energy emissions & (built) environment

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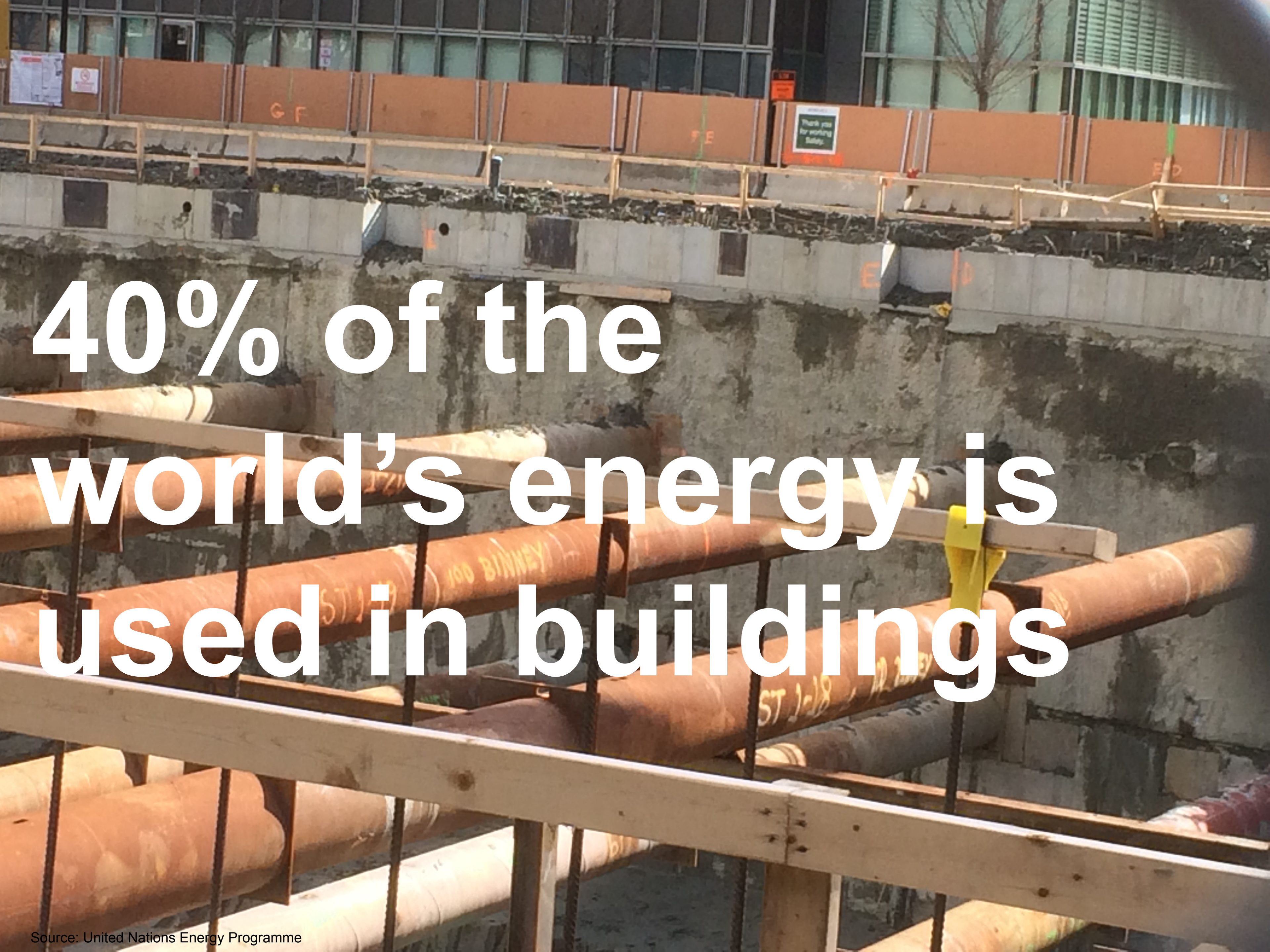
20160331


global population
2050
9.7 billion
2016
7.4 billion
Source: United Nations

Source: Timber Skyscrapers



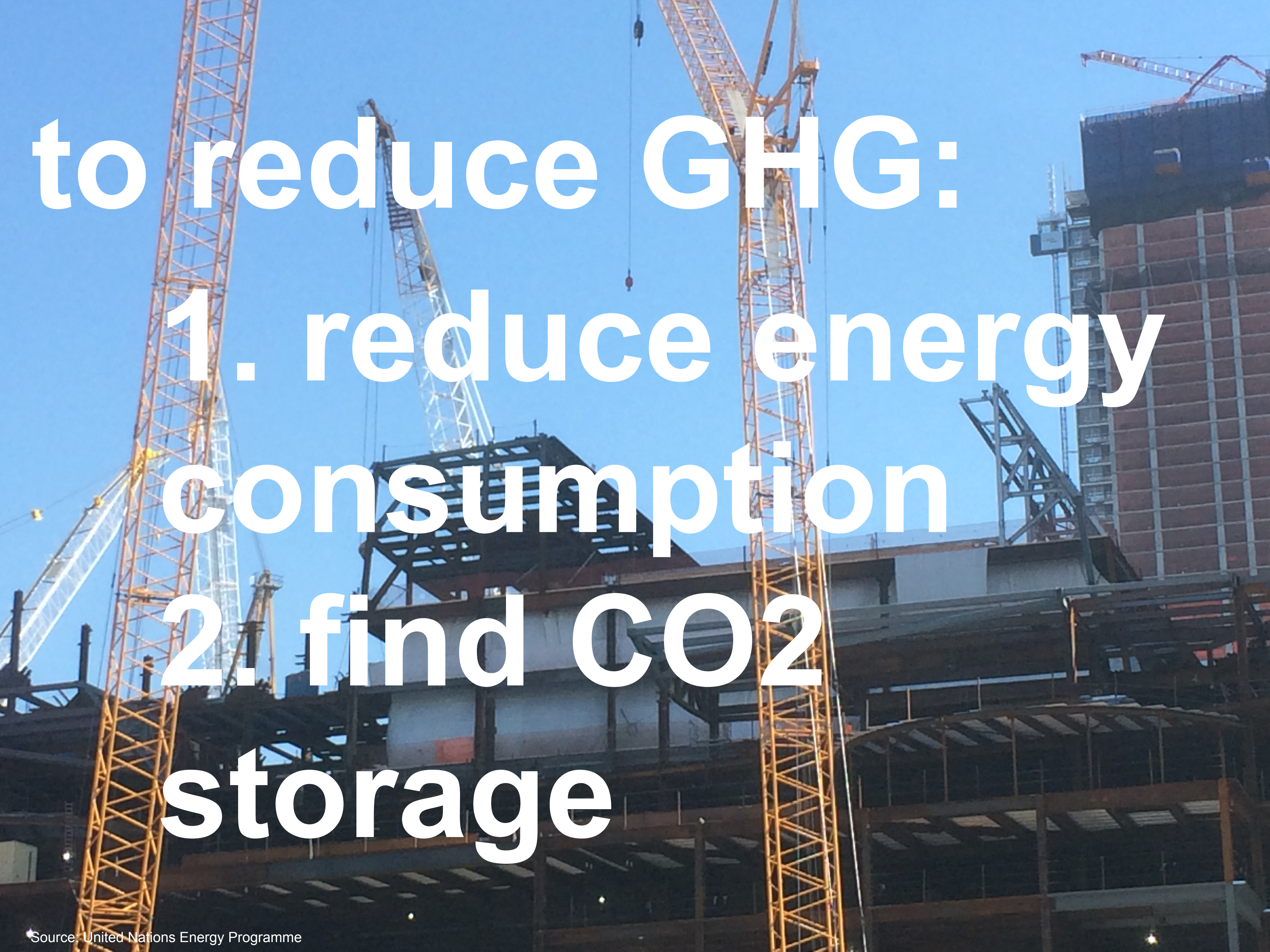
40% of the world’s energy is used in buildings

Source: United Nations Energy Programme


buildings emit
1/3 of global GHG
Source: United Nations Energy Programme

buildings are the largest contributor to global GHG emissions

Source: United Nations Energy Programme


to reduce GHG:
1. reduce energy consumption
2. find CO2 storage
Source: United Nations Energy Programme

definitions

embodied energy sum of the energy requirements associated, directly or indirectly, with the delivery of a good or service

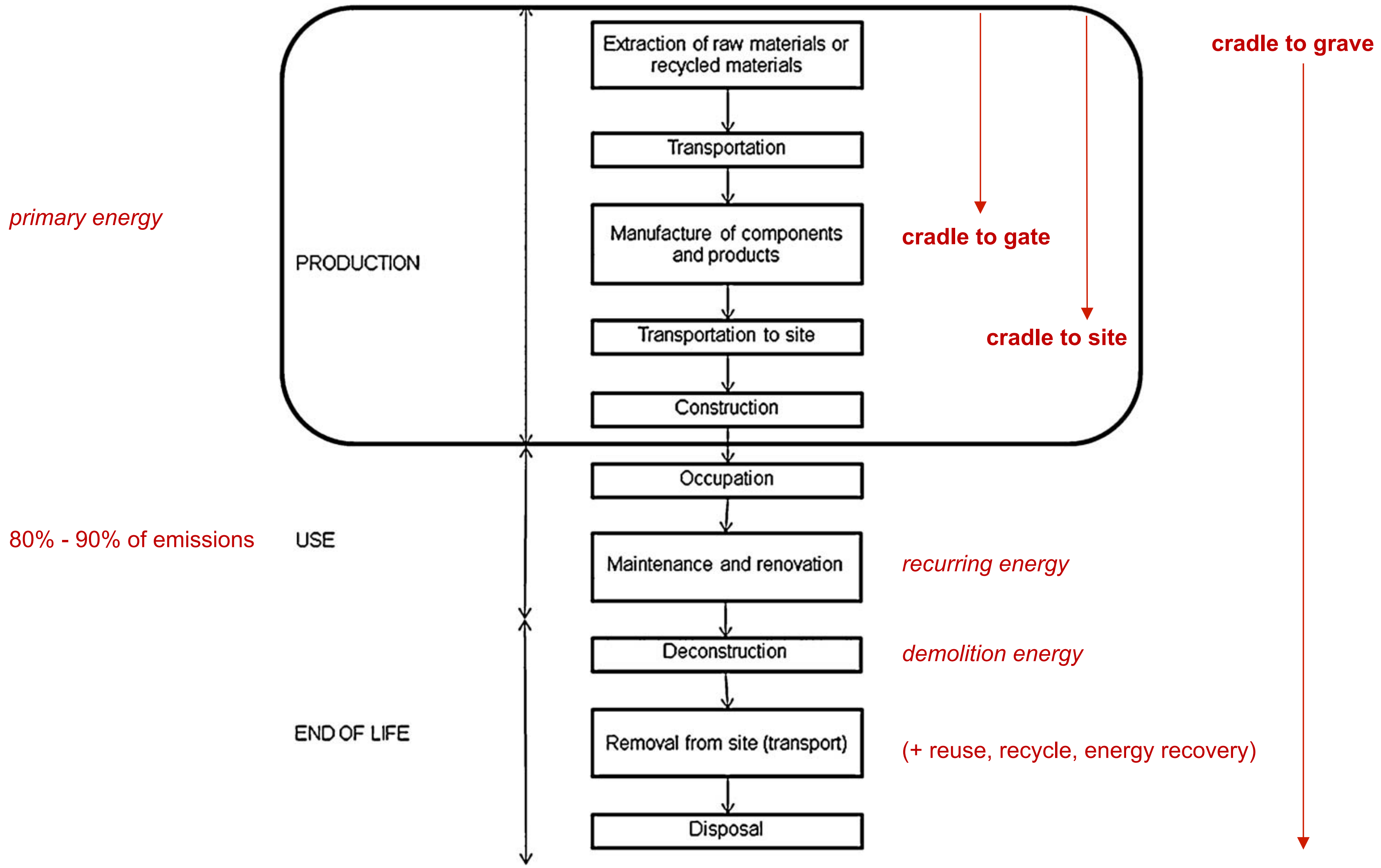
cradle to site embodied energy of individual building components as the energy required to extract raw materials, process them, assemble them into usable products and transport them to site. does not factor maintenance or end of life costs.

cradle to gate energy required to produce the finished product.

cradle to grave energy consumed by a building throughout its life:

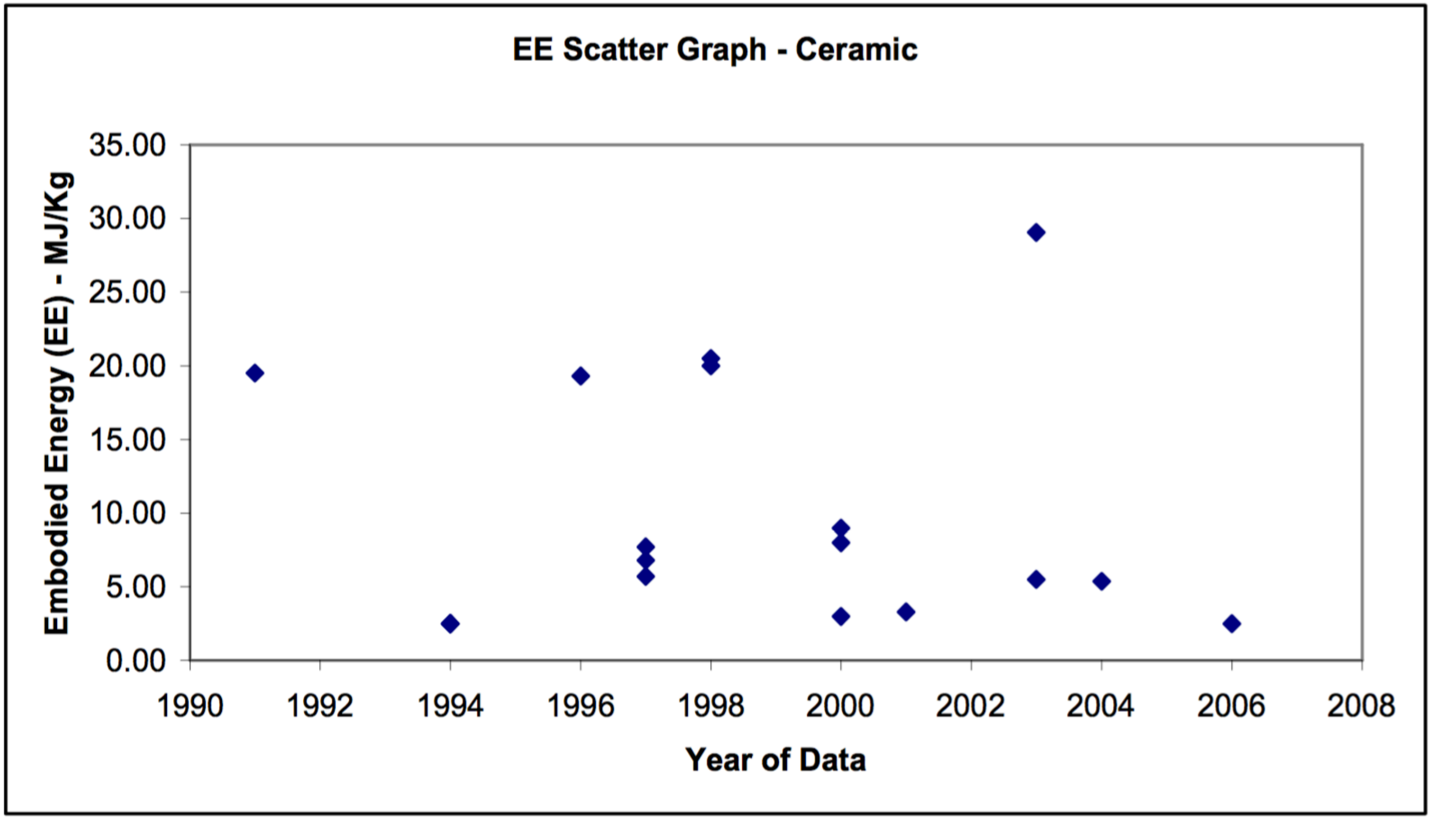
initial embodied energy energy required to initially produce the building, including energy for abstraction ("primary energy"), processing, and manufacture of materials of the building + their transportation + assembly on site
recurring embodied energy energy needed to renovate and maintain the building over its lifetime **demolition energy** energy necessary to demolish and dispose of the building at the end of its life

simplified life cycle process flow chart.



Source: Innovation in Low Carbon Construction Technologies

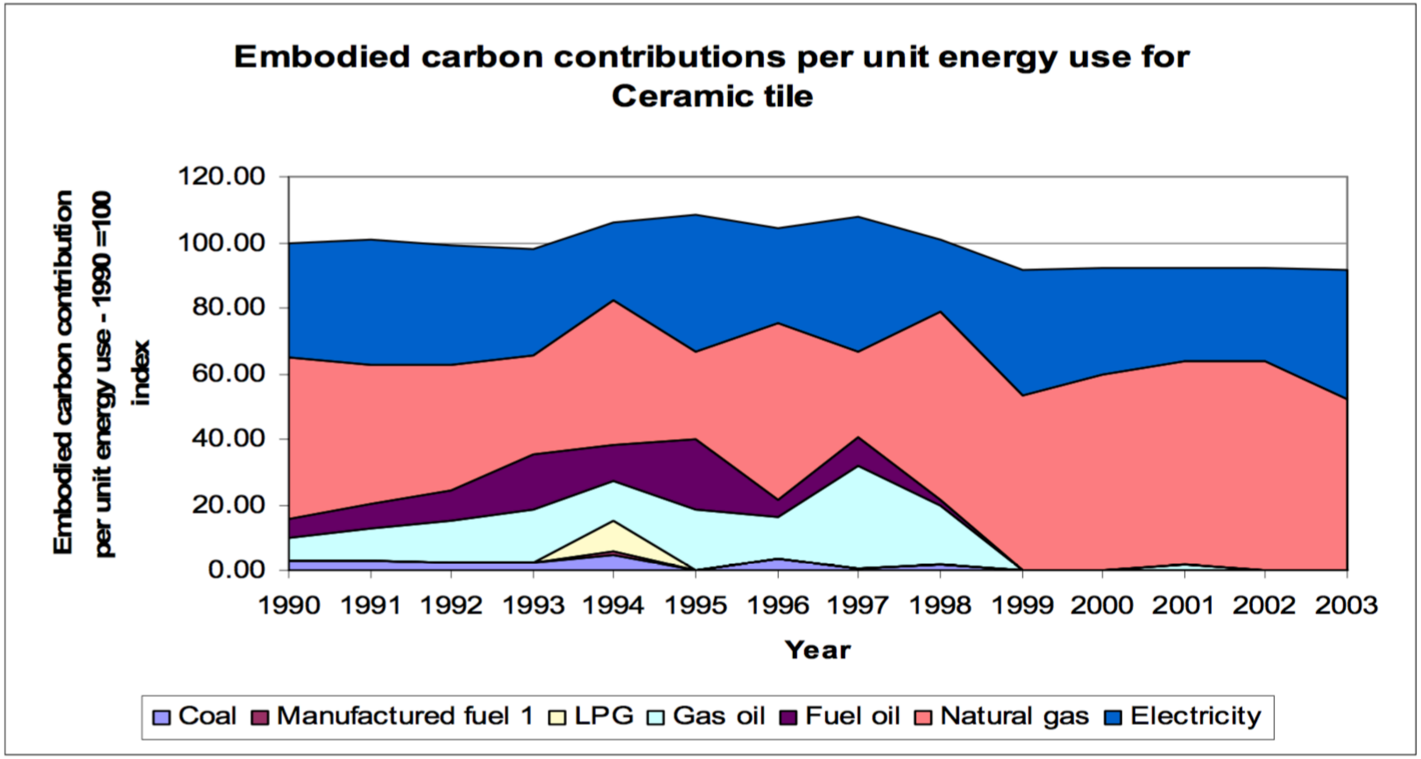
life cycle analysis. material profile. embodied energy



34 main building material groups: aggregate, aluminum, asphalt, bitumen, brass, bronze, carpets, cement, ceramics, clay (including bricks), concrete, copper, glass, insulation, iron, lead, lime, linoleum, miscellaneous materials, paint, paper, plaster, rubber, sand, sealants & adhesives, soil, steel, stone, timber, tin, titanium, vinyl flooring, zinc.

Source: Inventory of Carbon and Energy, University of Bath

material profile. historical embodied carbon. fuel split



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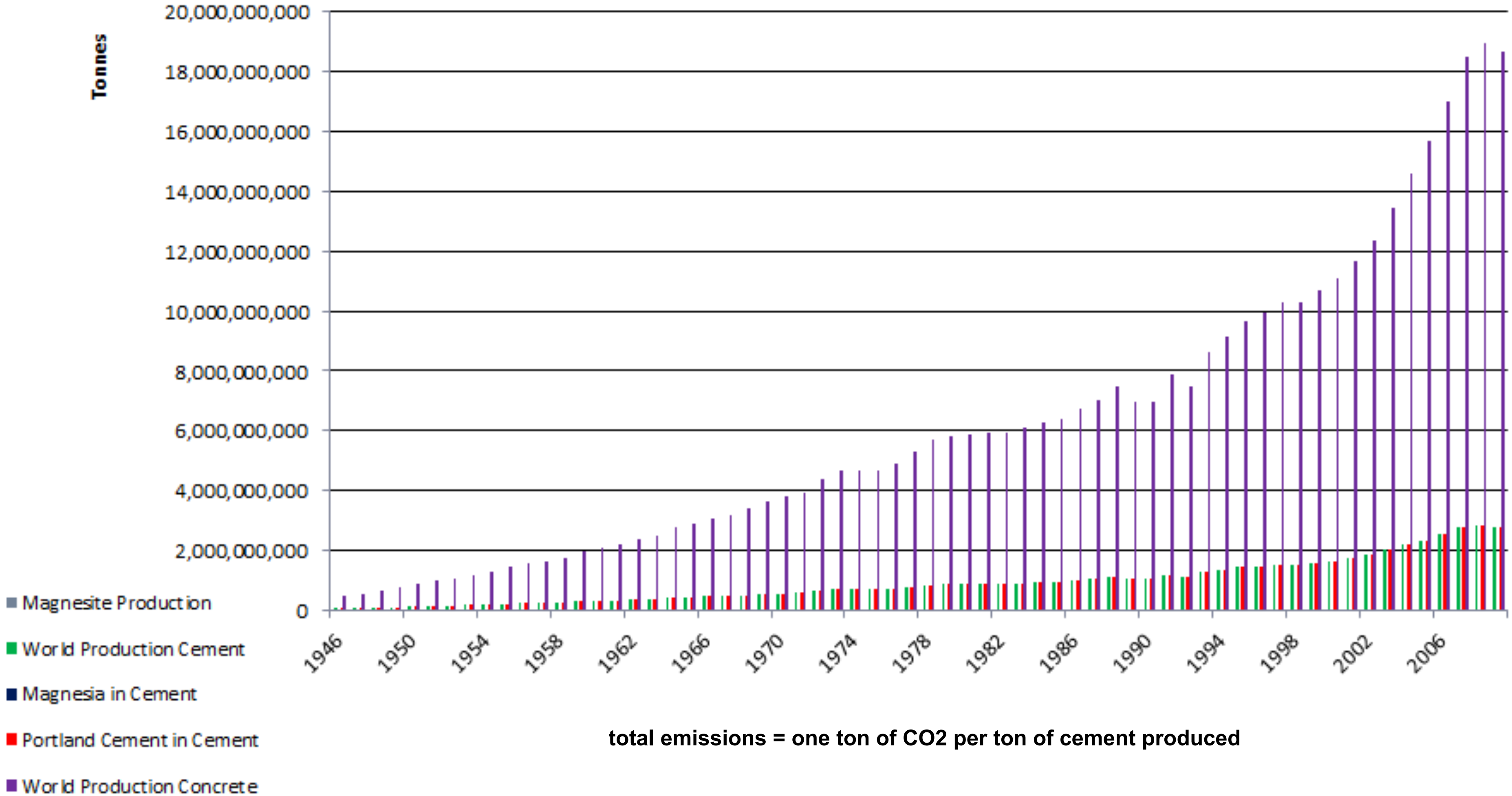
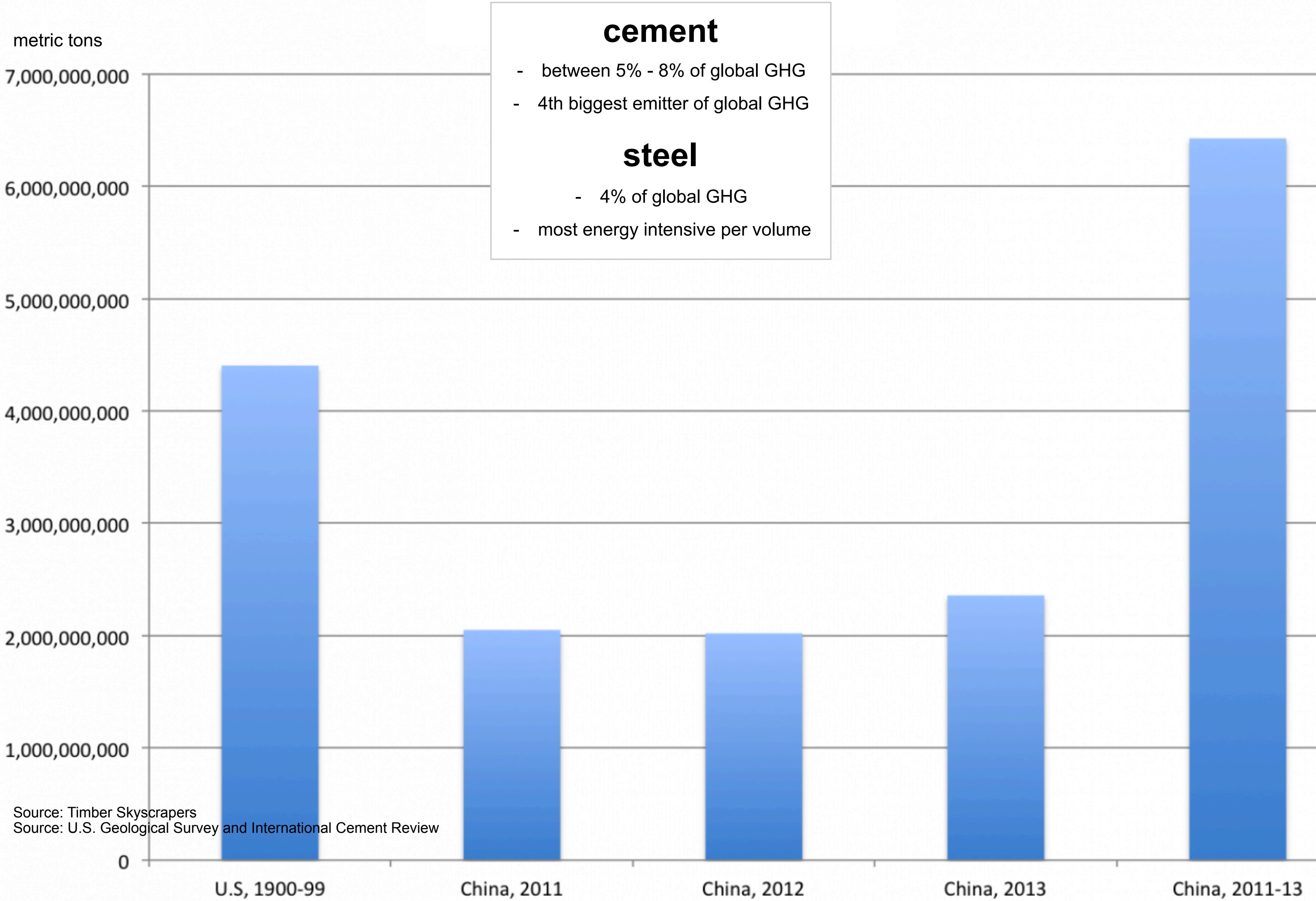
Source: Inventory of Carbon and Energy, University of Bath

building industry primarily uses concrete and steel.



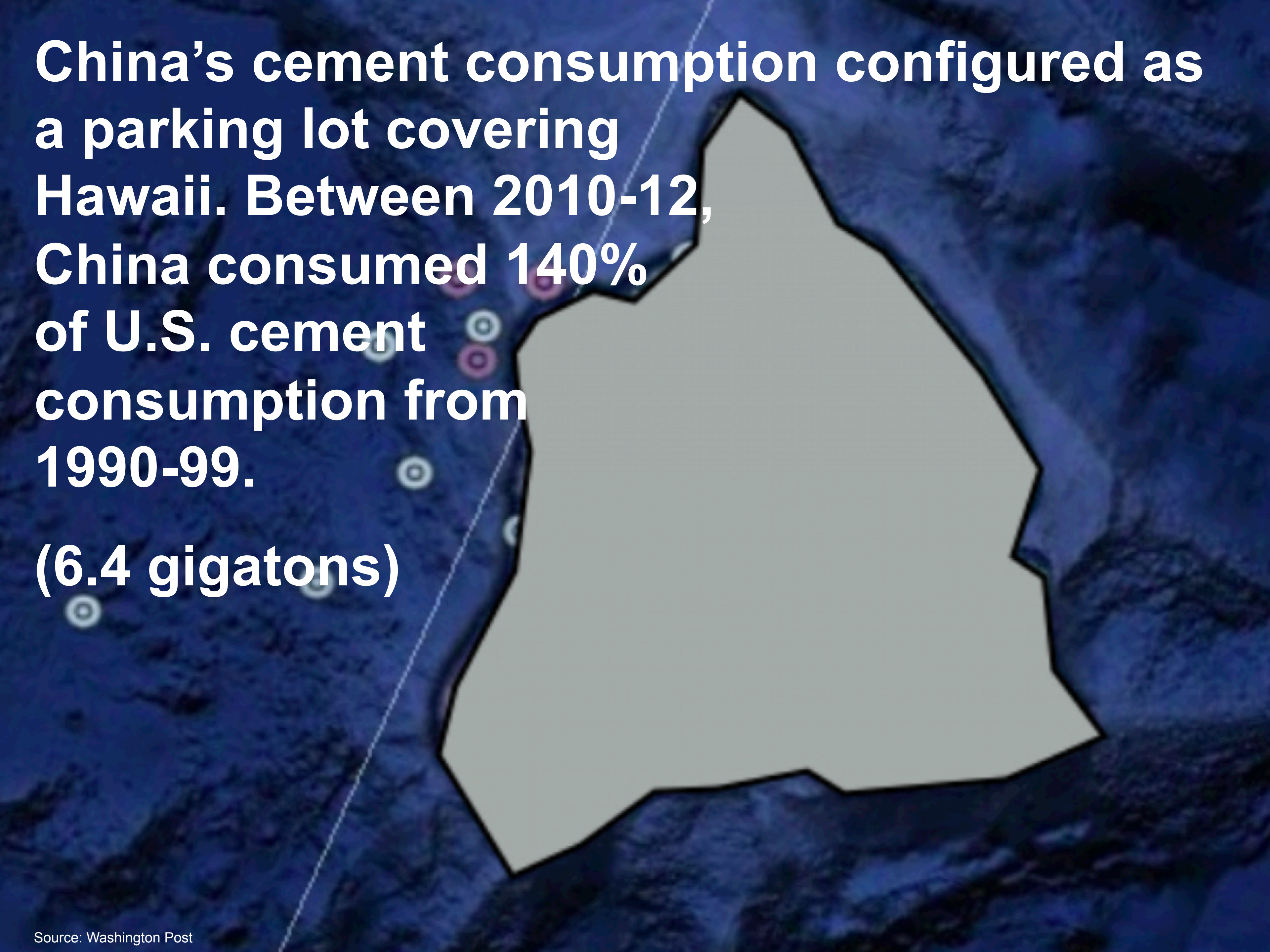
total emissions = one ton of CO2 per ton of cement produced

Source: Cement Data: USGS Minerals Yearbooks


cement
- between 5% - 8% of global GHG
- 4th biggest emitter of global GHG
steel
- 4% of global GHG
- most energy intensive per volume
metric tons
7,000,000,000
6,000,000,000
5,000,000,000
4,000,000,000
3,000,000,000
2,000,000,000
1,000,000,000
0
U.S, 1900-99
China, 2011
China, 2012
China, 2013
China, 2011-13
Source: Timber Skyscrapers
Source: U.S. Geological Survey and International Cement Review

China's cement consumption configured as a parking lot covering Hawaii. Between 2010-12, China consumed 140% of U.S. cement consumption from 1990-99.

(6.4 gigatons)



Source: Washington Post

life cycle analysis. construction

two phases as major sources of the emissions

1. crane lifting involved in erecting structural components, lifting precast facade, precast staircase elements and large panel formworks;

2. excavation phase, employing plant and equipment to digging holes, handling materials, lifting and placing pipes on the site.

Table 1
Examples of the equipment and plant used for Tung Tau Public Housing Project.

Summary of Equipment						
Type of equipment/ plant	Manufacturer	Series	Year	Power source	Power [diesel (hp)] [electric (kw)]	Total operation hour
Vibrator rammer/ plate	compactor	Xingchen			HCR80K	2009
Diesel	5.0 hp					
		5200				
Compaction roller	Wacker	RD-7H	2003	Diesel	7.5 hp (5.5 kw)	1840
Generator	Wantong	WT6500SD	2009	Diesel	5.5 kw	1120
Excavator/ backhoe	Sumitomo	SH125X	2002	Diesel	87 hp (64.9 kw)	3000
Concrete vibrator	Kezhuwang	ZXR	2008	Diesel	5 hp	17,040

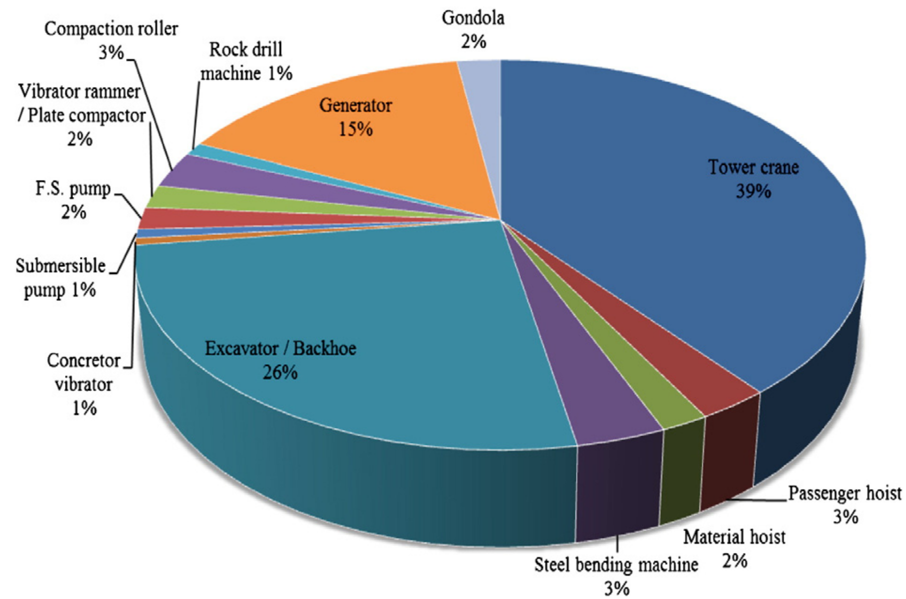


Fig. 4. CO_2 emissions from plant and equipment in the TTCAE Public Rental Housing Development Project.

Source: Toward Low-Carbon Construction Processes

life cycle analysis. construction

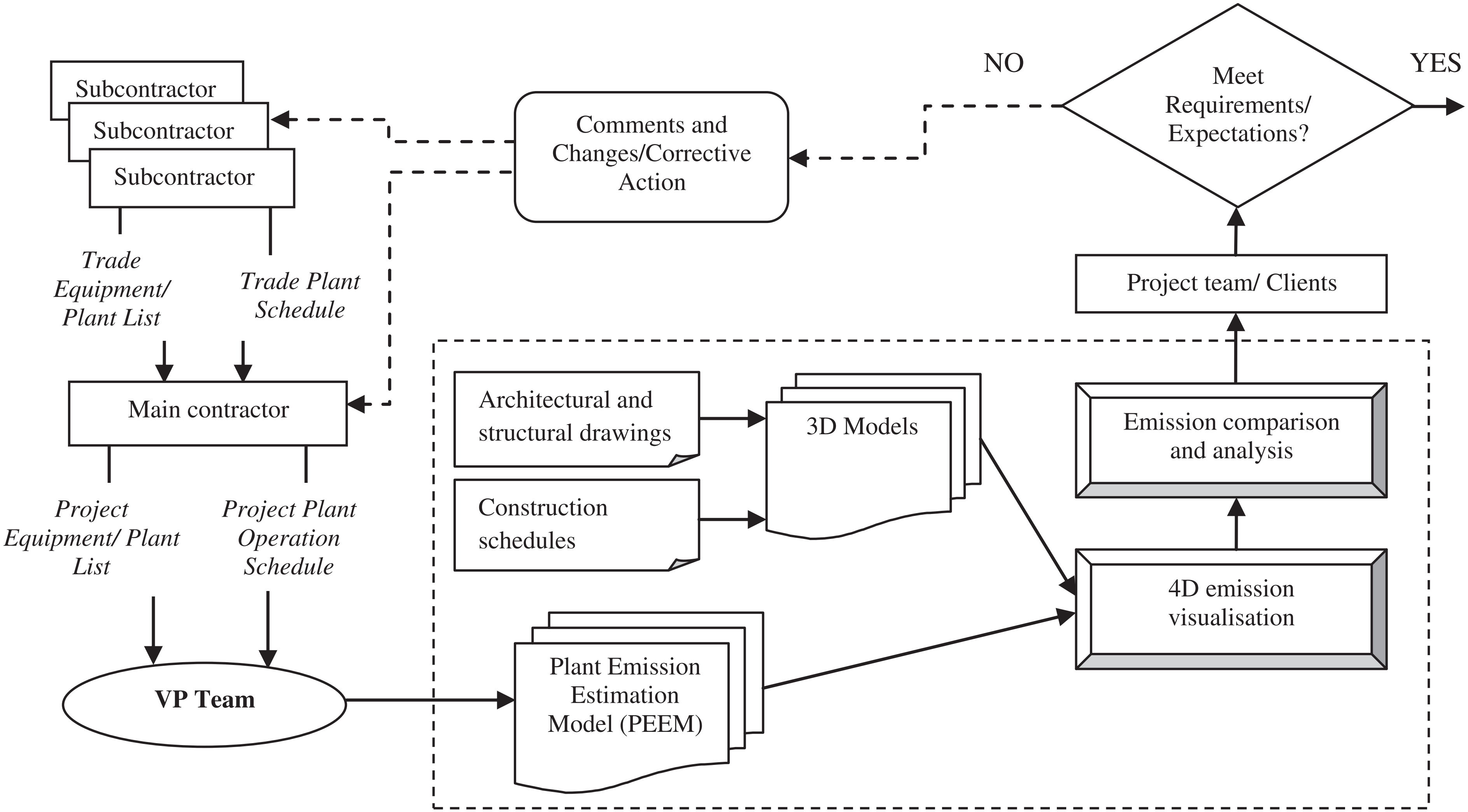


Fig. 1. VP-based emission prediction framework.

Source: Toward Low-Carbon Construction Processes

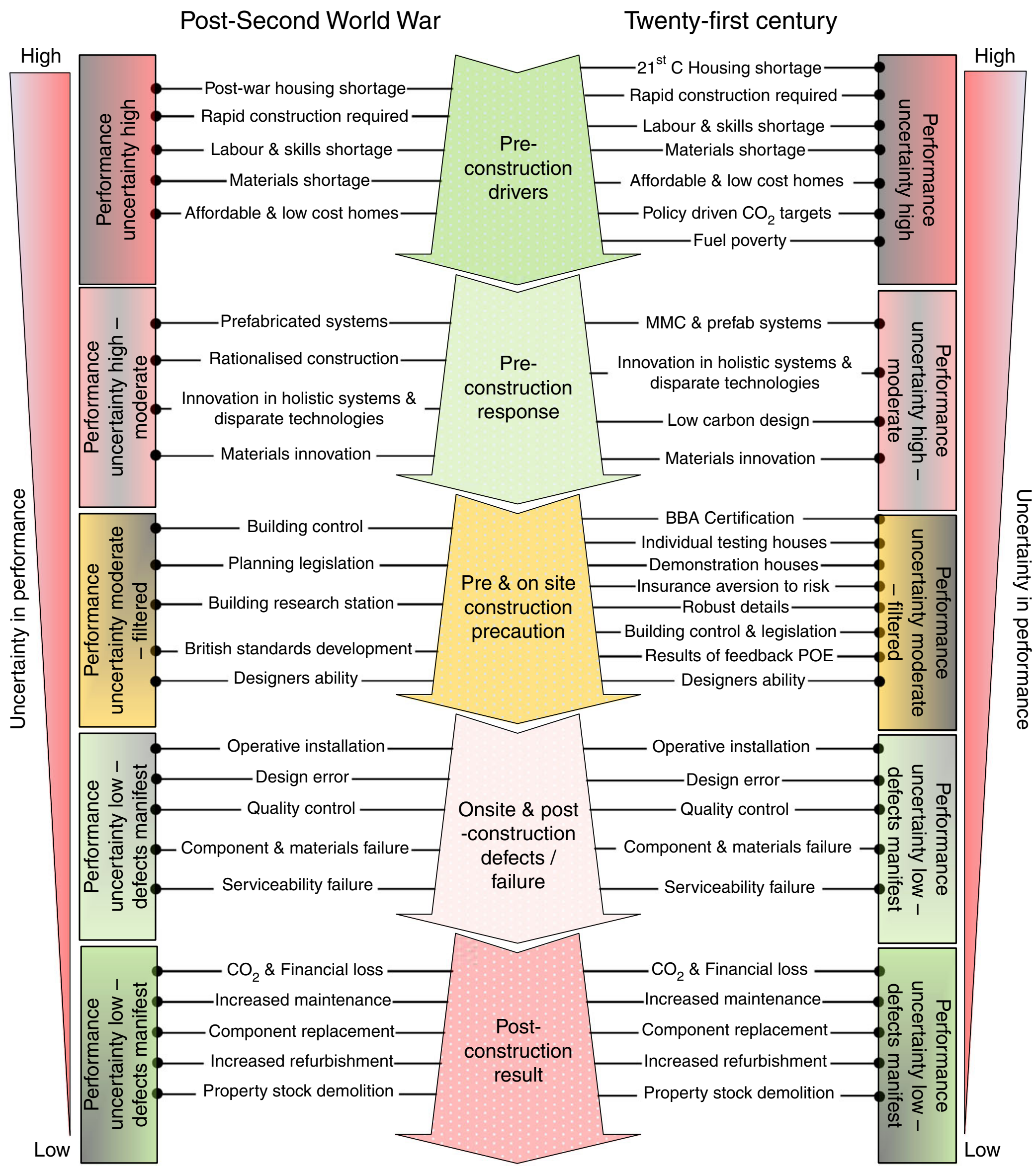
1945, 2013. housing shortage

Estimated 232,000 dwellings per year by 2033 required in England alone.

(Source: Office for National Statistics, 2010a)

- **4.6 million buildings;**
- **33% cheaper;**
- **50% quicker;**
- **50% reduction in green-house gas emissions**

(Source: HM Government, 2013)



Source: Innovation in Low Carbon Construction Technologies

planning, design, construction roles and responsibilities (56)

owner

- Capital sourcing
- Financing
- Leasing
- Geotechnical (site)
- Surveyor (record what is)
- Lawyer (contracts)
- Lawyer (permitting)
- Partnering Consultant
- Broker/Public Relations
- Advertising/Marketing
- Landscape Architect
- Civil Engineer
- Owner's Representative
- Appraiser
- Market Researcher
- Insurance
- Commissioning Agent
- Testing

architect

- Landscape
- Programmer
- Structural
- Mechanical/HVAC
- Electrical
- Plumbing
- Fire Protection
- Civil Engineering
- Sustainability
- Lighting
- Daylighting
- Acoustics
- Interior Design
- Exterior Envelope
- Security/Access
- Spec Writer
- Code (accessibility)
- Cost Estimator
- Door Hardware
- Food Service

contractor

- Excavator/Site Work/ Geotechnical Engineer
- Surveyor (layout new)
- Door & Door Hardware
- Concrete
- Masonry
- Steel
- Framer/Carpenter
- Glass & Glazing/Curtain Wall
- Mechanical
- Electrical
- Paint
- Drywall (taper)
- Floor – Carpet
- Elevator
- Miscellaneous Metals
- Fire Protection
- Waterproofing
- Curtain Wall

high degree of separation between design and construction process increases communication complexity and confusion.

problems between designer and operative (architect does not tell the builder how to construct it):

"the client, via the designer, tells the builder what is required – he does not tell the contractor how to go about it."

process also reversed: inadequate feedback between installer and designer.

further exacerbated by unique nature of products as every project is different.

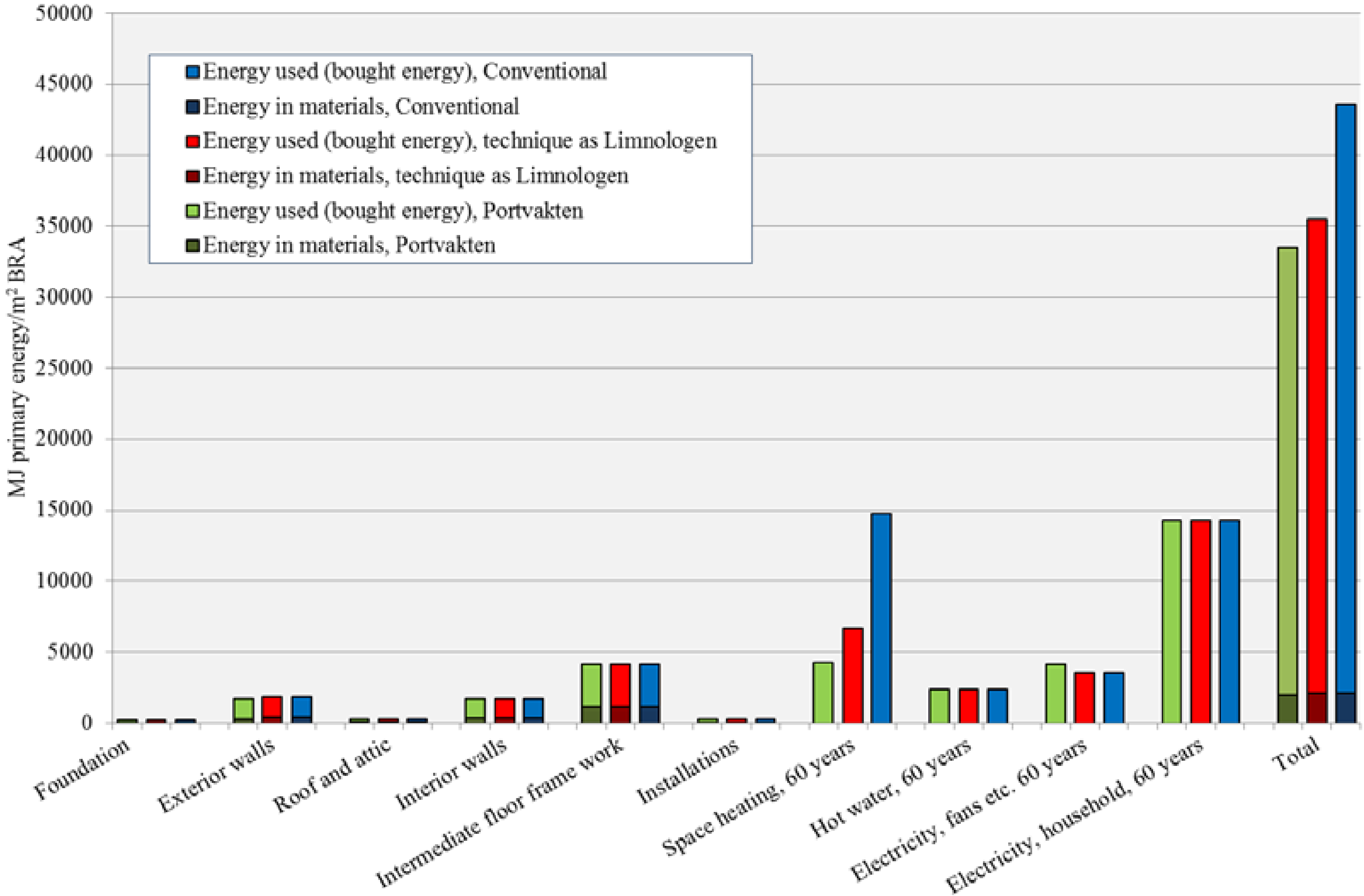
Source: Innovation in Low Carbon Construction Technologies

low-energy building. southern portvaken, växjö, sweden

high rise apartment buildings, eight stories, 2009

low-energy building. southern portvaken, växjö, sweden

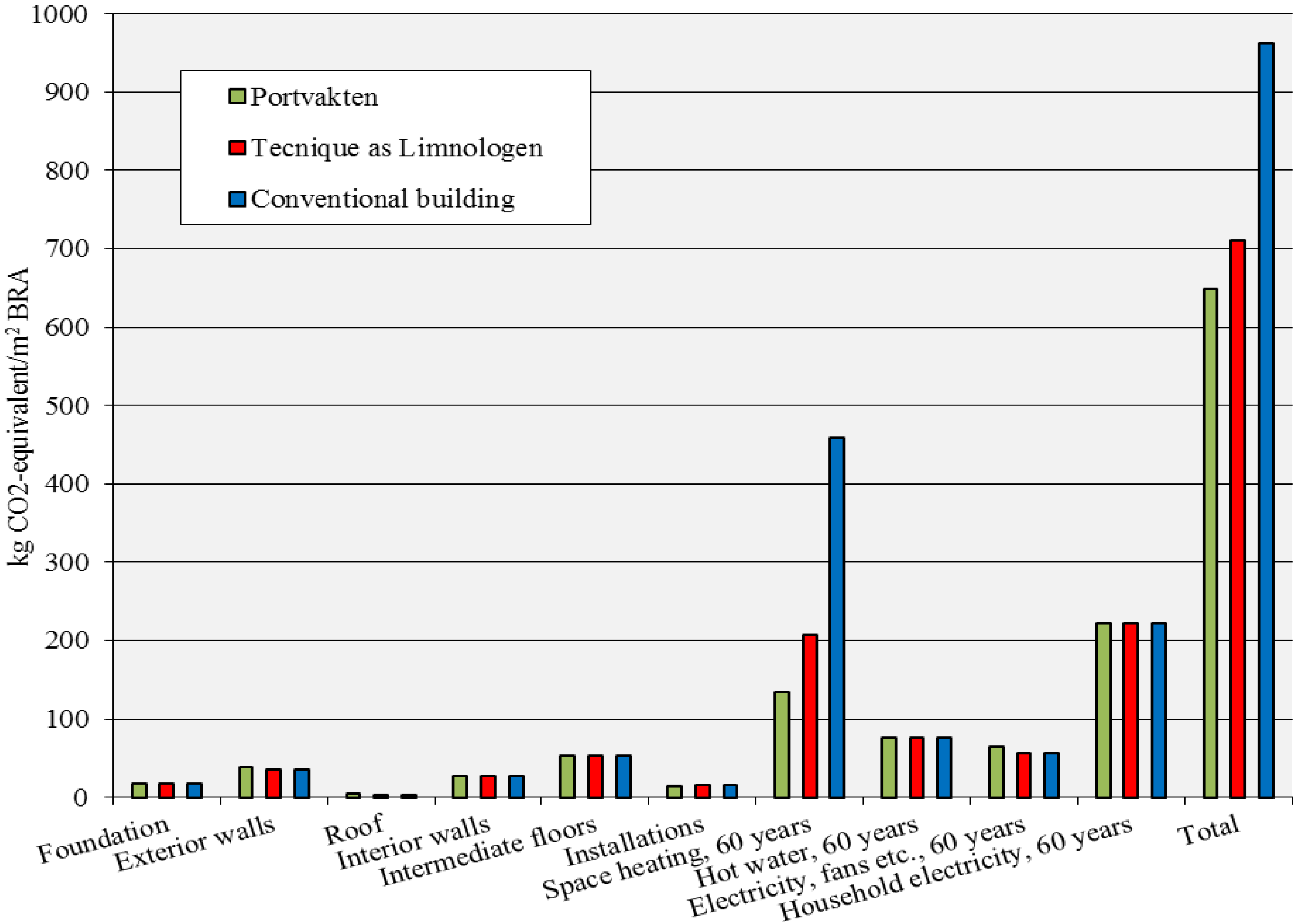
Figure 8. Use of primary energy, including 60 years of operation MJ/m^2.



Source: Energy Performance of Two Multi-Story Wood-Frame Passive Houses in Sweden

low-energy building. southern portvaken, växjö, sweden

Figure 9. Potential contribution to global climate change, including 60 years of operation, kg CO_2-eq/m^2.



Source: Energy Performance of Two Multi-Story Wood-Frame Passive Houses in Sweden, 2015

low-energy building. southern portvaken, växjö, sweden

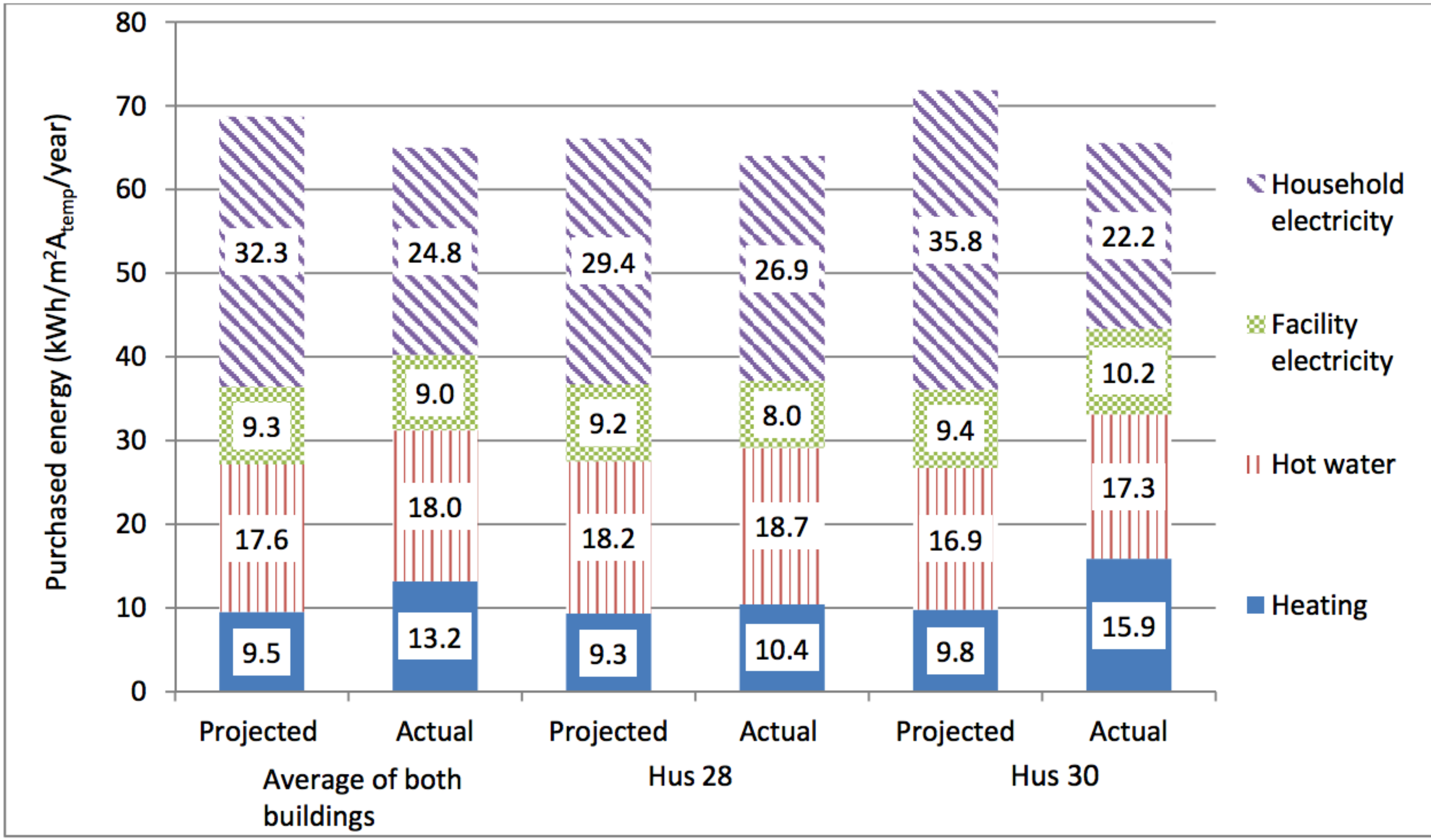


Figure 2. Projected (revised from [7]) and actual energy use in 2012 of the Portvakten Söder buildings. Energy use for heating is normalized.

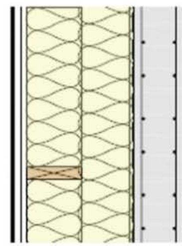
Source: Energy Performance of Two Multi-Story Wood-Frame Passive Houses in Sweden, 2015

low-energy building. southern portvaken, växjö, sweden

Figure 1. Cross section of the outer wall elements, with concrete-bearing wall at the ground floor and the timber-bearing wall at all upper floors.

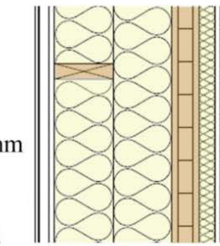
Ground floor outer wall

Cement fibre panel 8 mm
Sealing joint 2 mm
Wooden bolt 28*45 mm
Gypsum board 17 mm
Horizontal wooden stud 45*195 mm
Insulation (mineral wool) 195 mm
Vertical wooden stud 45*170 mm
Insulation (mineral wool)170 mm
Plastic foil
Concrete 180 mm



First to eight floor outer wall

Cement fibre panel 8 mm
Sealing joint 2 mm
Vertical wooden bolt 28*95 mm
Gypsum board 17 mm
Horizontal wooden stud 45*170 mm
Insulation (mineral wool)170 mm
Vertical wooden stud 45*170 mm
Insulation (mineral wool) 170 mm
Plastic foil
Massive timber
Vertical wooden bolt 45*45 mm
Insulation (mineral wool) 45 mm
Gypsum board, fire protective



Multi-story wood-framed passive houses are relatively new to Sweden, as well as to Europe.

Question: Is it possible to build renewable-material-based buildings with low energy use and climatic impact?

Answer: Yes.

Energy Performance of Buildings Directive (EPBD) directive for all new buildings in the EU Member States be nearly zero-energy buildings by 31 December 2020.

Source: Energy Performance of Two Multi-Story Wood-Frame Passive Houses in Sweden

mass timber.

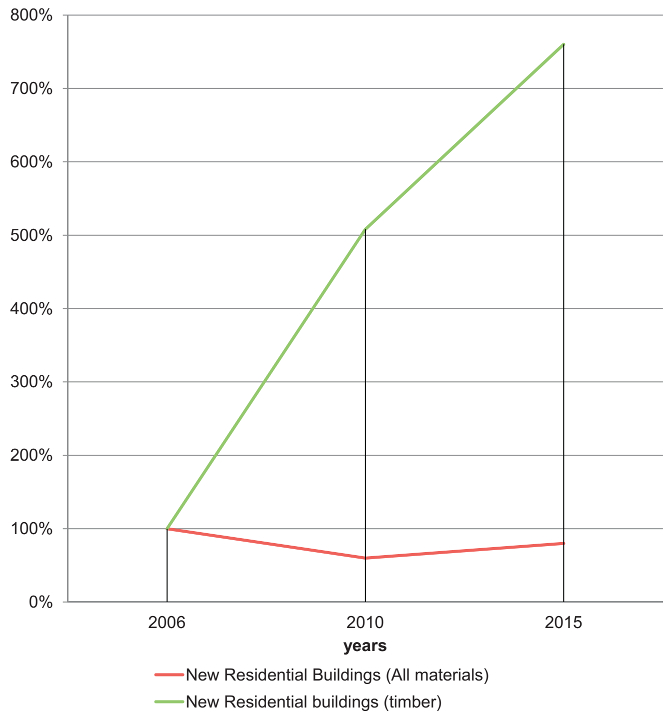
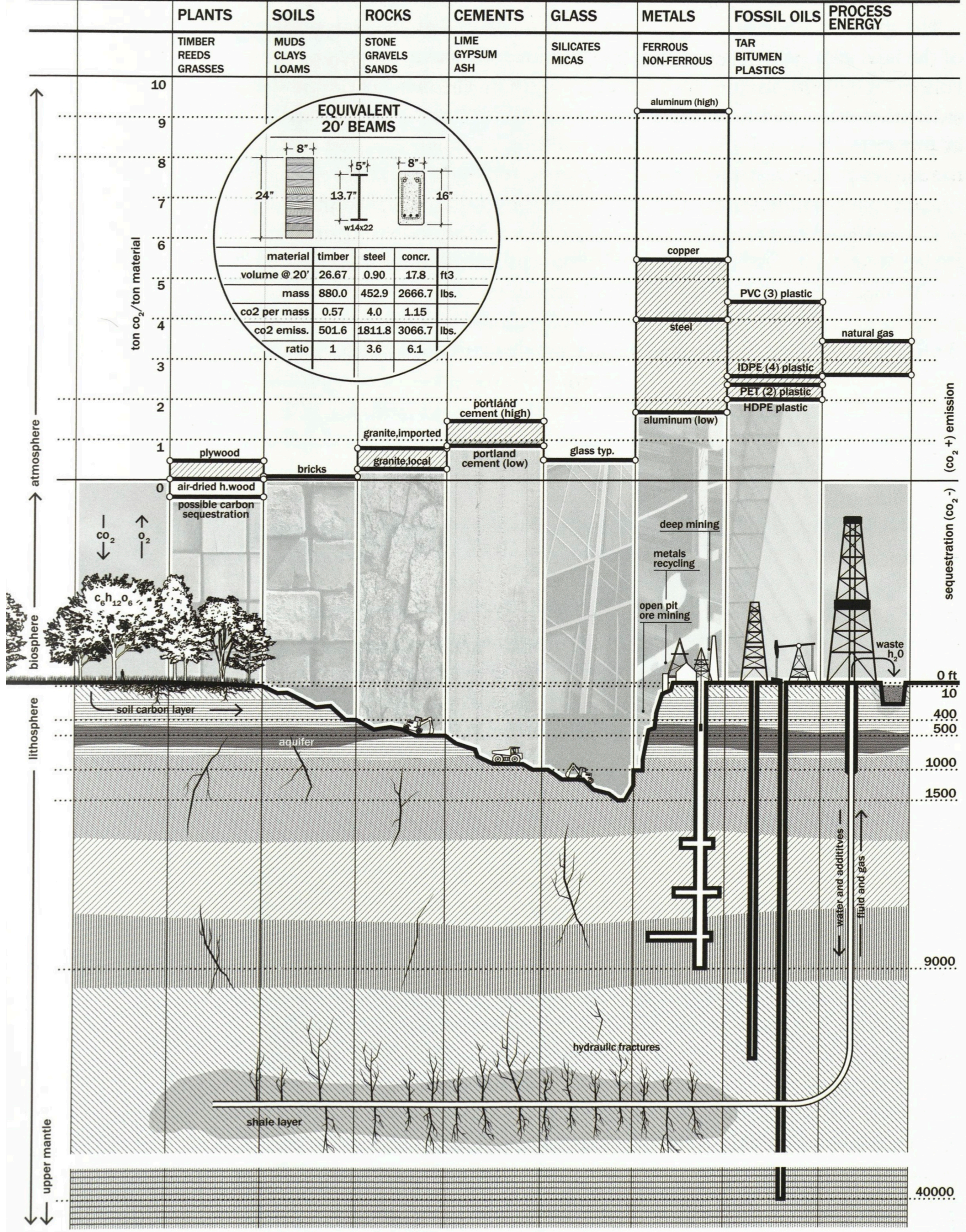
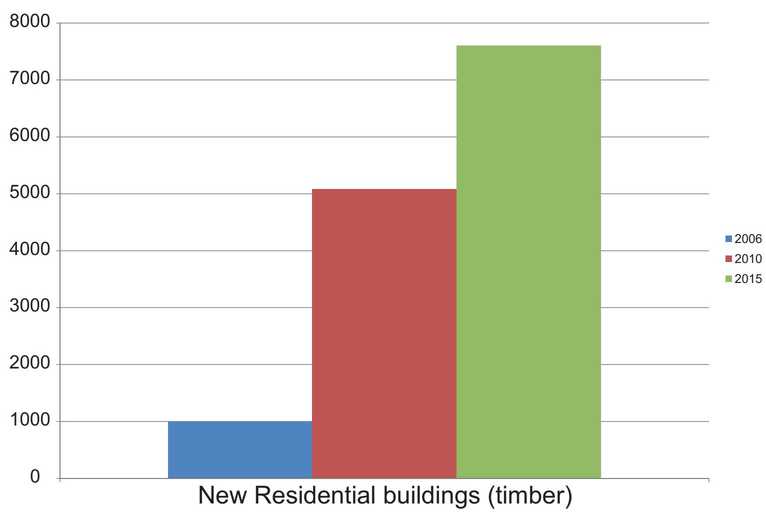


Fig. 3. Trend of new timber residential buildings base 2006 = 100%.



Source: Timber Buildings and Thermal Inertia
Source: Timber in the City

mass timber.



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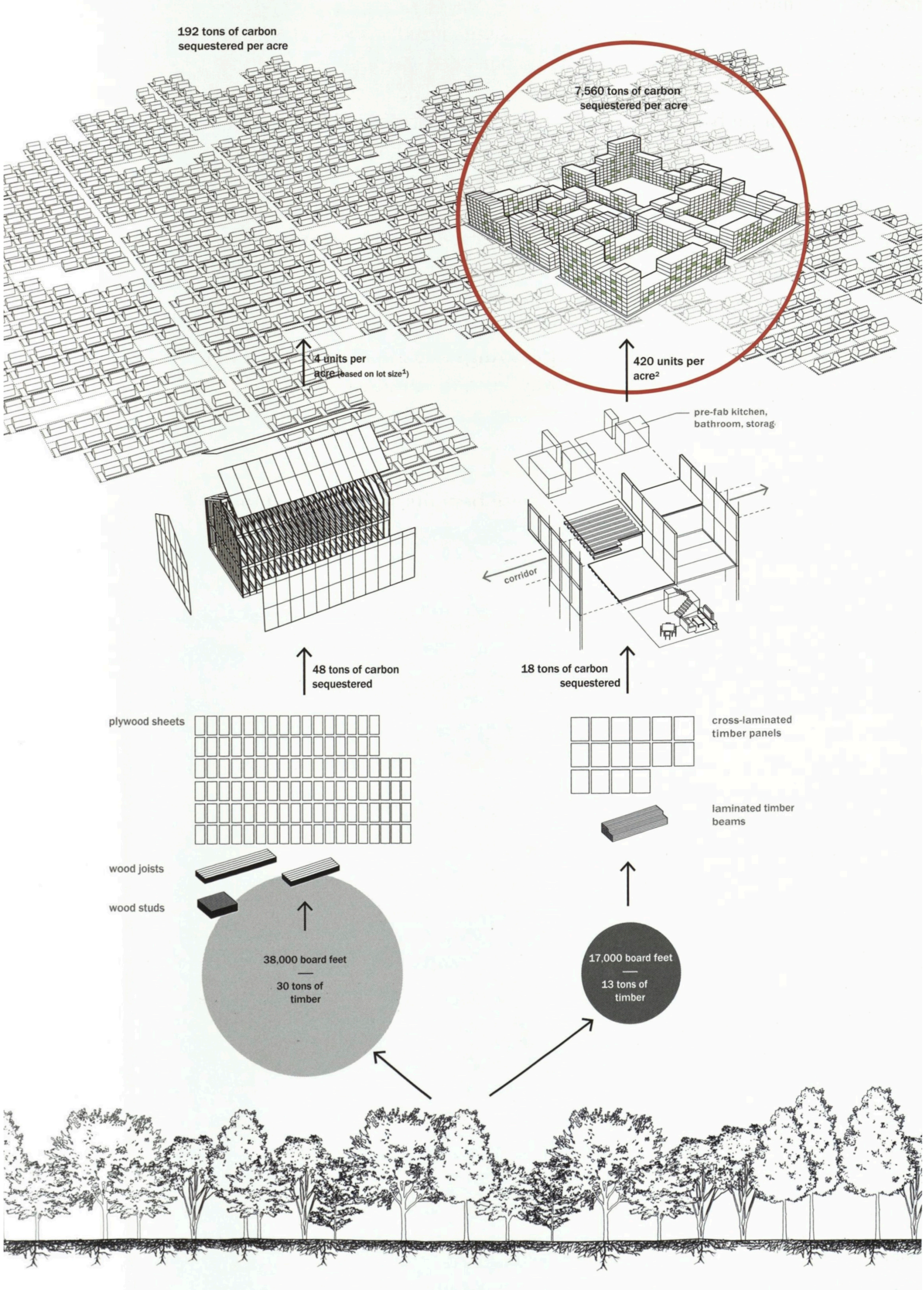


Source: Timber Buildings and Thermal Inertia
Source: Timber in the City

mass timber. cross-laminated timber (CLT)

- invented in 1970s
- cross-laminated timber panels are formed using planed “lamellas” (planed boards from 1” thick x 5”-7” wide) laid and glued using formaldehyde-free, food-grade glue in a vacuum press in alternate layers, at 90 degrees to each other, creating panels that are from 3 to 11 layers thick (jumbo ply)
- young trees 10, 12, 15 years old
- 8ft wide x 64ft long, various thicknesses (Europe); 10ft wide x 24ft long (U.S.)
- carbon sink (1 ton of carbon sequestered/1m3 of wood)
- renewable
- thermal efficiency: CLT buildings can double the energy efficiency of conventional buildings
- quick, cost efficient construction: 18-month conventional to 1 year mass timber construction
- responsible cultivation practice maintains and even enhances the long-term productivity and health of the forest

Source: Solid Timber Construction Report

mass timber. cross-laminated timber (CLT)

Glue Laminated Timber; Structured Composite Lumber, Cross-Laminated Timber; Dowel Laminated Timber, Nail Laminated Timber, Cross and Nail Laminated Timber, Interlocking Cross-Laminated Timber

Source: Solid Timber Construction Report

mass timber. murray grove

Perceived risks

fire
deforestation
earthquakes
weather
durability
longevity
high winds
termites
building codes
market acceptance
cost & value

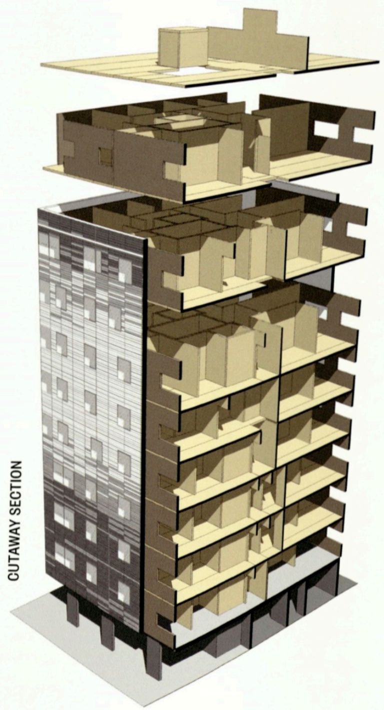
- "For a 20 story building, North American forests grow enough wood every 13 minutes."
- Building a 20 story building out of cement and concrete, emissions are 1,215 tons of CO2.
- Building out of wood sequesters 3,150 tons.
- Net difference: 4,360 = 900 cars removed from the roads in one year.
- Wood building requires skills of the carpenter: from slabs and columns to flat pieces of timber, which work as beams, which work as floor slabs.
- "Timber as a carbon store is only really effective for the first half of the tree's life. A sixty-year-old tree soaks up carbon from the atmosphere for the first 25-30 years; the rest of the time is actually just in a cycle. So, when you cut a tree down and grow another, you're soaking up more CO2 from the atmosphere into the tree."

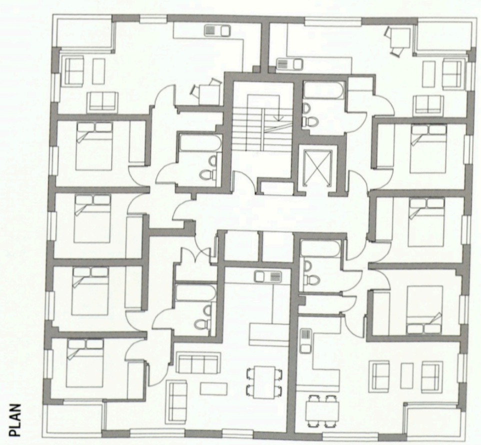
Source: Timber Skyscrapers
Source: Timber in the City

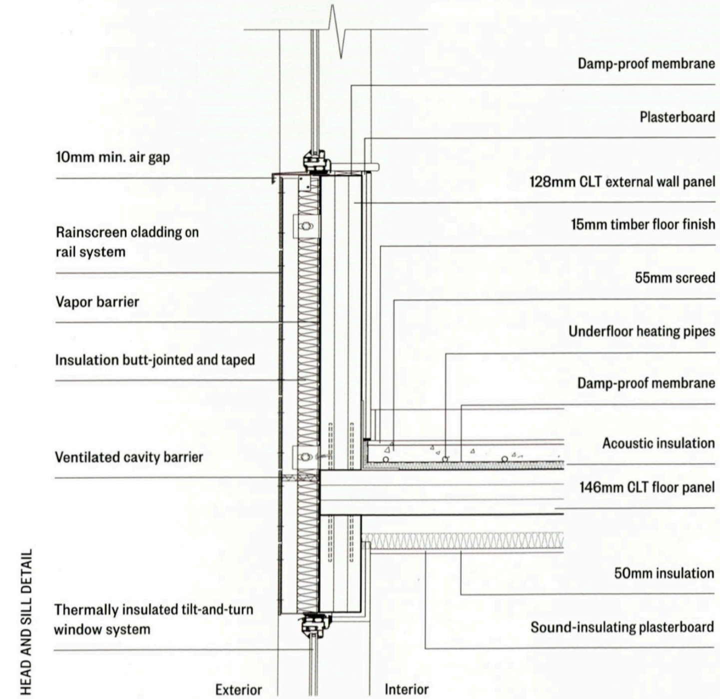
mass timber. murray grove

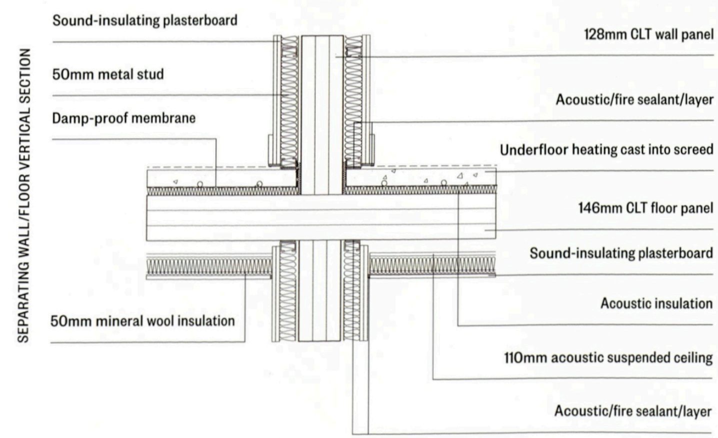
Source: Timber in the City

mass timber. murray grove



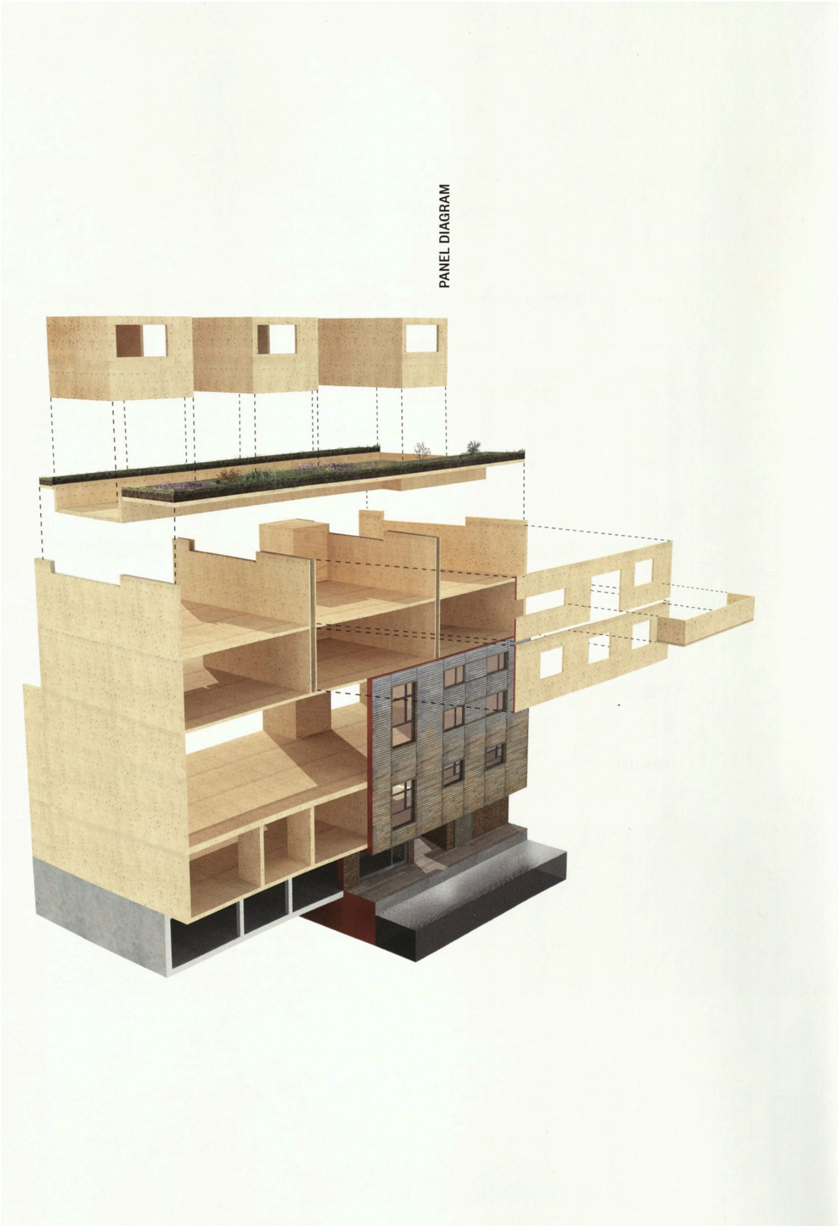






Source: Timber in the City

mass timber. 52 whitmore road



Source: Timber in the City

mass timber. heat transfer

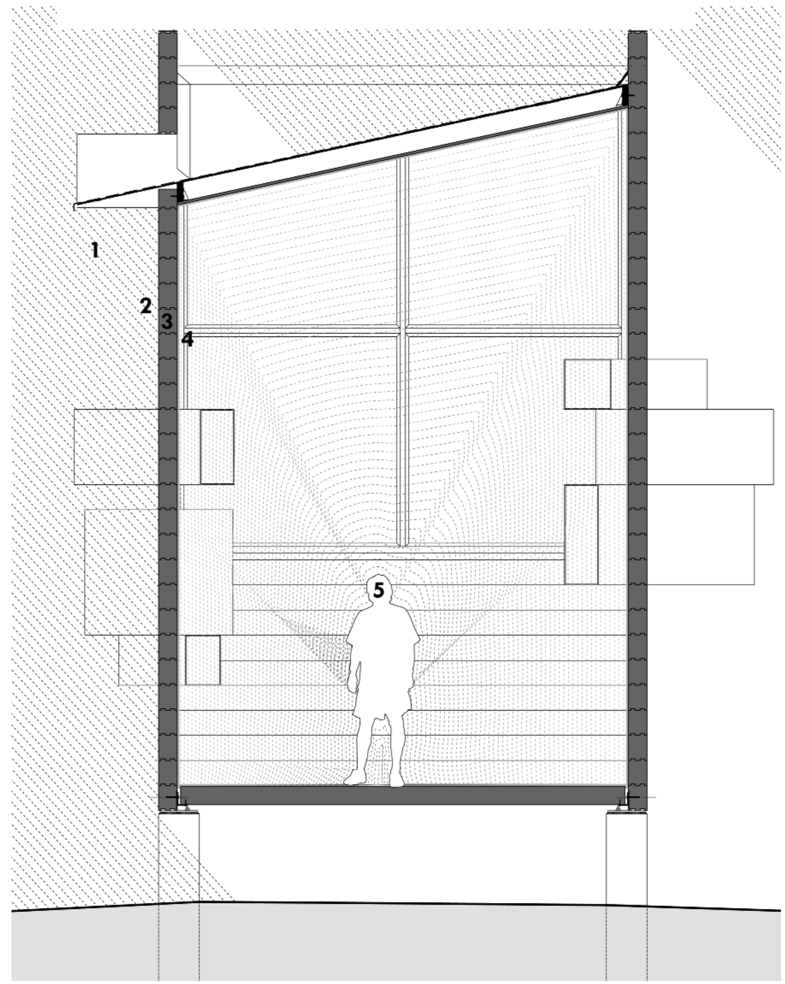


Figure 9. Different modes of heat transfer in a solid wood building. 1.) Solar radiation, 2.) Absorptivity of wood wall, 3.)Thermal diffusivity of wood, 4.) Effusivity of wood , 5.) Effusivity and absorptivity of human body.

Source: Insulating North America

mass timber. carbon sink

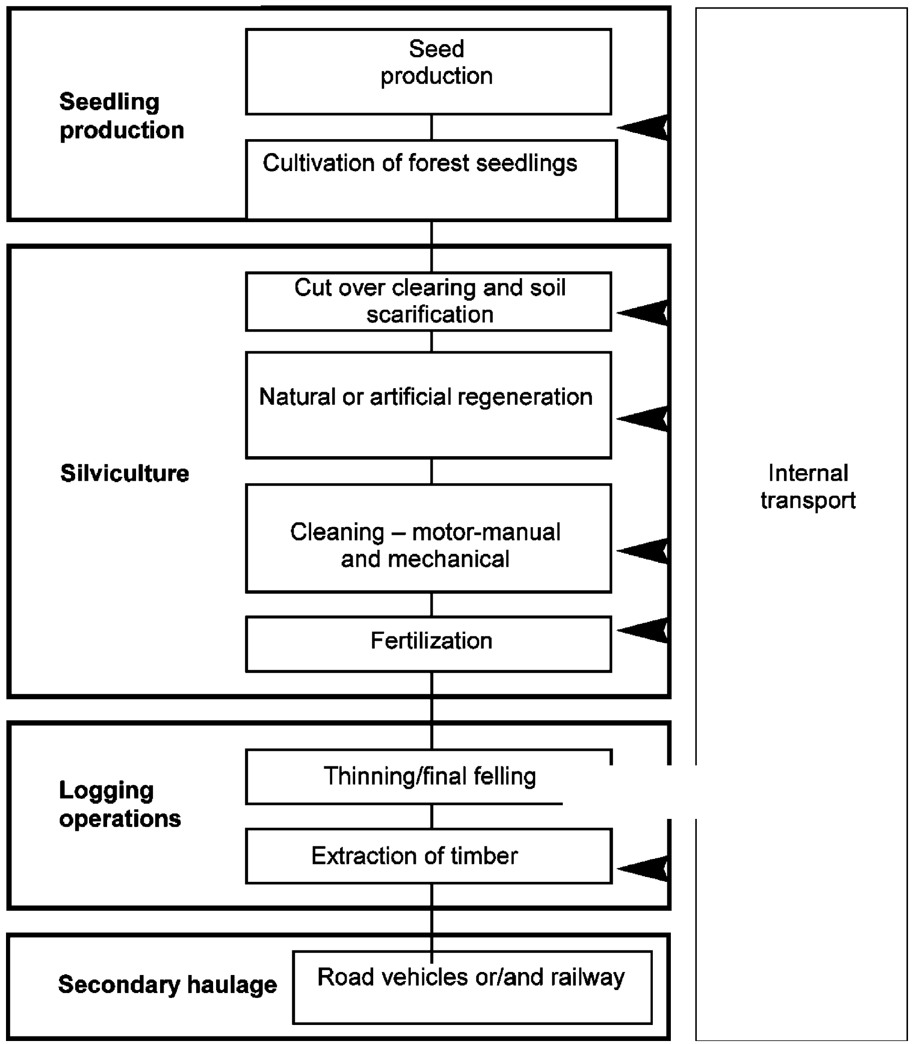
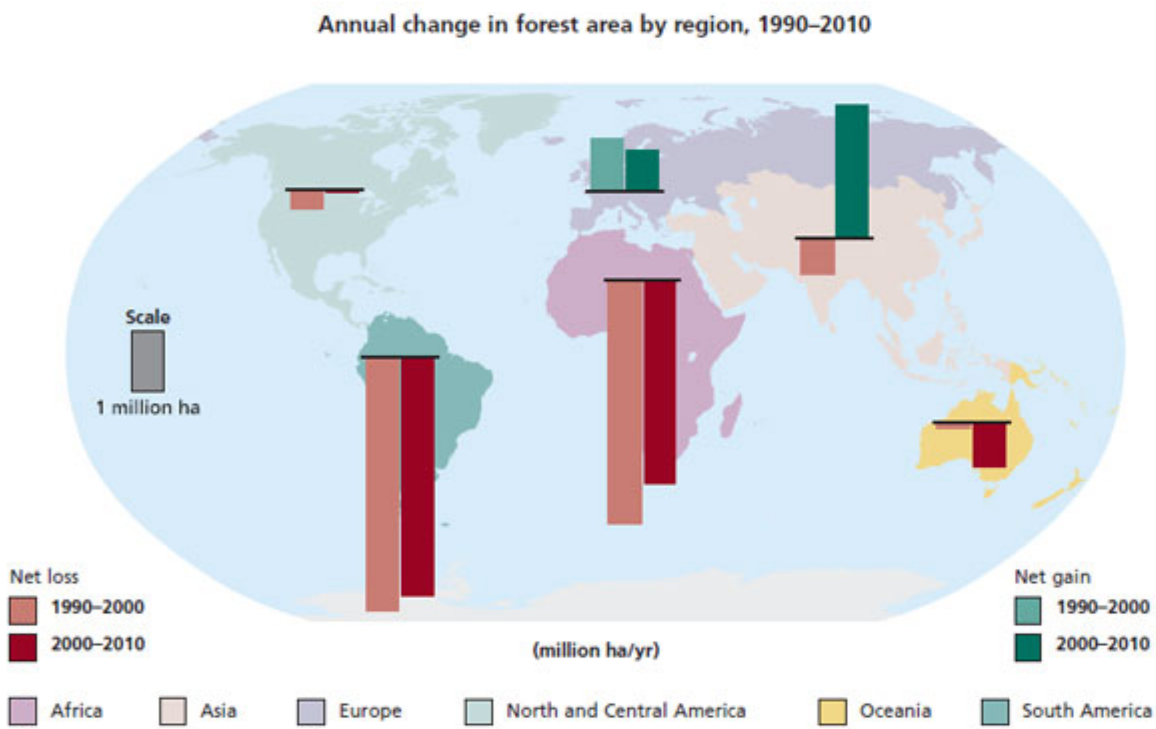


Fig. 1. Unit processes (boxes and text in bold) and their comprising forest operations. Internal transports are allocated to unit processes.

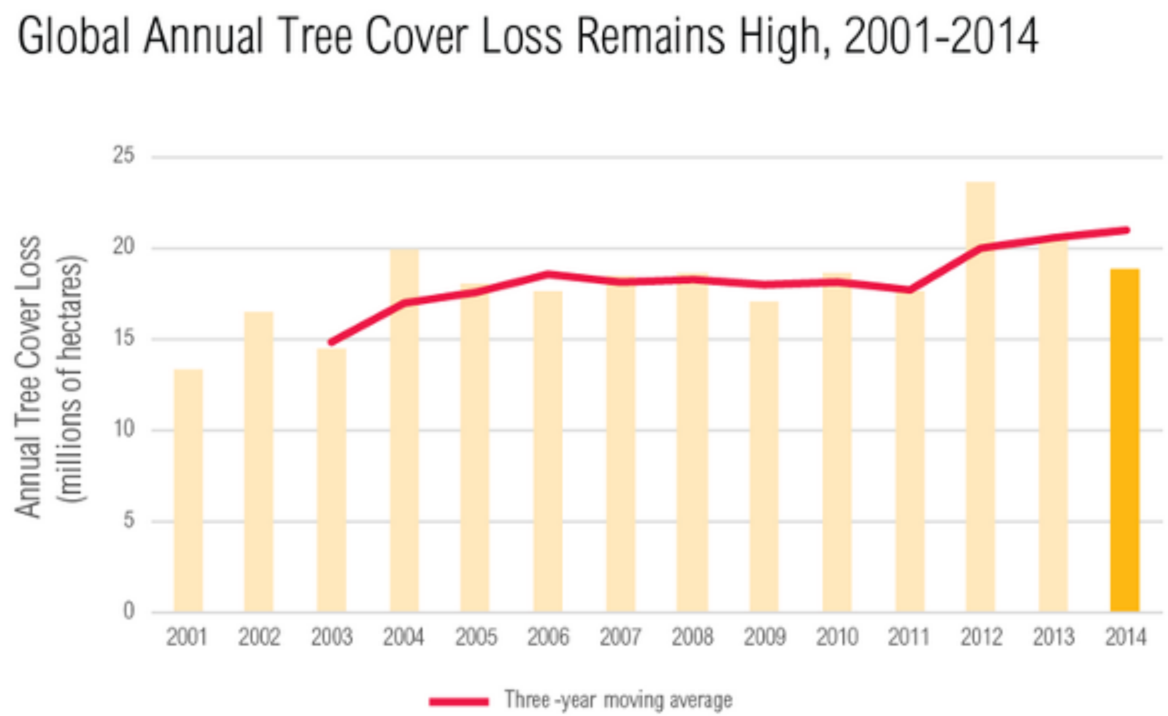
Source: Energy Use and Environmental Impacts of Forest Operations in Sweden

mass timber. carbon sink



Source: Food and Agriculture Organization of the United Nations

mass timber. carbon sink



Source: World Resources Institute

mass timber. forest management

Table 2 – Characterisation of the forest management and wood use scenarios.

	Reference year 2000	Optimized increment		Kyoto-optimized	Business-as-usual	Reduced forest maintenance
		Construction	Energy			
Forest management						
Aim		Harvesting of maximum increment performance		Harvesting of higher increment performance; use of Kyoto 'cap'	Continuation of actual forest management principles	Maximum C sinks in forests
Principles		Reduced thinning, optimized regional rotation periods, even-aged class distribution		Reduced tending, optimized regional rotation periods, even-aged class distribution, stock increase to 'cap'	Continuation of forest management principles between the national forest inventories NFI I and NFI II	Minimal forest management, particularly in protective forests
Extracted wood	5.4 mio. m^3 [a]	+70%		+60%	+10%	−45%
Wood use						
Principles		Increased construction use of long-living wood products and subsequent energetic use	Increased use of biofuels	Construction use of long-living wood products and subsequent energetic use	Extrapolation of actual consumption patterns	Significant reduction of wood use for products and energy
Wood products	2.5 mio. m^3	+80%	+/−0%	+80%	+20%	−25%
Fuel wood	1.3 mio. m^3	+120%	+340%	+65%	+20%	−80%
Foreign trade						
Import	1.4 mio. m^3	+/−0%		+/−0%	+/−0%	+/−0%
Export	2.2 mio. m^3					

[a] Extrapolation from the Swiss forestry statistics (BfS/BUWAL, 2000), including merchantable timber ($d > 7$ cm); stumps, bark and 14% of the mortality remain unused.

Source: National and Global Greenhouse Gas Dynamics of Different Forest Management and Wood Use Scenarios

mass timber. forest management

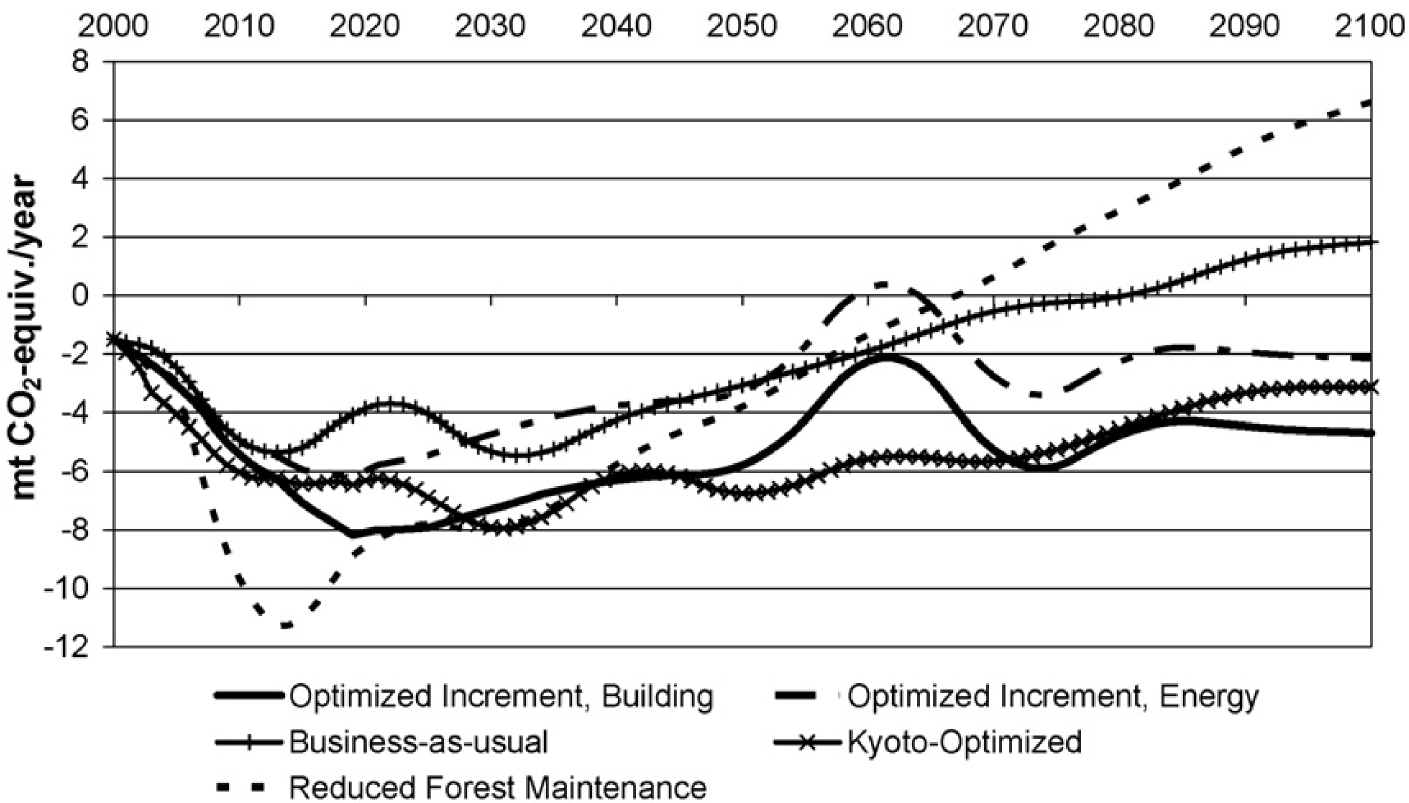


Fig. 4 – Annual global net GHG effects of the scenarios (2000–2100).

Source: National and Global Greenhouse Gas Dynamics of Different Forest Management and Wood Use Scenarios

mass timber. forest management

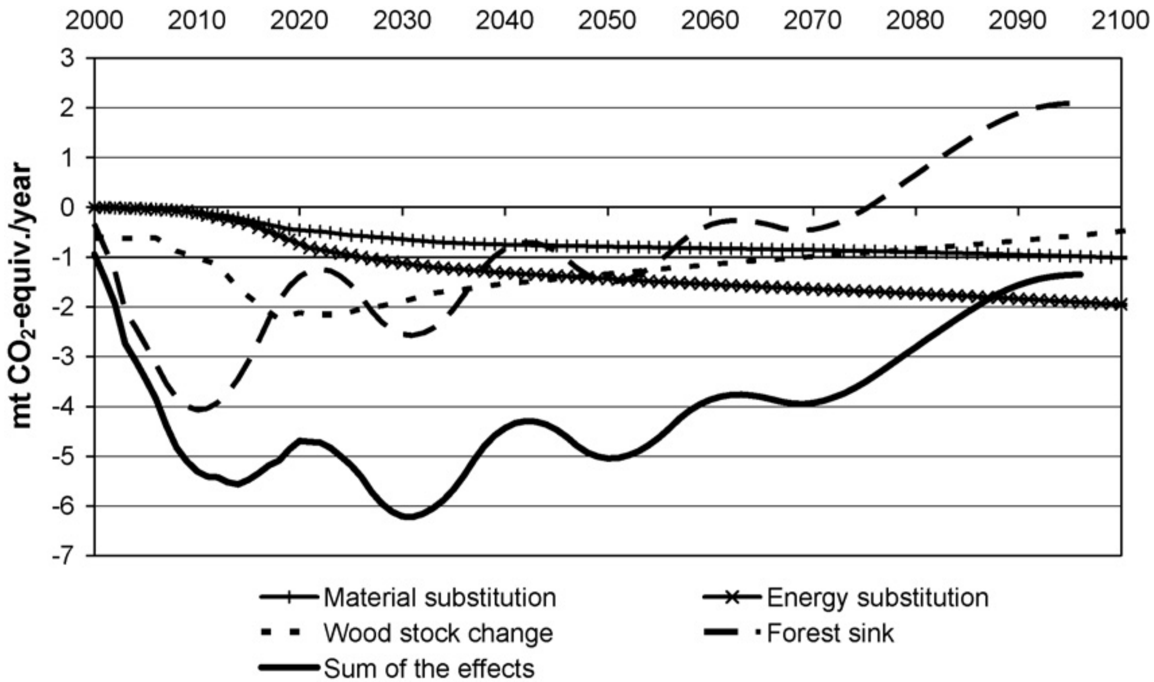


Fig. 6 – Temporal sequence of individual global annual stock and material effects based on the *Kyoto-Optimized* scenario (2000–2100).

Source: National and Global Greenhouse Gas Dynamics of Different Forest Management and Wood Use Scenarios

mass timber. wood and non-wood substitutes

Table 1 – Material substitution: wooden products and their non-wooden substitutes.

Use	Wood product	Non-wooden product
Structure		
Exterior walls	Solid wood panel	Brick cavity masonry
Columns	Glulam column	Steel column
Storey ceiling/floor	Wood joist ceiling/floor	Reinforced concrete ceiling/floor
Insulation	Wood fibre insulation board[a]	Rockwool[b]
Roof	Exposed beam structure	Aerated concrete steep roof
Structural engineering	Wood palisade	Concrete palisade
Finish		
Wall and ceiling covering	Spruce panelling	Interior plastering
Stairs	Oak staircase	Precast concrete stairs
Floor coverings	3-Layer parquet	Glazed ceramic tiles
Façades	Raw wood siding including lath[a]	Exterior plastering[b]
Fittings	Architrave from derived timber products	Architrave frame
Furniture	Wood furniture	Steel furniture
Other wood products		
Packaging	Raw wood siding including lath[a]	Same volume of plastic (polypropylene)
Wood products	Raw wood siding including lath[a]	Same volume of plastic (polypropylene)
Auxiliary construction materials	Formwork panels (3-layer spruce panel)	Aluminium formwork
Do-it-yourself	Spruce panelling	Interior plastering

[a] In solid wood panel construction.
[b] In brick cavity masonry.

Source: National and Global Greenhouse Gas Dynamics of Different Forest Management and Wood Use Scenarios

mass timber. methane. transport

Material Profile: Timber

Embodied Energy (EE) Database Statistics - MJ/Kg

Main Material	No. Records		Average EE		Standard Deviation		Minimum EE		Maximum EE	
Timber	**162**		**9.36**		**8.19**		**0.30**		**61.26**	
Timber, General	63		7.75		4.81		0.72		21.30	
Unspecified		38		6.78		3.58		0.72		14.85
Virgin		25		9.29		6.07		1.33		21.30
Timber, Hardboard	12		21.54		15.84		3.43		61.26	
Predominantly Recycled		1		3.43		3.43		3.43		-
Unspecified		8		17.85		8.78		4.00		31.70
Virgin		3		37.42		22.68		16.12		61.26
Timber, Hardwood	12		4.59		4.47		0.33		16.00	
Predominantly Recycled		1		0.33		0.33		0.33		-
Unspecified		10		5.15		4.68		0.50		16.00
Virgin		1		3.30		3.30		3.30		-
Timber, MDF	4		11.02		1.40		8.96		11.90	
Unspecified	3		10.72		1.55		8.96		11.90	
Virgin		1		11.90		11.90		11.90		-
Timber, Particle Board	23		12.48		10.14		2.00		36.29	
50% Recycled		1		5.10		5.10		5.10		-
Other Specification		1		10.22		10.22		10.22		-
Unspecified		16		11.41		9.41		2.00		36.00
Virgin		5		17.82		13.35		4.60		36.29
Timber, Plywood	12		13.58		6.34		7.58		27.60	
Unspecified		7		14.33		4.92		8.30		21.40
Virgin		5		12.53		8.48		7.58		27.60
Timber, Softwood	33		5.55		3.26		0.30		13.00	
Unspecified		24		5.42		3.43		0.30		13.00
Virgin		9		5.88		2.92		2.80		9.70
Timber, Woodwool	3		11.98		7.50		5.13		20.00	
Unspecified		3		11.98		7.50		5.13		20.00

Comments on the Database Statistics:

None

Selected Embodied Energy & Carbon Values and Associated Data

Material	Embodied Energy - MJ/Kg	Embodied Carbon - Kg CO2/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
				Low EE	High EE	
General	8.5	0.46	Cradle to Gate	High range, perhaps +/- 40%		Estimated from UK consumption of timber products in 2004
Glue Laminated timber	12	0.65 (?)		8	14	Unknown embodied carbon
Hardboard	16	0.86	Cradle to Gate	15	35	
Laminated Veneer Lumber	9.5	0.51 (?)		-	-	Ref 126
MDF	11	0.59		Not enough data for accurate range. Estimated range +/- 30%		AUS & NZ data, only two data points
Particle Board	9.5	0.51		4	15	Very large data range, difficult to select best value
Plywood	15	0.81	Cradle to Gate	10	20	
Sawn Hardwood	7.8	0.47		0.72	16	Highly dependent upon the distance travelled, which explains the incredible range. The selected values represent typical UK timber, they were selected giving high preference to values from UK sources
Sawn Softwood	7.4	0.45		0.72	13	
Veneer Particleboard (Furniture)	23	1.24		(+/- 40%)		

Comments

Data on timber was particularly difficult to select, of all the major building materials timber presented the most difficulties. These values do not include the effect of carbon sequestration. The inclusion or exclusion of sequestered carbon is a complex argument. The following extract highlights some of the difficulties:

The following extract was taken from A. Amato *"A comparative environmental appraisal of alternative framing systems for offices"* 1996, Reference 1: *"There are counter arguments against taking sequestered CO2 into consideration. In measuring embodied CO2, what is being sought is the CO2 burden to society which consequent upon society's use of a particular material. The deduction of a CO2 value sequestered by the material during its manufacture from the total embodied CO2 burden is not appropriate just because a material is deemed renewable and is surely only appropriate when a world wide steady state has been achieved between consumption and production, i.e. it has achieved sustainability. Renewability does not automatically confer the attribute of sustainability to a material. If we consider the world resource of timber and its consumption as a complete system, then clearly much greater quantities of timber are being consumed than are being replenished at present, most being consumed as fuel in third world countries. Thus, in terms of anthropogenic CO2 resultant from the world's use of its timber resource, more is being released into the atmosphere than is fixed by the renewal of timber in new plantations and by natural seeding. it therefore appears that the sequestered CO2 argument is only applicable where a steady state has been achieved.*

...Finally, it seems a somewhat dubious practice to credit timber benefit of sequestered CO2 without taking into account the methane emissions resultant from the disposal of timber. Methane, like CO2 is a greenhouse gas, but it is estimated as being 24 times more potent than carbon dioxide as stated previously. It is emitted in the UK, mainly from landfill waste, animals, coal mining, gas pipe leakage and offshore oil and gas operations. Methane is produces as timber bio-degrades in landfill sites."

The focus of this study is on energy and carbon dioxide, but as the previous paragraph highlights the topic of carbon sequestration in an environmental context goes beyond this because of the importance of methane, which is considered outside the scope of this study. Furthermore it would be inappropriate to include carbon sequestration without considering the end of life of timber, which may or may not result in the release of methane. For the reasons highlighted above and the scope of this study the author chose to exclude the effects of carbon sequestration, this leaves it open for the user to decide if the effects of carbon sequestration should be included or excluded.

Source: Inventory of Carbon and Energy, University of Bath

recommendations

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design leaner structures and material optimization

- minimizing quantity of materials reduces energy used to make the building in the first place.

design for deconstruction, reuse and recovery

- buildings often have a service life far less than the materials they are made of
- building with deconstruction in mind enhances reuse of materials, effectively increasing lifespan and energy efficiency of the buildings

design for future use, adaptability and flexibility

- designing to make buildings suited to different uses increases their life-span and reduces need for new construction materials.

minimize waste

- construction industry responsible for +/-120m tons of construction, demolition and excavation waste every year – **around a third of all waste arising in the UK** – what accounts for **22% of all construction embodied energy and 19% of embodied carbon**.

Source: Inventory of Carbon and Energy, University of Bath

canopia. bordeaux

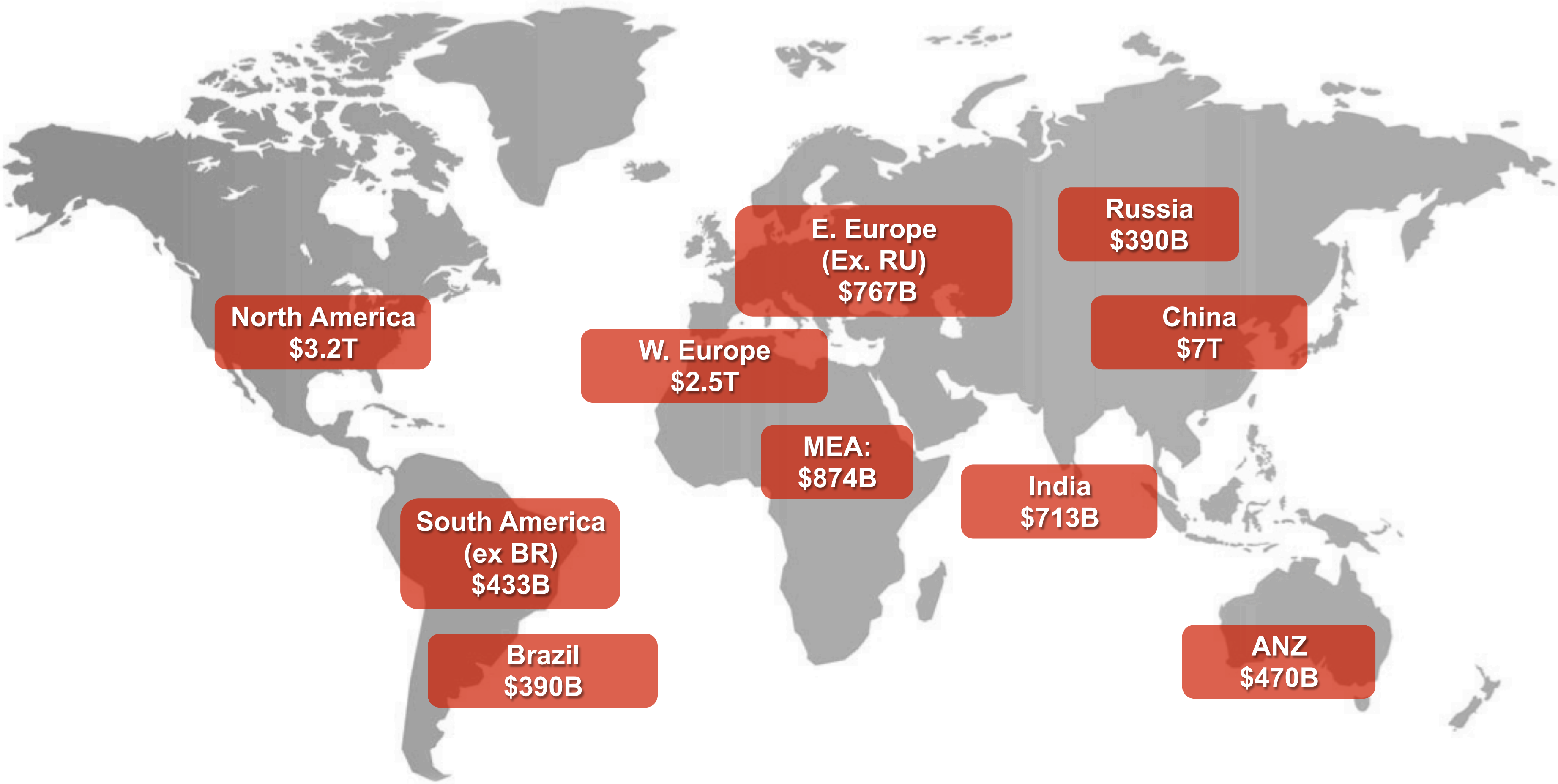
Sou Fujimoto and laisné roussel
Canopia, 2016
wooden mixed-use tower
Bordeaux

- silver fir and spruce beams and posts
- cross-laminated timber floors, silver fir or spruce
- glu-lam post-and-beam timber frame

Source: Archdaily

global forecasted infrastructure spending. mckinsey

Total current $7+T
2030 forecast total = $18T



Source: Infrastructure Stock and Spend Database