalette.org

[redacted]

75



[redacted]

76

2.16 billion tons of grain straw **were grown globally in 2016. That's enough carbon storage to** offset all current transportation GHG emissions **and more than** replace all current insulation materials.

77

BUILD SHELTER.

78

BUILD SHELTER.

NOT TOO BIG.

79

BUILD SHELTER.

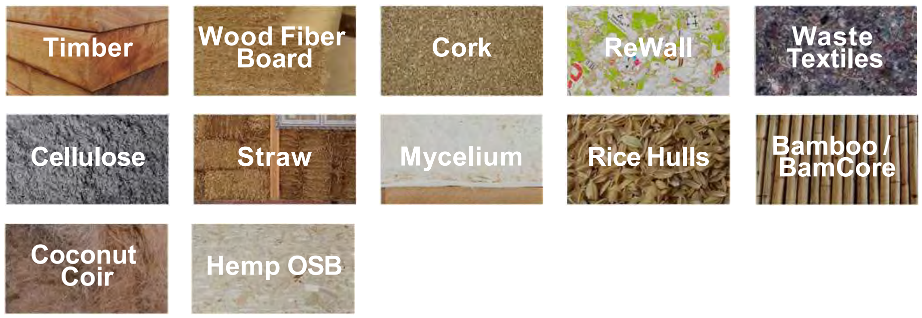
NOT TOO BIG.

MOSTLY PLANTS.

[with thanks / apologies to Michael Pollan / 'Food Rules']

80

There are lots of plant-based, carbon-storing building materials

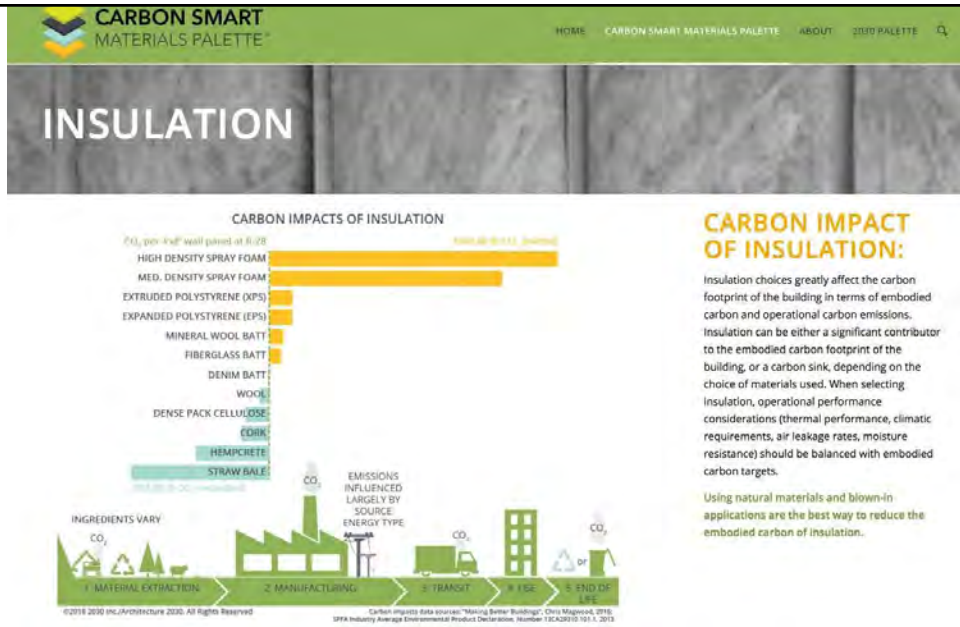


… materials that are healthier and safer too!

81

Insulation Products

82



83

Cellulose **Sheep's Wool** **Cotton / Denim**

CAVITY INSULATION

84

Cork Stramit / Durra Wood Fiberboard

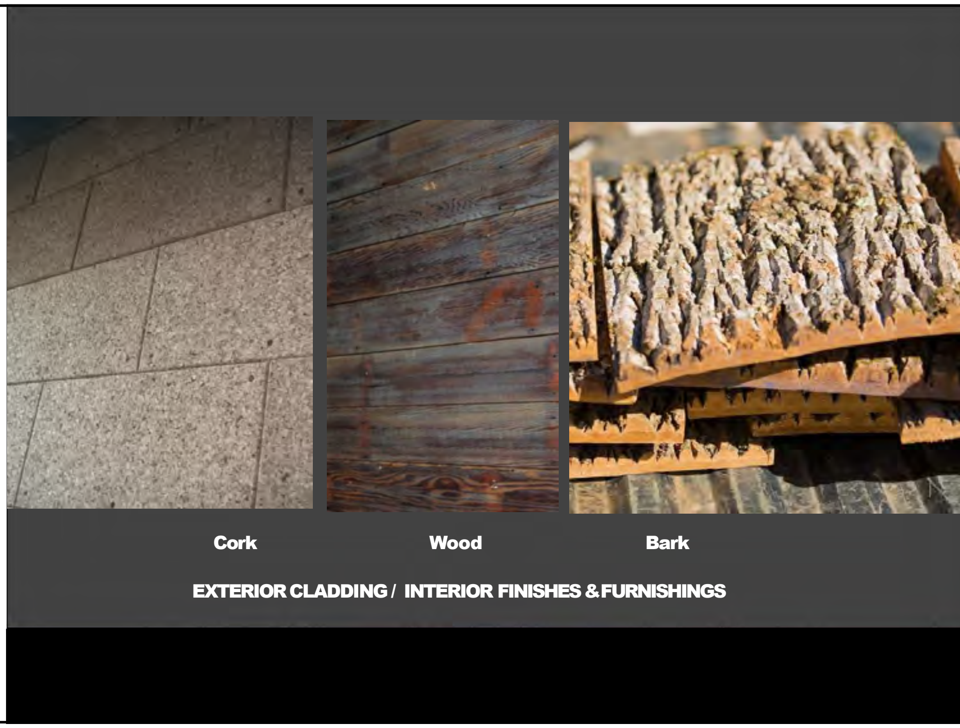
SHEATHING / ENVELOPE WRAP

85

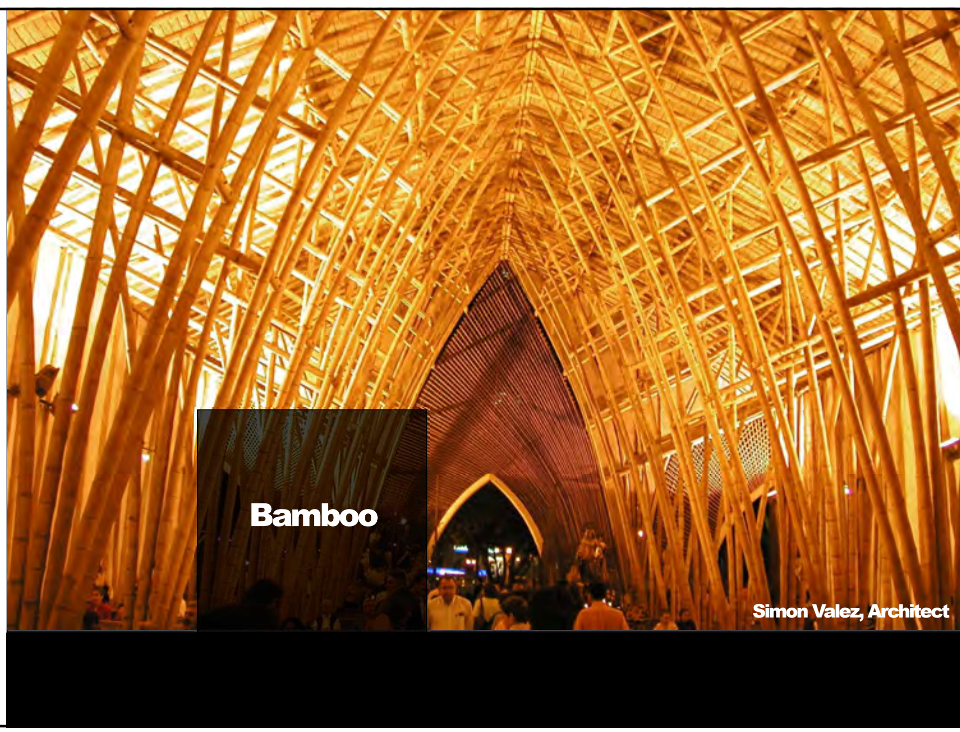
Mycellium Root Mat

EMERGING INSULATION PRODUCTS

86


Cork
Wood
Bark
EXTERIOR CLADDING / INTERIOR FINISHES & FURNISHINGS

87


Bamboo
Simon Valez, Architect

88

BamCore House by 361 Architecture – Mill Valley, CA

89

Hempcrete

Marks & Spencer Cheshire Oaks Store, UK
Aukett Swanke Architects

90

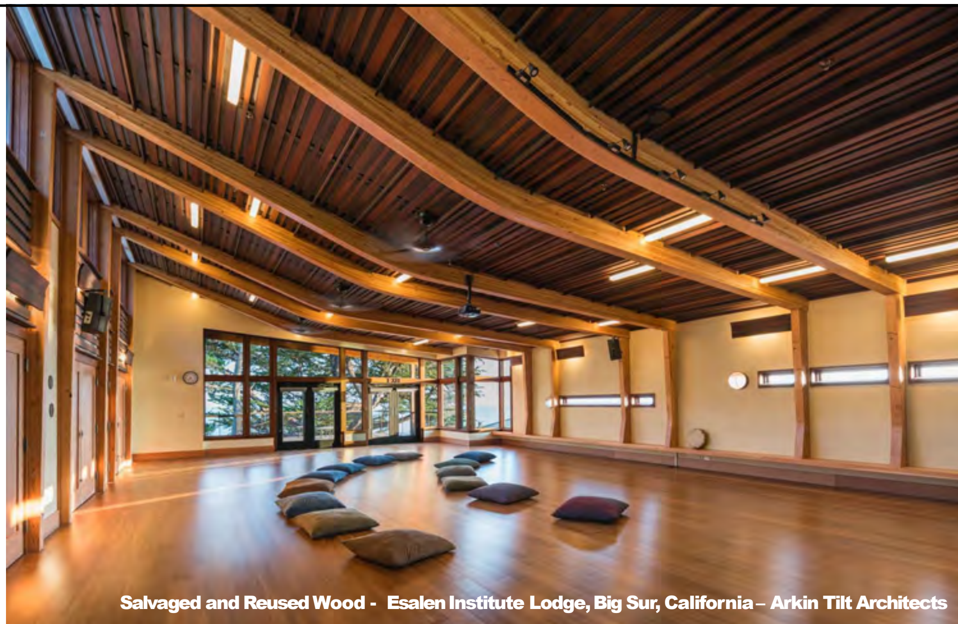

LIME BINDER
WATER
HEMPCRETE INSULATION.
The void space in a hempcrete mix creates pockets of trapped air and is part of the reason the material has desirable thermal properties.


Push House, Asheville, North Carolina
Anthony Brenner Architect

91


Good
Wood
Esalen Institute Lodge, Big Sur, CA – Arkin Tilt Architects

92



Salvaged and Reused Wood - Esalen Institute Lodge, Big Sur, California – Arkin Tilt Architects

93

Esalen Institute Lodge, Big Sur, California – Arkin Tilt Architects

94

CROSS-LAMINATED TIMBER

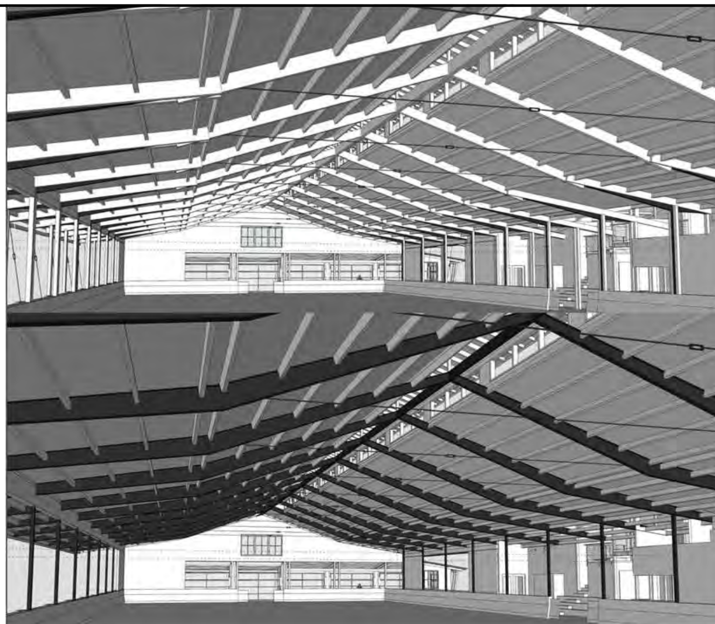
Mo/Dus Architects / Austrian Timber Network

95

TALL TIMBER

T3 Tower, Minneapolis – Michael Green Architecture / DLR Group

96



Wood Hybrid Truss

44,430 BTU per truss (primarily the steel)

Sequestered Carbon: 1357.2 lbs. (wood)

Long-Span Truss Carbon Comparison

Steel I-Beam Truss

71,330 BTU per truss

(60% more carbon, none sequestered)

97

Zero House Project

Clarksburg, Ontario
1,100 square feet, $254/sq.ft.
24 tons of CO_2 storage

- Zero toxins
- 75% net energy production on site
- 90% of materials <250km radius
- 95% less construction waste

98

Unicorn Farm Residence

Middlesex, Vermont

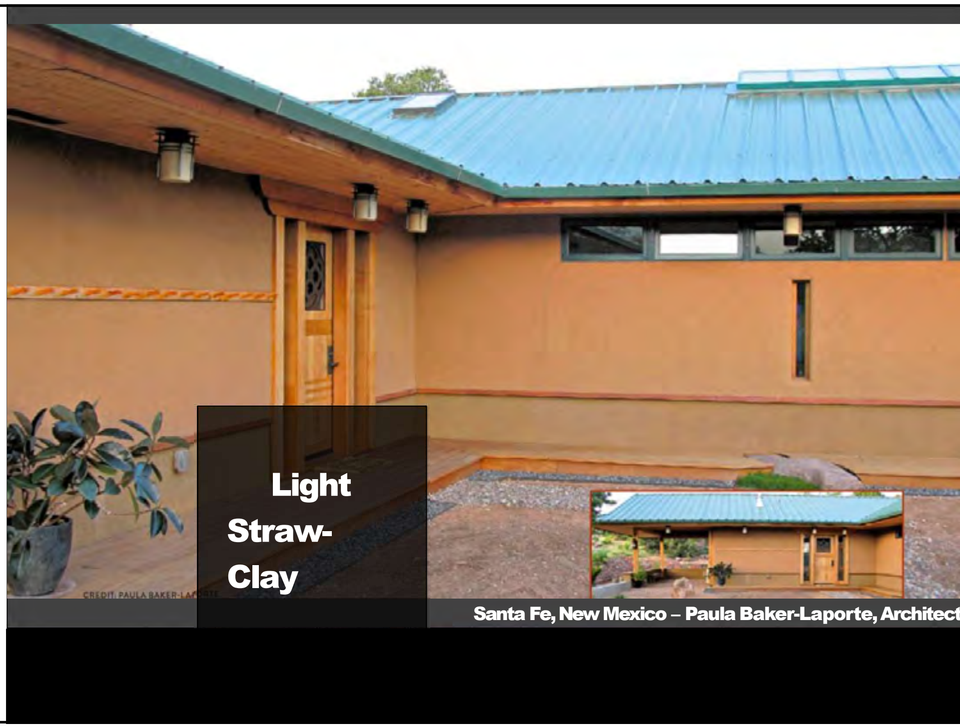
1,650 sf, $303/sq.ft.

Off-grid, fossil fuel and foam-free

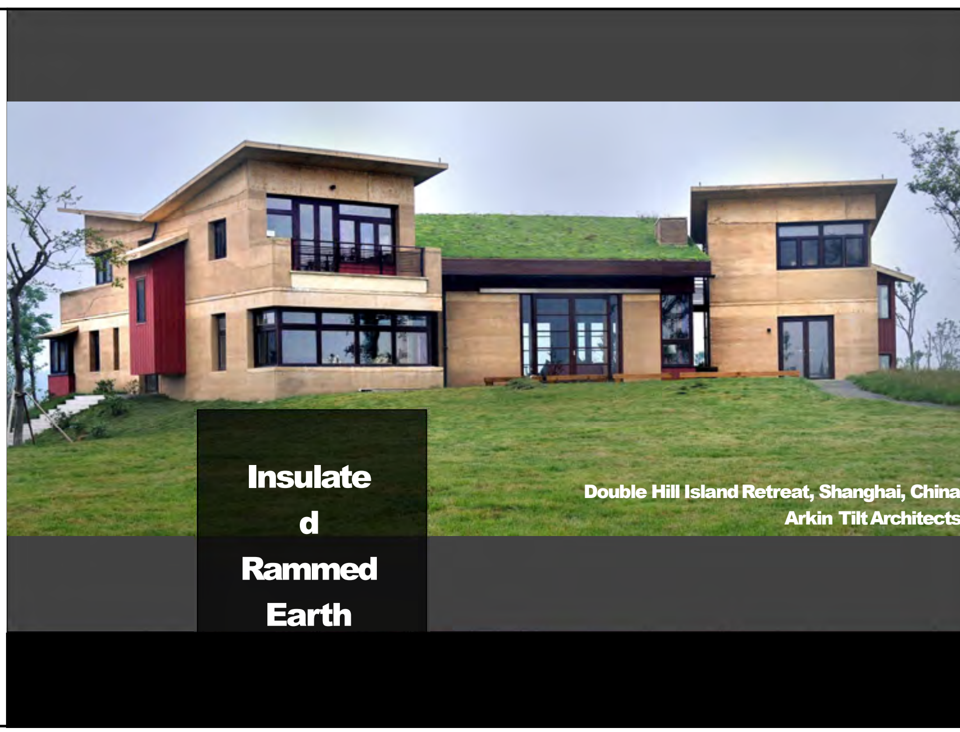
600 kg of net CO_2e storage

99

100


Light Straw-Clay
Santa Fe, New Mexico – Paula Baker-Laporte, Architect

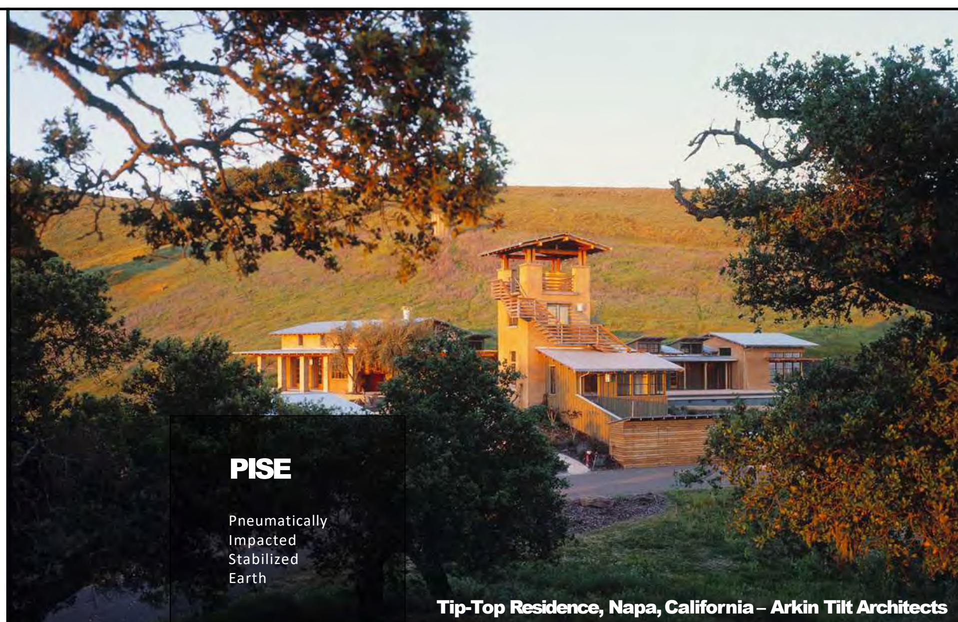
101


Insulated Rammed Earth
Double Hill Island Retreat, Shanghai, China
Arkin Tilt Architects

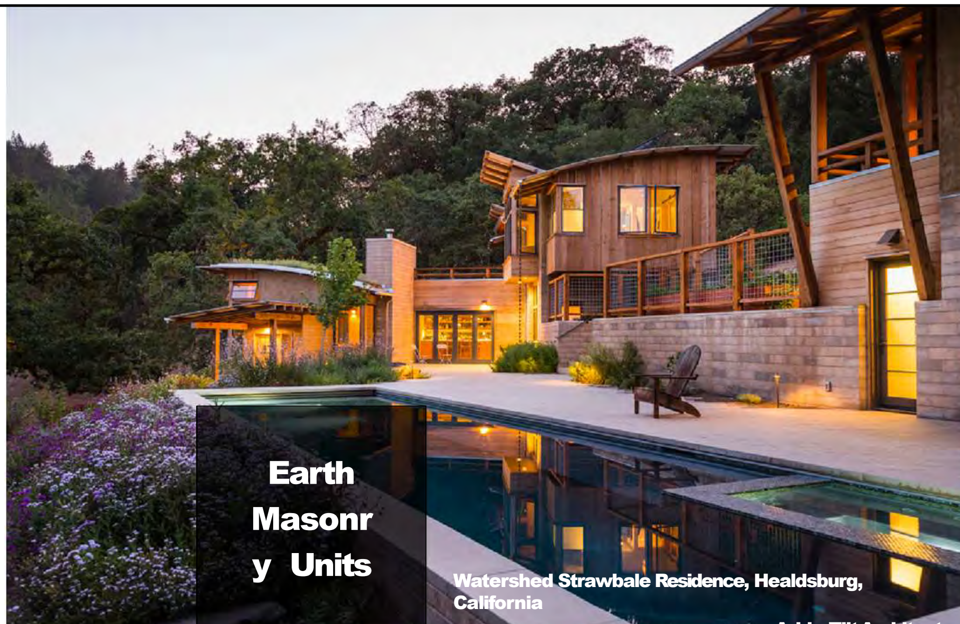
102


Canyon Road Bridge Residence, Santa Fe, New Mexico – Arkin Tilt Architects

103


PISE
Pneumatically
Impacted
Stabilized
Earth
Tip-Top Residence, Napa, California – Arkin Tilt Architects

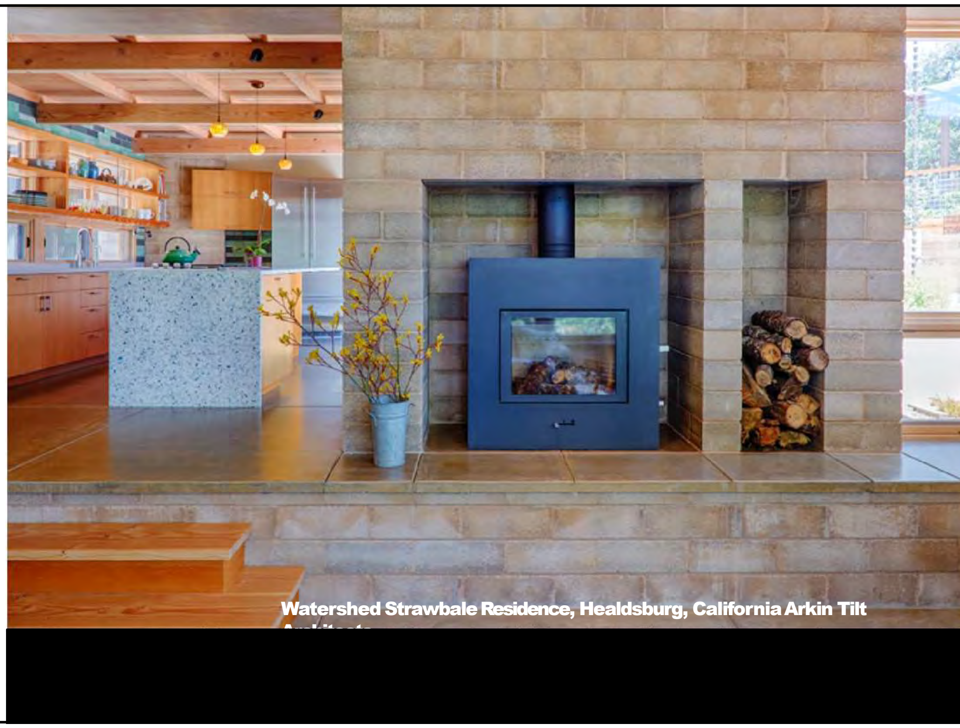
104


Earth
Masonr
y Units
Watershed Strawbale Residence, Healdsburg, California

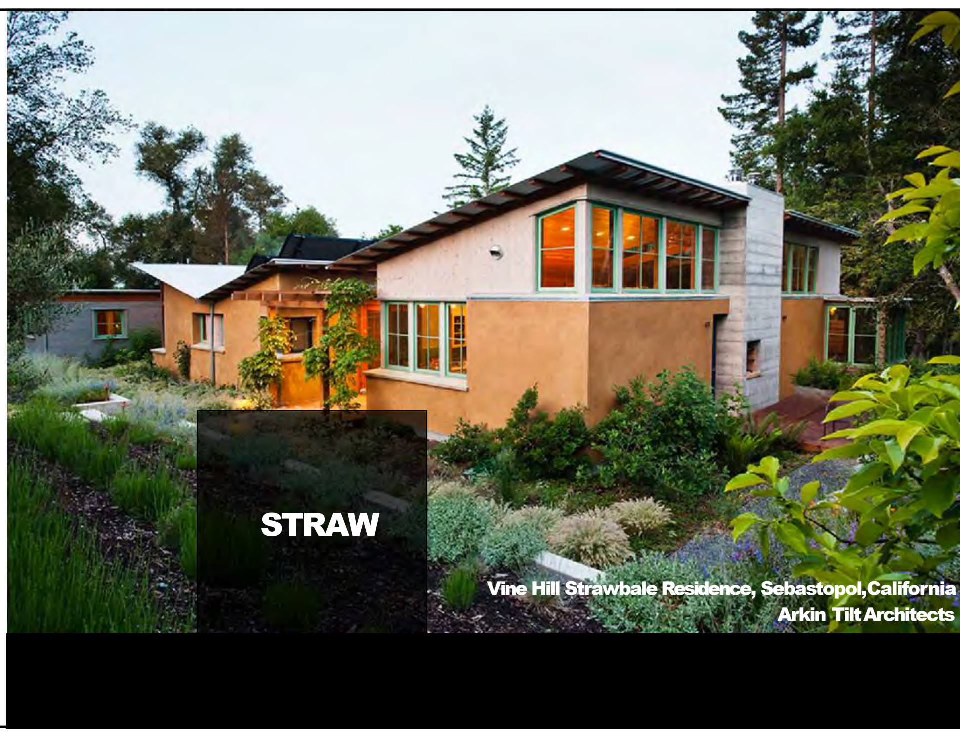
105


Watershed Materials, Napa, California

106


Watershed Strawbale Residence, Healdsburg, California Arkin Tilt

107


STRAW
Vine Hill Strawbale Residence, Sebastopol,California
Arkin Tilt Architects

108

Simonton House – Purdum, Nebraska 1908

Burritt Museum – Huntsville, Alabama 1938

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Appendix S: Strawbale Construction

SECTION AS101 GENERAL

AS101.1 Scope. This appendix provides prescriptive and performance-based requirements for the use of baled straw as a building material. Other methods of strawbale construction shall be subject to approval in accordance with Section 104.11 of this code. Buildings using strawbale walls shall comply with the this code except as otherwise stated in this appendix.

SECTION AS102 DEFINITIONS

AS102.1 Definitions. The following words and terms shall, for the purposes of this appendix, have the meanings shown herein. Refer to Chapter 2 of the *International Residential Code* for general definitions.

BALE. Equivalent to straw bale.

CLAY. Inorganic soil with particle sizes less than 0.00008 inch (0.002 mm) having the characteristics of high to very high dry strength and medium to high plasticity.

CLAY SLIP. A suspension of clay particles in water.

FINISH. Completed compilation of materials on the interior or exterior faces of stacked *bales*.

PRECOMPRESSION. Vertical compression of stacked bales before the application of finish.

REINFORCED PLASTER. A plaster containing mesh reinforcement.

RUNNING BOND. The placement of *straw bales* such that the head joints in successive courses are offset not less than one-quarter the bale length.

SHEAR WALL. A strawbale wall designed and constructed to resist lateral seismic and wind forces parallel to the plane of the wall in accordance with Section AS106.13.

SKIN. The compilation of plaster and reinforcing, if any, applied to the surface of stacked bales.

STRUCTURAL WALL. A wall that meets the definition for a load-bearing wall or shear wall.

STACK BOND. The placement of straw bales such that head joints in successive courses are vertically aligned.

STRAW. The dry stems of cereal grains after the seed heads have been removed.

STRAW BALE. A rectangular compressed block of straw, bound by ties.

STRAWBALE. The adjective form of straw bale.

STRAW-CLAY. Loose straw mixed and coated with clay slip.

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IRC CODE SECTION – IBC NEXT

110

Straw= 1.62 lb. CO_2 per lb. of straw, stored annually – 2,000sf home = approx. 10.5 tons CO_2

111

STACKED BENEFITS

- **Annually Renewable– By-Product of Grain**
- **High Insulation Value – R-30 (1.2 – 2.0/in.)**
- **Thick Walls – Deep Jambs at Openings**
- **Good IAQ and Humidity Control**
- **STORES CARBON !**
- **Acoustic Control**
- **Structural Integrity**
- **Excellent Fire Resistance**
- **Durable and Long Lasting**
- **Thermal Mass and Time Lag**
- **User Friendly- Community Building**

112

113


Santa Cruz Mountains Residence – Debrae Lopes and Michele Landeggar, Boa Constructor Design-Build

114

Norrbom Road Strawbale Home (wildfire survivor), Sonoma, California – Arkin Tilt

115

116

117

Los Padres US Forest Service Statio, King City, California – WRNS Studio

118

Ridge Winery – Lytton Springs, California - Freebairn-Smith and Crane Architects

119

Trillium-Lakelands Elementary Teachers' Union Office

Lindsay, Ontario
2,400 sf, $208/sq.ft.

86 tons of net CO_2 storage

- **Zero toxins**
- **105% net energy production on site**
- **90% of materials <250km radius**
- **80% less construction waste**

Endeavor Centre – Chris Magwood

120

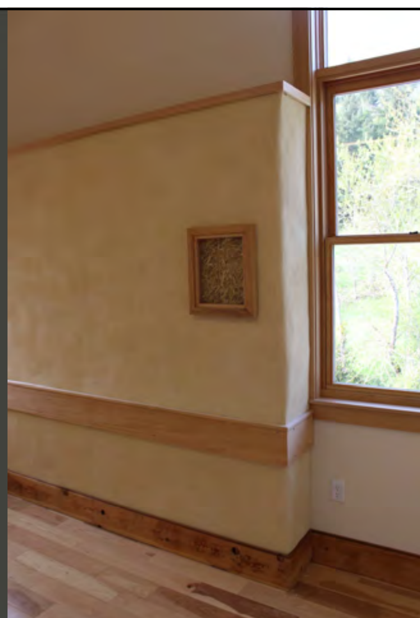
Mahonia Mixed-Use Buidling, Warehouse & Office – Anni Tilt AIA, Arkin Tilt Architects

121

122

Erica Ann Bush – Day One Design

123



Mahonia Building

Eugene, Oregon

34,000sf, $147/sq.ft.

12tons net CO2e storage in straw / wood walls

salvaged resources
rainwater catchment
daylight and community

124

Ludwigstein, Germany – Architects

[redacted]

125

5 story Ijburg Amsterdam, Netherlands - Rene [redacted]

126


Panelized Straw Walls – EcoCocon – Lithuania - Bjorn Kiefulf, Architect

127



MODCELL (panelized straw bale) – Knowle West Media Centre, UK – White Design Architects

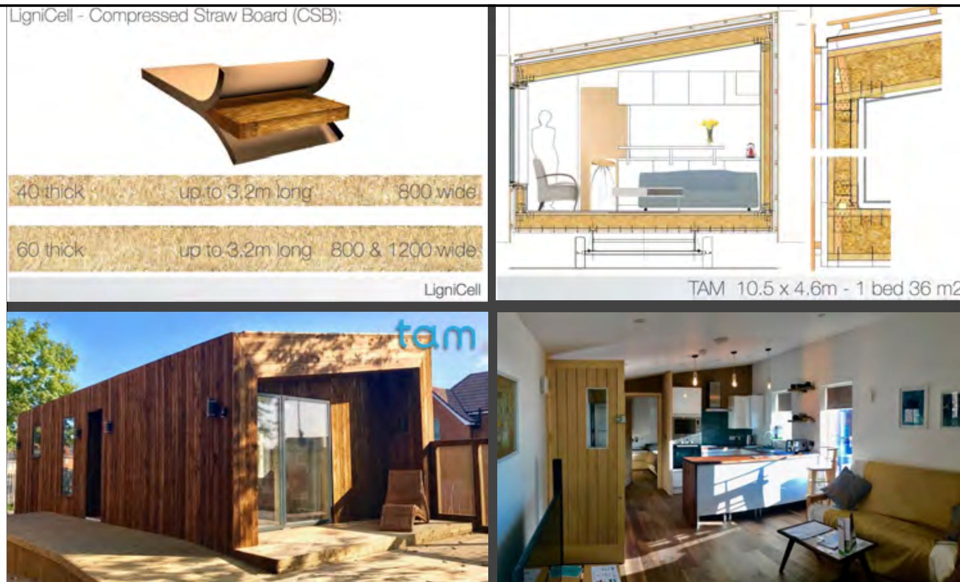
128

MODCELL (panelized straw bale) – Inspire, Bradford, UK – White Design Architects

129

MODCELL (panelized straw bale) – LILAC Co-Housing, UK – White Design Architects

130

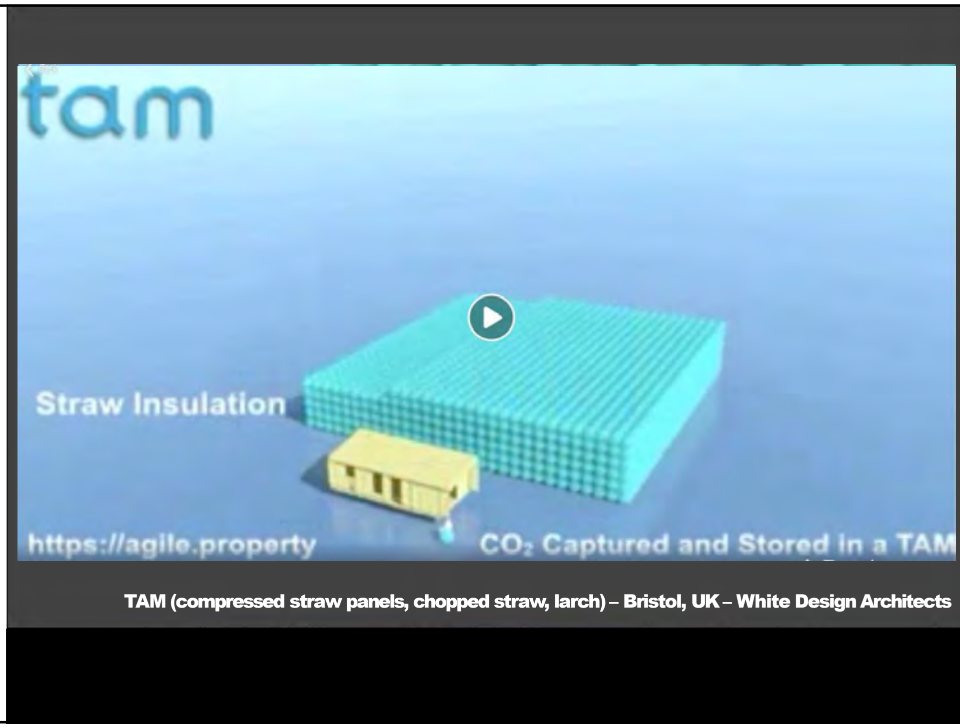


TAM (compressed straw panels, chopped straw, larch) – Bristol, UK – White Design Architects

131

TAM (compressed straw panels, chopped straw, larch) – Bristol, UK – White Design Architects

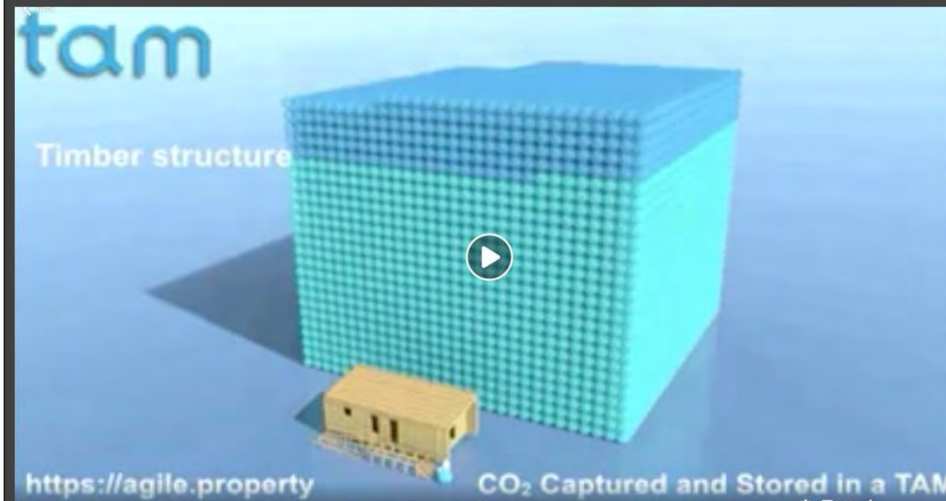
132


tam
Straw Insulation
https://agile.property
CO_2 Captured and Stored in a TAM
TAM (compressed straw panels, chopped straw, larch) – Bristol, UK – White Design Architects

133

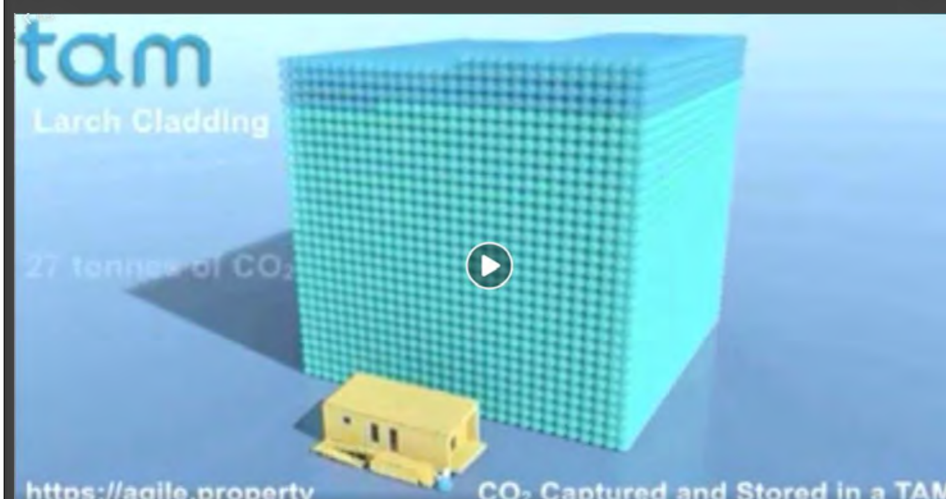

tam
Compressed
Straw Board
https://agile.property
CO_2 Captured and Stored in a TAM
TAM (compressed straw panels, chopped straw, larch) – Bristol, UK – White Design Architects

134



TAM (compressed straw panels, chopped straw, larch) – Bristol, UK – White Design Architects

135

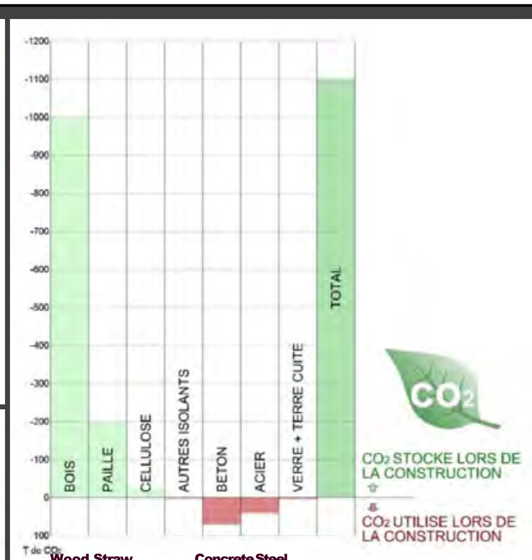


TAM (compressed straw panels, chopped straw, larch) – Bristol, UK – White Design Architects

136

Residence Jules Ferry, Saint Die, France – Antoine Pagnaux, ASP Architecture

137



Residence Jules Ferry, Saint Die, France – Antoine Pagnaux, ASP Architecture

138

Resources for Getting There

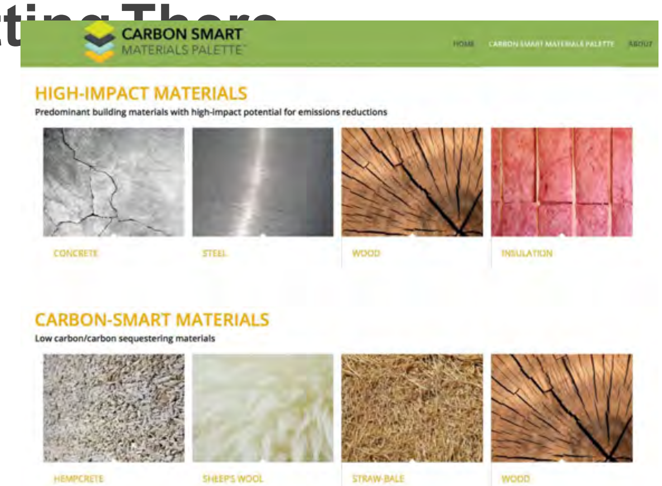
- Embodied Carbon Network
- Carbon Leadership Forum
- Architecture 2030
- CarbonSmart Materials Pallette
- International Living Future

- One Click LCA
- Tally LCA (Revit)
- Athena Impact Estimator
- EC3 (due to release Nov. 19th)
- ICE Database (v.3 coming soon!)
- BuildWell Library
- California Straw

[redacted]

139

Resources for Getting There

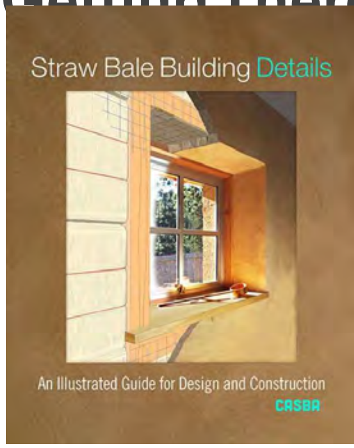


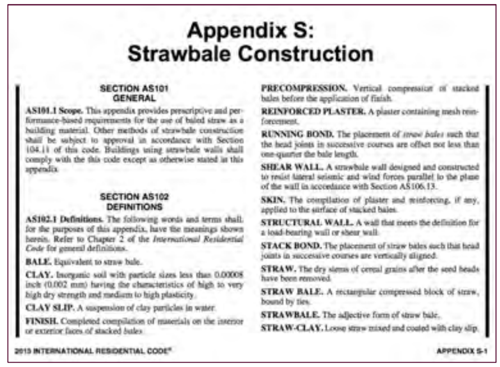
www.materialspalette.org

[redacted]

140

Resources for Getting There





Appendix S: Strawbale Construction

SECTION AS101 GENERAL

AS101.1 Scope. This appendix provides prescriptive and performance-based requirements for the use of baled straw as a building material. Other methods of strawbale construction shall be subject to approval in accordance with Section 104.11 of this code. Buildings using strawbale walls shall comply with the this code except as otherwise stated in this appendix.

SECTION AS102 DEFINITIONS

AS102.1 Definitions. The following words and terms shall, for the purposes of this appendix, have the meanings shown herein. Refer to Chapter 2 of the *International Residential Code* for general definitions.

BALE. Equivalent to straw bale.

CLAY. Inorganic soil with particle sizes less than 0.00008 inch (0.002 mm) having the characteristics of high to very high dry strength and medium to high plasticity.

CLAY SLIP. A suspension of clay particles in water.

FINISH. Completed compilation of materials on the interior or exterior faces of stacked bales.

PRECOMPRESSION. Vertical compression of stacked bales before the application of finish.

REINFORCED PLASTER. A plaster containing mesh reinforcement.

RUNNING BOND. The placement of *straw bales* such that the head joints in successive courses are offset not less than one-quarter the bale length.

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STRAW-CLAY. Loose straw mixed and coated with clay slip.

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Free download of code w/commentary from CASBA: www.strawbuilding.org

[redacted]

141

Resources for Getting There

[redacted]

142

143

Real Zero Carbon Buildings by 2050

or

"Building like we're listening to Greta..."

Chris Magwood, Endeavour Centre, October 9, 2019

144

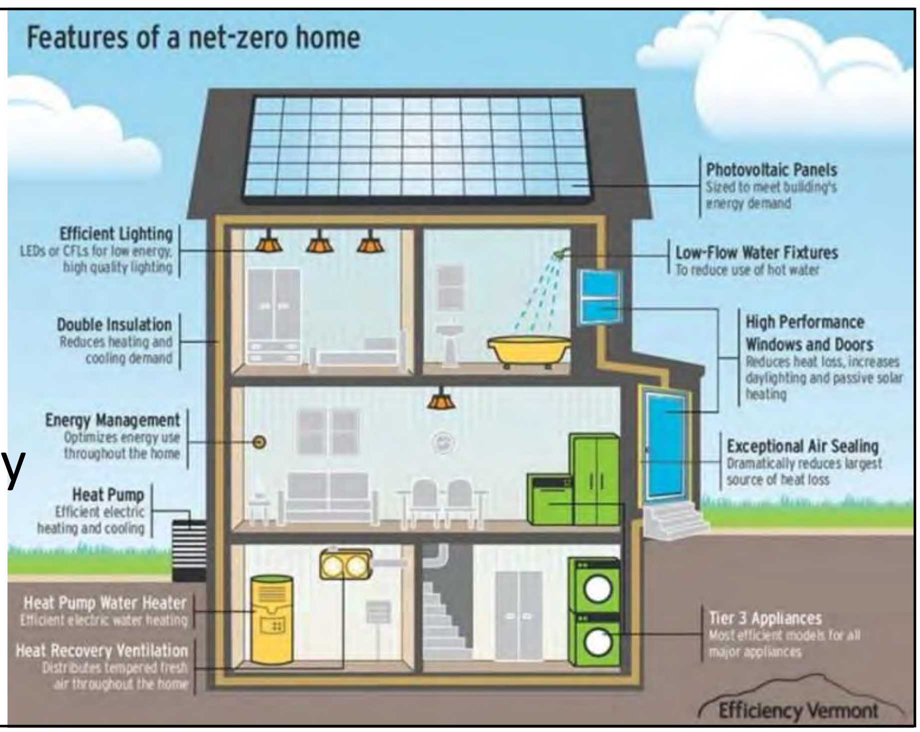
No more numbers games.

We need to make *real zero carbon* buildings, and we need to start *now*.

145

"Net zero building"

Does a net zero energy building help solve climate change?

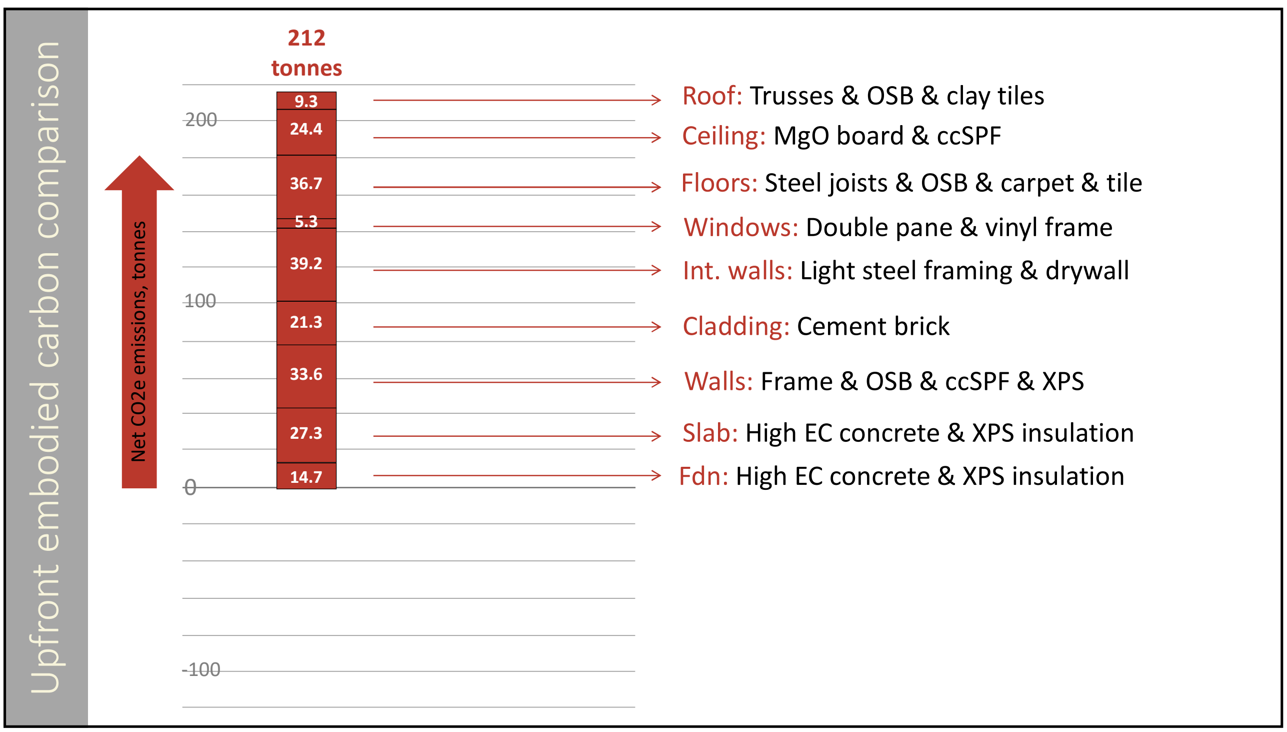


146

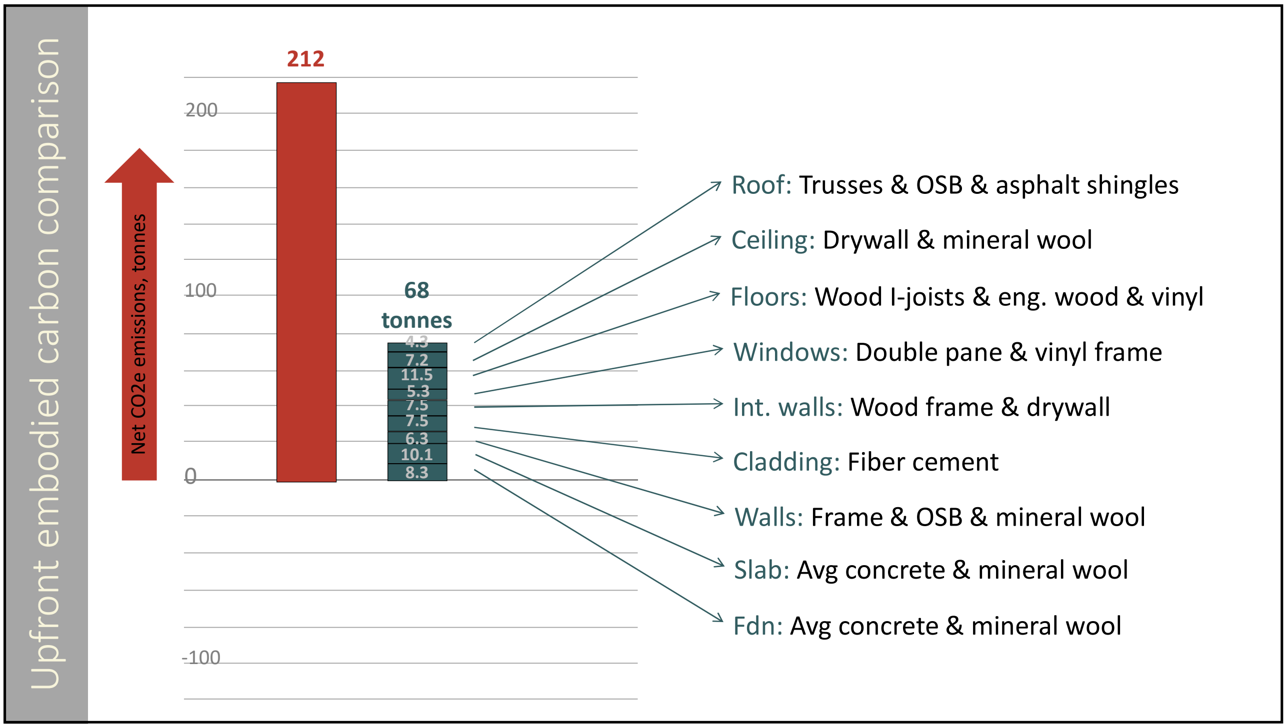
Study of two common low-rise buildings with different materials

And different levels of energy efficiency

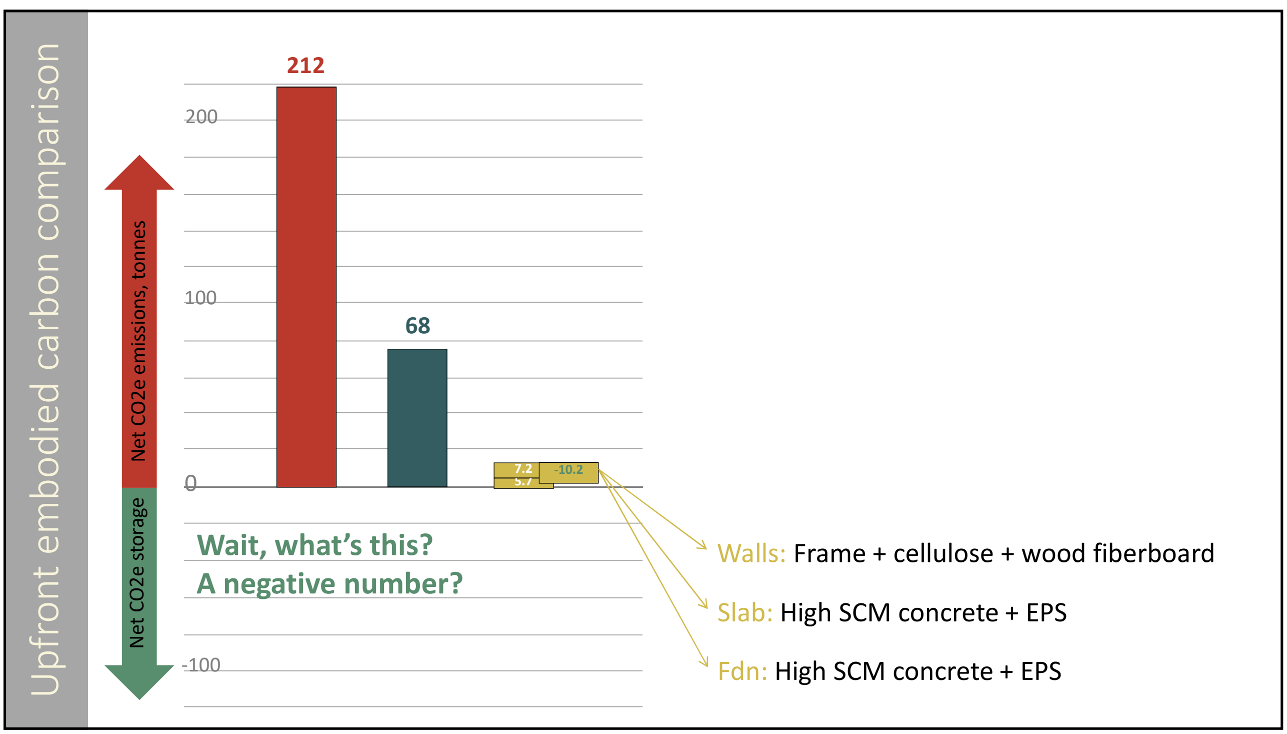
147



148


Upfront embodied carbon comparison
Net CO2e emissions, tonnes
212
68
tonnes
200
100
0
-100
4.3
7.2
11.5
5.3
7.5
7.5
6.3
10.1
8.3
Roof: Trusses & OSB & asphalt shingles
Ceiling: Drywall & mineral wool
Floors: Wood I-joists & eng. wood & vinyl
Windows: Double pane & vinyl frame
Int. walls: Wood frame & drywall
Cladding: Fiber cement
Walls: Frame & OSB & mineral wool
Slab: Avg concrete & mineral wool
Fdn: Avg concrete & mineral wool

149


Upfront embodied carbon comparison
Net CO2e emissions, tonnes
Net CO2e storage
212
68
200
100
0
-100
7.2
-10.2
Wait, what's this?
A negative number?
Walls: Frame + cellulose + wood fiberboard
Slab: High SCM concrete + EPS
Fdn: High SCM concrete + EPS

150

Wait! What's this? A negative number?

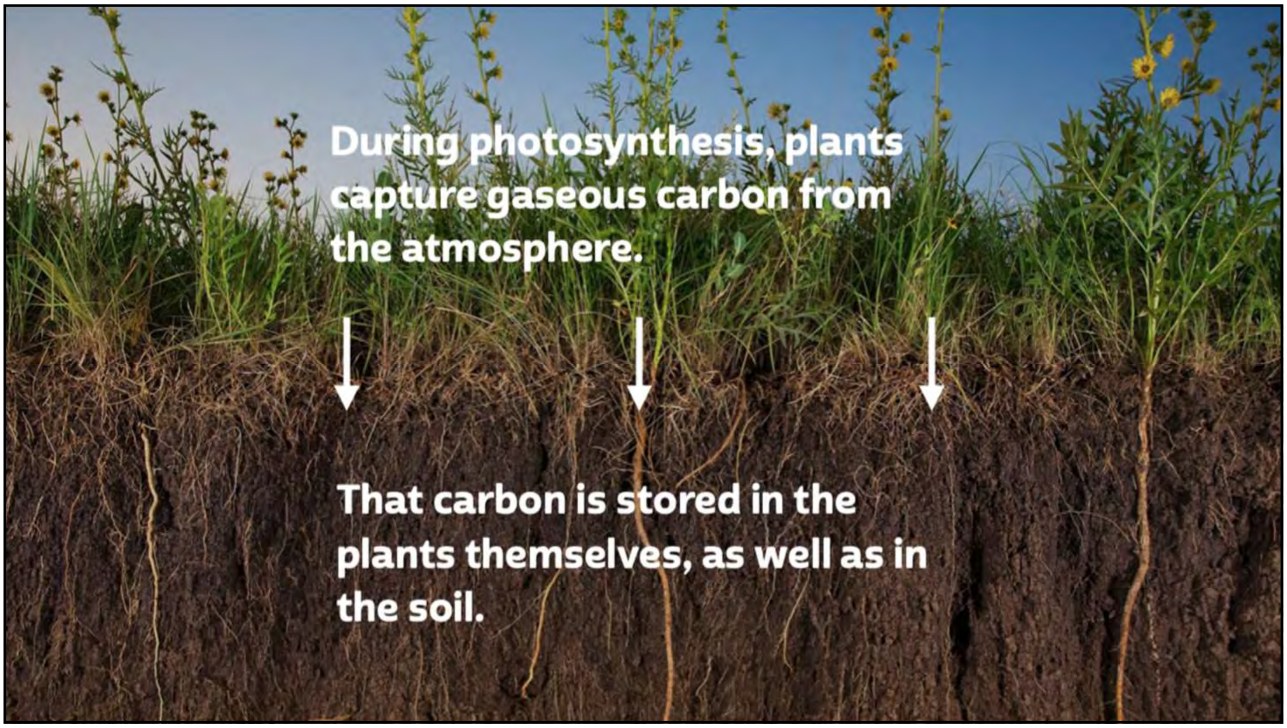
Cellulose	-4510 kg

Yes, a material that stores more atmospheric carbon than was emitted in harvesting & manufacturing! This opens up a whole new paradigm — **materials with carbon capture and storage potential!**

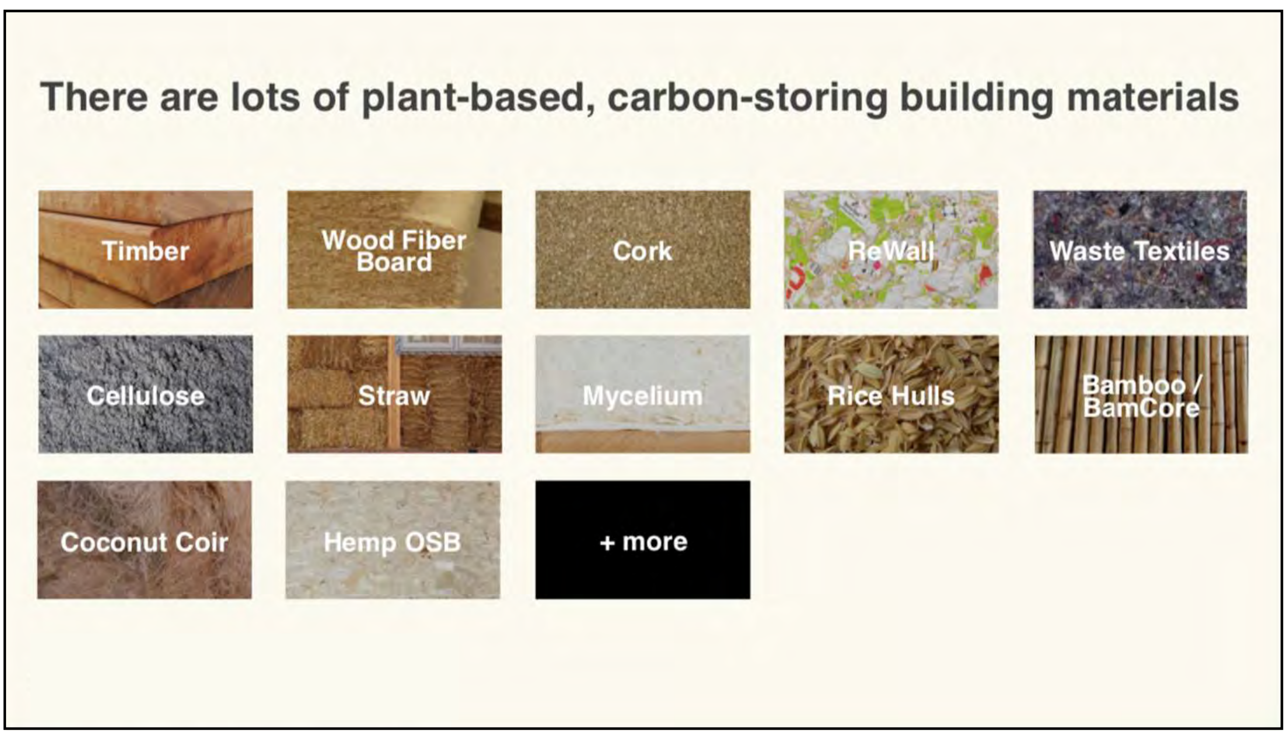
151

How does this work?

152


During photosynthesis, plants capture gaseous carbon from the atmosphere.
That carbon is stored in the plants themselves, as well as in the soil.

153


There are lots of plant-based, carbon-storing building materials
Timber
Wood Fiber Board
Cork
ReWall
Waste Textiles
Cellulose
Straw
Mycelium
Rice Hulls
Bamboo / BamCore
Coconut Coir
Hemp OSB
+ more

154

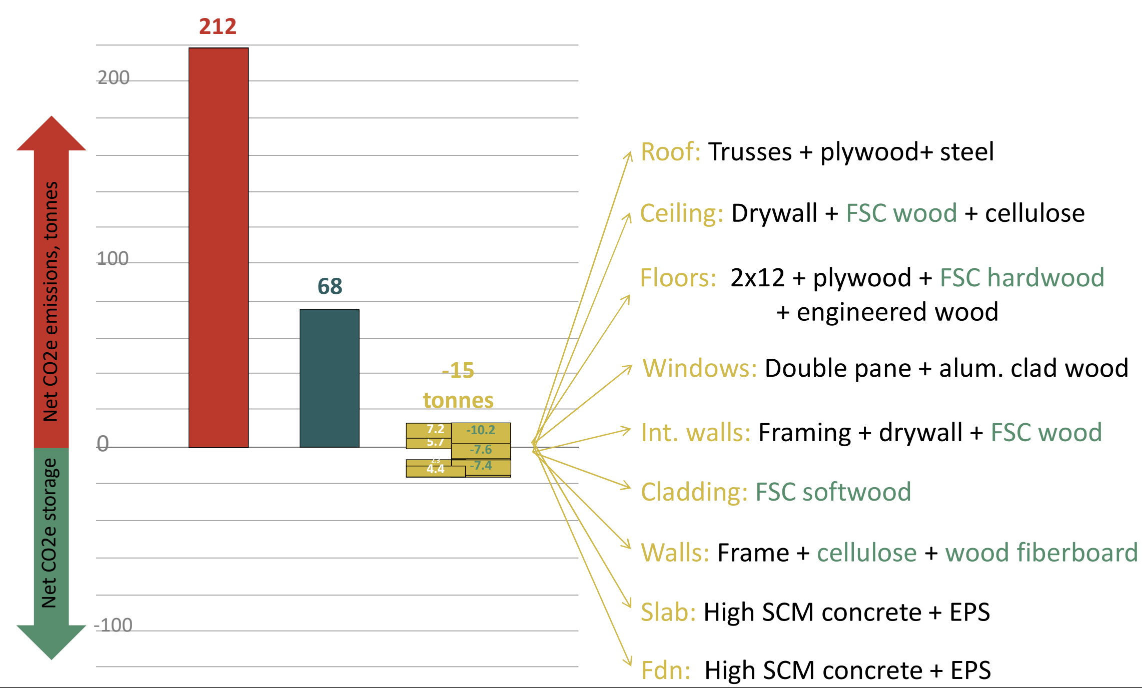
In 2016, there were 2.16 billion tonnes of grain straw produced globally, drawing down 8 billion tonnes of CO_2. *That's almost ¼ of all annual GHG emissions.*

It's also enough to replace all insulation materials and still leave 20% to return to soils.

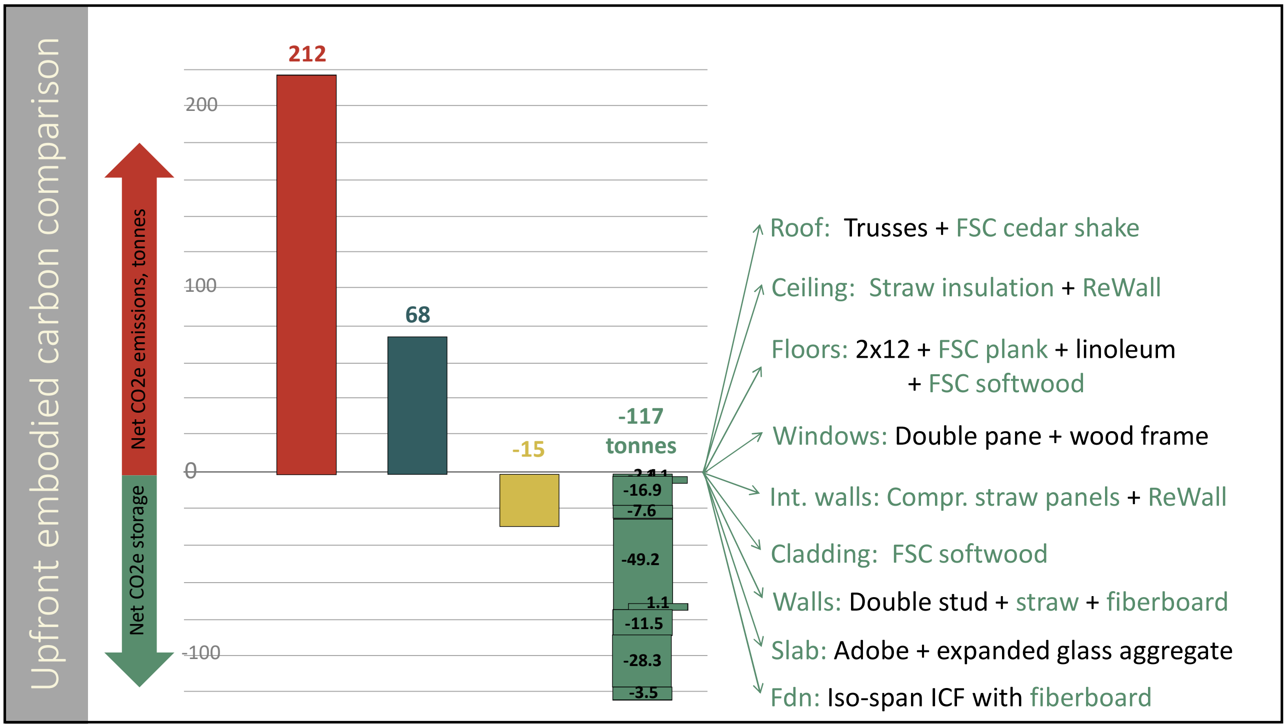
And we already have the manufacturing know-

155

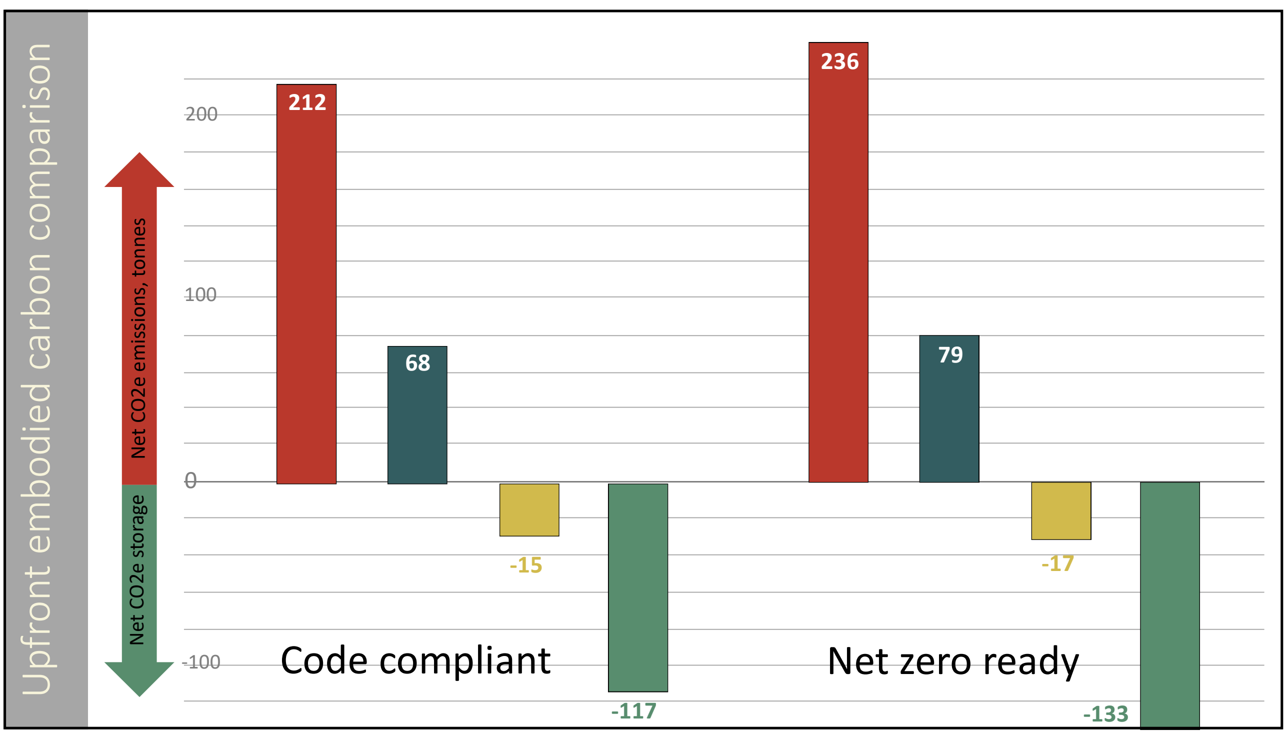
Upfront embodied carbon comparison



156


Upfront embodied carbon comparison
Net CO2e emissions, tonnes
Net CO2e storage
200
100
0
-100
212
68
-15
-117
tonnes
-16.9
-7.6
-49.2
1.1
-11.5
-28.3
-3.5
Roof: Trusses + FSC cedar shake
Ceiling: Straw insulation + ReWall
Floors: 2x12 + FSC plank + linoleum + FSC softwood
Windows: Double pane + wood frame
Int. walls: Compr. straw panels + ReWall
Cladding: FSC softwood
Walls: Double stud + straw + fiberboard
Slab: Adobe + expanded glass aggregate
Fdn: Iso-span ICF with fiberboard

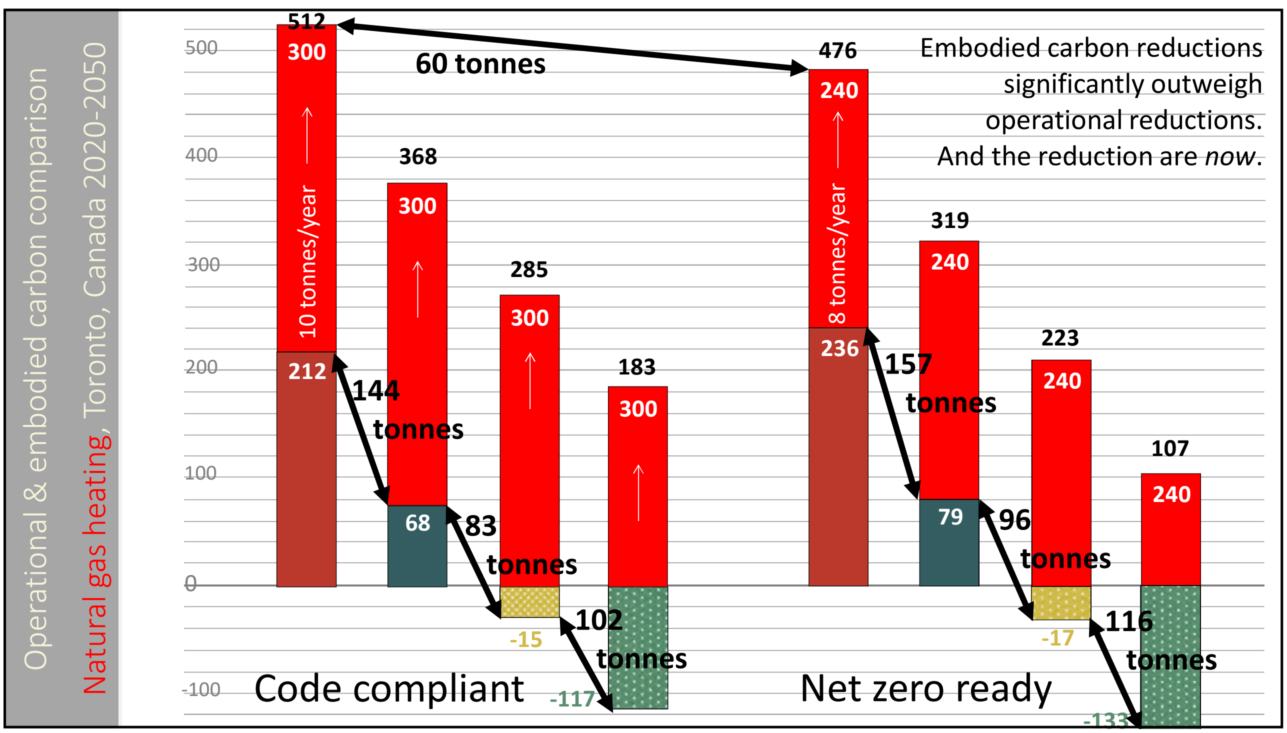
157


Upfront embodied carbon comparison
Net CO2e emissions, tonnes
Net CO2e storage
200
100
0
-100
212
68
-15
-117
Code compliant
236
79
-17
-133
Net zero ready

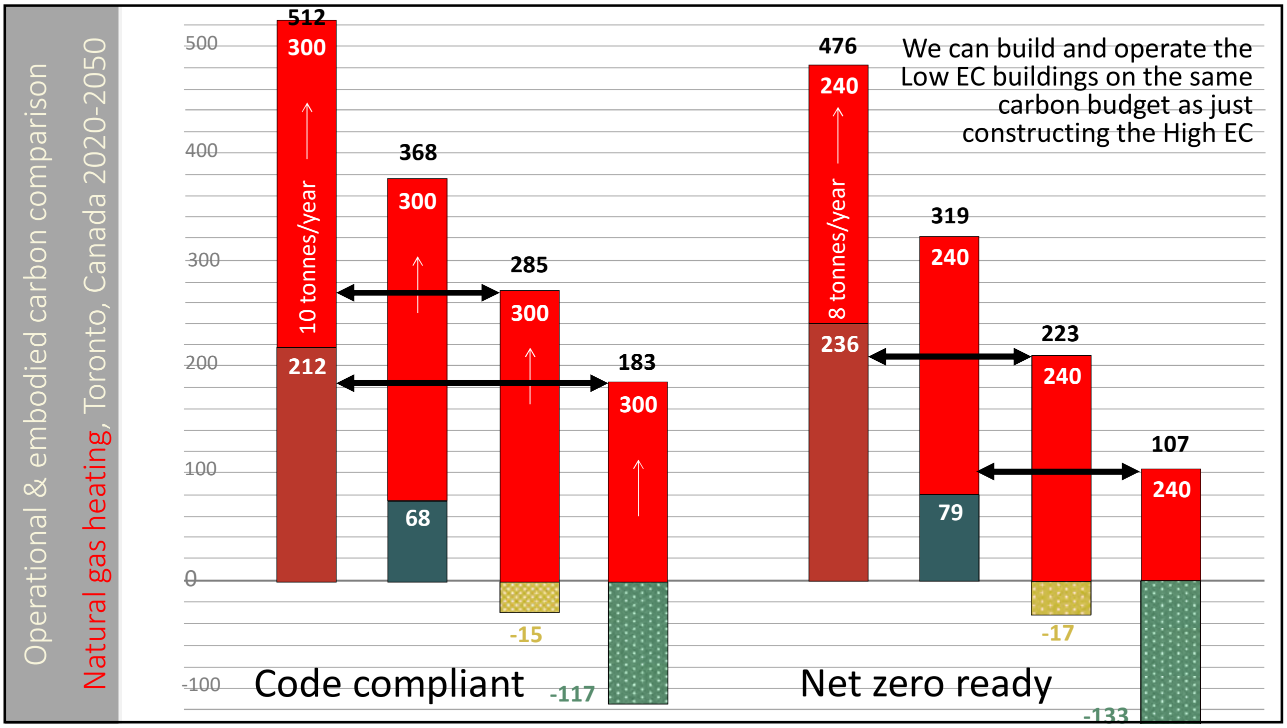
158

Adding Operational GHG Emissions

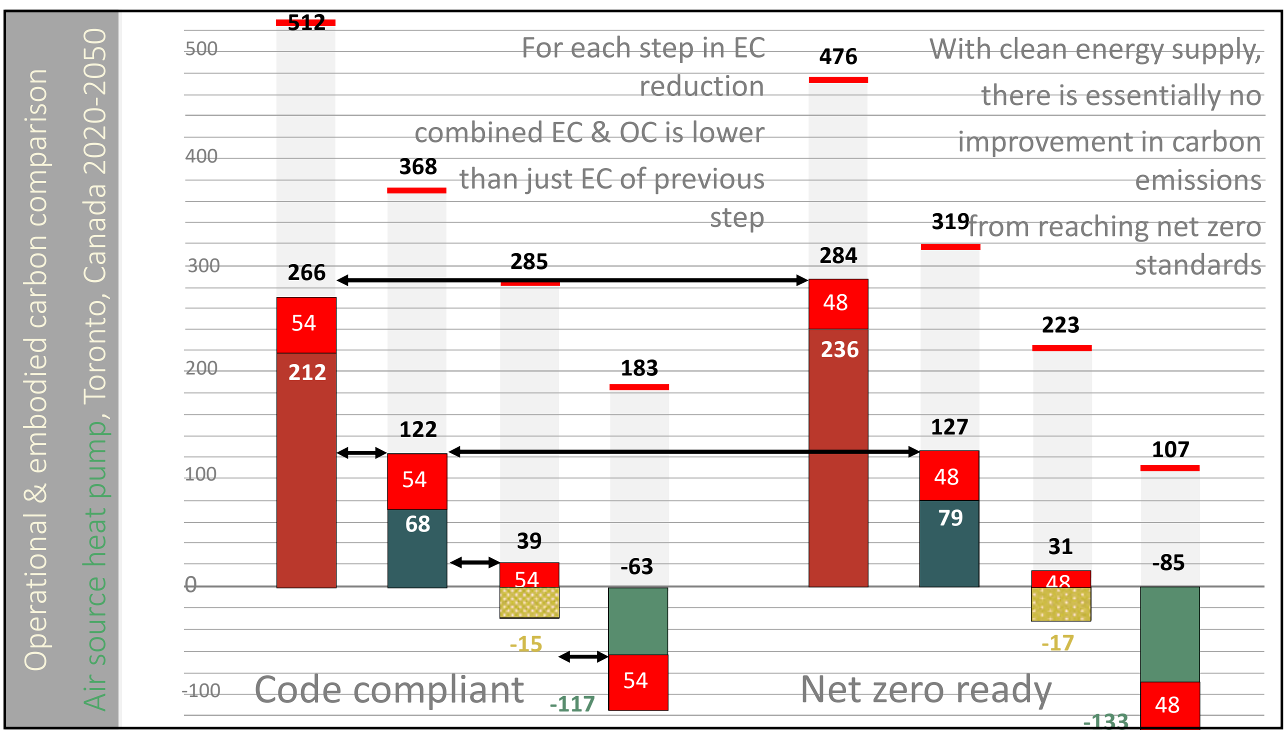
159



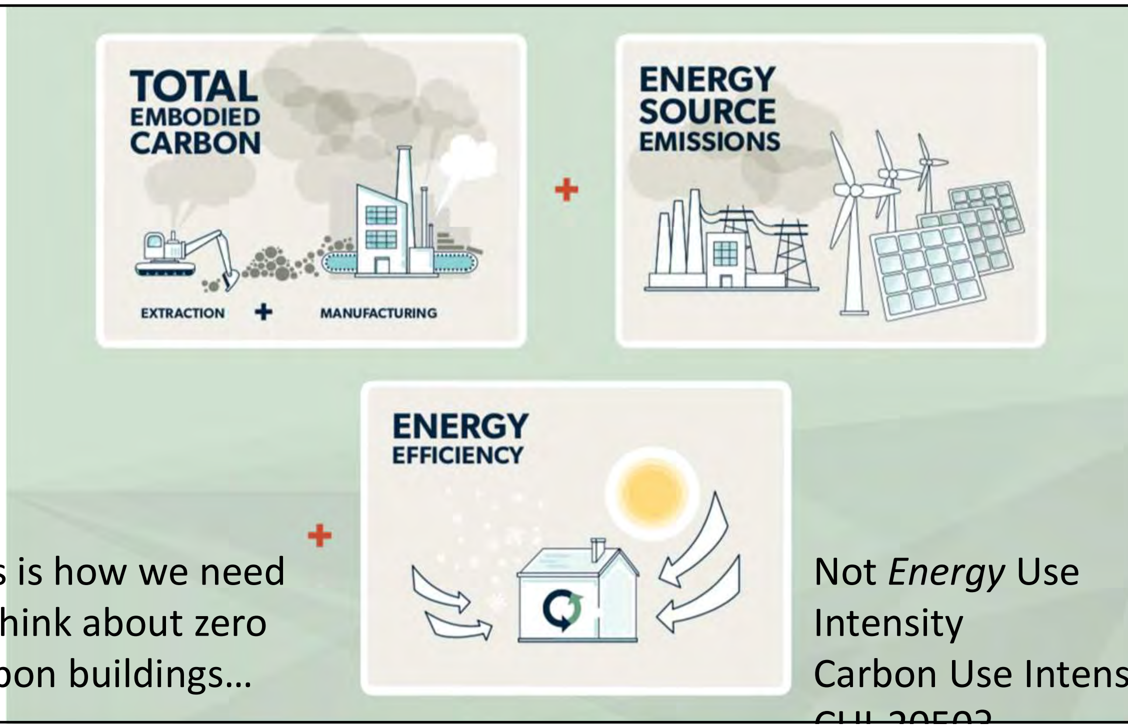
160


Operational & embodied carbon comparison
Natural gas heating, Toronto, Canada 2020-2050
512
300
10 tonnes/year
212
368
300
68
285
300
-15
183
300
-117
Code compliant
476
240
8 tonnes/year
236
319
240
79
223
240
-17
107
240
-133
Net zero ready
We can build and operate the Low EC buildings on the same carbon budget as just constructing the High EC
500
400
300
200
100
0
-100

161


Operational & embodied carbon comparison
Air source heat pump, Toronto, Canada 2020-2050
512
266
54
212
368
122
54
68
285
39
54
-15
183
-63
54
-117
Code compliant
For each step in EC reduction
combined EC & OC is lower than just EC of previous step
476
284
48
236
319
127
48
79
223
31
48
-17
107
-85
48
-133
Net zero ready
With clean energy supply, there is essentially no improvement in carbon emissions from reaching net zero standards
500
400
300
200
100
0
-100

162



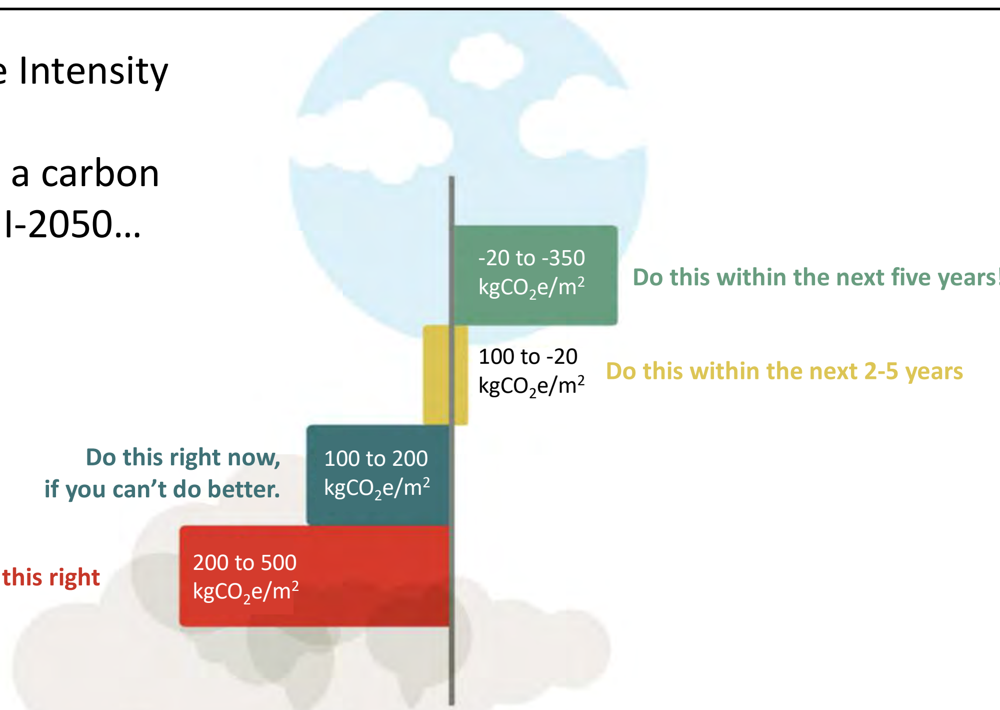
This is how we need to think about zero carbon buildings…

Not *Energy* Use Intensity
Carbon Use Intensity

163

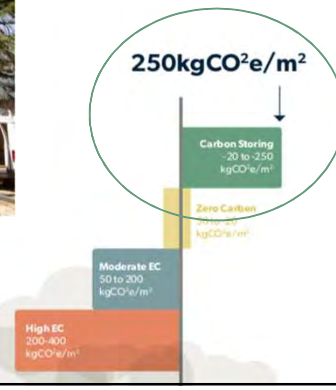
Carbon Use Intensity

Pathway to a carbon positive CUI-2050…



164

CASE STUDIES

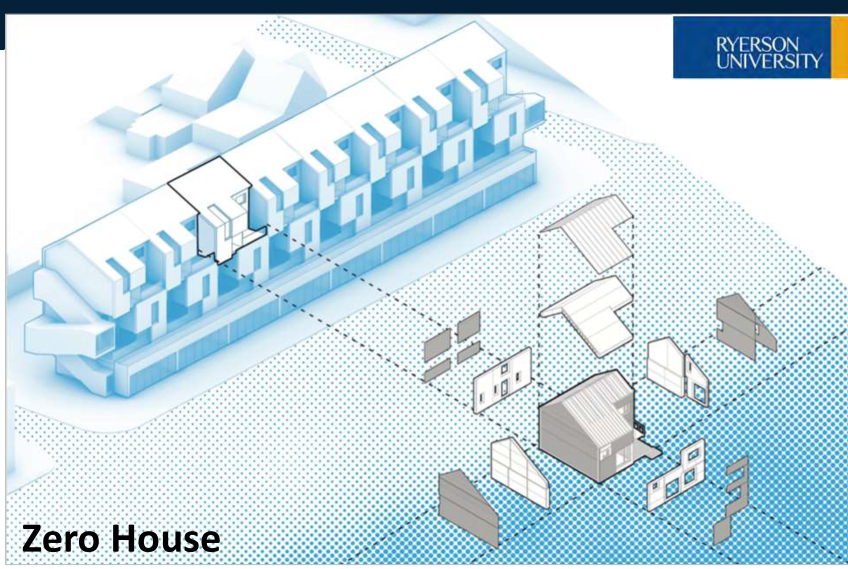


Zero House

ZERO CARBON, ZERO TOXIN, ZERO WASTE,

165

CASE STUDIES



Zero House

Fully panelized. Stackable row house design.

166

CASE STUDIES



Simple, affordable panelization. Off-the-shelf *and* innovative materials.


167

CASE STUDIES



One day assembly for floors, walls & roof

168

CASE STUDIES

Zero construction emissions

Near zero construction waste

169

CASE STUDIES

Completely non-toxic materials

170

Built by a tiny not-for-profit building school.

R&D budget of $0.

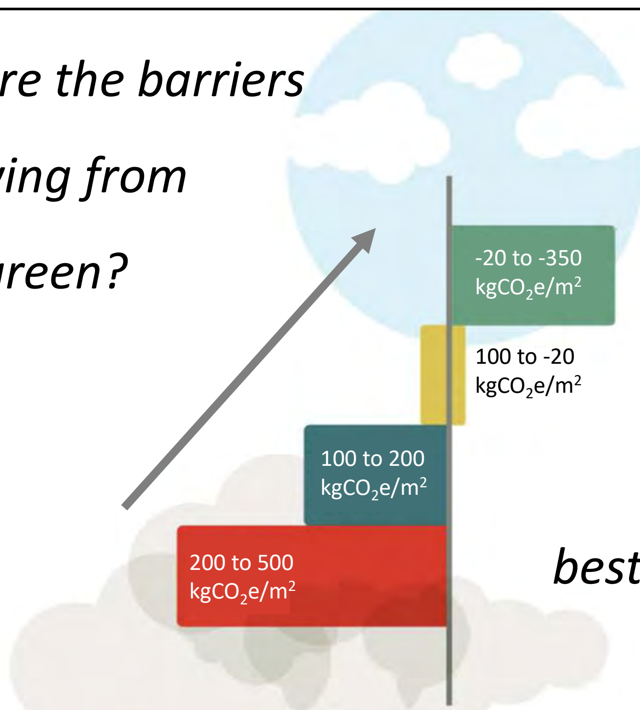
Assembled in 6 days. Three times.

Built for $280/square foot.

What are the barriers?

171

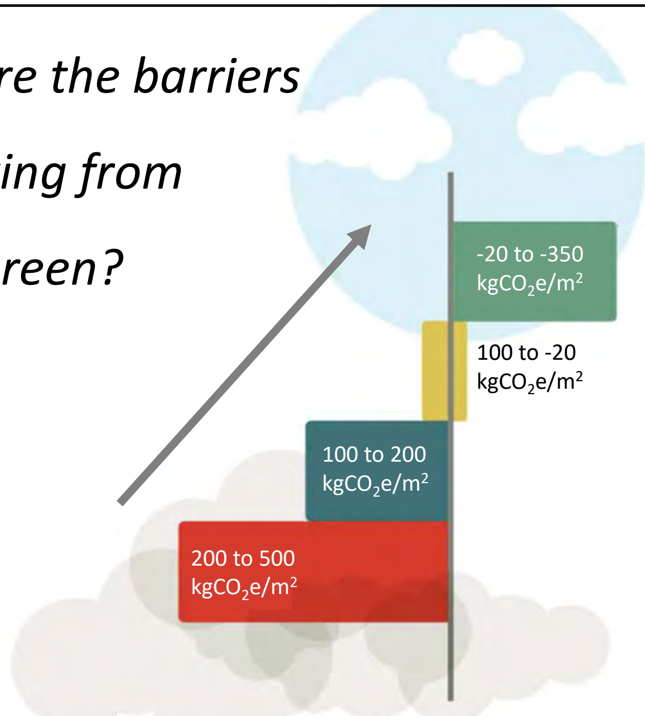
What are the barriers for moving from red to green?



This is our best chance at making real zero carbon

172

What are the barriers for moving from red to green?



Can you explain away the barriers to the youth in

173