Urban Mining and CDW in a Circular Economy

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Earth Engineering Center (EEC)

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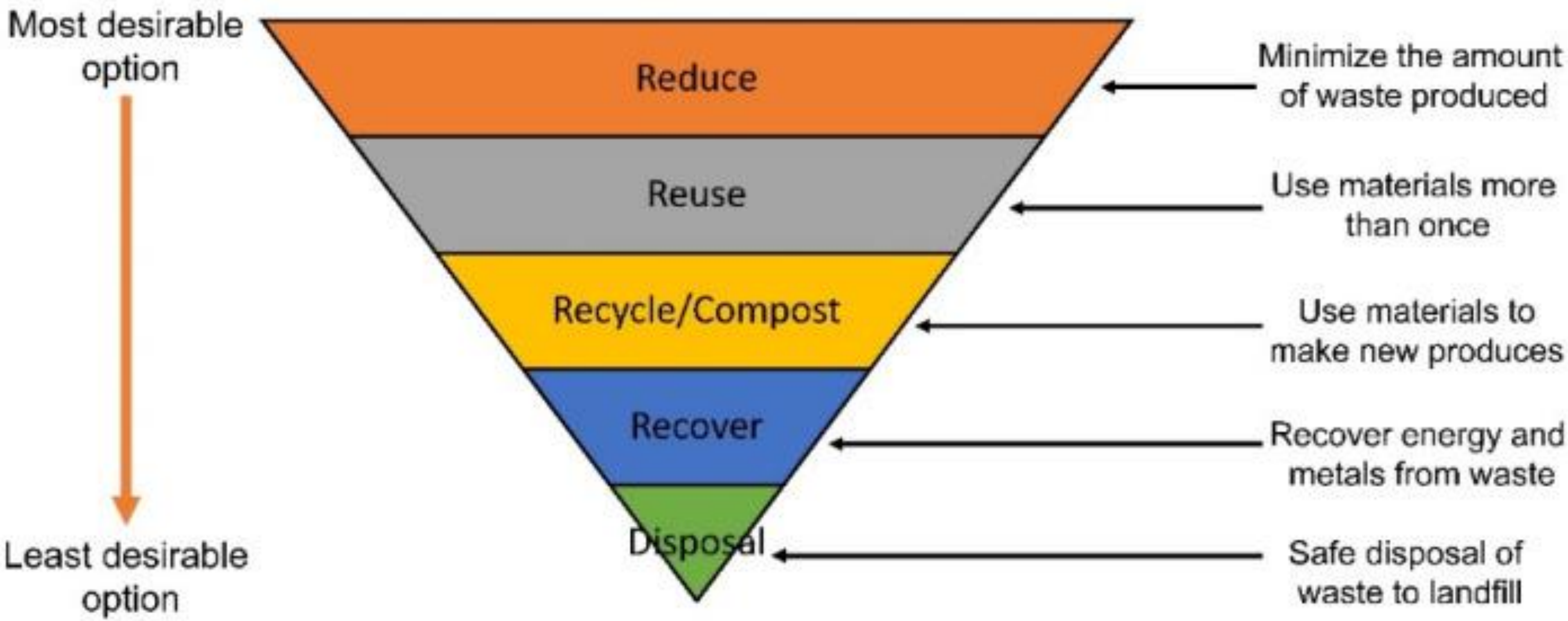
The mission of the EEC is to:

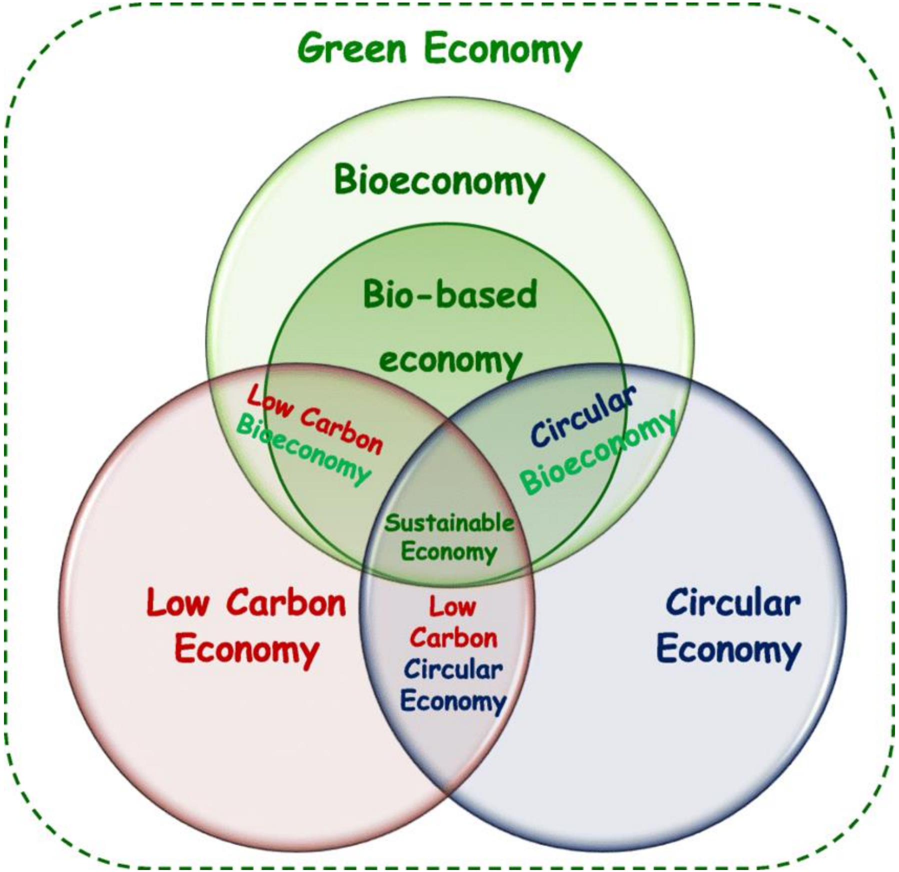
- Conduct research and education on the use of materials and energy resources for sustainable development, with preservation of land and water resources
- Disseminate this information by means of publications, presentations, and the web.

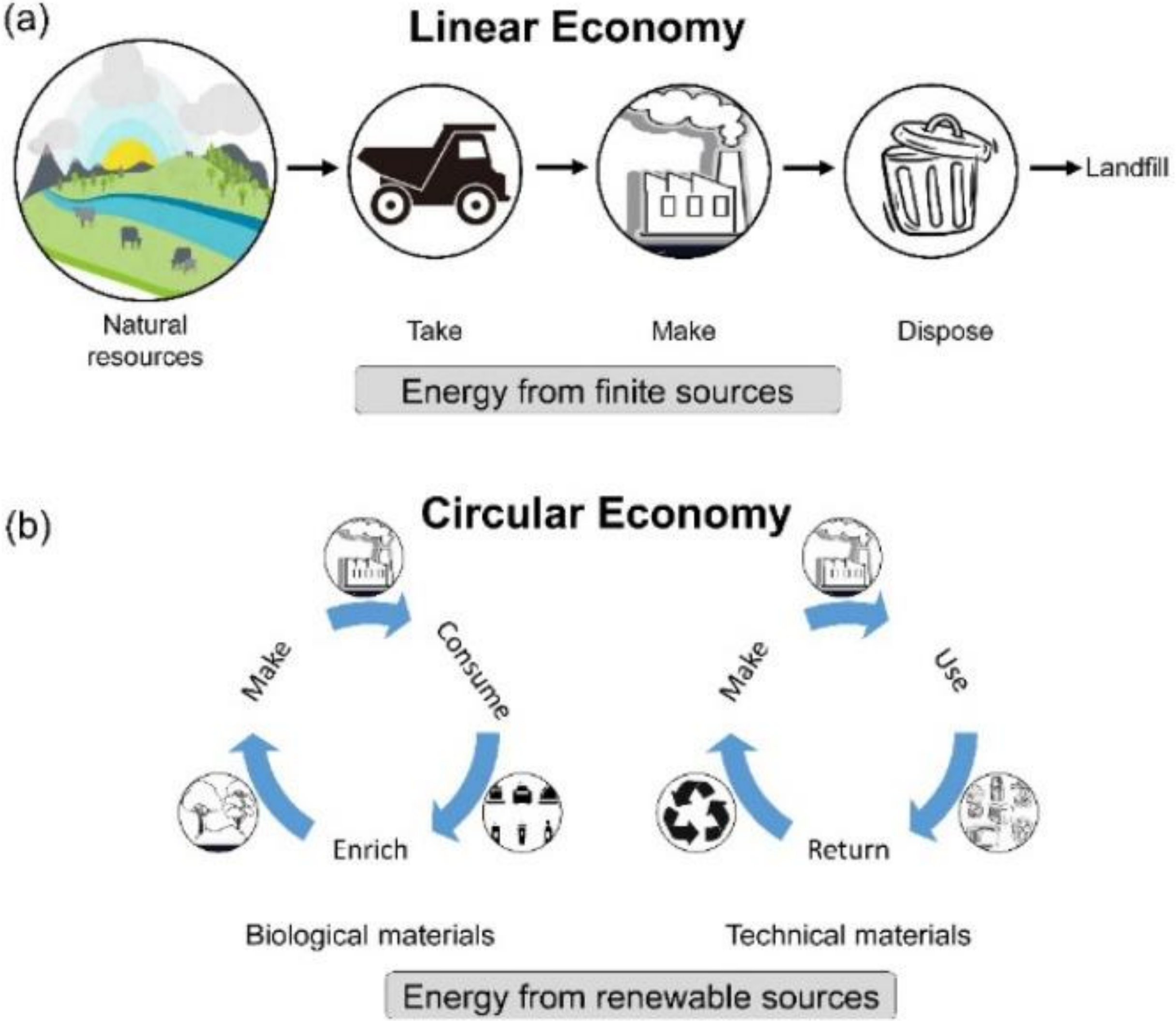
The guiding principle is that responsible management of renewable and non-renewable resources must be based on science, best available technology, and economics that include "external" environmental costs.

Hierarchy of sustainable waste management



Venn diagram depicting various economies in green economy (adapted from Kardung and Wesseler 2019)





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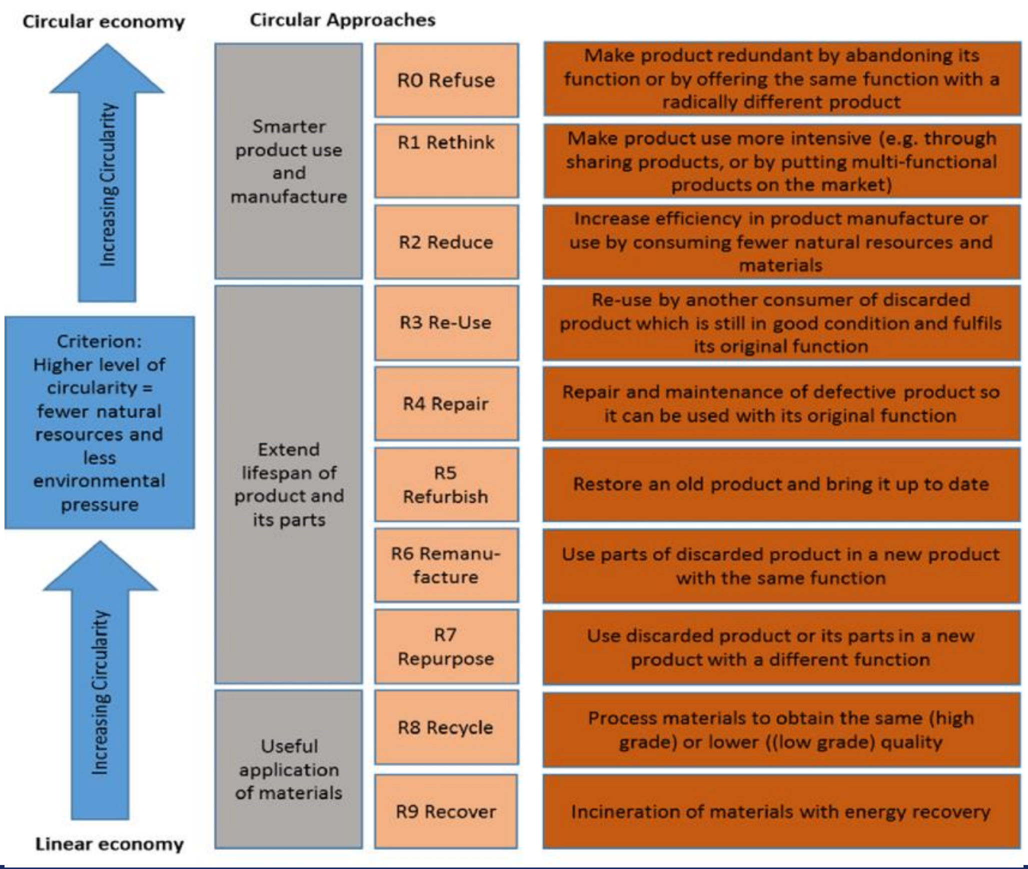
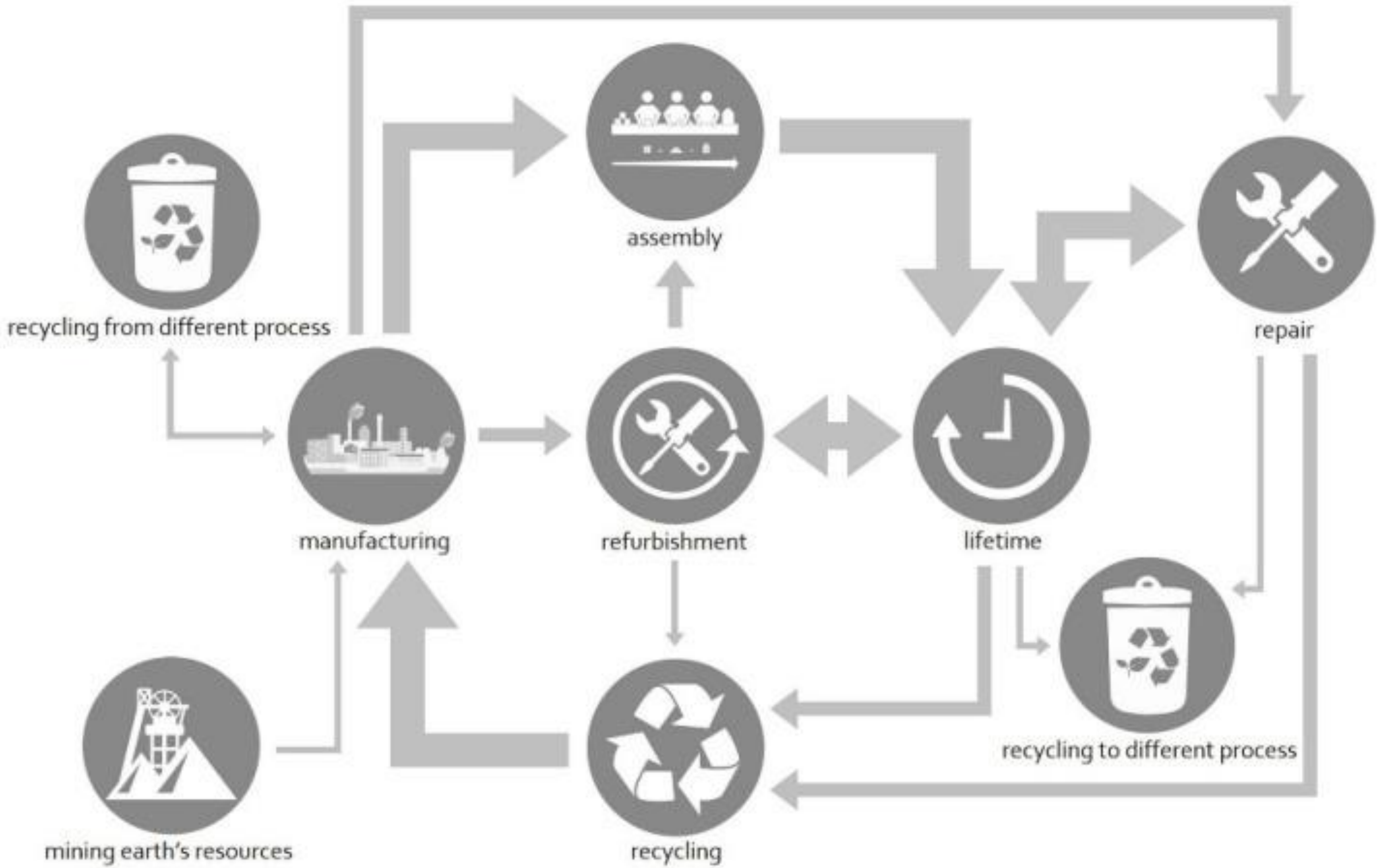
The 9R framework of Circular Economy approaches



DOI:10.3390/en11113009

Illustration of material flowchart in the circular economy



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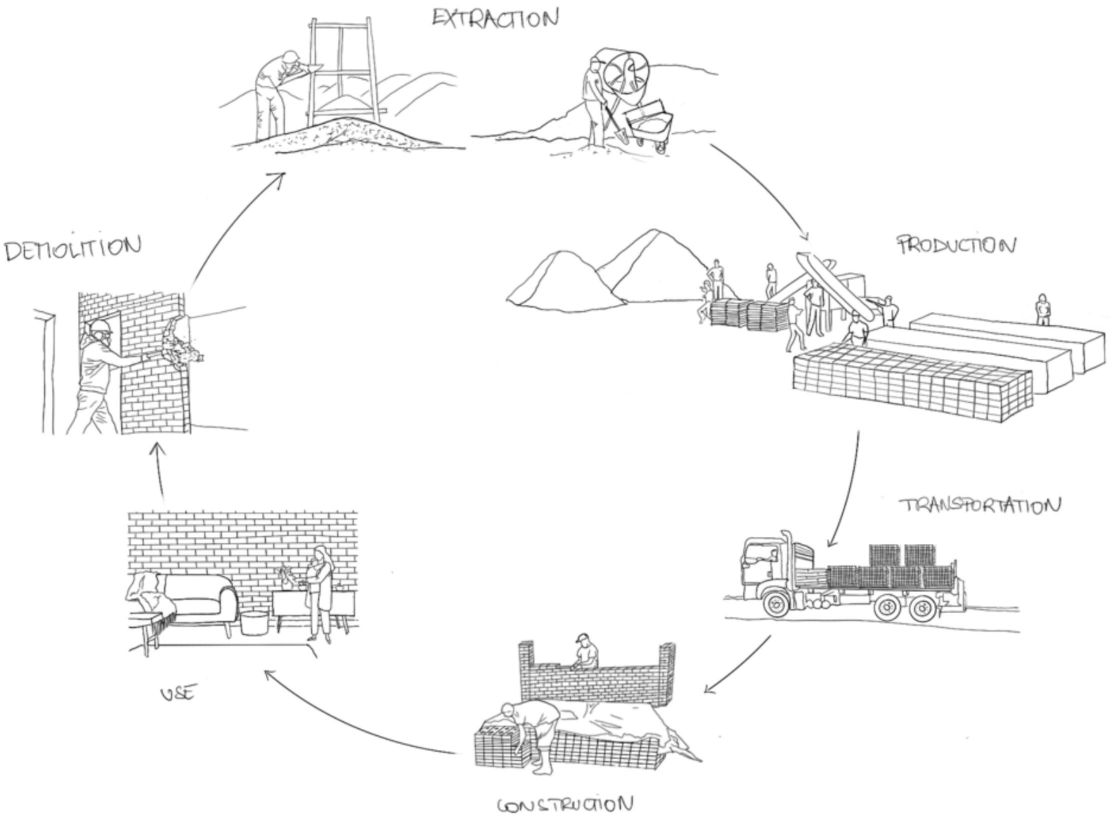
Life cycle stages in the construction



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Life cycle environmental impacts of Construction and Demolition Waste treated according to different methods

Treatment	Global warming potential, kg CO_2e/Mg	Primary Energy, MJ/Mg	Land Use*, PDF m^2 a/Mg
Collection	6	100	0.15
Landfill	15	300	0.80
Recycling	2.5	45	0.18

*Potentially Disappeared Fraction [PDF $\cdot$ m^2 y] of species over a certain amount of m^2 during a certain amount of year is the unit to "measure" the impacts on ecosystems. "The PDF m^2 y represents the fraction of species disappeared on 1 m^2 of earth surface during one year. For example, a product having an ecosystem quality score of 0.2 PDF m^2 y implies the loss of 20% of species on 1 m^2 of earth surface during one year."

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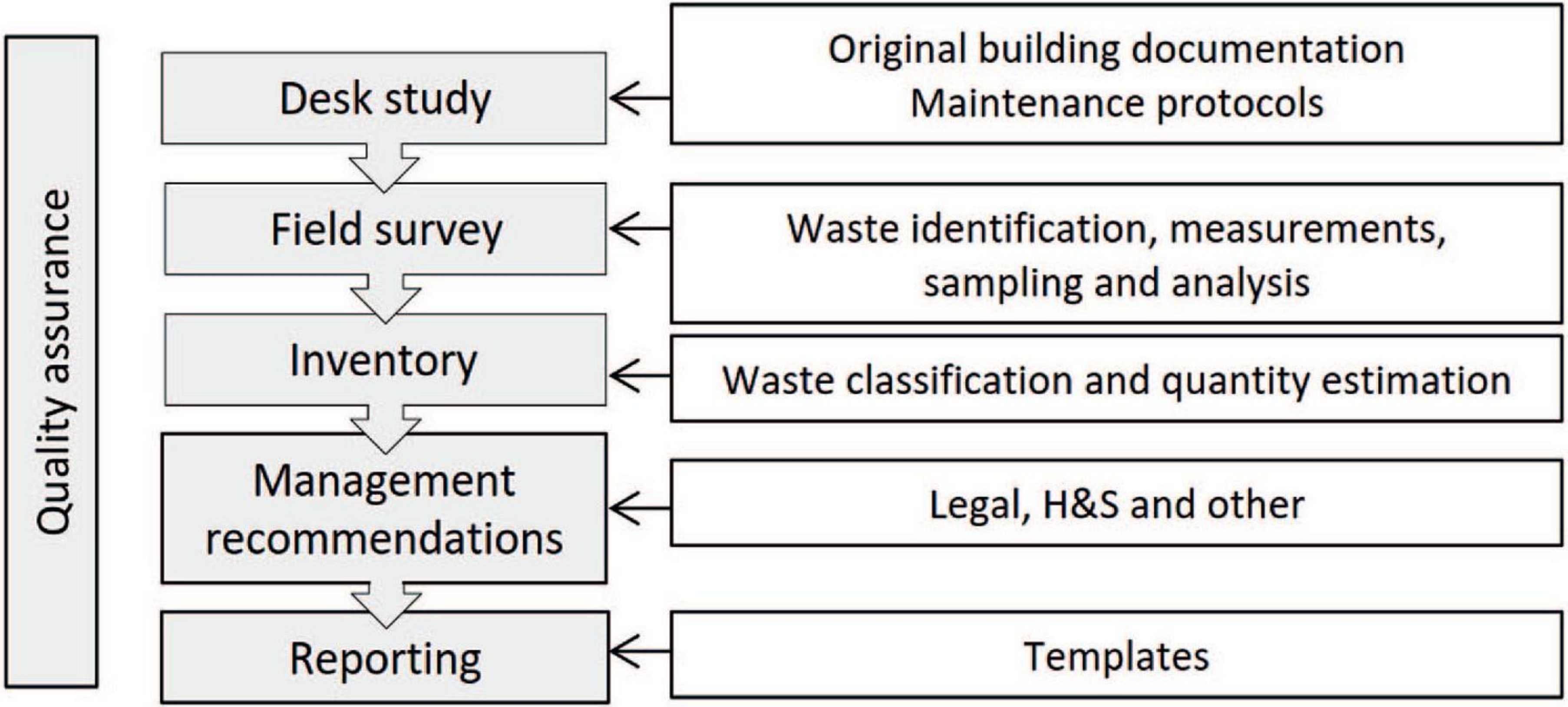
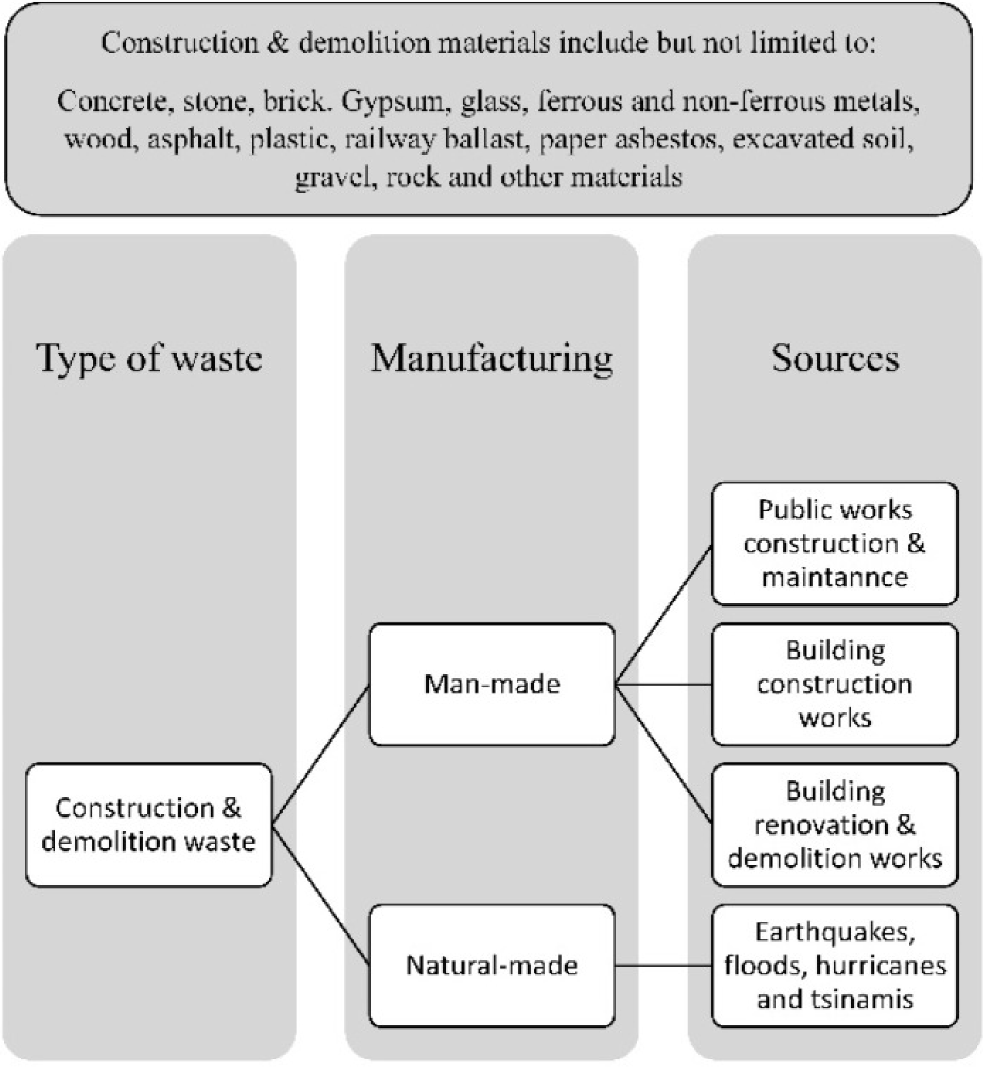
The pre-demolition waste audit process



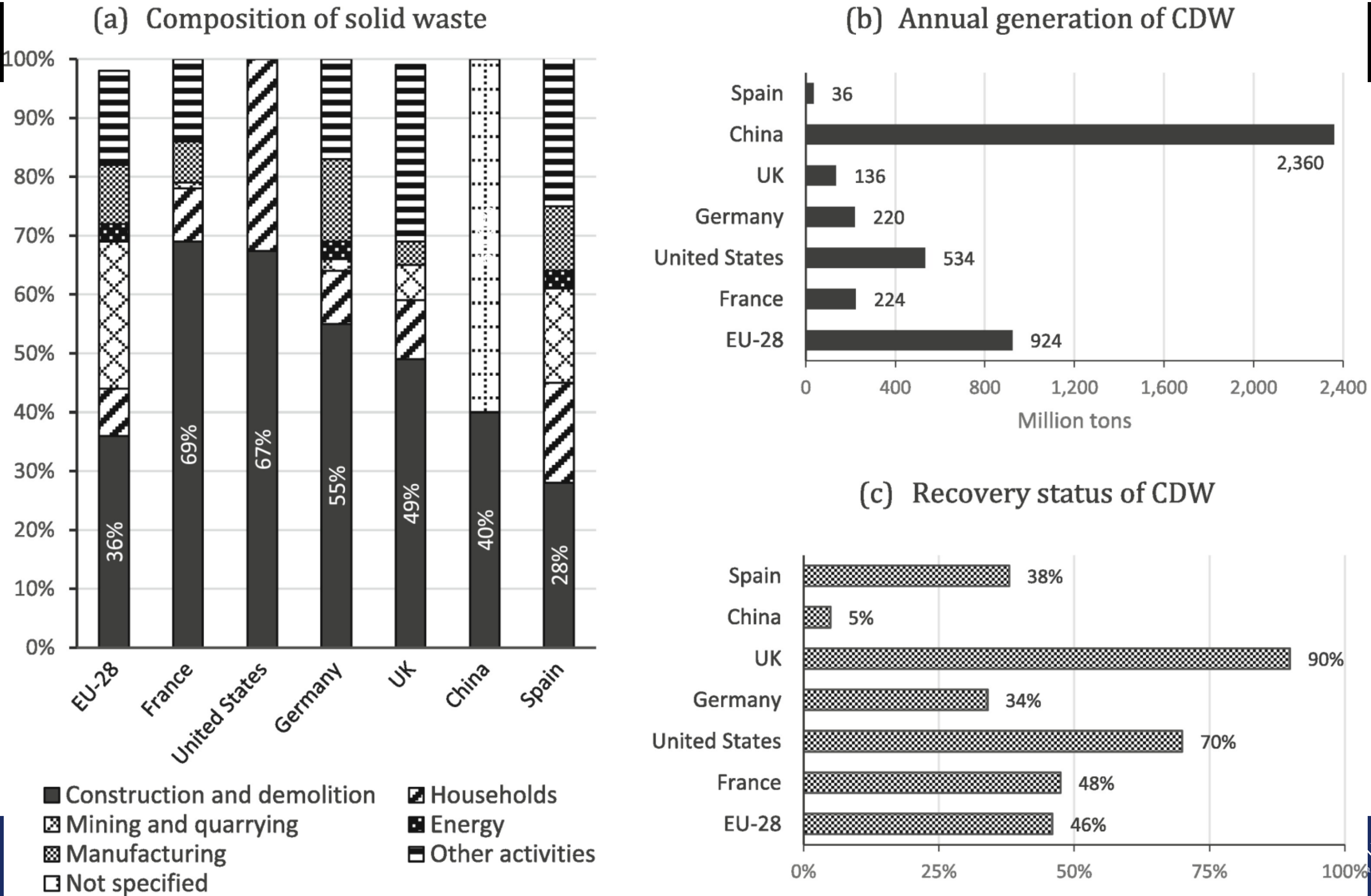


https://doi.org/10.1177/0734242X209367

Some facts:

- 600 million tons of C&D debris were generated in the United States in 2018
- Nationwide, C&D debris accounts for 25% to 45% of the total solid waste stream
- In NYC, C&D accounts for more than 60% of the solid waste stream
    - When clean fill materials (concrete, dirt, brick or asphalt) are excluded, C&D in NYC accounts for about 39% of the waste stream, which is comparable with national figures.
- NYC produces 19,500 tons of "fill material“, 13,500 tons of other C&D materials per day

https://www.nyc.gov/html/ddc/downloads/pdf/waste.pdf
https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/construction-and-demolition-debris-material


(a) Composition of solid waste
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
36%
69%
67%
55%
49%
40%
28%
EU-28
France
United States
Germany
UK
China
Spain
Construction and demolition
Mining and quarrying
Manufacturing
Not specified
Households
Energy
Other activities
(b) Annual generation of CDW
Spain 36
China 2,360
UK 136
Germany 220
United States 534
France 224
EU-28 924
0
400
800
1,200
1,600
2,000
2,400
Million tons
(c) Recovery status of CDW
Spain 38%
China 5%
UK 90%
Germany 34%
United States 70%
France 48%
EU-28 46%
0%
25%
50%
75%
100%

Construction and Demolition Waste composition

Waste Category	%, min–max range
Concrete and Masonry	40–84
Concrete	12–40
Masonry	8–54
Asphalt	4–26
Others (mineral)	2–9
Wood	2–4
Metal	0.2–4
Gypsum	0.2–0.4
Plastics	0.1–2
Miscellaneous	2–36

https://doi.org/10.1016/j.resconrec.2018.04.016

Regenerate: Encouraging to move the focus from traditional to renewable technologies and prevent the destruction of ecosystem.

Share: Driving towards increasing the lifespan via efficient maintenance schemes and sharing the recyclable and reusable resources and assets.

Optimize: Enhancing the efficacy of recycled goods by cutting unwanted wastes via efficient and green supply chain.

Loop: Providing the required technology to recreate and recycle the wastes.

Virtualize: Dematerializing in both direct and indirect way.

Exchange: Encouraging and enhancing the adoption of innovative construction materials and newer techniques.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8745857/

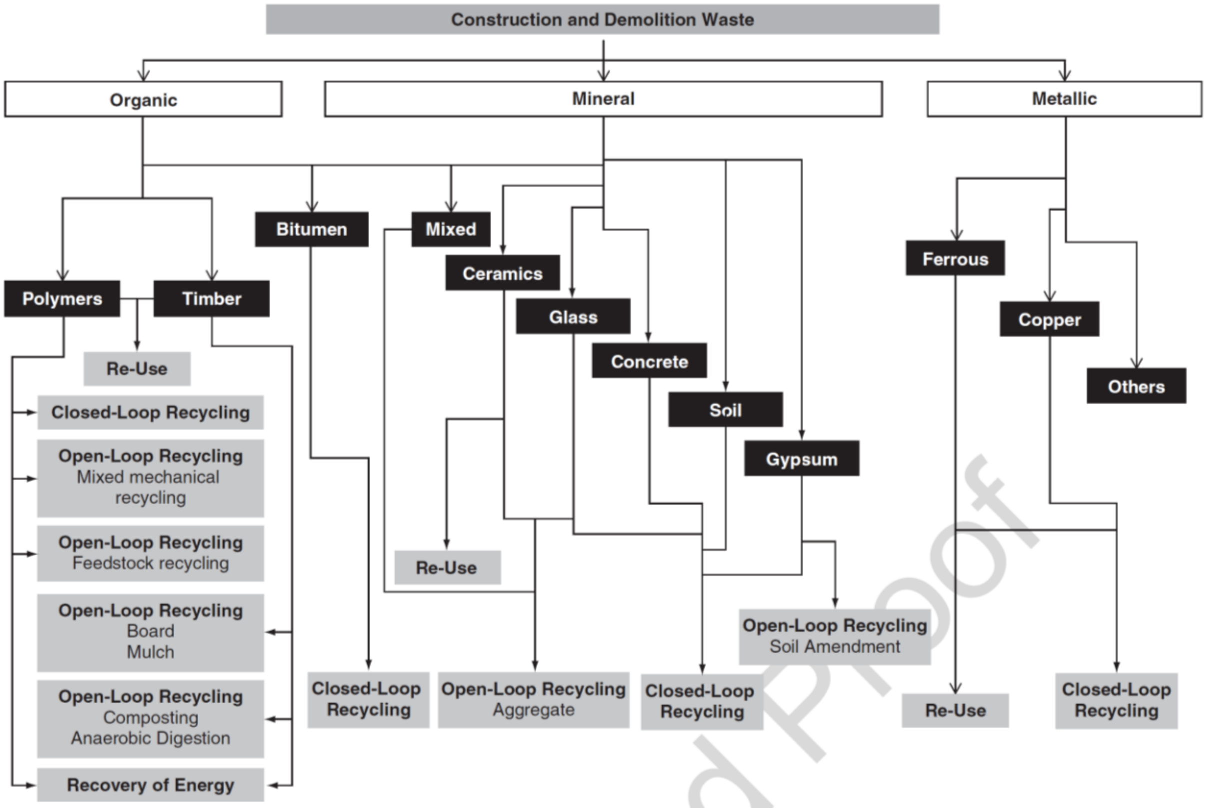
Closing loops consists of creating a circular flow of resources resulting from the use phase that are generally considered waste. This is achieved through recycling processes.

Slowing loops refers to lengthening the use and reuse of a product through actions such as repair, refurbishment and remanufacture.

Narrowing loops is about reducing the use of resources and maximizing efficiency in production processes

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8745857/

Closed-loop recycling of demolition waste



Summary of different wastes which can be incorporated as aggregates in concrete.

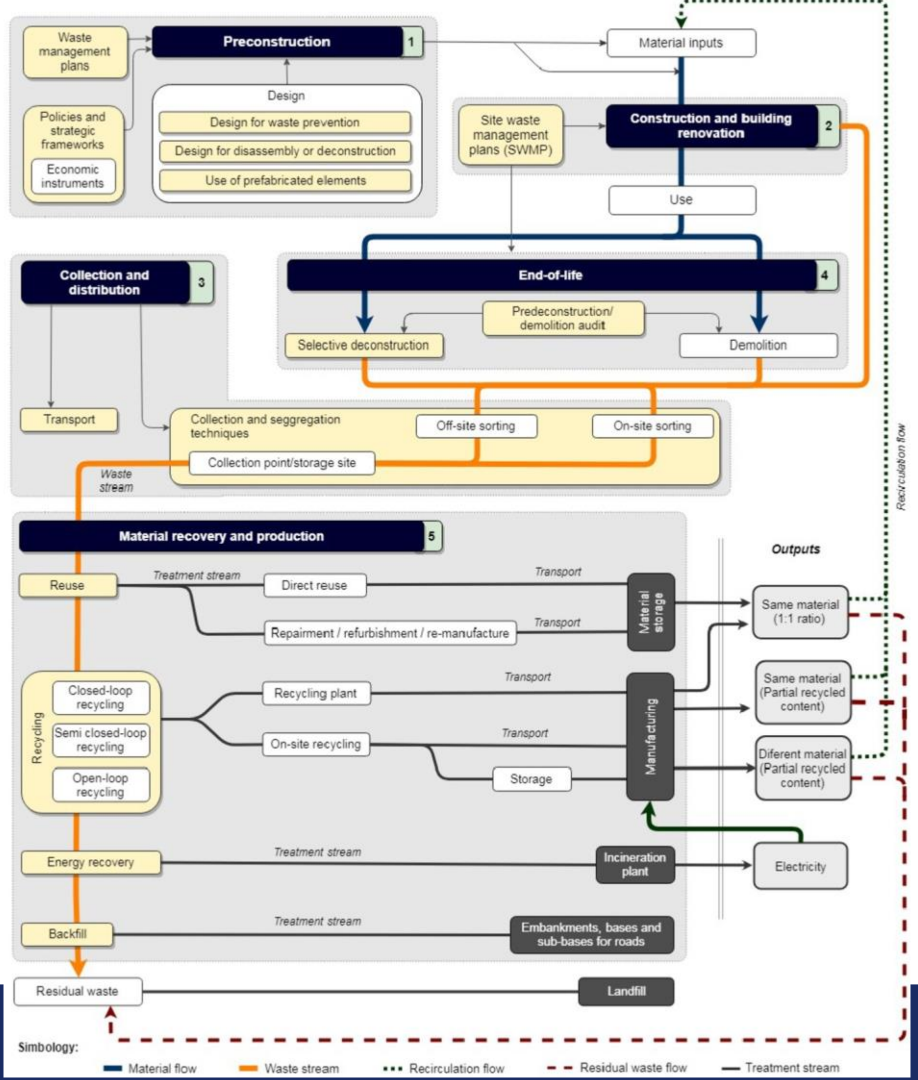
Material	Benefits
Glass	Pozzolanic in nature, high thermal conductivity, reduced shrinkage, improved water absorption, reduced ecological emissions.
Plastics	Increased ductility, reduced shrinkage cracks, lightweight concrete.
Ceramics	Enhanced strength, required water absorption, low specific weight, and high pozzolanic nature.
Rubber	Protection against high temperatures and increase in strength.
Concrete	Pozzolanic in nature, high thermal conductivity, reduced shrinkage, improved water absorption, reduced ecological emissions.
Coir & Almond Wastes	Increased air content, improved mechanical strength and lower air density.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8745857/

Summary of different wastes which can be incorporated as supplementary cementitious materials (SCMs) in concrete.

Material	Benefits
Metal Slag	High shear modulus, chemical stability, high strength.
Silica Fume	Pozzolanic nature, increased strength.
Rice Husk Ash	Enhanced compressive strength and improved water absorption.
Coal Ash/Fly Ash	Pozzolanic nature, good durability, low permeability, increased mechanical strength, reduced the alkali–silica reaction.
Ceramic Wastes	Increased strength, reduced permeability of concrete and increased efficiency.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8745857/



https://doi.org/10.1016/j.jclepro.2019.119238

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Integration of the identified best environmental management practices into the construction value chain

- Policy and Governance
- Quality and Performance
- Information
- Cost/capital
- Perception and culture
- Knowledge, education, and technology availability
- Permits and specifications

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8745857/

Other possibilities to decarbonize the construction sector

The cement industry alone contributes to about 7% of global CO2 emissions

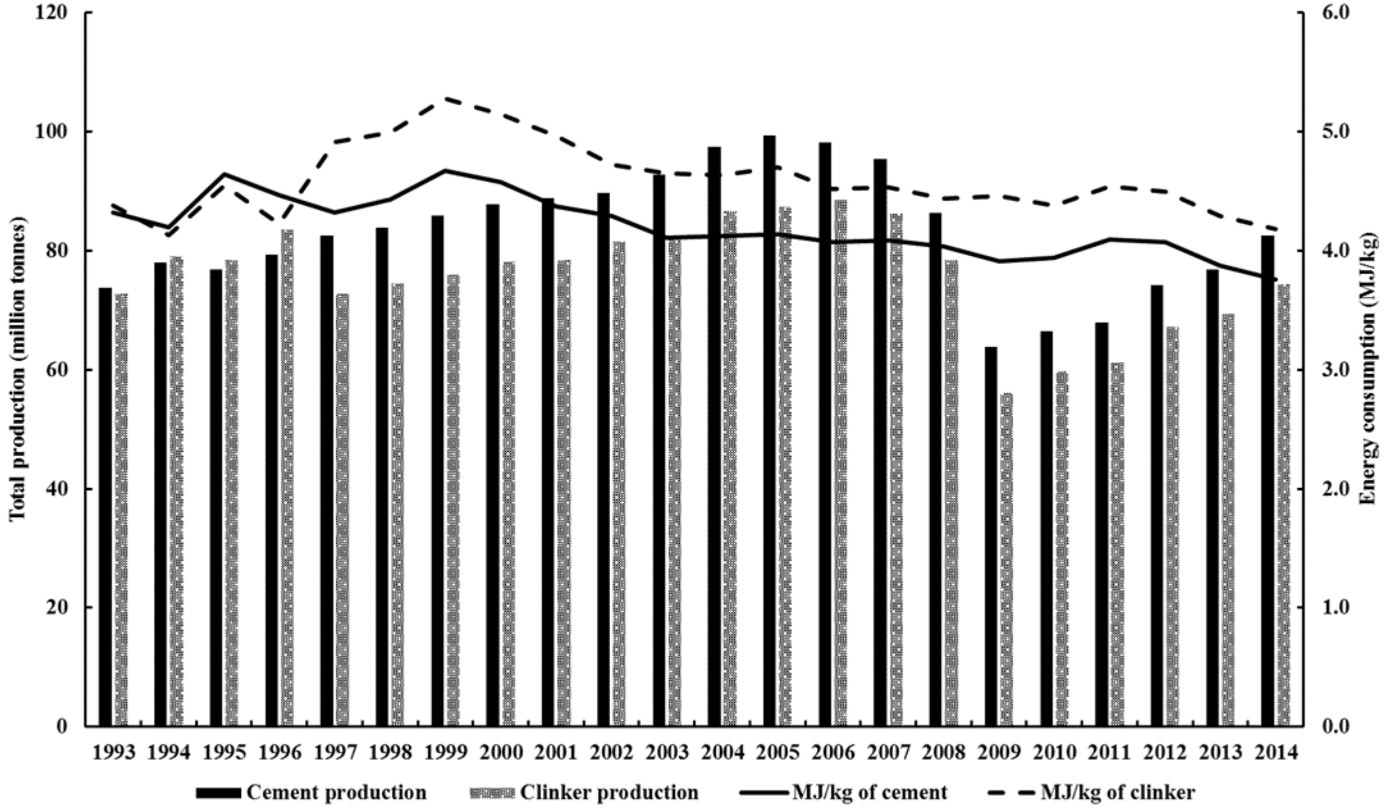
$$CaCO_3 + \mathrm{Heat} \rightarrow CaO + CO_2.$$

one ton of clinker approximately produces 0.51 tCO2

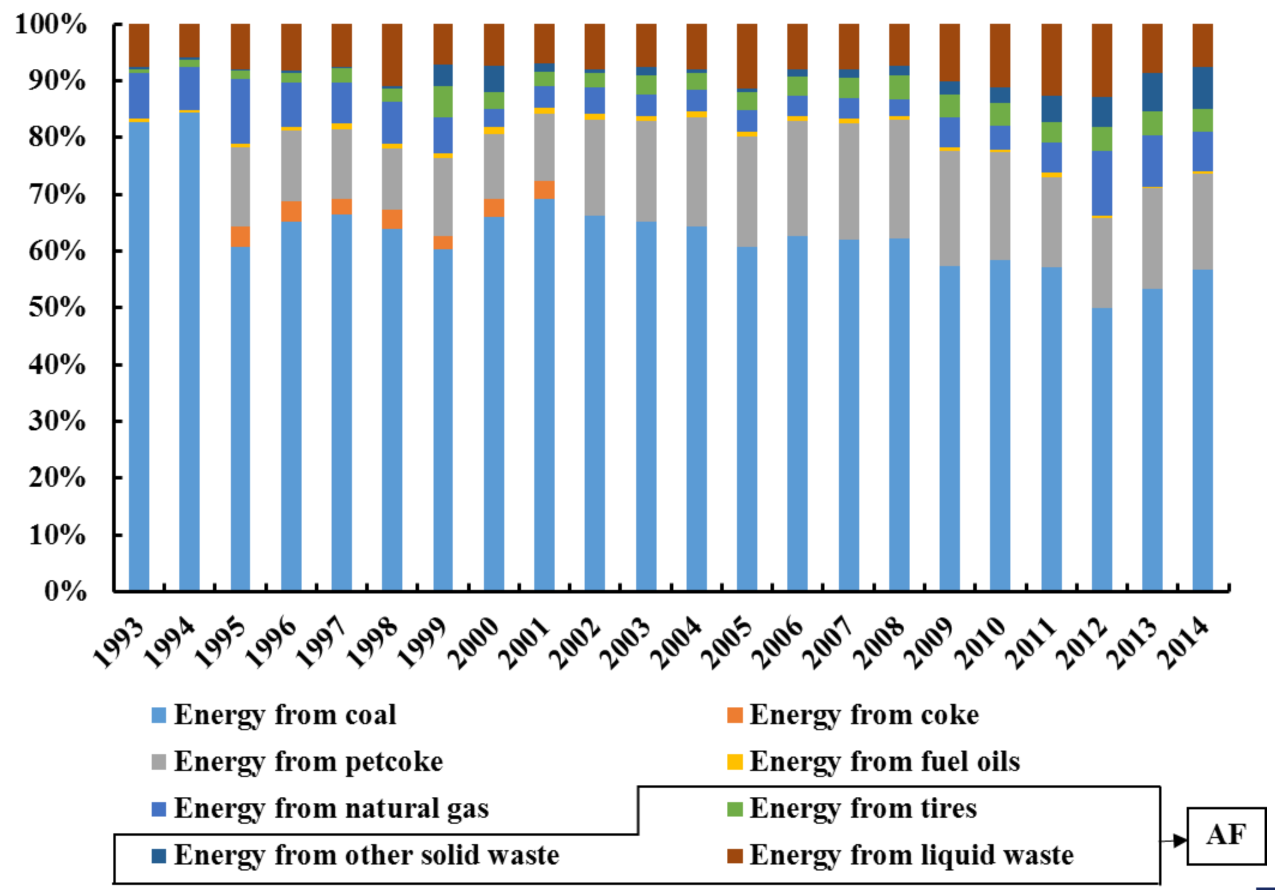
(1) increasing energy efficiency in both cement and construction industries; and
(2) using alternative fuels (e.g., biofuels, municipal wastes, etc) in cement kiln; clinker substitution/blended cement; reuse of C&D waste using circular economy concept

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8745857/

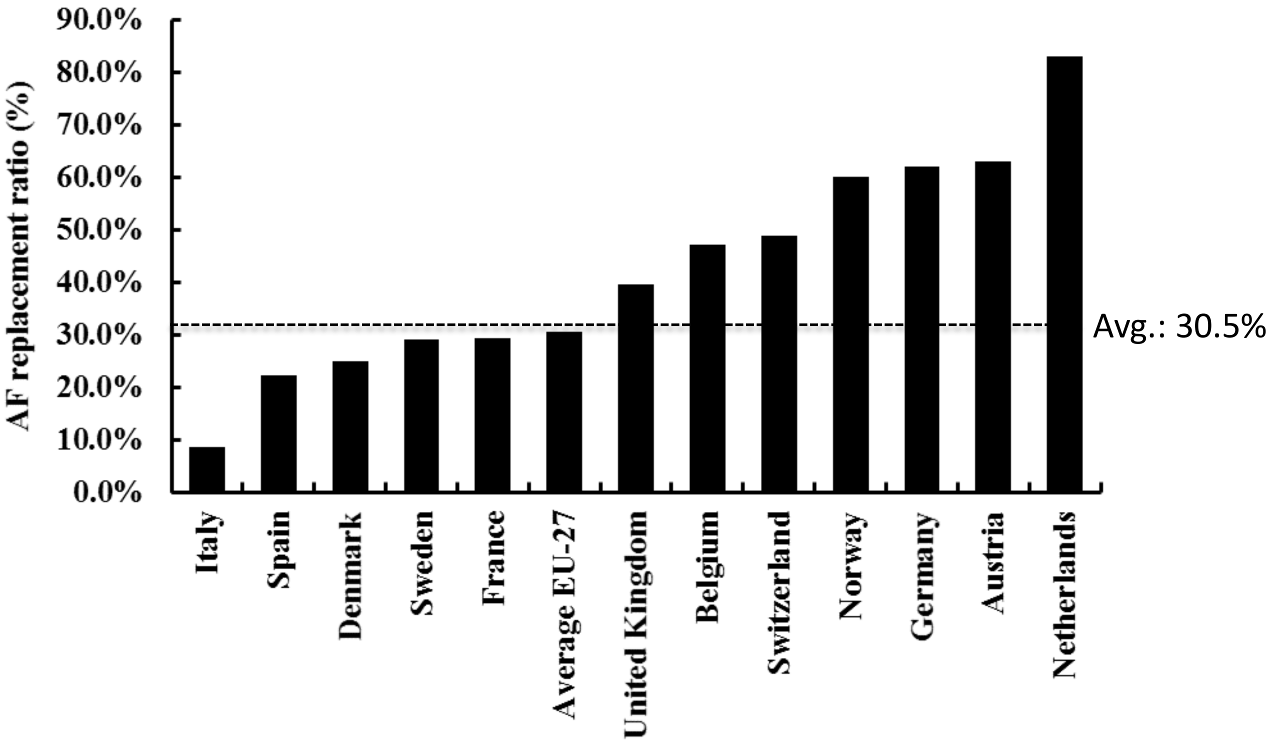
Clinker and cement production and energy consumption, US



Energy use by different fuels in U.S. cement industry



Replacement ratios of fossil fuels with AF in European countries



Fuels used in cement industry

Fuel Type	Proximate Analysis (wt. %, as received)				Ultimate Analysis (wt. %, dry basis)						Alkali		LHV	HHV
	Moisture	Volatile Matter	Fixed Carbon	Ash	C	H	N	S	Cl	O	Na	K	MJ/kg MMBTU/ton	MJ/kg MMBTU/ton
Wood[a] (12), (18)	5.6-6.3	69.5-78.5	15-16.1	0.5- 8.8	46-51.3	5.7-5.8	0.07-3.8	0.01-0.05	≈0	35.4-36	≈0	≈0	**17.1*-22.5*** **14.7-19.4**	**18.6-23.9** **16.0-20.6**
RDF[b] (4) –(11), (14), (19), (20), (21), (31), (32)	3.7-20	71.9-76	3.9-13.2	10.2-13.8	41.7-50.2	4.4-7.8	0.75-1.65	0.1-0.76	0.7-1.13	28.5-36.3	0-0.93	0-0.37	**15.9*-17*** **13.7-14.6**	**17.5-18.4** **15.1-15.9**
Tires (15), (16), (23), (28)	0.7-4	63.8-68.7	24-31.1	2.2-8.2	76.7-89.4	7-7.8	0.2-0.5	0.8-2.2	≈0-0.1	0.4-4.5	0-0.9	0-1.1	**32-35.6** **28.4-30.7**	**34.6*-37.3** **29.8-32.1**
TDF[c] (19), (20)	0.9-1.9	63.4-64	30.4-30.7	3.3-4.4	83.8-86.7	6.9	0.3-0.6	1.9-2	≈0	0.9-2.3	n/a	n/a	**31.8-36.8** **27.4-311.7**	**33.5*-38.4*** **28.9-33.1**
Pecan Shells (28)	14.6	n/a	n/a	2.32	46.84	5.41	0.44	n/a	n/a	n/a	n/a	n/a	**18.2*** **15.7**	**19.8** **17.1**
MBM[d] (22), (23) (29)	1.4-8.1	64.5-79.7	7.2-9.7	10.4-28.3	42.1-55.7	5.8-8	7.2-8.9	0.05-0.4	0.2	15.3-38.4	1.5	0.3	**19.6-28.8*** **16.9-24.8**	**21*-30.6** **18.1-26.4**
PE[e] (20), (24)	≈0-0.17	99.8-100	≈0	≈0-0.06	86	14	≈0	≈0	≈0	≈0	n/a	n/a	**44.6** **38.4**	**44.9*** **38.7**
PVC[f] (13), (24), (30)	≈0-0.2	85.9-91	6.3-9	1-7.6	35.9-38	4.4-5	0-0.11	≈0	57	≈0	n/a	n/a	**17.1*** **14.7**	**18.1** **15.6**
Sewage Sludge (19), (23)	5.2-5.6	40.5-85	5-10.1	17.9-29.5	36.4-40.5	4.7-7	0.84-5.0	0.1-0.6	≈0-1	22	≈0	≈0	**9.3-15.8** **8.0-13.6**	**10.4*-17.5** **9.0 – 15.1**
Pet. Coke (21), (23)	0.8-1.5	7.6-10	88.6-89.6	0.5-1	89.5-92.7	2.4-3.7	1.2-1.7	1.5-4	≈0	1.1-1.2	≈0	≈0	**33.5-35.4*** **28.9-30.5**	**34.4*-36.2** **29.6-31.2**
Coal[g] (19, 25-27)	1.1-3.3	23-35.3	44.2-66.8	6.4-15.5	65.3-80.9	3.7-5.1	1.2-1.41	0.6-5.5	≈0-0.33	5.9-12.5	0-0.03	0-0.19	**25.4-31.8*** **21.9-27.4**	**26.3*-32.9** **22.7 – 28.3**

- The waste obtained from C&D activities should be efficiently dealt with and handled such that its quality is not impaired; therefore, its utilization as aggregates or cementitious resource should remain feasible.
- Selective demolition should be practiced for hazardous materials, such as tubes, asbestos, etc. The handling should be efficient so that mixing does not occur, which can cause contamination of recyclable materials.
- On-site sorting should be practiced such that mixing of waste may be avoided. The waste should be classified on basis of nature and possible economic benefits.
- Efficient quality control systems should be enforced with proper check and balance on method of material recovery, waste acceptance criterion, material properties, and pros and cons of material utilization in construction activities.
- As the concept of CE in the construction sector is not mature, the local and central governments should come forward and play their part in enlightening the organizations regarding the ecological, economic, and social benefits of the CE approach.

Actions in the different stages of construction

- Adoption of 3R principles of reduce, reuse and recycle is imperative at each stage of the construction cycle as the reduce principle should be prioritized at both planning and designing stage and procurement stage. Meanwhile, all 3R principles should be utilized at the construction and demolition stage to ensure the waste generated at this stage will be properly managed.

- At the planning and designing stage, modern construction methods reduce the waste generation. Selecting an appropriate material also could help reducing the waste generation at this stage. Modular design can promote standardization of building components.

- At the procurement stage, it is important to create awareness among the construction actors on having a proper management of C&D wastes and at the same time provide sufficient training related to the management of C&D wastes. It is necessary to revise the current standard form of contracts to ensure a better management of C&D wastes gaining more attention from the construction actors.
- Regulations related to the management of C&D wastes should be enhanced by emphasizing the environmental impacts of poor waste management.

- During the stage of construction and demolition, site management is critical in controlling waste generation at this stage. Labour’s attitudes also need to be monitored. Besides that, access to recycling facilities should be increased.

- Planning and designing stage should include “Waste Management Plan” and “Construction Methods”.
- Procurement stage should consider “Awareness and Awards” and “Regulations Enhancement”.
- Construction and demolition stage should include “Effective Management”.

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Thank you very much for your attention!
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