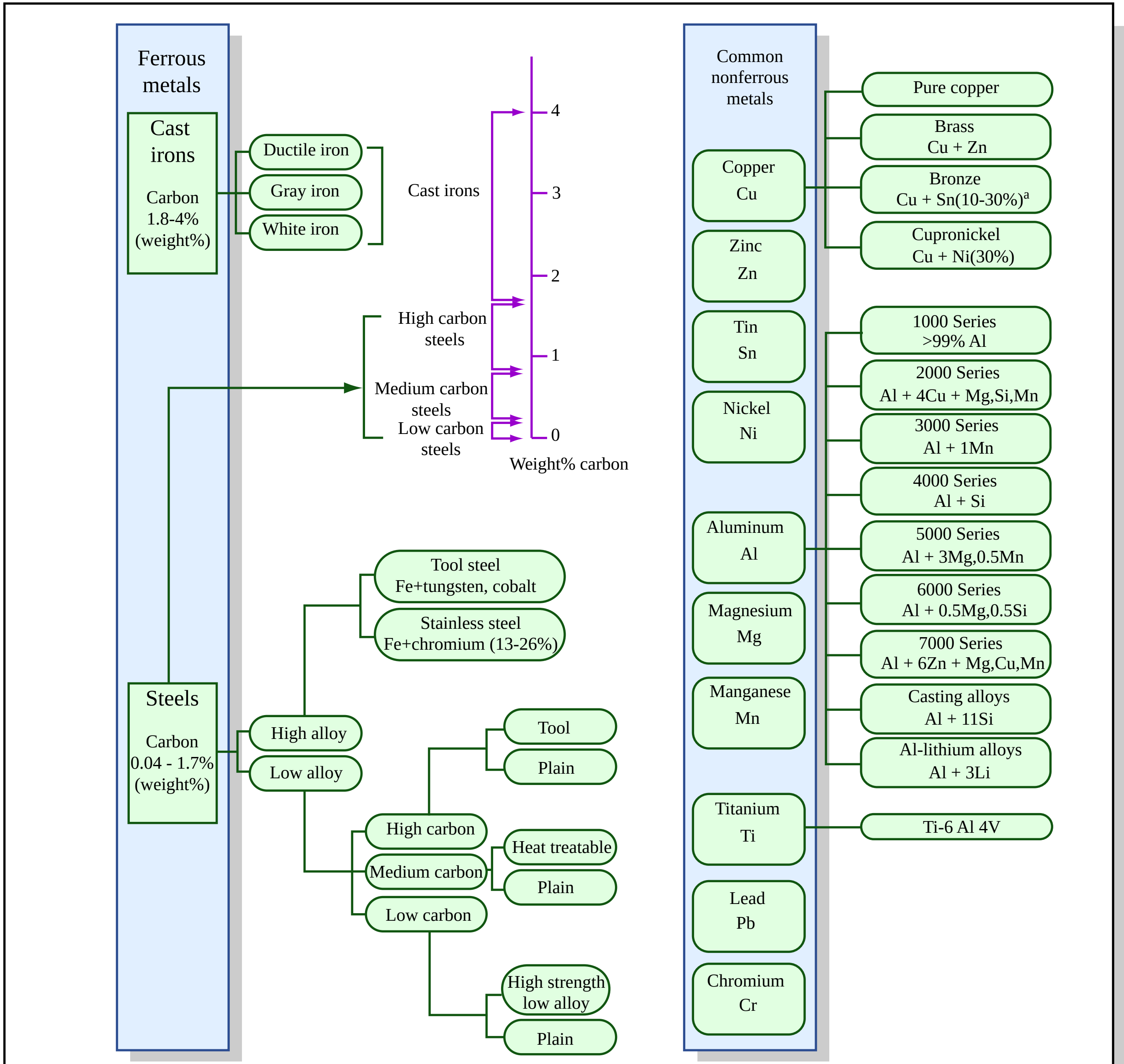
Resource-efficient building materials for a sustainable built environment

John E. Fernández

Container City: India Wharf, London, UK



[a]All alloying proportions given in terms of percentage weight.
[b]Aluminum series 1000-7000

Figure by MIT OCW.

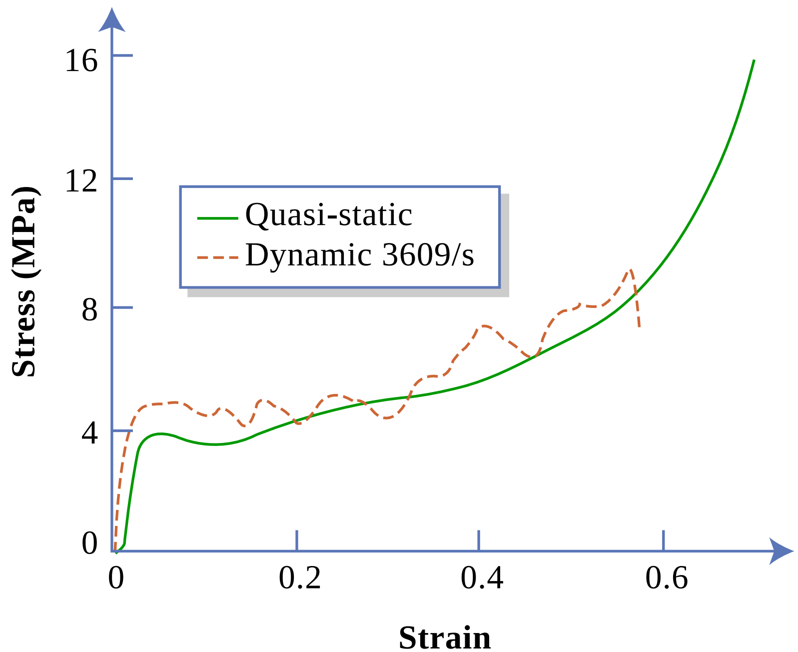


Figure by MIT OCW.

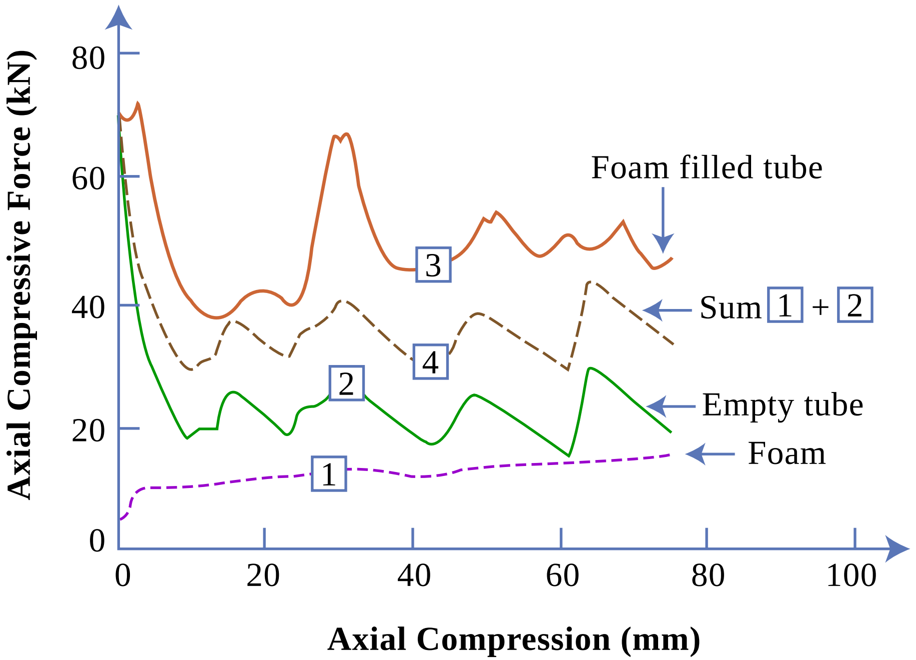


Figure by MIT OCW.

metal foams

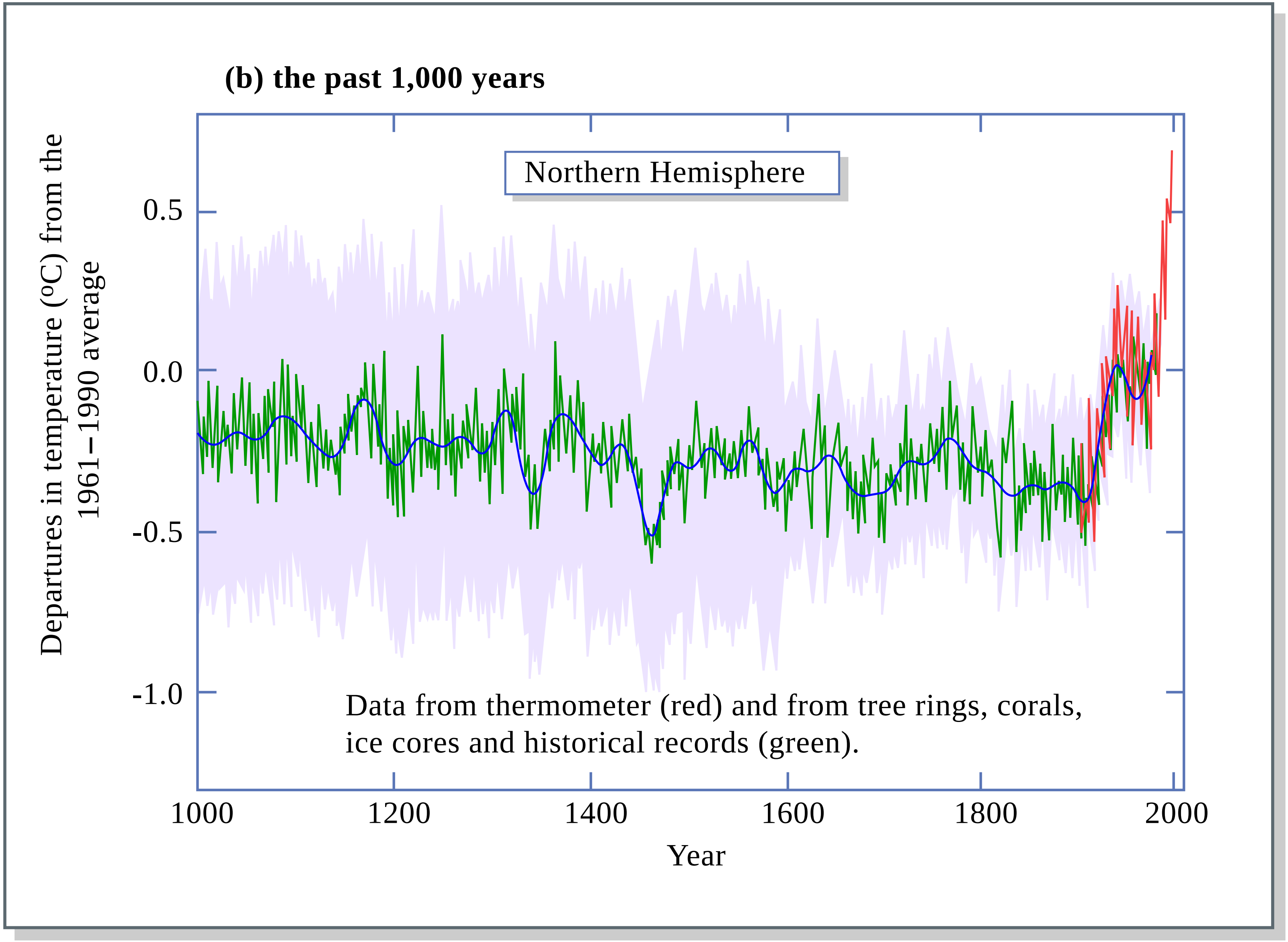


Figure by MIT OCW.

source:

Low, M. (2005) MFA of concrete in the US. MSBT thesis, MIT: pg. 16

Adapted from:

van Oss, Hendrik G. and Padovani, Amy C.

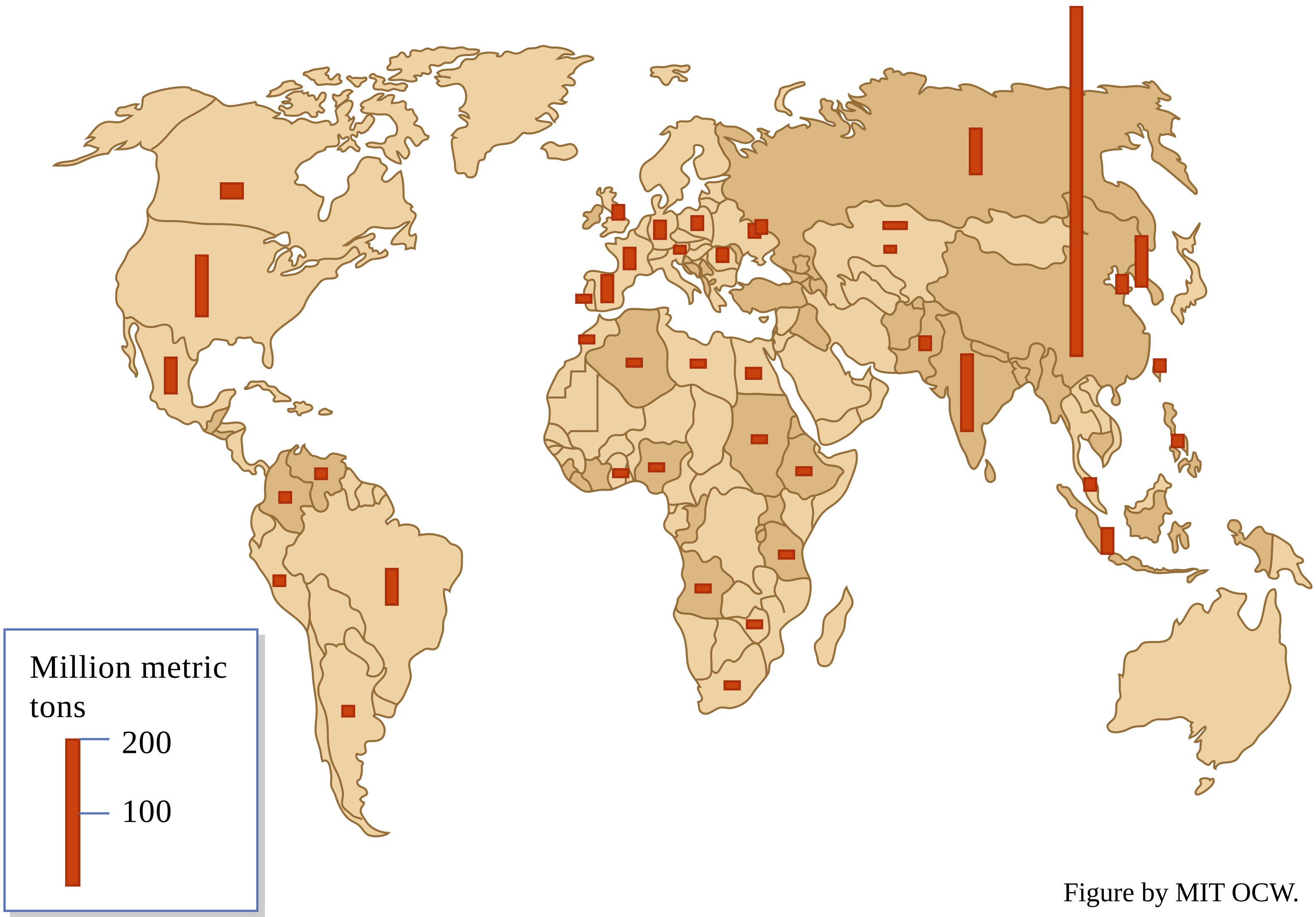
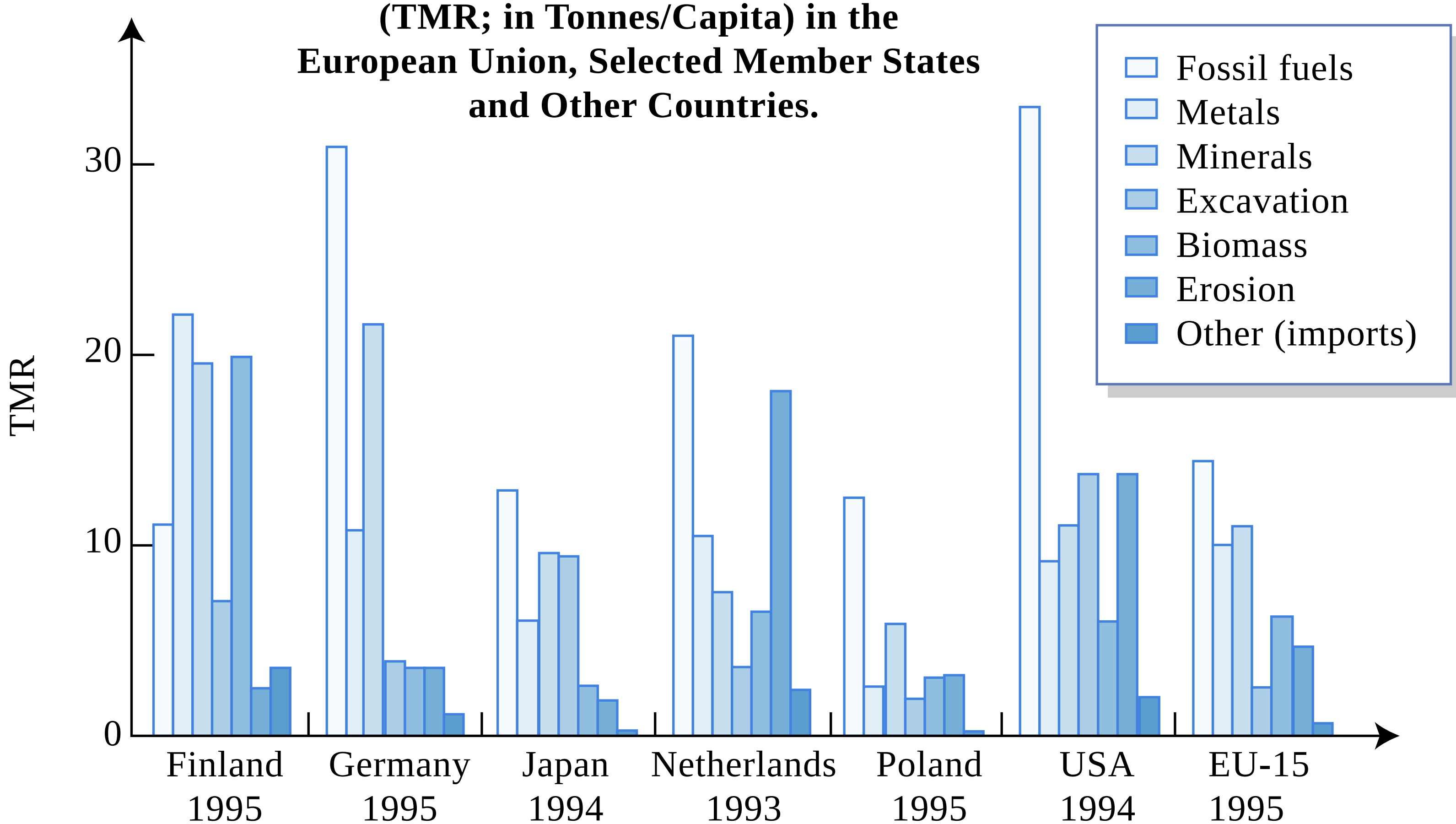


Figure by MIT OCW.

Global CO_2 emissions from cement manufacturing production

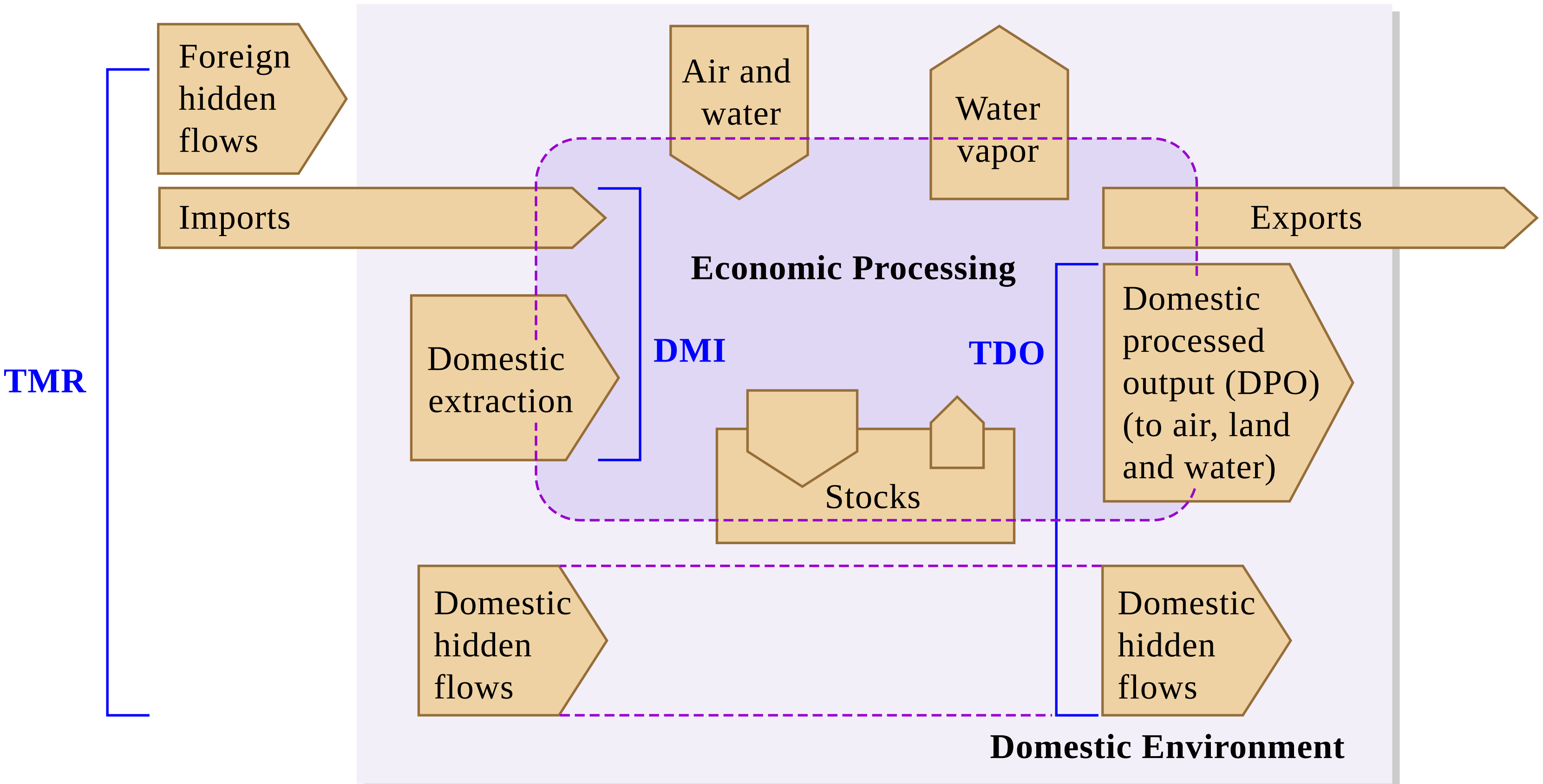
Composition of Total Material Requirement (TMR; in Tonnes/Capita) in the European Union, Selected Member States and Other Countries.



Note: Hidden flows are included in fossil fuels, metals and minerals or are represented by excavation and erosion.

Figure by MIT OCW.

source: Bringezu, S. (2003) Industrial Ecology and Material Flow Analysis. Greenleaf Publishing: pg.28



TMR (Total Material Requirement) = DMI+Domestic Hidden Flows+Foreign Hidden Flows

DMI (Direct Material Input) = Domestic Extraction+Imports

NAS (Net Additions to Stock) = DMI-DPO-Exports

TDO (Total Domestic Output) = DPO+Domestic Hidden Flows

DPO (Domestic Processed Output) = DMI-Net Additions to Stock-Exports

Figure by MIT OCW.

source: Mathews et al. (2000) The Weight of Nations: material outflows from industrial economies. World Resources Institute, Washington DC: pg. 14

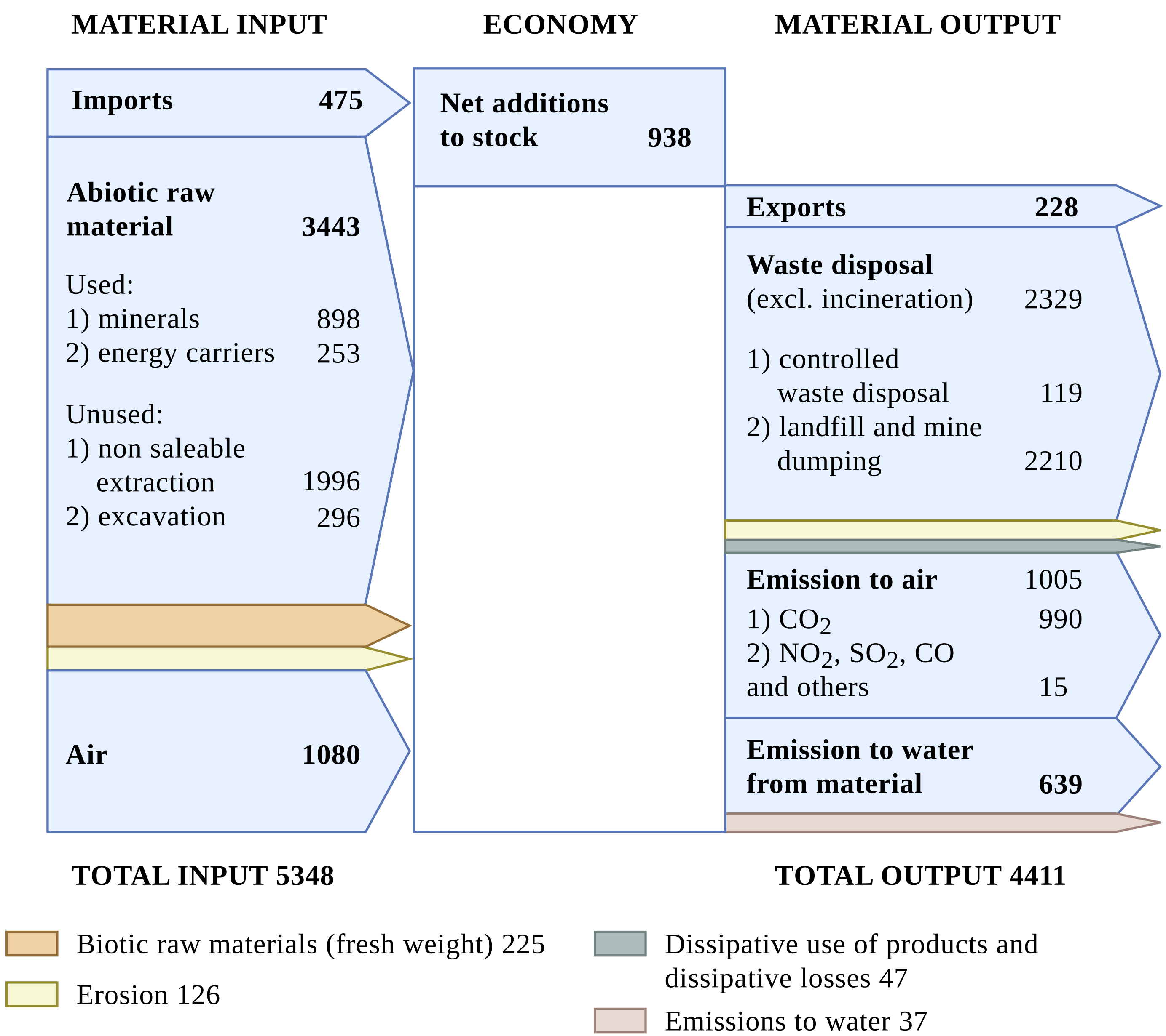


Figure by MIT OCW.

source: Mathews et al. (2000) The Weight of Nations: material outflows from industrial economies. World Resources Institute, Washington DC: pg. 46

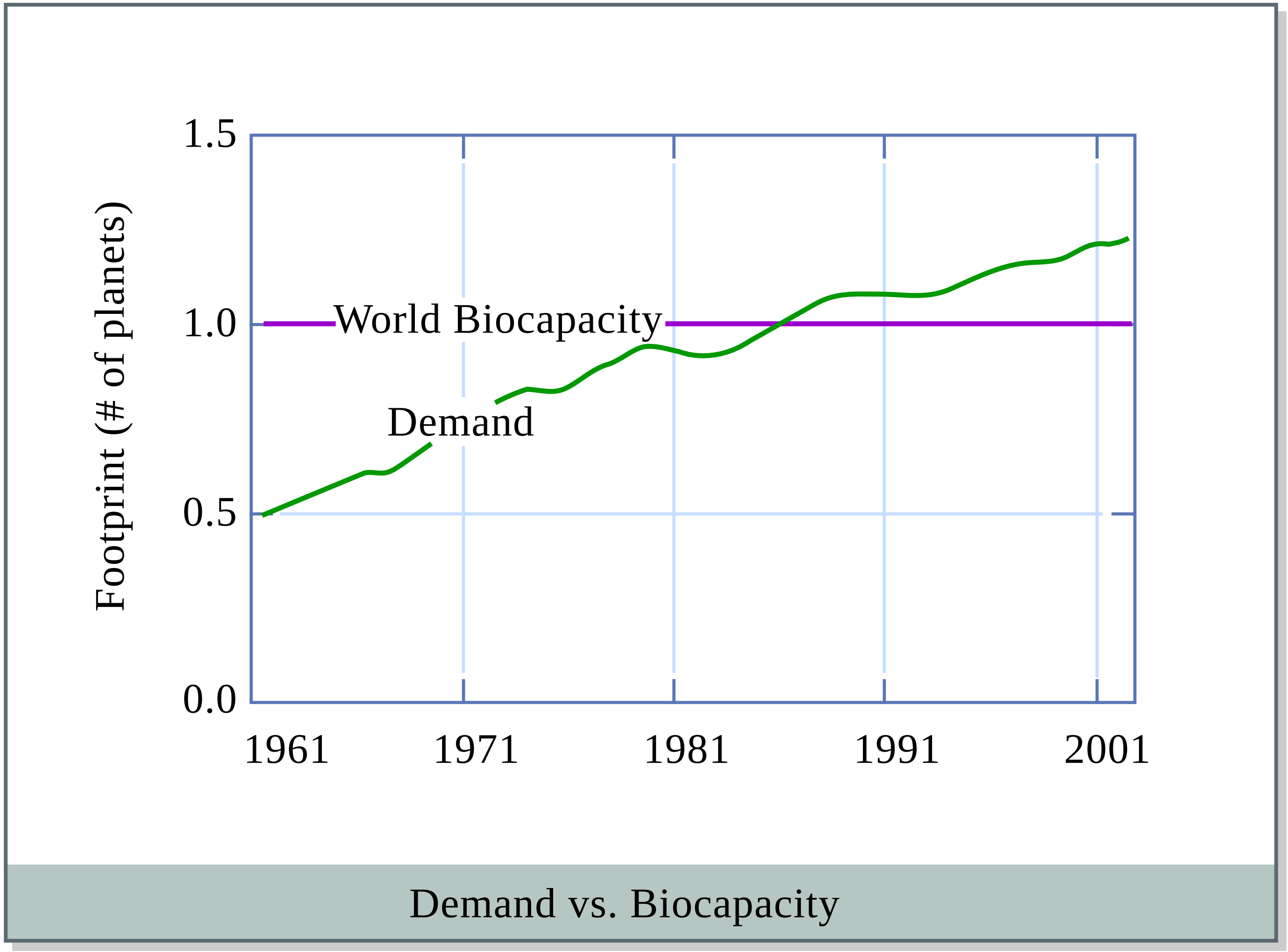


Figure by MIT OCW.

source: Living Planet Report 2004. World Wildlife Fund International.

Material Resources

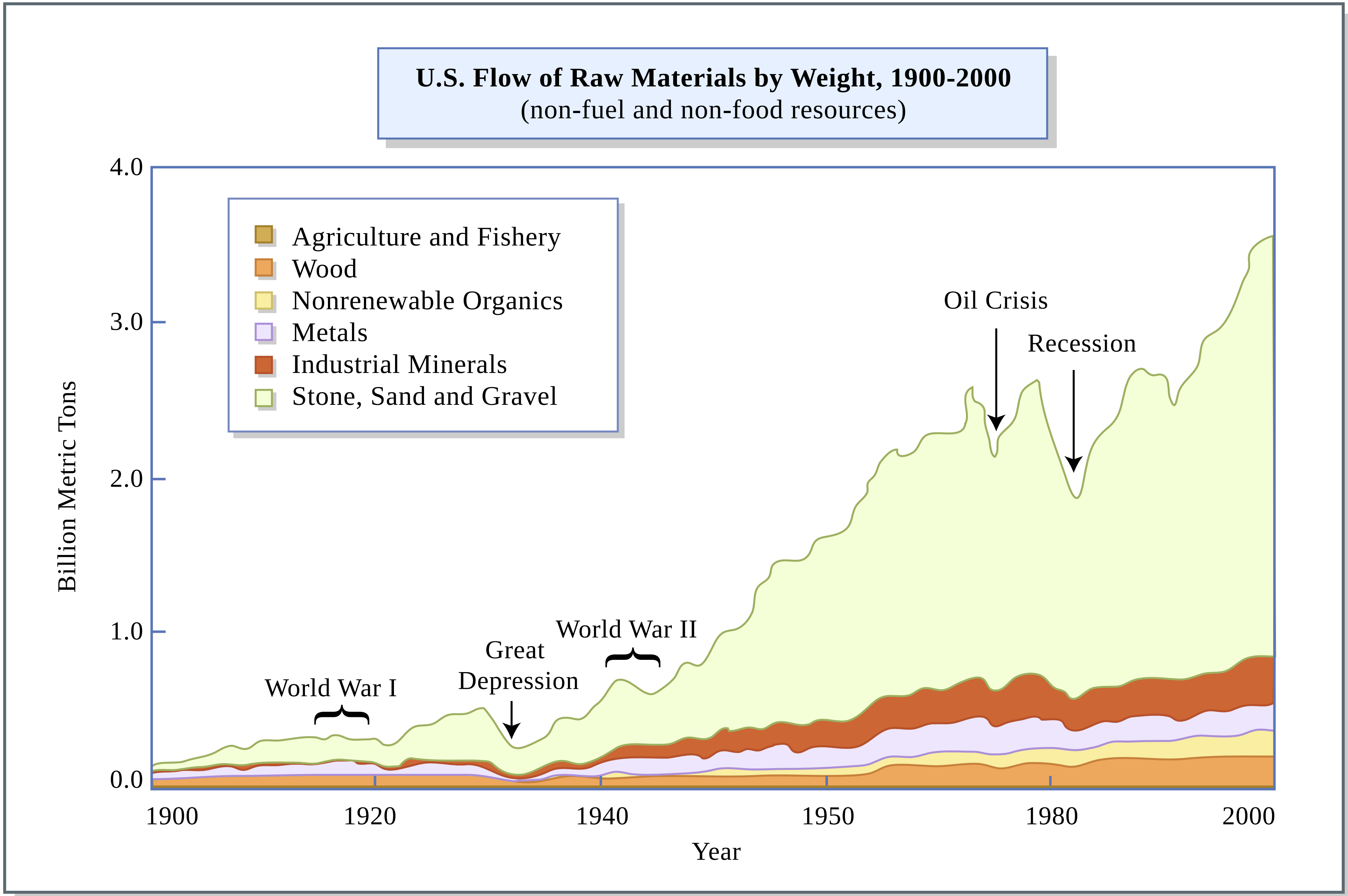
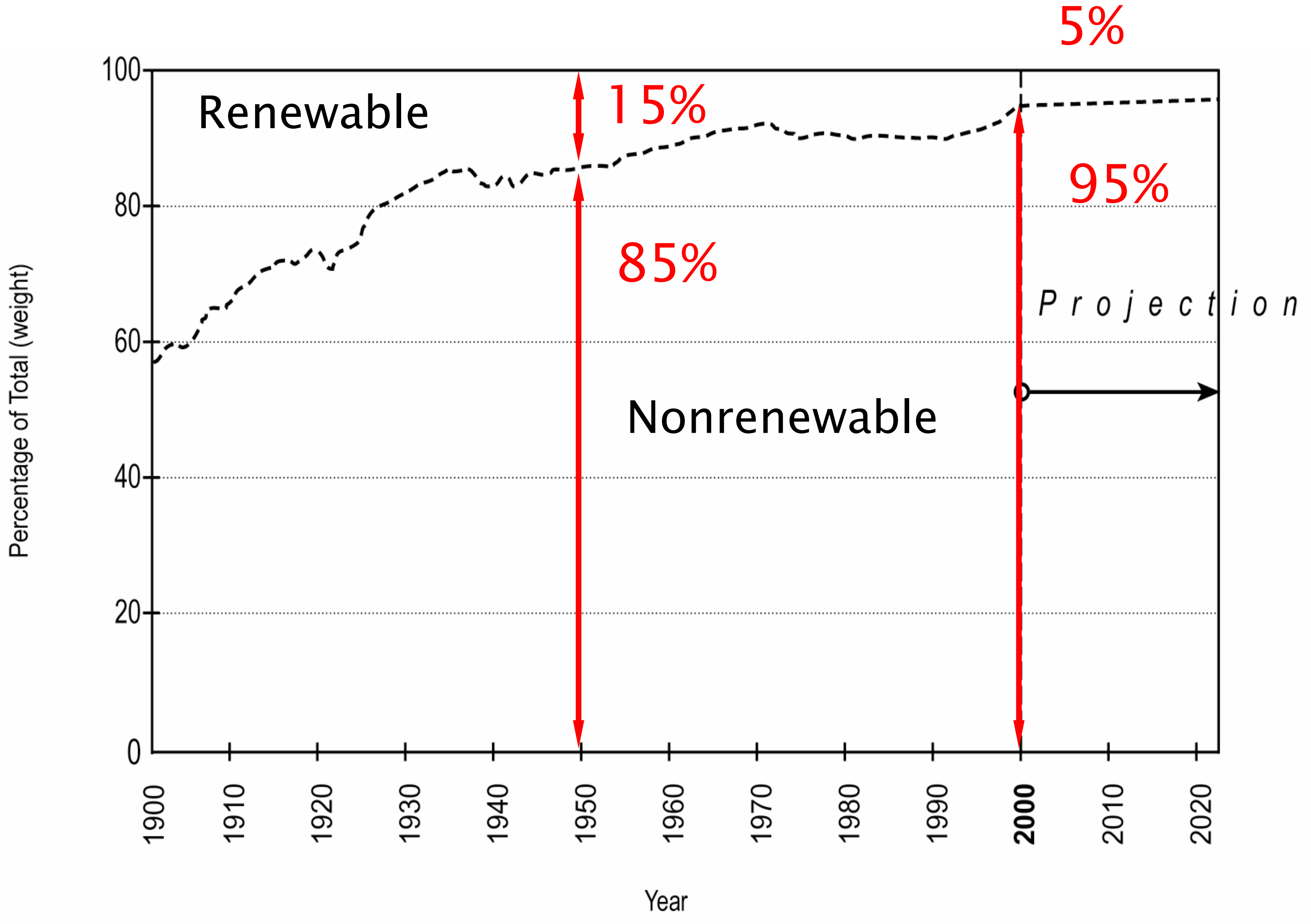
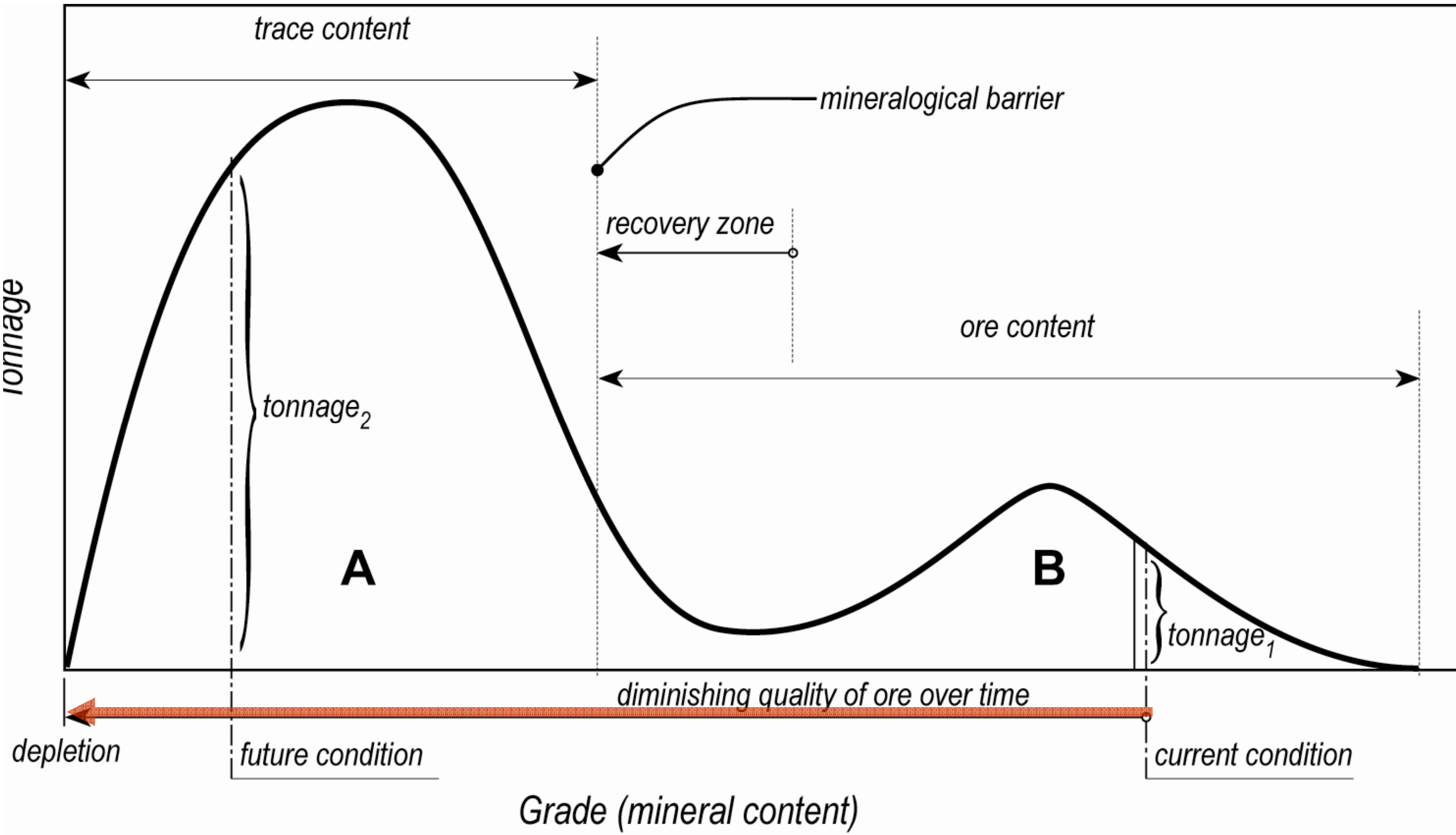
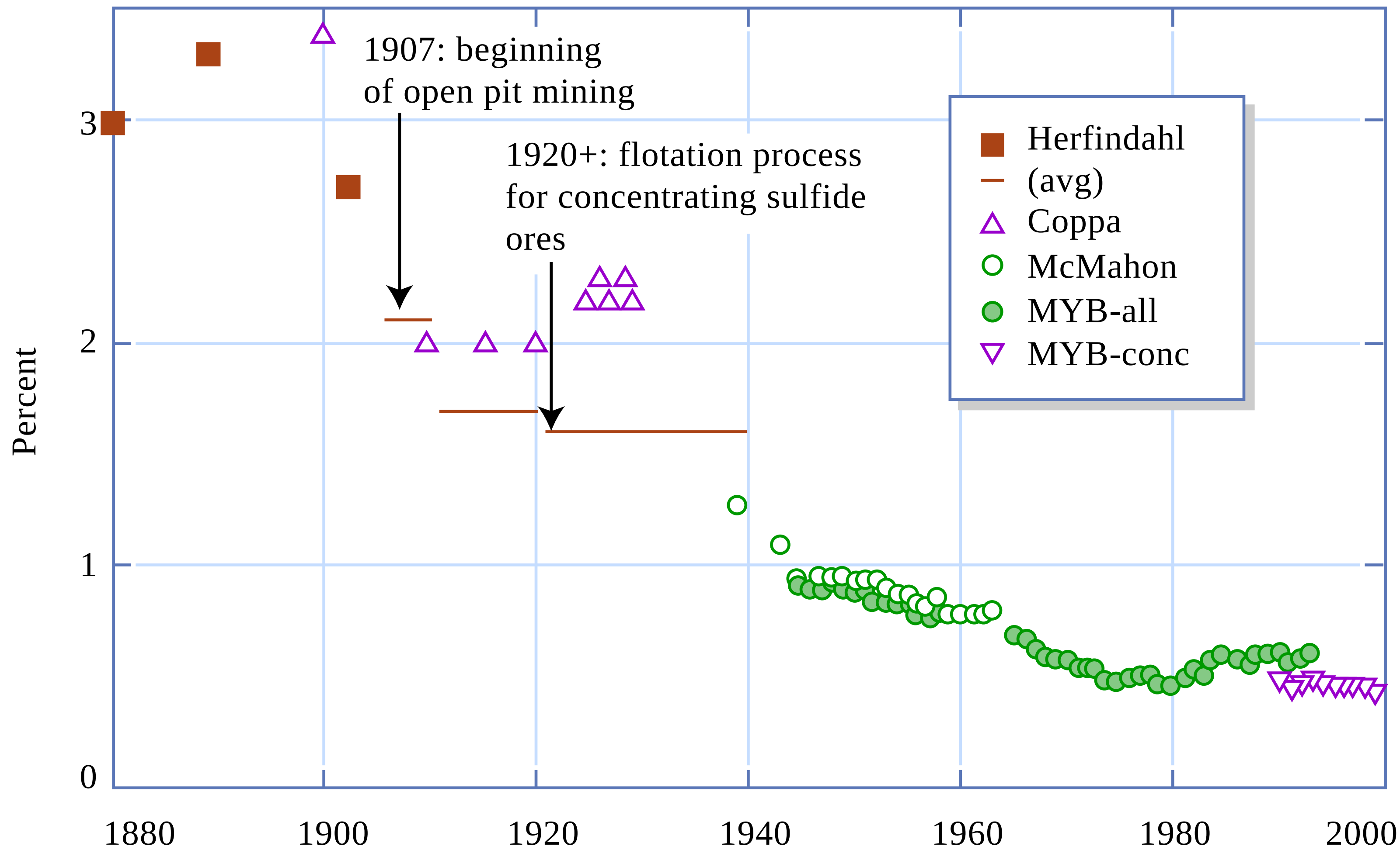


Figure by MIT OCW.


5%
100
80
60
40
20
0
Renewable
15%
85%
95%
Projection
Nonrenewable
Percentage of Total (weight)
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year


trace content
mineralogical barrier
recovery zone
ore content
Tonnage
tonnage2
A
B
tonnage1
diminishing quality of ore over time
depletion
future condition
current condition
Grade (mineral content)



U.S. Copper Ore Grade Percent, 1880-2000

Figure by MIT OCW.

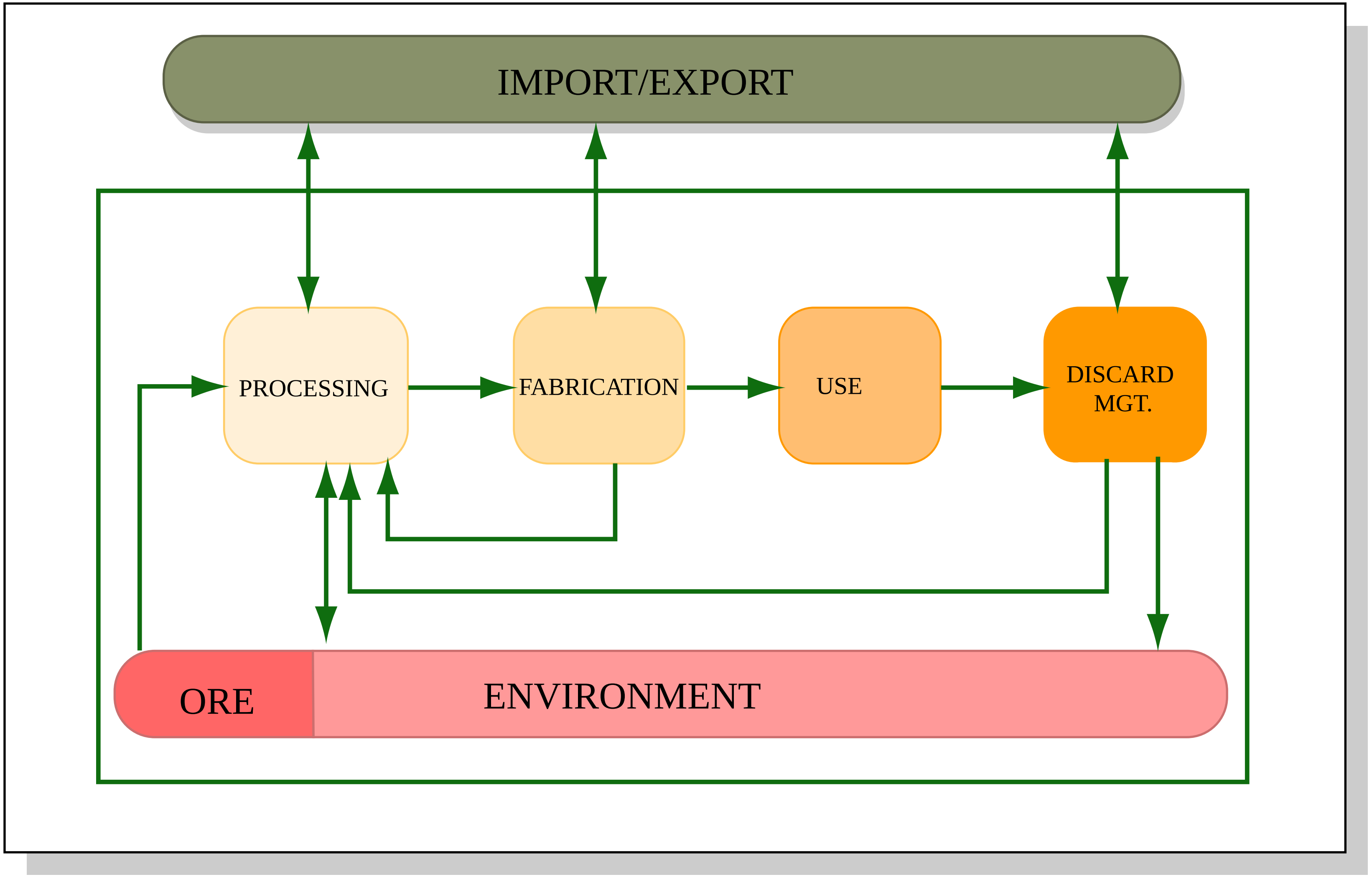


Figure by MIT OCW.

Japan Copper cycle: One Year Stocks and Flows, 1990s

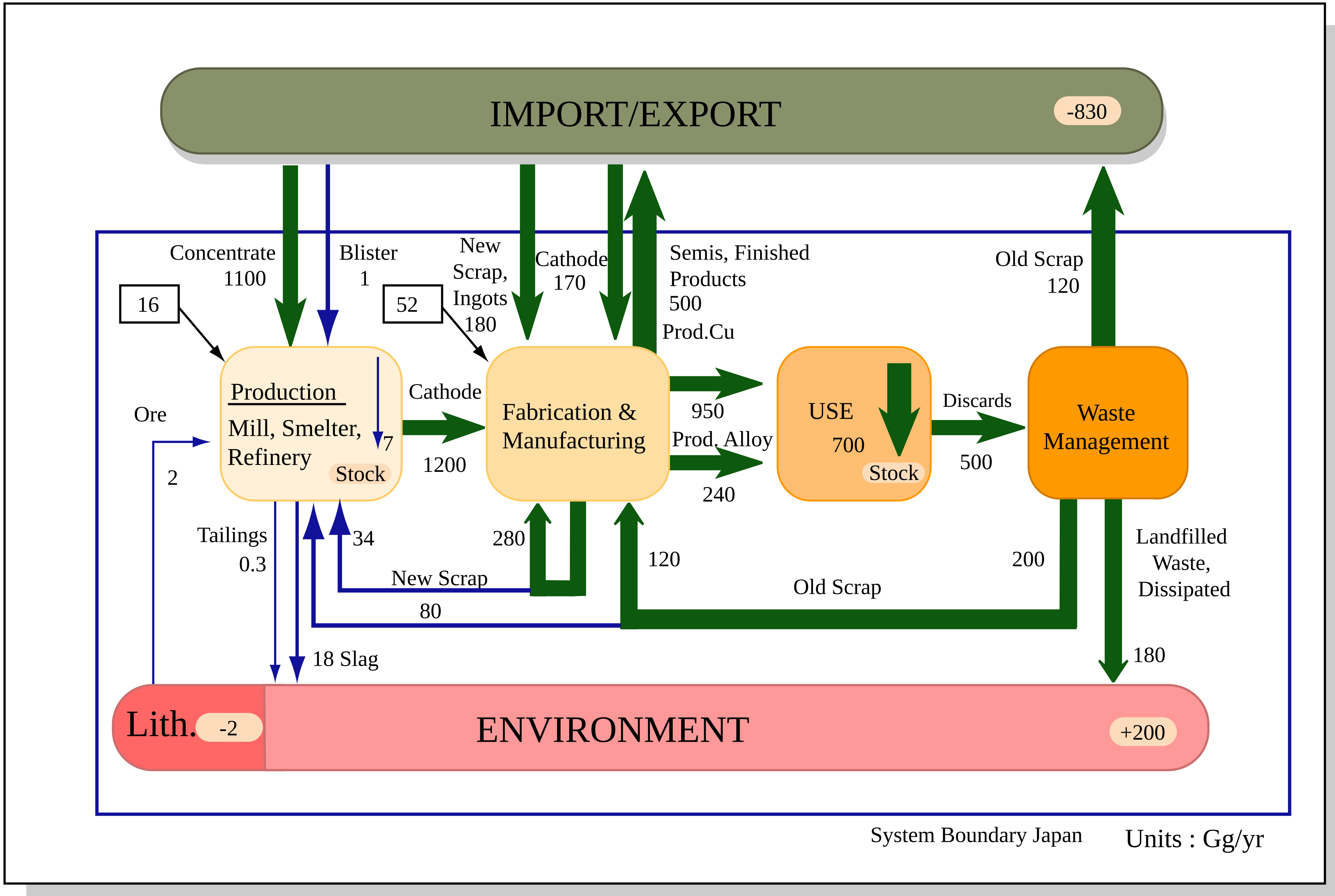


Figure by MIT OCW.

Zambia's Copper Cycle: One Year Stocks and Flows, 1994

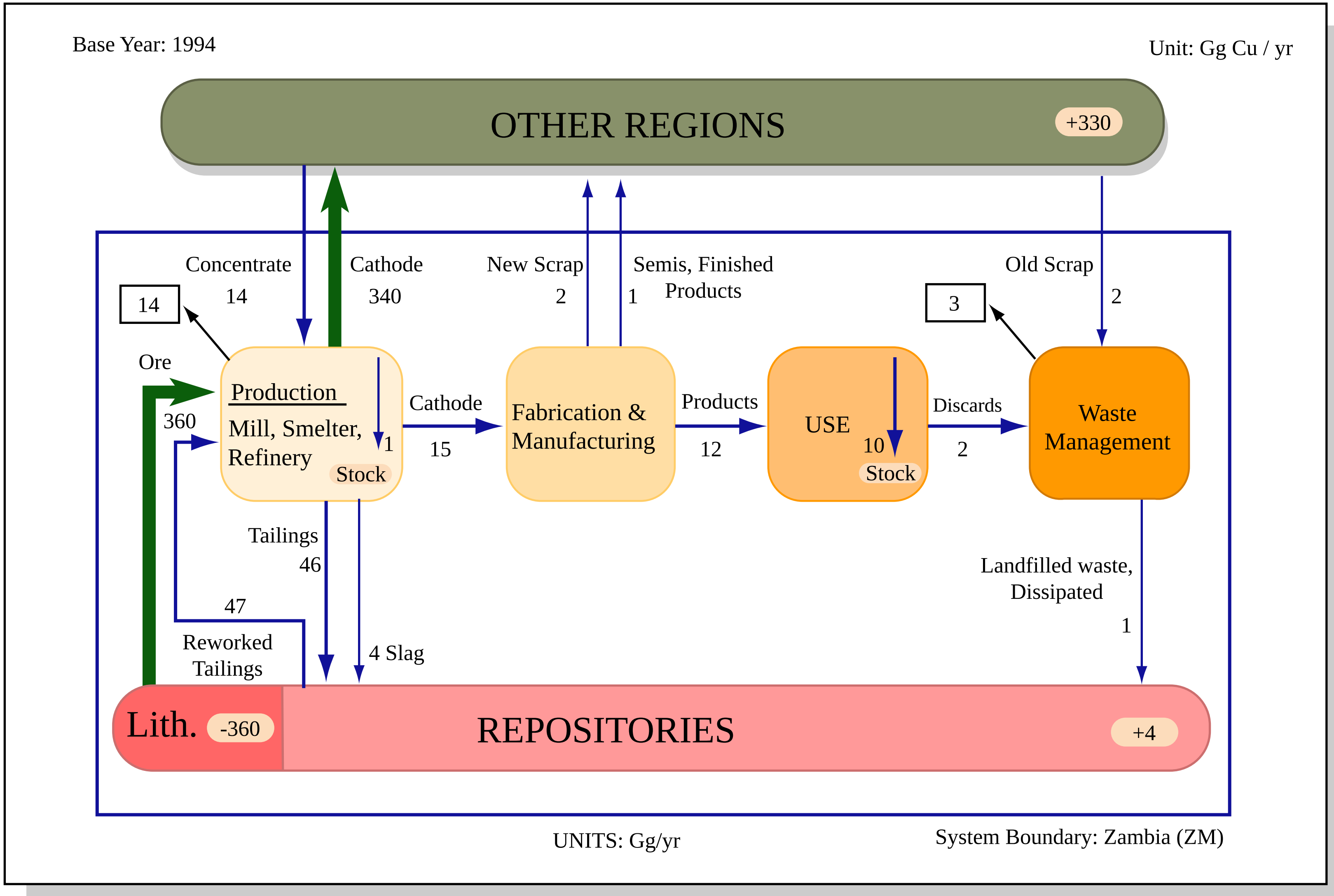


Figure by MIT OCW.

China's Copper Cycle: One Year Stocks and Flows, 1994

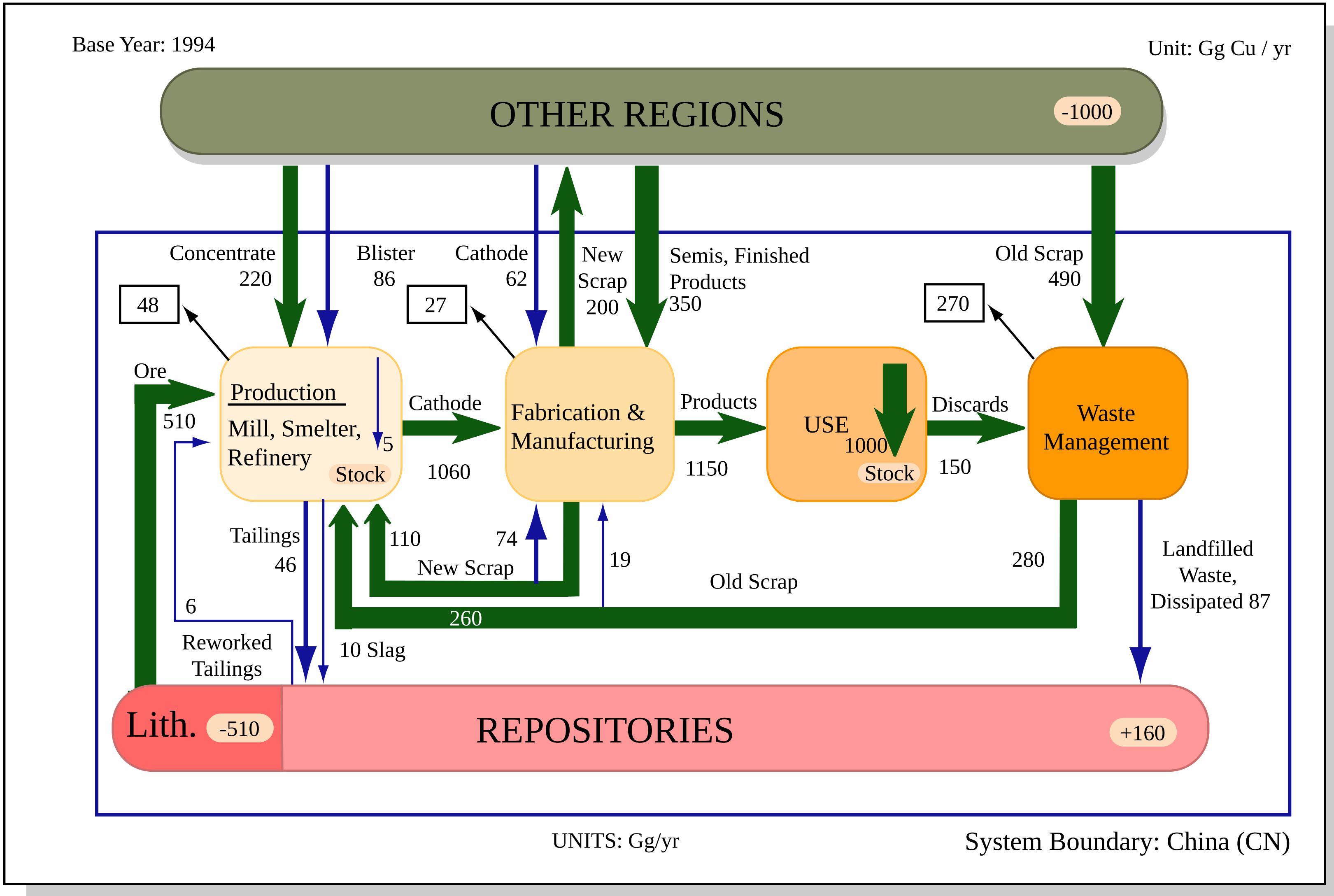
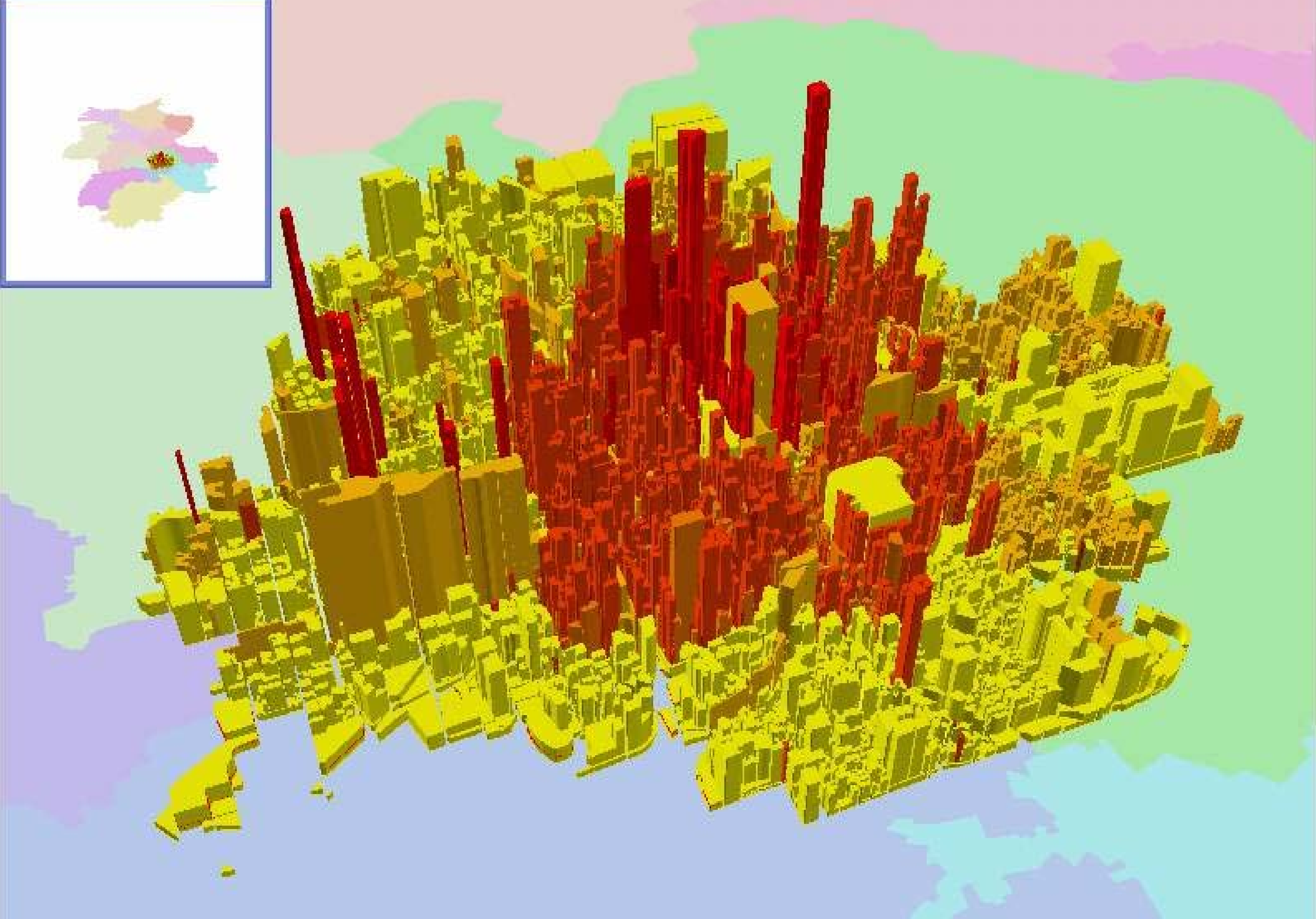


Figure by MIT OCW.



2002 Estimated In-Use Copper Stocks in Beijing—3D View

Source: T. Wang and T.E. Graedel, unpublished research, Center for Industrial Ecology, Yale University, New Haven, CT, 2005.

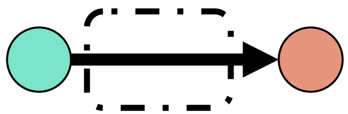
IPAT

$$I = P \times A \times T$$

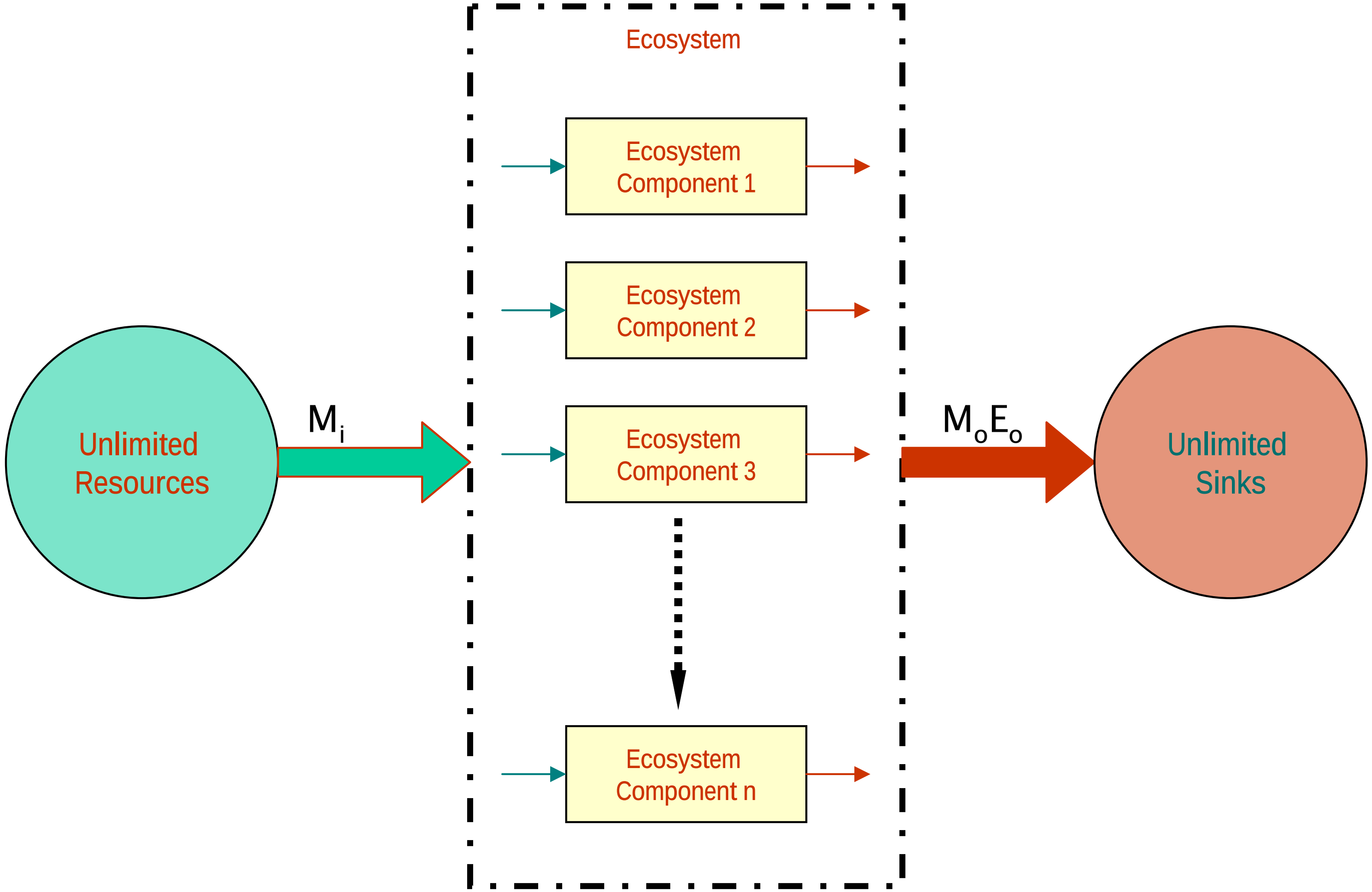
MIPS

$$MI = \frac{\text{resource}}{\text{unit service}}$$

Type I



Type I icon

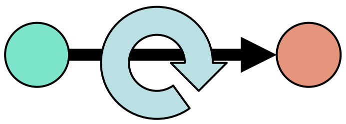


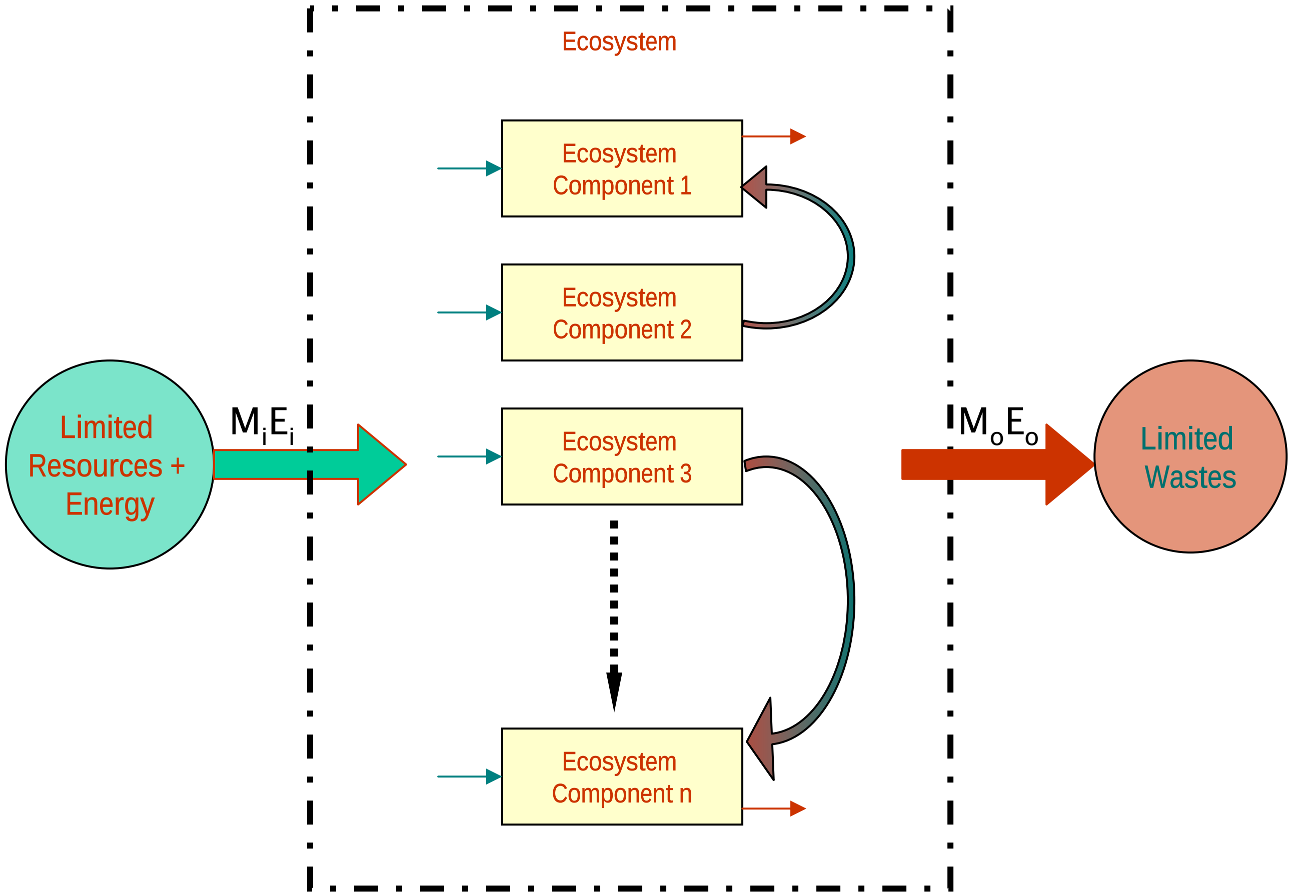
M_i = Material resources

M_oE_o = Wastes

Source: Fernandez

Type II

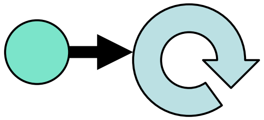

Type II icon



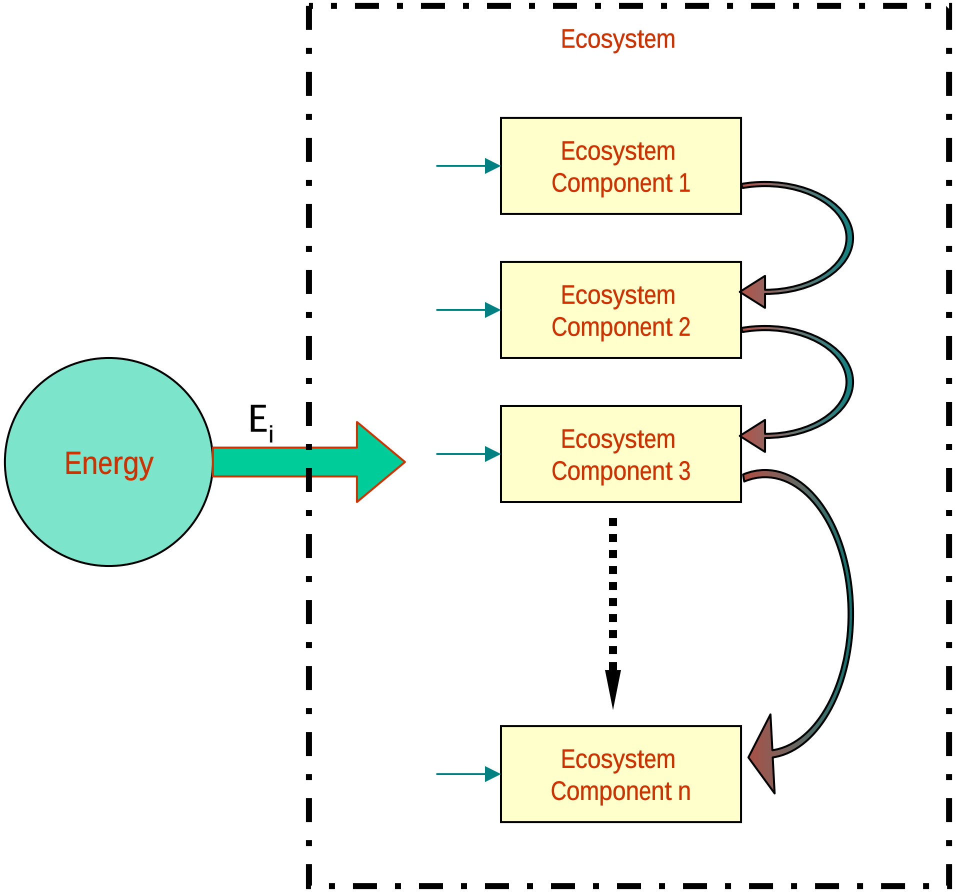
M_iE_i = Material and energy resources

M_oE_o = Wastes

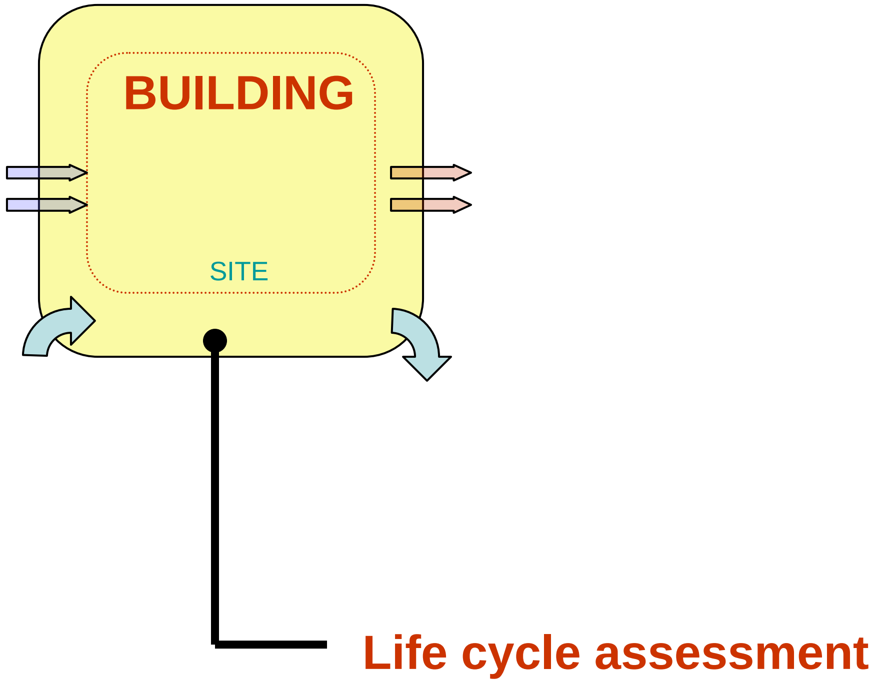
Type III



Type III icon



E_i = Energy input (solar radiation)


BUILDING
SITE
Life cycle assessment

Consumption attributes of contemporary buildings

Temporal

- Actual service lifetimes are uncertain (shorter or longer than intended)
- Buildings often outlast the firms that build them
- Buildings are one of the very few human artifacts that can span generations

Spatial

- Buildings are immobile over lifetime
- Materials and processes (energy) converge to site
- Materials (wastes or "residues") are dissipated from site

Physical

- Buildings (cities and infrastructure) constitute the largest single stock type
- Each building is a "prototype"
- Buildings are meta-systems composed of complex semi-autonomous systems (with distinct lifecycles)

Comparative analysis of resource requirements

1.Brick and concrete masonry block wall

2.Glass and aluminum curtainwall

3.Precast concrete panel and structural steel stud wall

4.Structural straw bale, wood stud and exterior finish plaster construction

Data sources:

US EPA Lifecycle Methods (1993)

SETAC (1993)

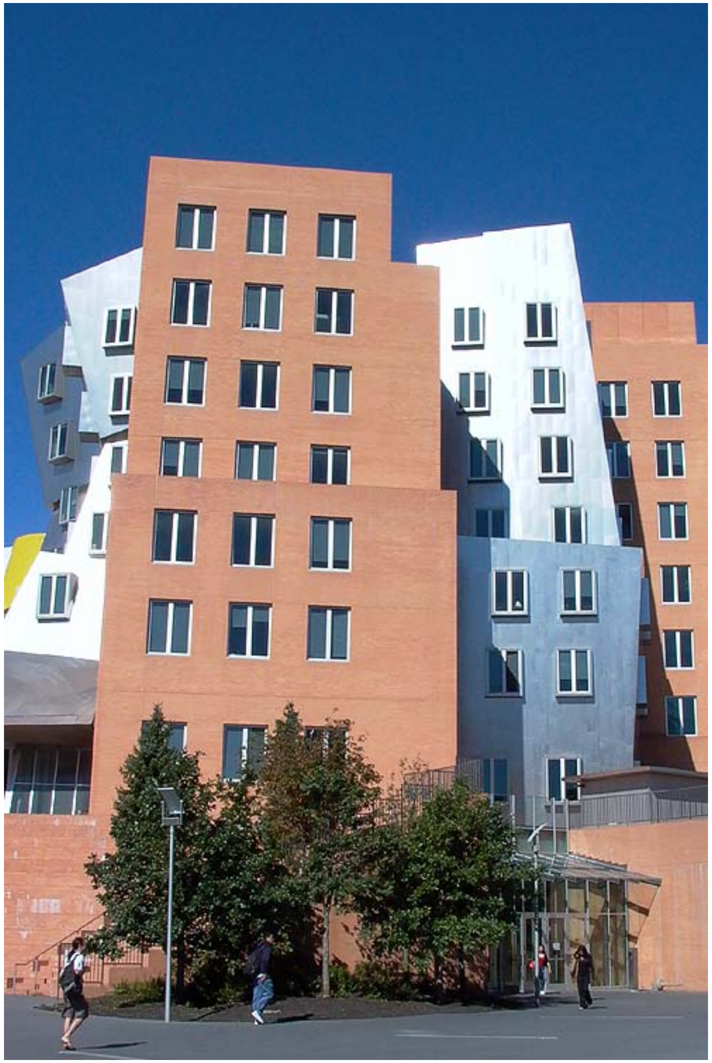
BEES (2000)

ISO 1401 (1998)

Scientific Certification Systems (1995)

Keoleian, G. (2001)

CES Materials Selector 4.5 (Beta version)



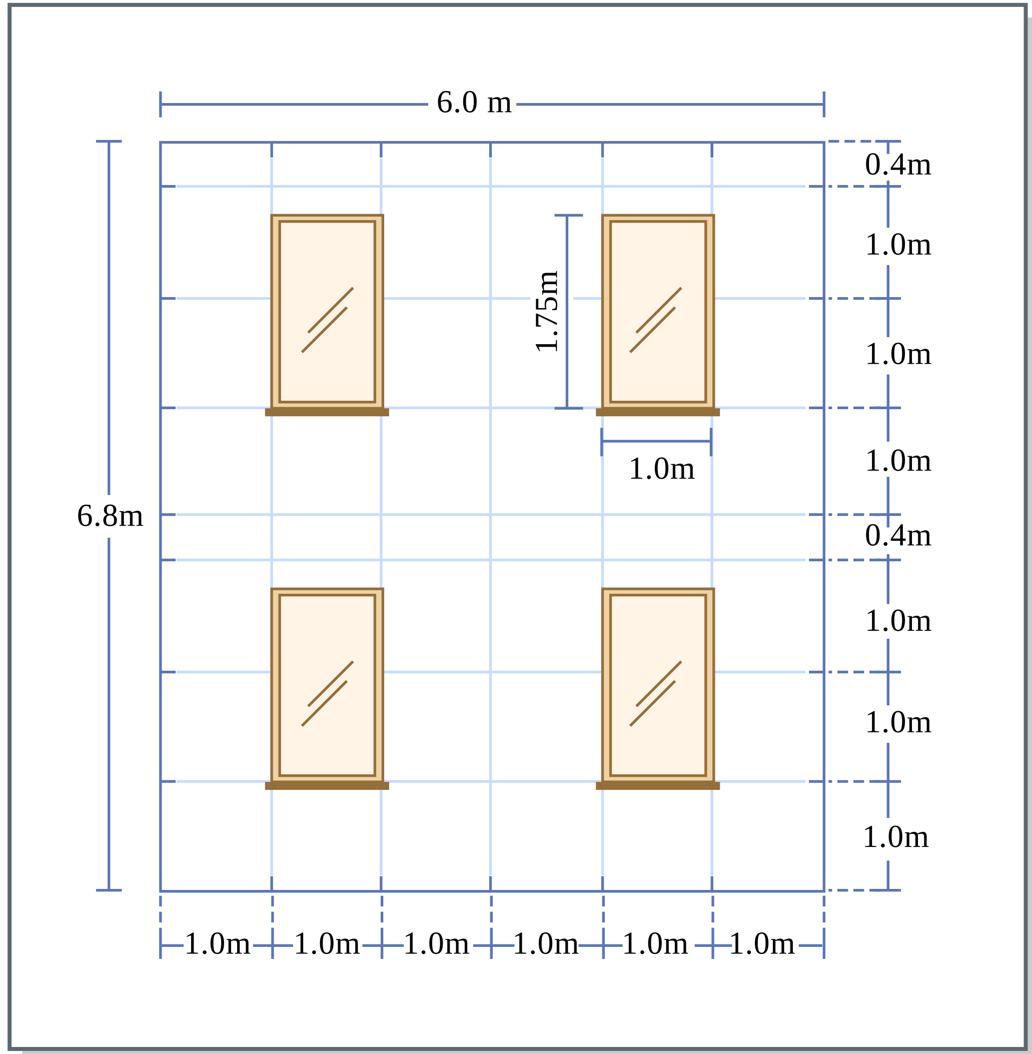
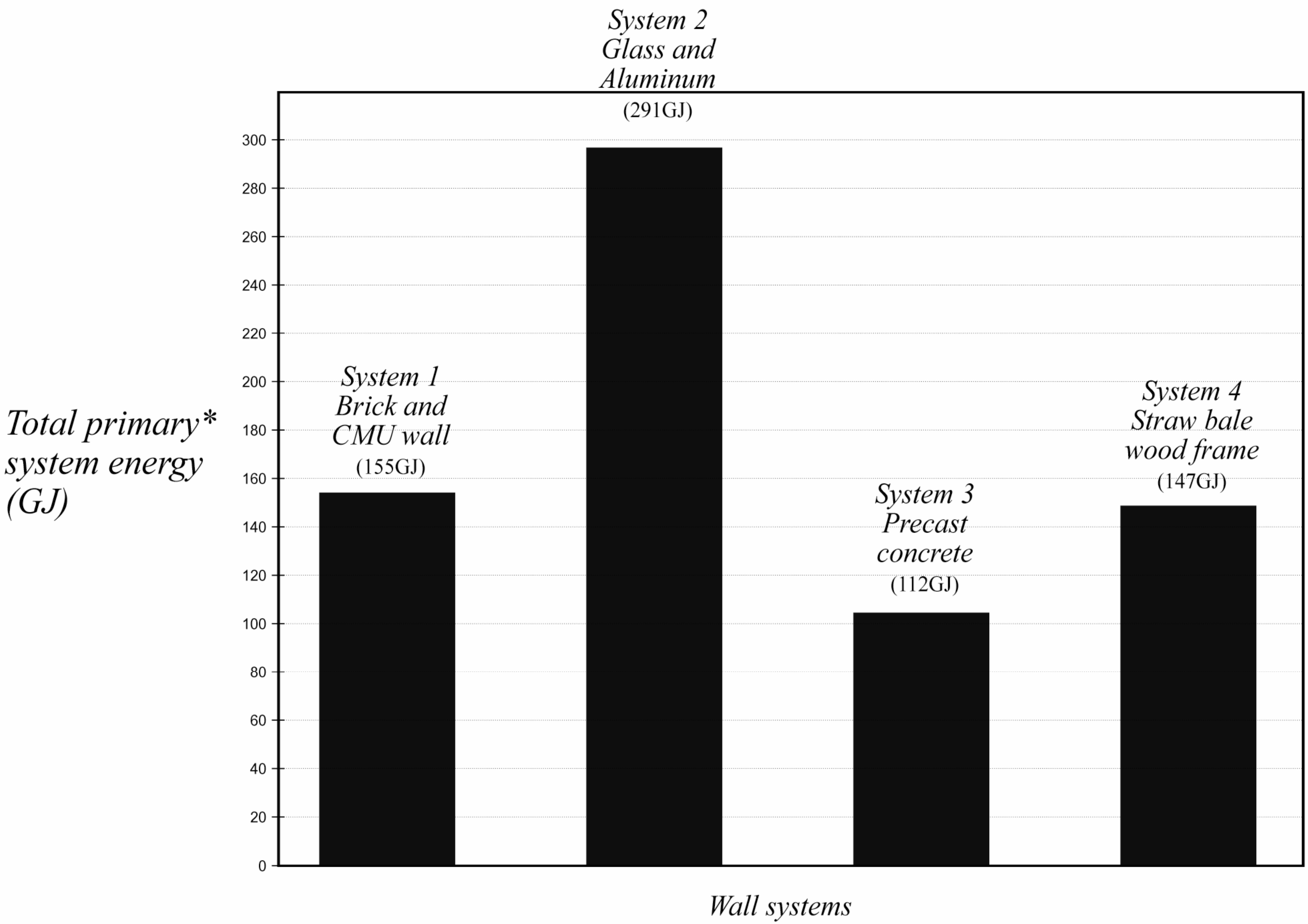


Figure by MIT OCW.



* Primary energy includes pre-use phase extraction, manufacturing, fabrication, assembly, and transportation.

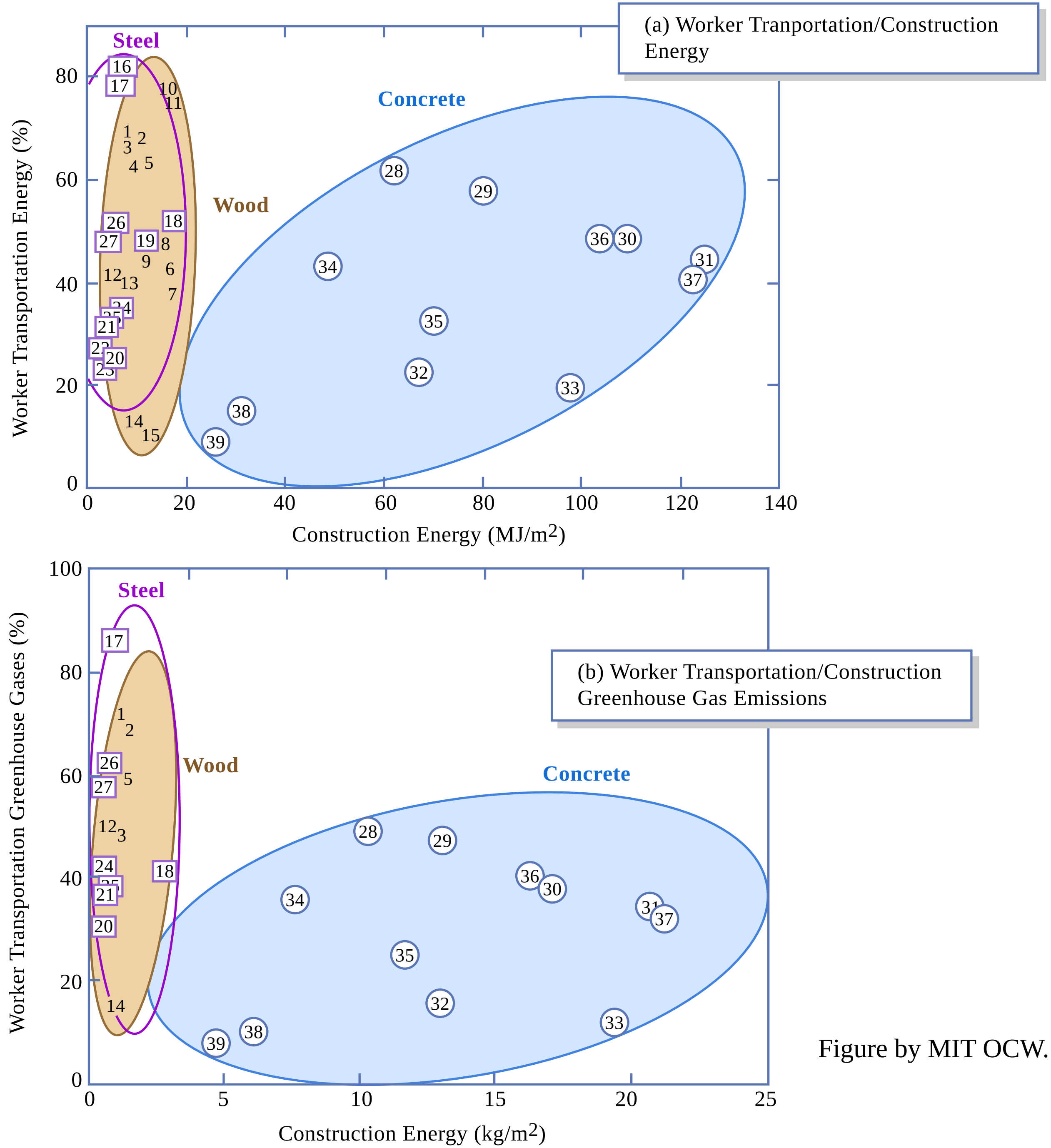
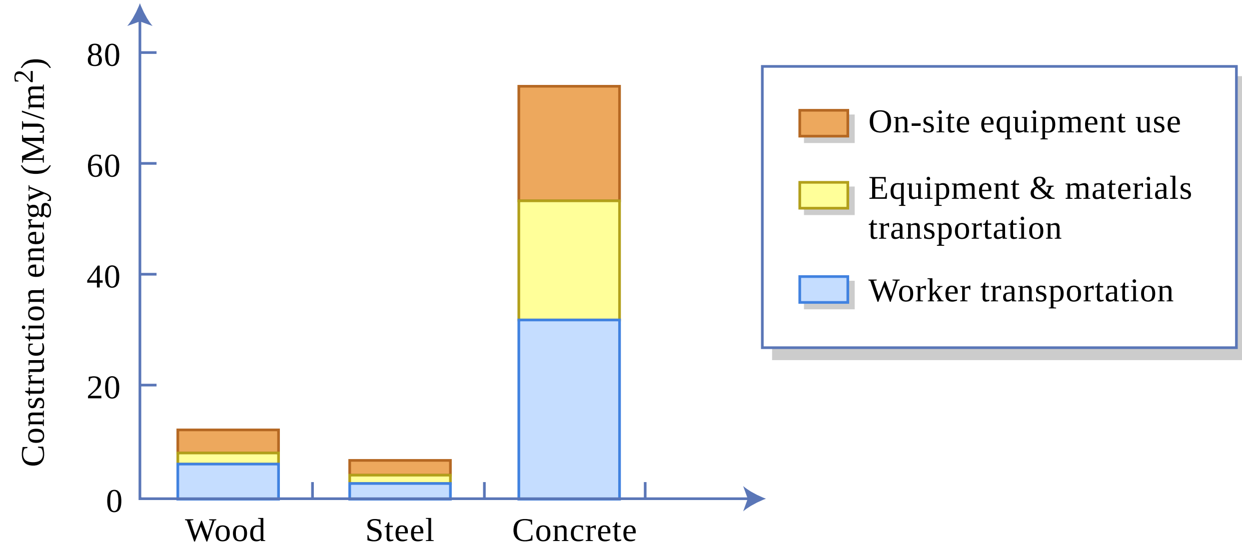


Figure by MIT OCW.

Conclusion

Transportation - of workers and equipment - to and from the site represents the largest proportion of construction energy use for every material system and a substantial proportion of emissions.



(a) Average Construction Energy for Wood, Steel and Concrete Assemblies

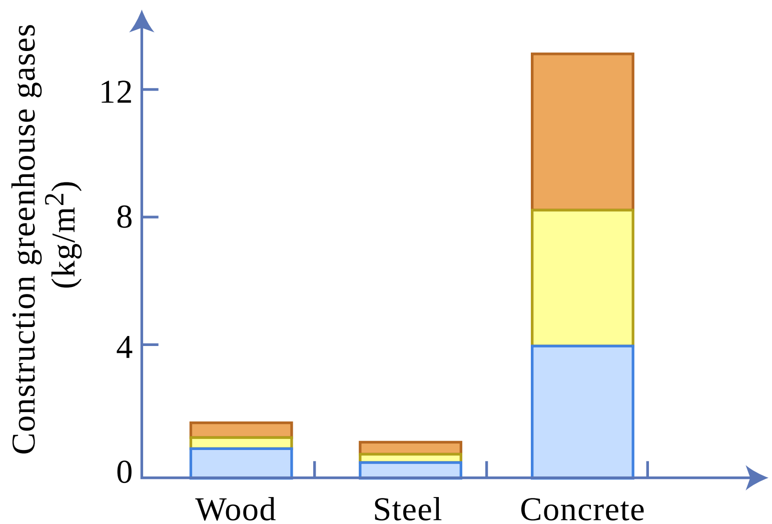
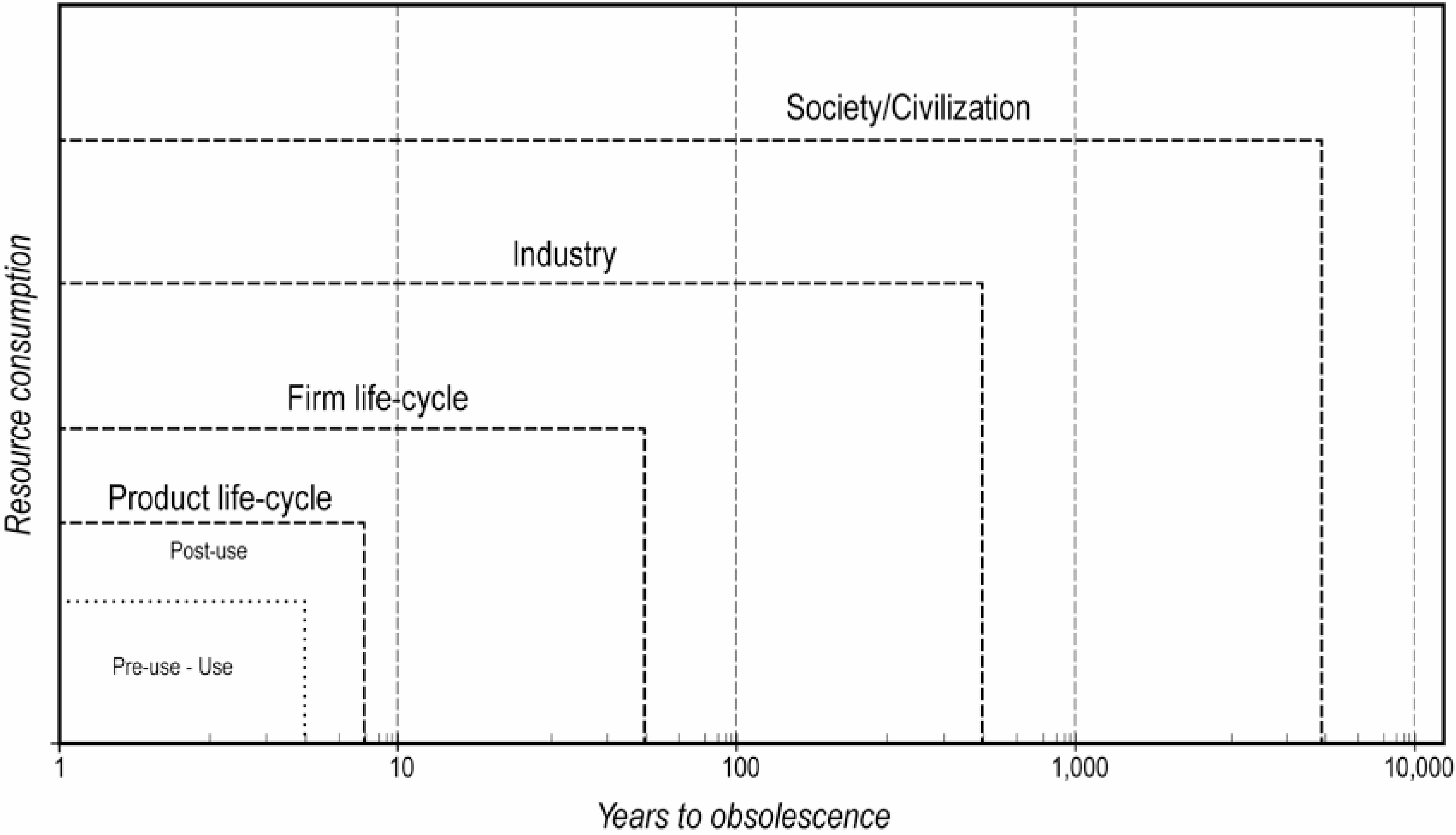
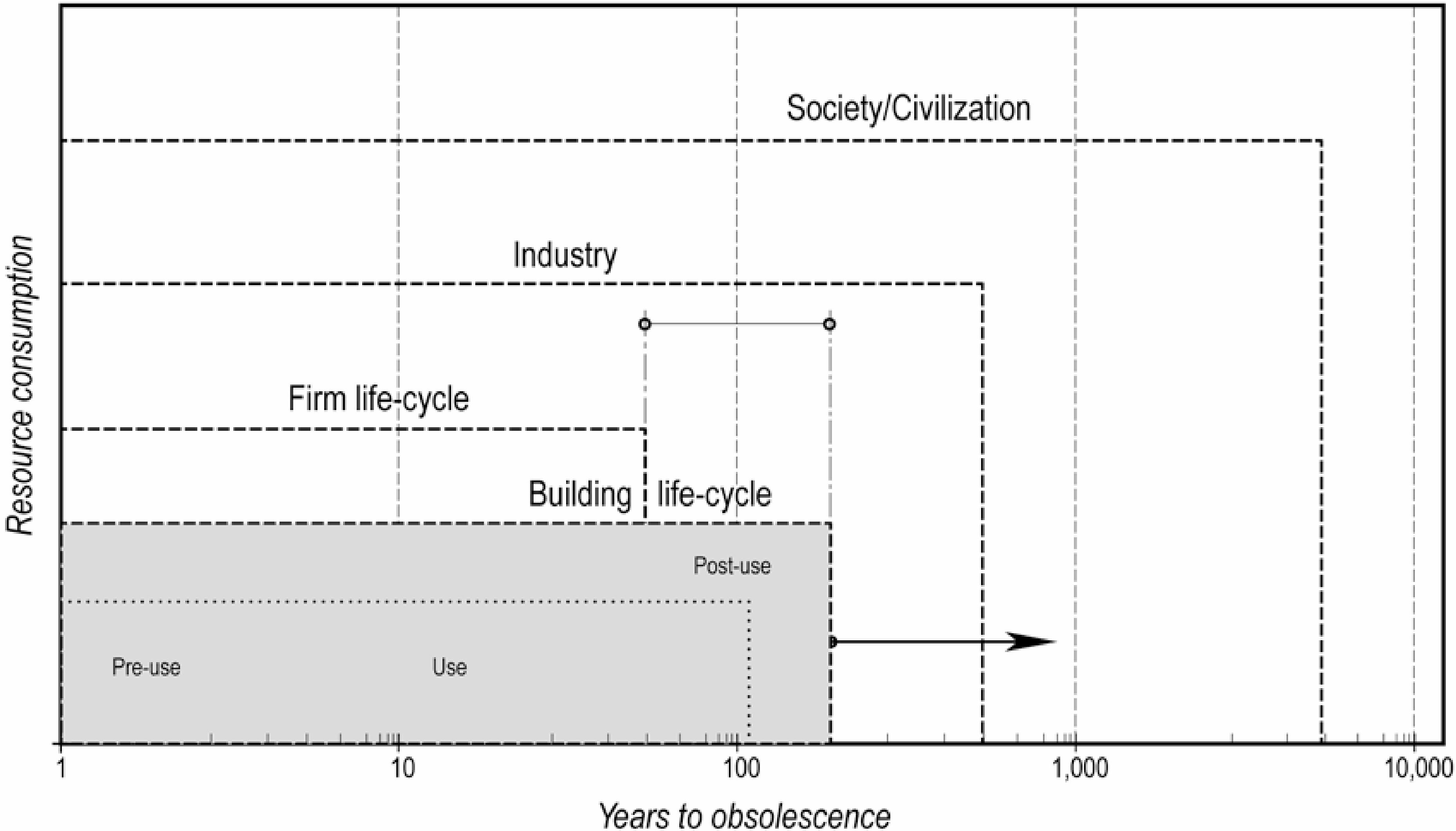


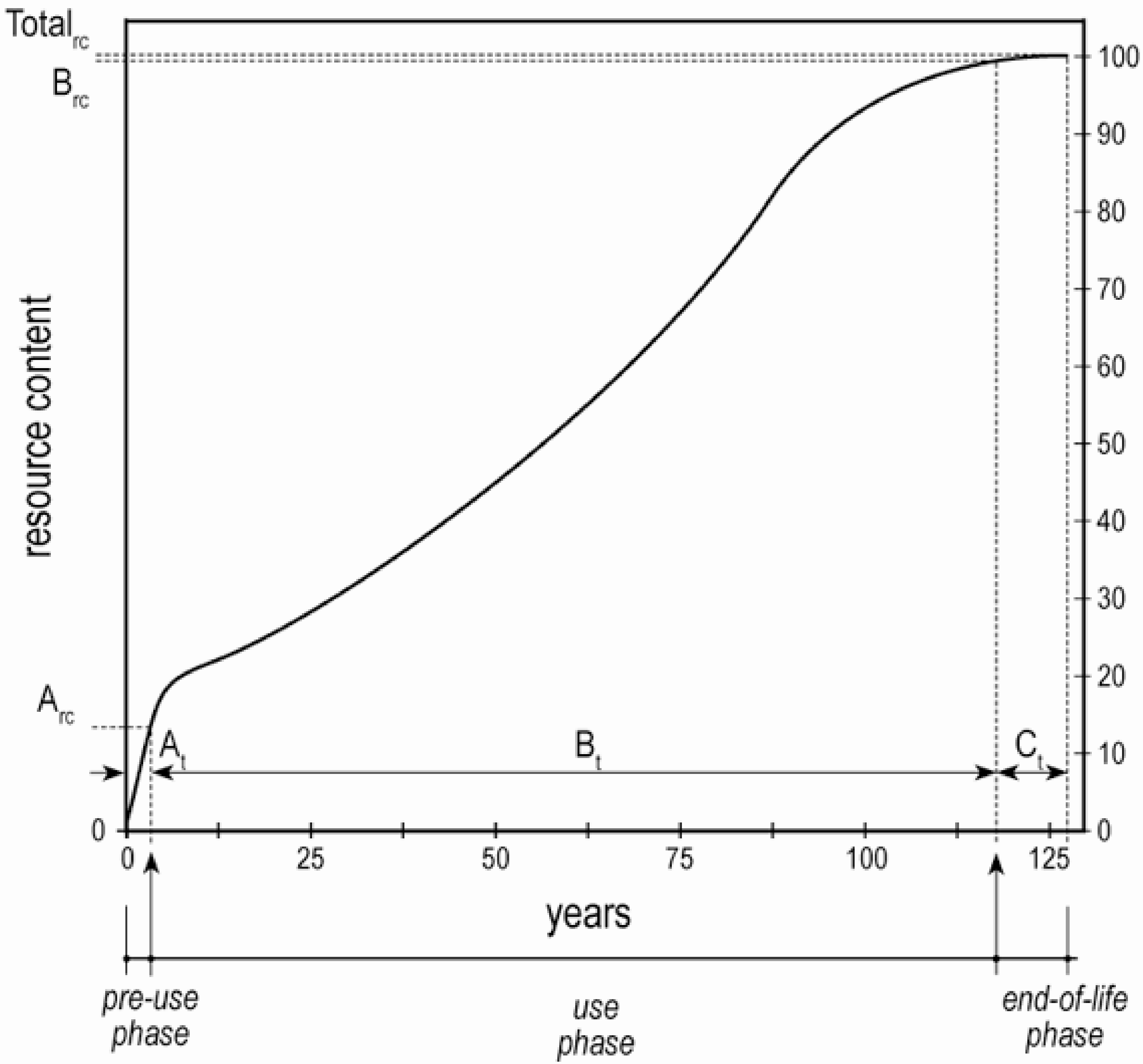
Figure by MIT OCW.

(b) Average Construction Greenhouse Gas Emissions for Wood, Steel and Concrete Assemblies



Source: *adapted from,* Bras, B. and Graedel and Allenby


Society/Civilization
Industry
Firm life-cycle
Building life-cycle
Post-use
Pre-use
Use
Resource consumption
1
10
100
1,000
10,000
Years to obsolescence



Total$_{rc}$
B$_{rc}$
A$_{rc}$
resource content
A$_t$
B$_t$
C$_t$
0
100
90
80
70
60
50
40
30
20
10
0
0
25
50
75
100
125
years
pre-use phase
use phase
end-of-life phase

Low energy buildings and resource content

(whole building)

Increased energy efficiency continually recalibrates proportion of *pre-use* to *use phase* energy investment.

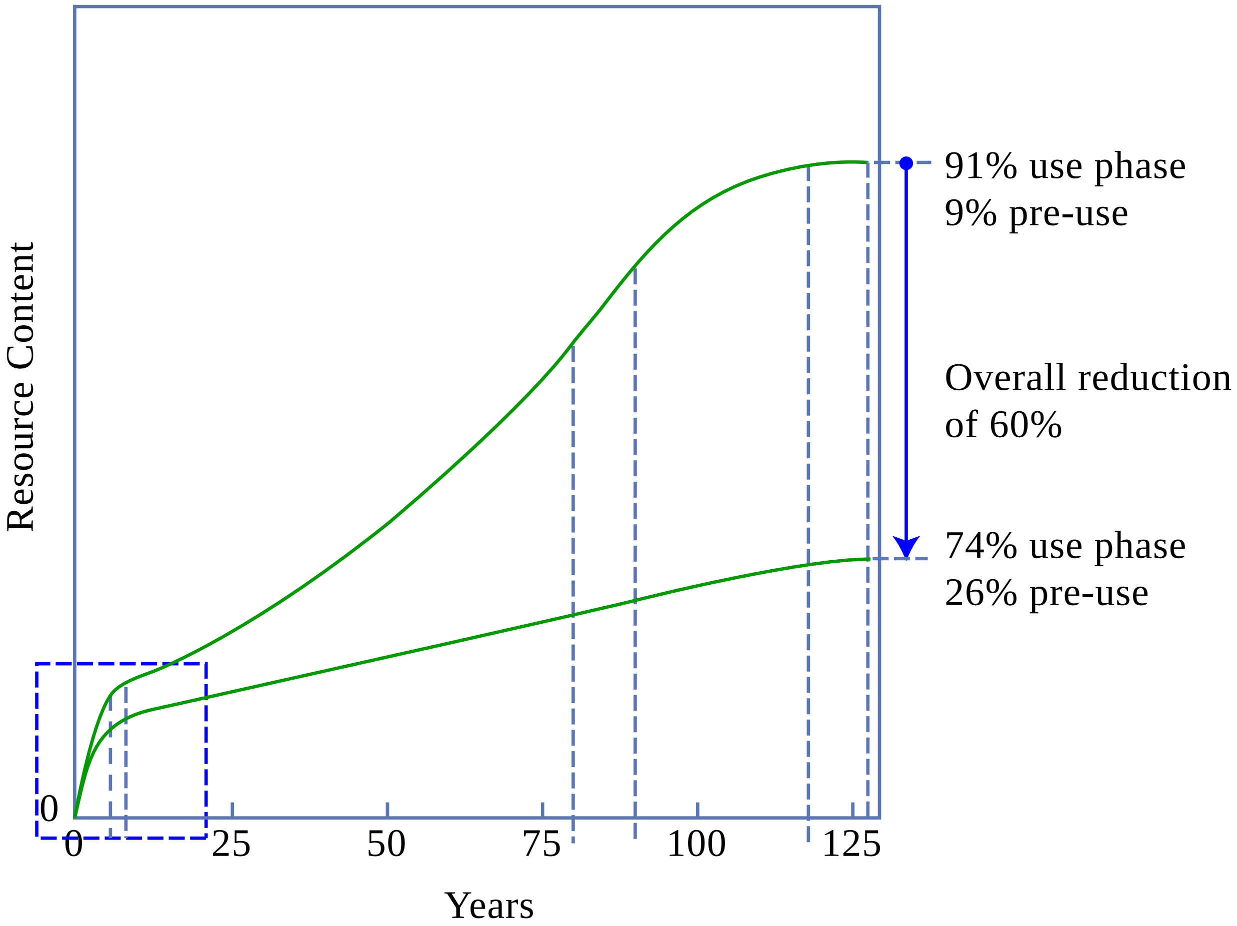


Figure by MIT OCW.

For example:

Single family detached house (USA)

Typical systems

9% pre-use, 91% use phase

Low energy systems

26% pre-use, 74% use phase

Keoleian, G. et al. 2001. **Life-cycle energy, costs, and strategies for improving a single-family house**. *JIE* Vol.4, No.2: pp. 135-156.

Strategies

Pre-Use

- Integrated delivery (construction) including premanufactured assemblies for dematerialized built environment (renewable and non renewable).

  Issues: employment, quality, material flow control, waste control and reuse, transportation energy in construction, firm MFA analysis, product LCA.

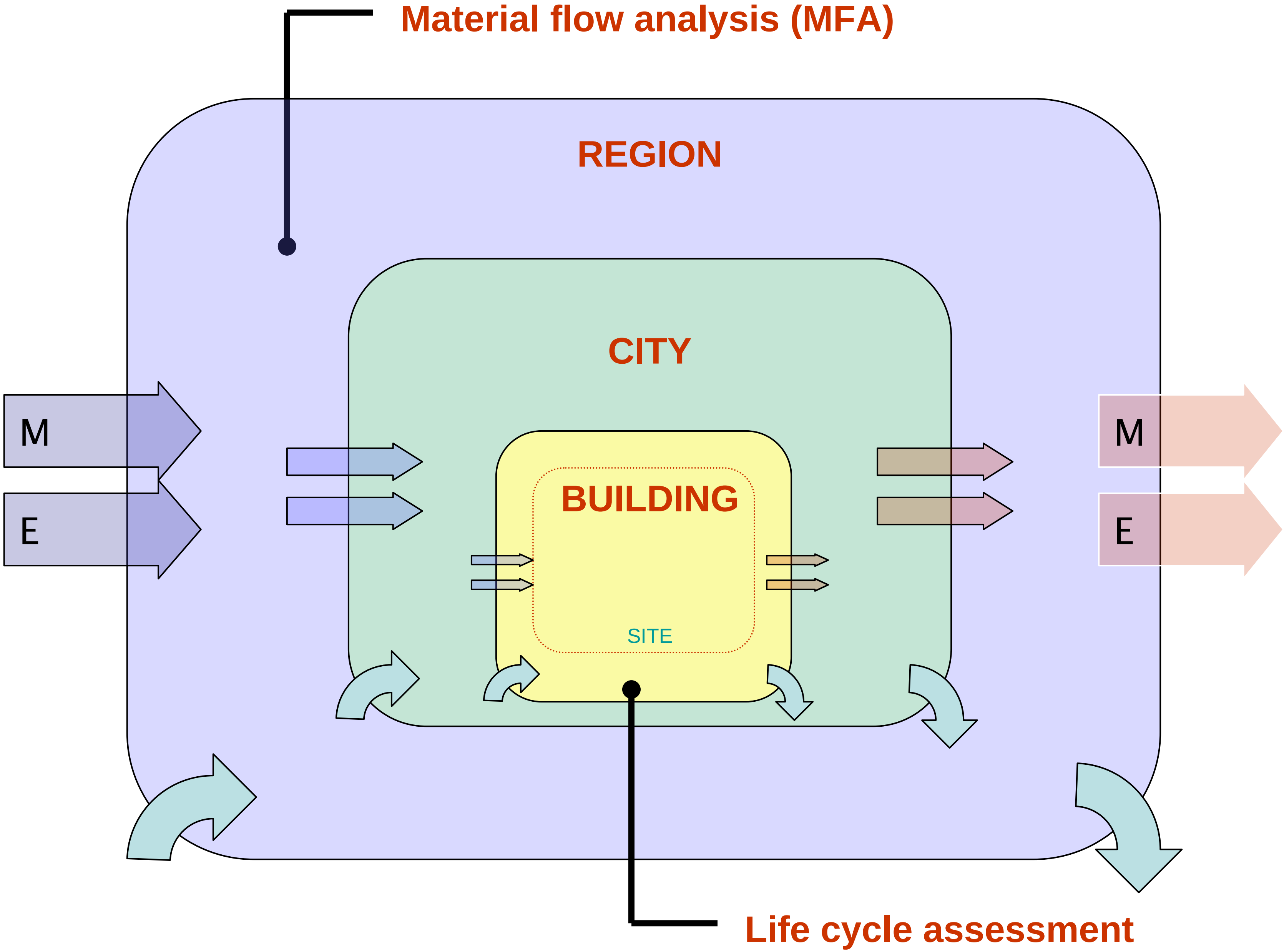
Use

- Extended Producer Responsibility (EPR) or better yet Extended Industry Responsibility (EIR): product LCA
- Material reclamation, recycle, downcycle.
- Comfort/Carbon Tax

Post-Use

- “Cities are the mines of the future.”, Jane Jacobs

Are we any closer to a Type III ecology?


Material flow analysis (MFA)
REGION
CITY
BUILDING
SITE
M
E
M
E
Life cycle assessment

Metabolism: the consumption of resources for the purpose of providing a unit of service.

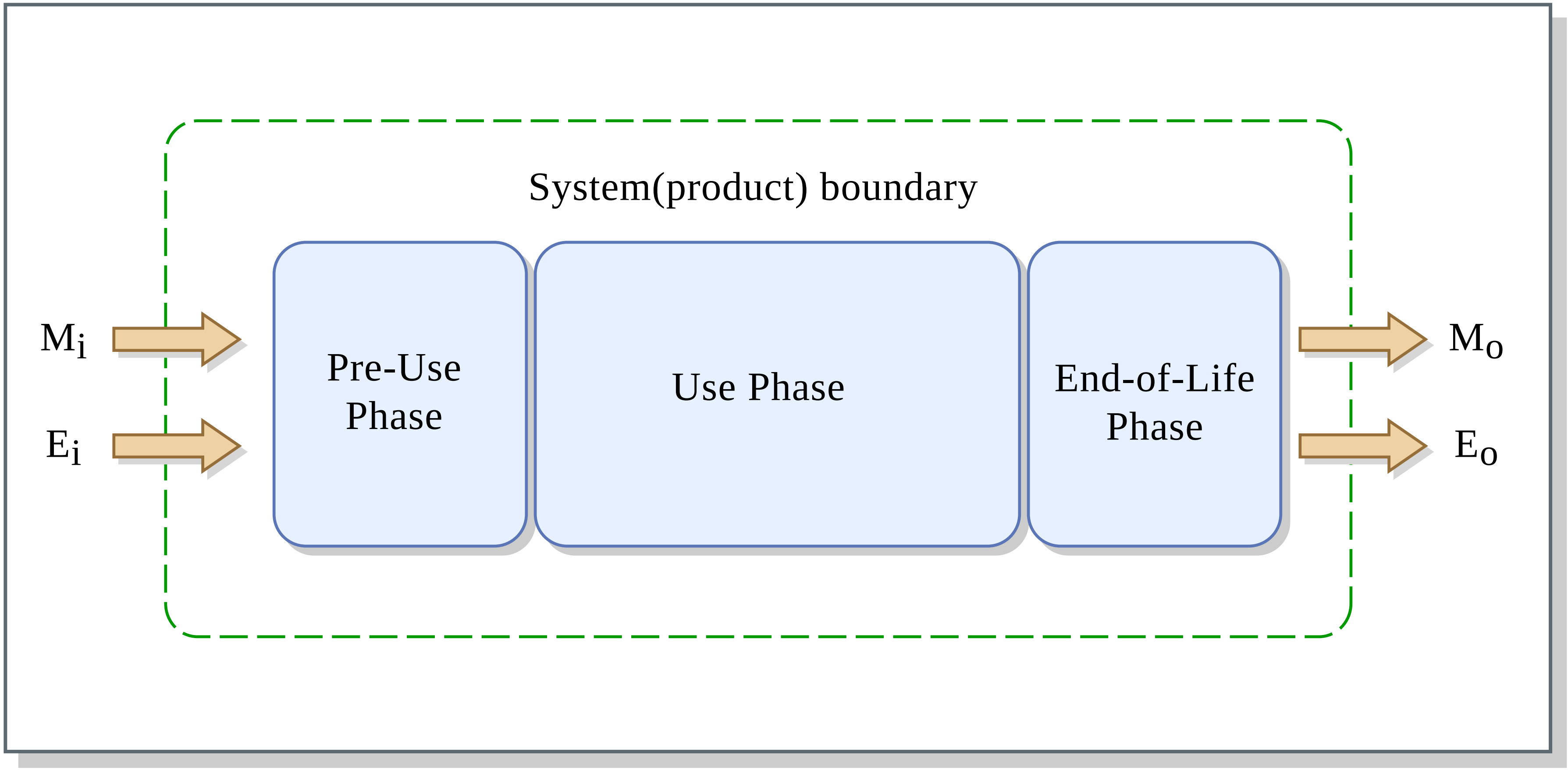


Figure by MIT OCW.

Industrial ecology as steward of tools of analysis for *resource consumption*

$$[M_i,E_i] = [M_o,E_o] + [A.S.]$$

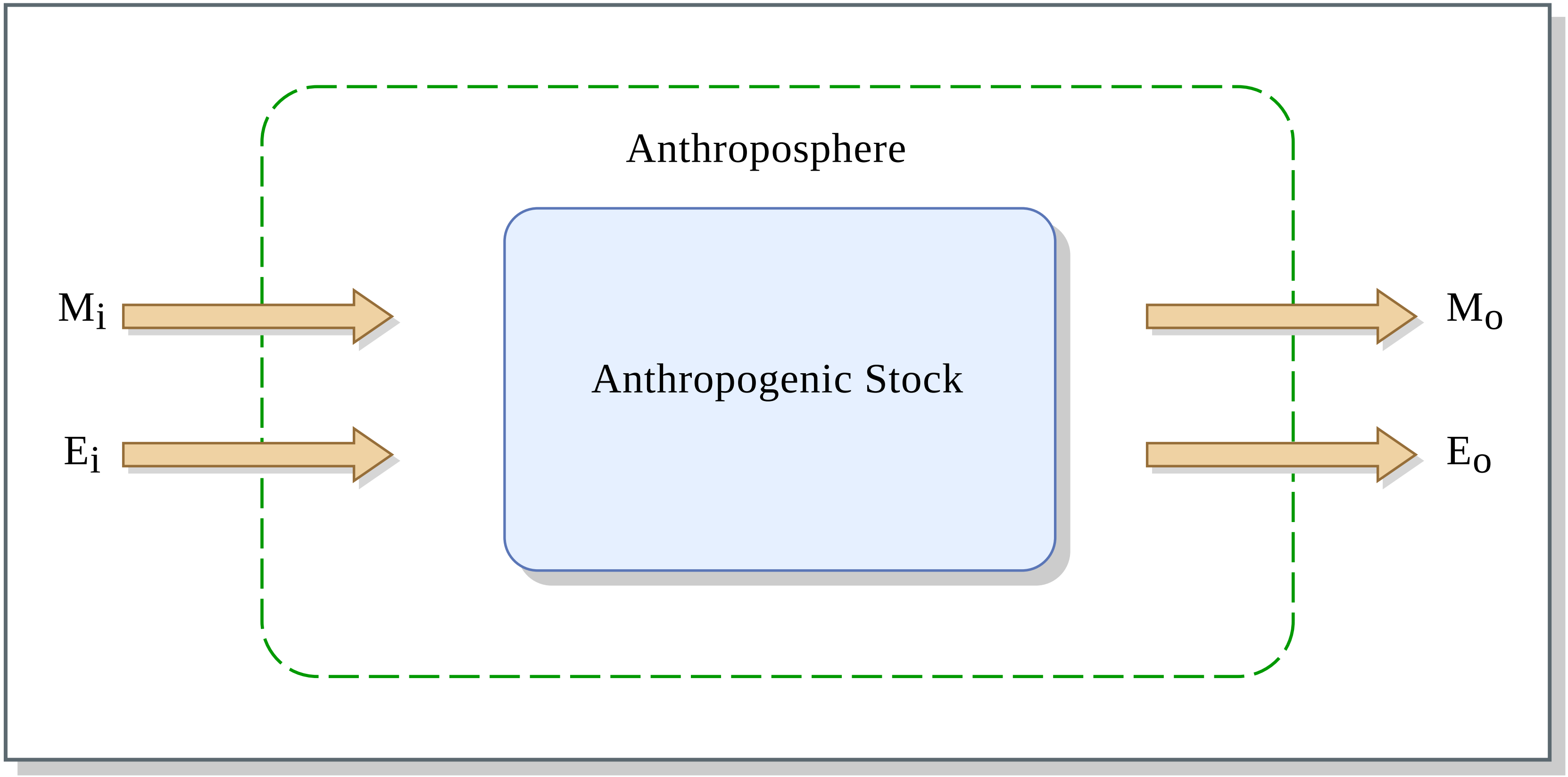
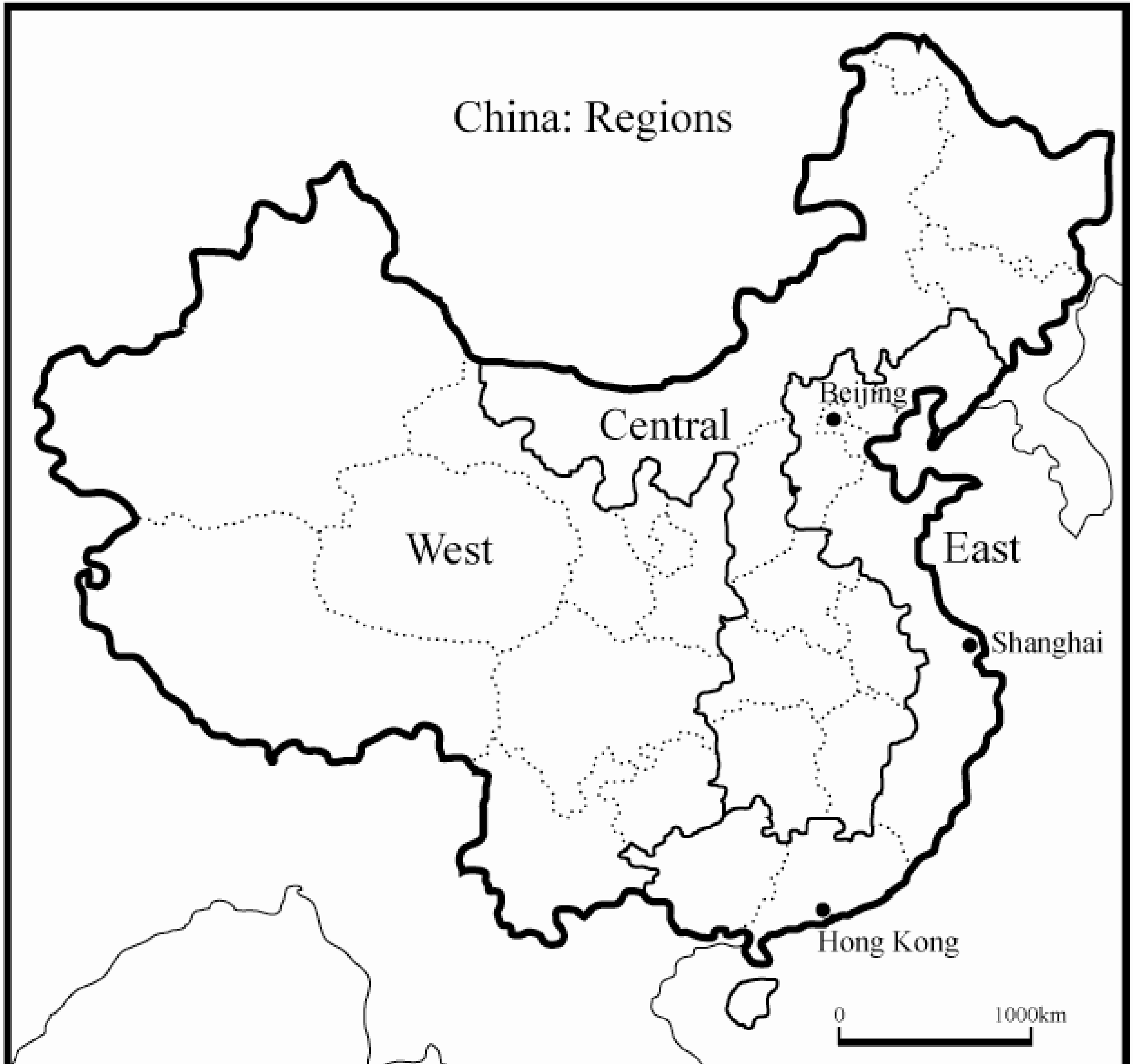


Figure by MIT OCW.


China: Regions
Central
West
East
Beijing
Shanghai
Hong Kong
0
1000km

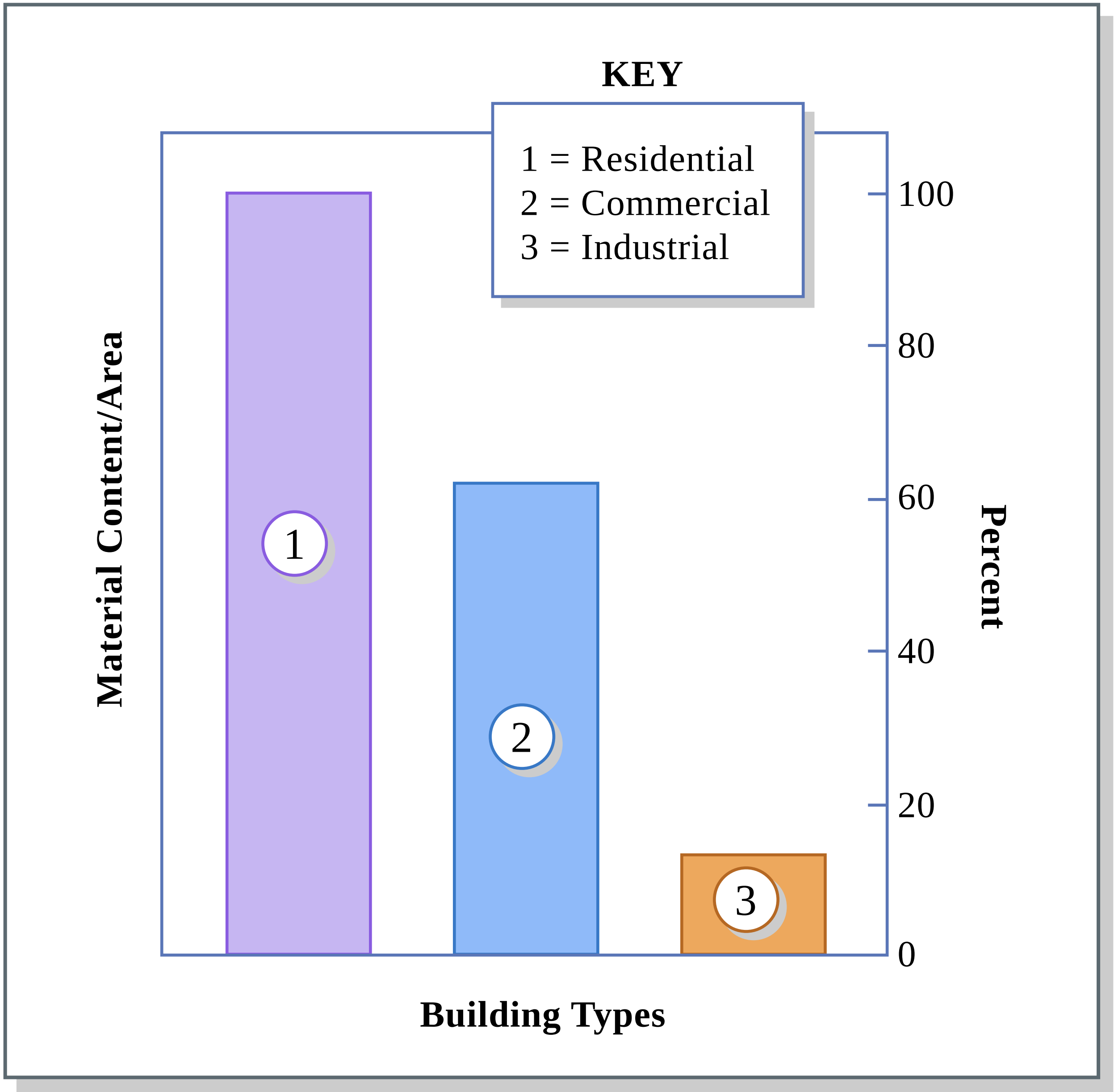


Figure by MIT OCW.

source: Fernandez, J. 2006 Resource consumption of new urban construction in China. *Journal of Industrial Ecology: In Press*

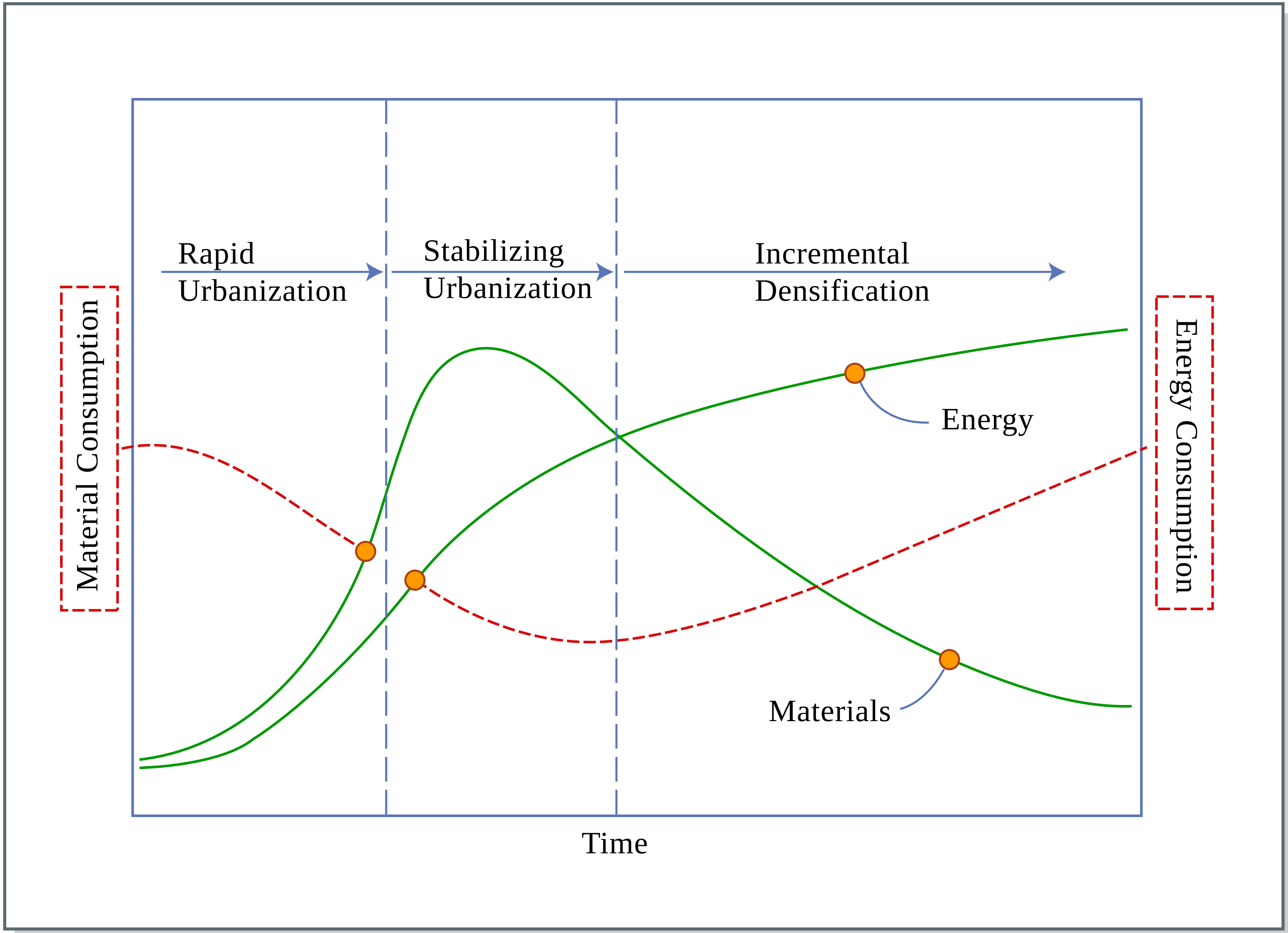


Figure by MIT OCW.

source: Fernandez, J. 2006 Resource consumption of new urban construction in China. *Journal of Industrial Ecology: In Press*

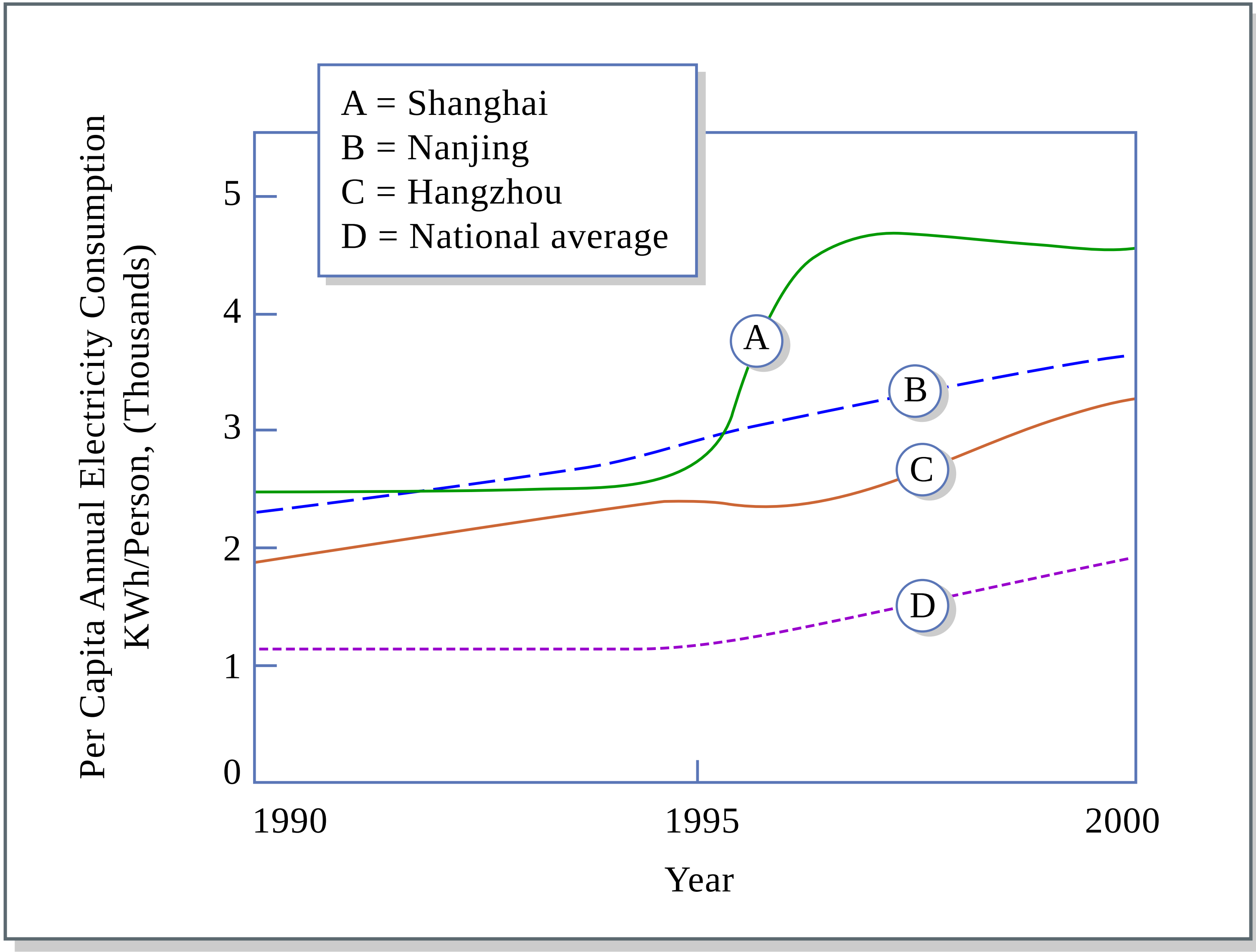


Figure by MIT OCW.

source: Fernandez, J. 2006 Resource consumption of new urban construction in China. *Journal of Industrial Ecology: In Press*

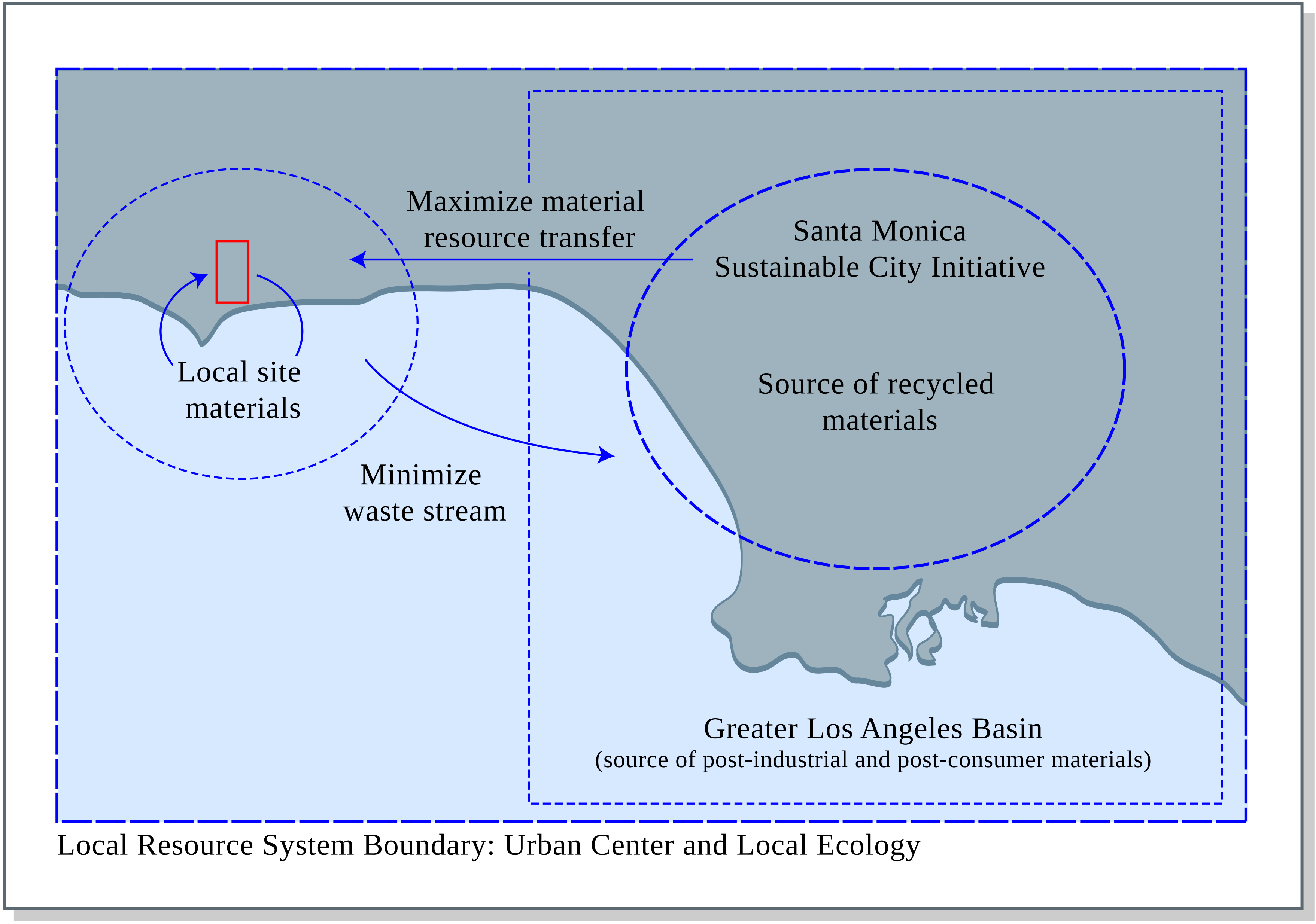


Figure by MIT OCW.

Ordnance Plant

Arden Hills, Minnesota

Built: 1930s

Dismantled: 2002

Materials recovered:

20,000 maple tongue and groove flooring,

500,000 board feet of structural timber

Cost of disassembly: $183,000

Cost of demo/landfilling: $600,000

Sears Catalog Warehouse Center

Chicago, Illinois

Built: 1906

Demolished: 1992-1994 (full 2 yrs of demolition)

Size: 9 story, 3 million sq. ft.

Materials recovered:

7.5 million board feet timber,

23 million bricks

Site recovered for housing

The photographs on this and the following pages were removed for copyright reasons.

Murray Grove Apartments

London, England

Cartwright Pickard Architects

(Yorkon Building Modules)

Built: completed 2001

Size: 30 apartments, 5 stories

On-site construction: 2 weeks

Overall cost reduction: 10% (affordable housing contract)

Premanufactured building modules

Yorkon

Foreman's

Container City

India Wharf, London, UK

source: photo J. Fernandez

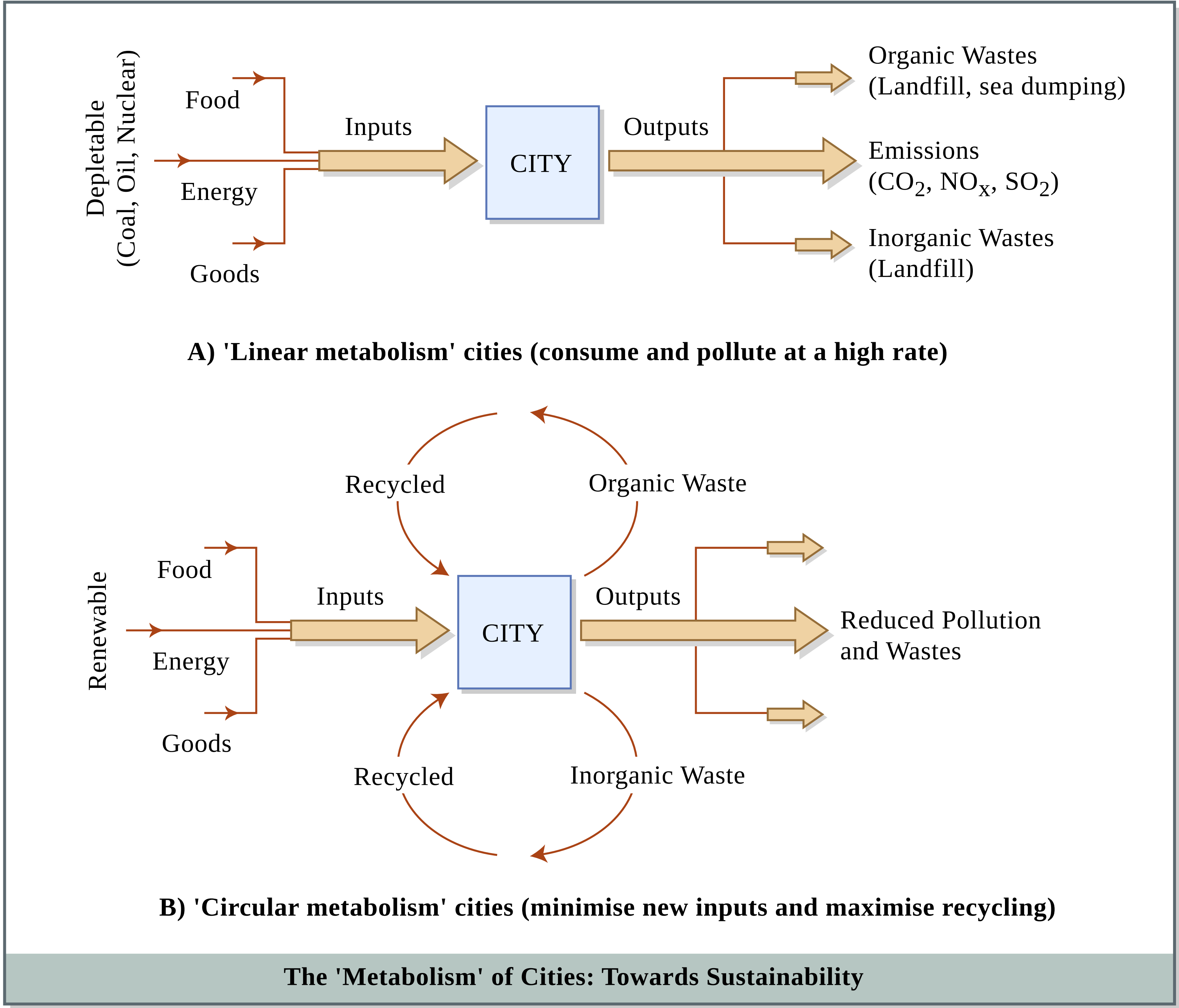
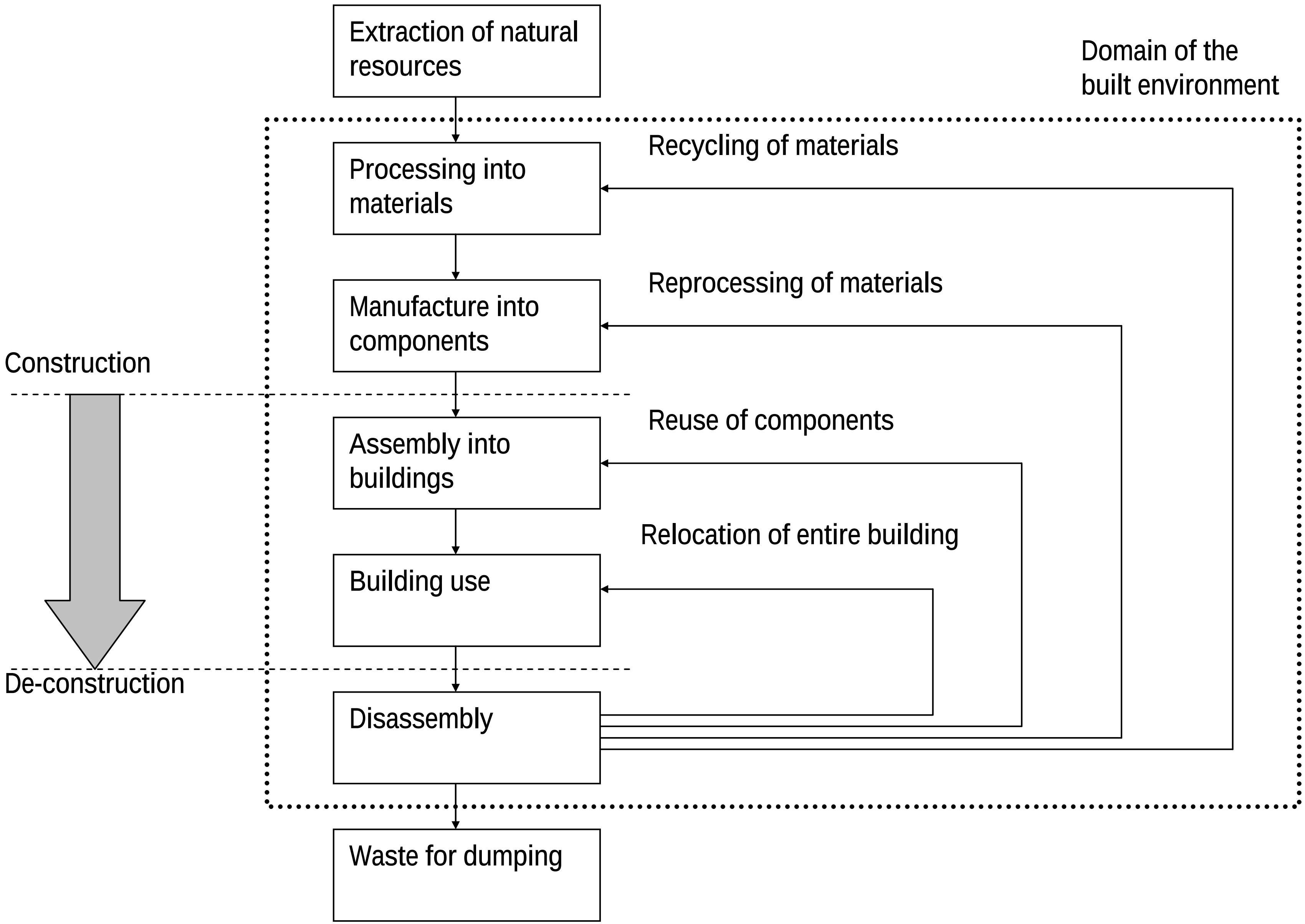


Figure by MIT OCW.



Materials cycles in construction

Scope

The analysis of the metabolism of the city of New Orleans may provide a unique understanding of the relationship between anthropogenic structures of industry and the built environment and the natural ecology of the lower Mississippi Delta.

1. System boundary
    i. Municipal (political)
    ii. Regional (geographic, ecological, etc.)
2. Physical accounting
    i. Listing of entities to ‘track’ (key resources)
    ii. Data sources