Life Cycle Assessment and Clean Energy for Low-Carbon Concrete Pilots

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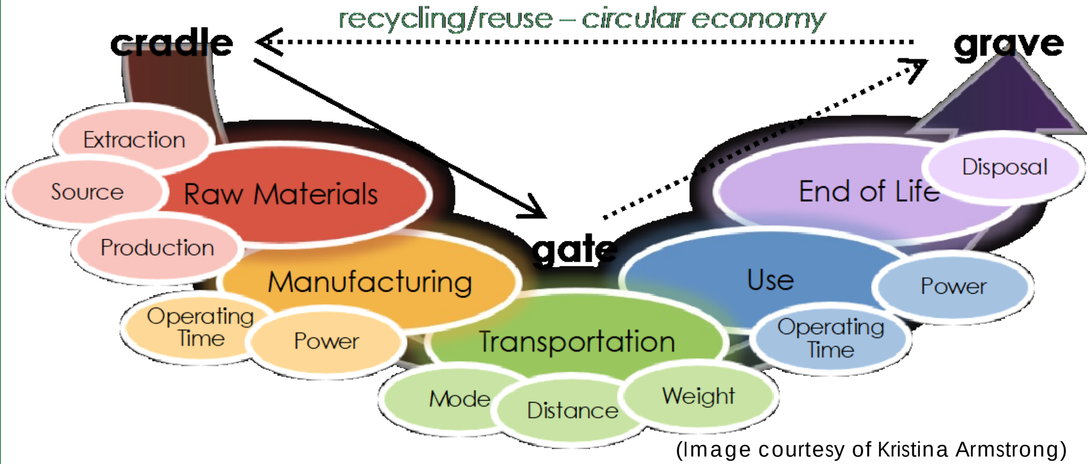
Life cycle assessment (LCA)

LCA assesses the **environmental impacts** associated with the life cycle of a product or process.



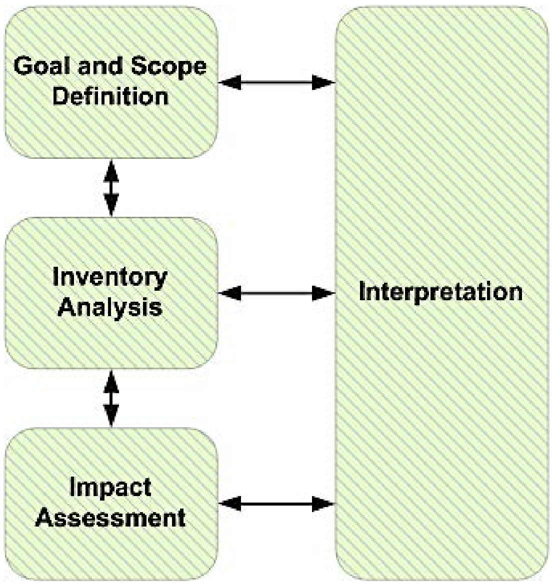
(Image courtesy of Kristina Armstrong)

Environmental impacts include a range of categories:

- Emissions (global warming potential, acidification, ozone depletion, ecotoxicity, etc.)
- Cumulative energy demand
- Resource (e.g., water) consumption
- Land use

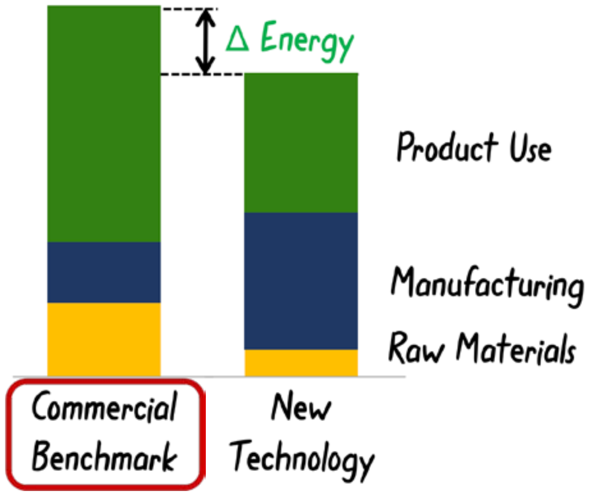
LCA is a **holistic** and **iterative** methodology.

Four phases of LCA



International standards for LCA: ISO 14040 & 14044

Benchmarking (attributional & consequential) LCA approach*



What's the state of the concrete market? Do we pick a universal or application-dependent baseline?

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* *"Introduction to LCA" tutorial video by DOE IEDO*

Low-carbon concrete pilots: role of clean energy

Raw materials, energy, and resources | **Clinker and cement manufacturing**

3 *Electrified cement production process*

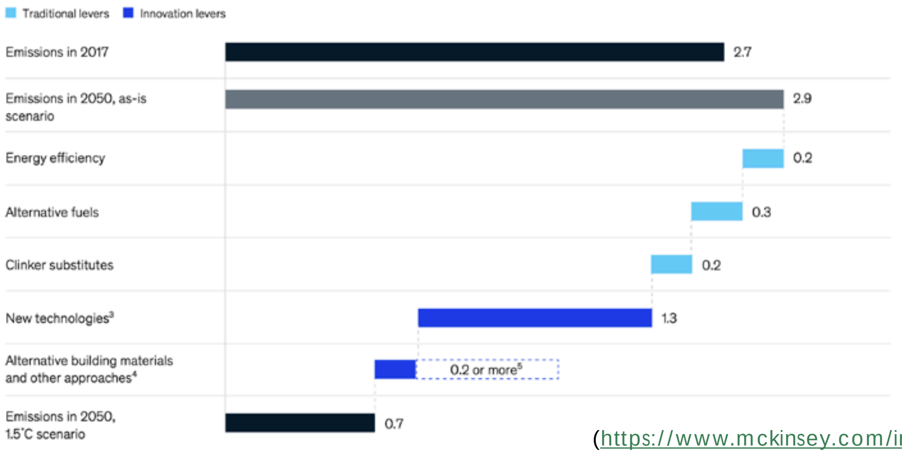
(e.g., with LC3, "electrification could eliminate 40–50% of the cement sector emissions"; see: https://www.aceee.org/blog-post/2023/06/electrification-key-decarbonizing-concrete-us-investments-should-open-path)

	Quarry	Crusher	Transport[1]	Raw mill	Kiln and preheater/ precalcinator[2]	Cooler[3]	Cement mill	Logistics[4]	Total
Energy, megajoule/ton	40	5	40	100	3,150	160	285	115	3,895
CO_2, kilogram/ton	3	1	7	17	479 Calcination process; 319 Fossil fuels	28	49	22	925

[1] Assumed with 1kWh/t/100m.
[2] Assumed global average, data from the Global Cement and Concrete Association, Getting the Numbers Right 2017.
[3] Assumed reciprocating grate cooler with 5kWh/t clinker.
[4] Assumed lorry transportation for average 200km.

The cement industry could cut three-quarters of its CO_2 emissions by 2050.[1]

Potential CO_2 emissions and reductions,[2] $GtCO_2$ anually



[1] Figures are global estimates for emissions potential, taking all potential levers into consideration.
[2] Effect might be smaller or larger depending on speed of shift.
[3] For example, carbon capture, use, and storage; carbon-cured concrete; 3-D printing.
[4] For example, cross-laminated timber, lean design, prefabricated/modular construction, building information modeling.
[5] Alternative building materials and other approaches will likely play an important role in decarbonizing the cement industry, but a great deal of uncertainty remains as to how much they will reduce emissions.

(https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement)

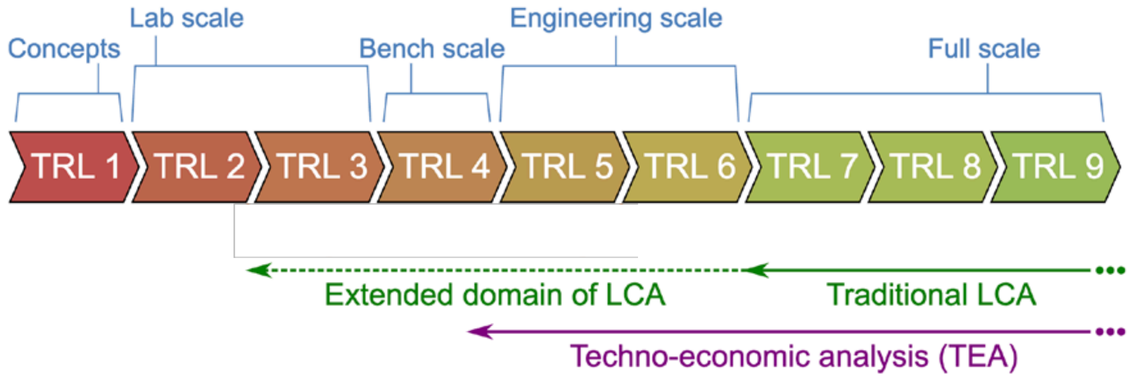
PRODUCTION: AT THE CEMENT PLANT	
Replace raw materials with decarbonated materials (1)	Using decarbonated materials eliminates CO_2 emissions from processing traditional raw materials, like limestone.
Use alternative fuels	Replacing traditional fossil fuels with biomass and waste-derived fuels lowers greenhouse gas (GHG) emissions and keeps materials out of landfills.
Continue efficiency improvements	Increasing energy efficiency reduces the amount of CO_2 emitted for each ton of product.
Implement carbon capture, utilization, and storage (CCUS) technology	CCUS directly avoids a significant portion of cement manufacturing emissions.
Promote new cement mixes	Creating new cements using existing and even alternative materials reduces emissions from mining for new materials, while optimizing the amount of clinker used ensures emissions correspond to necessary production.
Increase use of portland-limestone cement (PLC)	As an existing lower-carbon blend, universal acceptance of PLC will reduce clinker consumption and decrease emissions.
CONSTRUCTION: DESIGNING AND BUILDING	
Optimize concrete mixes (2)	Considering the specific needs of the construction project and using only the materials necessary, avoiding excess emissions.
Use renewable fuels	Switching to solar, wind and other renewable sources of energy directly reduces emissions from other energy sources.
Increase the use of recycled materials	Diverting these materials from landfills.
Avoid overdesign and leverage construction technologies	Designing for the specific needs of the construction project reduces unnecessary overproduction and emissions; incorporating just-in-time deliveries.
Educate design and construction community	Improve design and specifications to be more performance oriented which will permit innovation in cement and concrete manufacturing. Encourage the use of advanced technologies to improve structural performance, energy efficiency, resiliency, and carbon sequestration.
EVERYDAY: CONCRETE INFRASTRUCTURE IN USE	
Incentivize energy efficient buildings	Increasing buildings' energy efficiency can cut energy use and resulting emissions from heating and cooling.
Reduce vehicle emissions by improving fuel efficiency	Because of its rigidity, concrete pavements enhance the fuel efficiency of vehicles driving over them, reducing vehicle emissions.
Decreased maintenance	Due to their durability, concrete structures (buildings, pavements, bridges, dams, etc.) last longer and require less frequent maintenance.
Recycling	Concrete in place can be 100% recycled, limiting the use of raw materials and production emissions.
Carbonation	Every exposed concrete surface absorbs CO_2 and over the course of its service life, a building can reabsorb 10% of cement and concrete production emissions.

(https://www.cement.org/sustainability/roadmap-to-carbon-neutrality)

Low-carbon concrete pilots: LCA and beyond

- A comprehensive LCA study helps identify hotspots, alternatives, and potential pathways to lower the final product's impacts.

- Continuously updated LCA better informs the product's scale-up and commercialization.
  - throughout all RD&D stages; TRL-ARL-CRL
  - lab → pilot → full commercial scale



(https://e3sa.sites.clemson.edu/Projects/LCA-TRL.html)

- **LCA of early-stage/emerging vs. established/mature technologies**
  - challenges: comparability, scaling, data, uncertainty
  - solutions: Moni et al. (Table 2), van der Giesen et al., Blanco et al., etc. – no general standards or guidelines!
    - Uncertainty analysis (quantification, propagation) using Bayesian inference and Monte Carlo simulations; global sensitivity analysis

- Beyond LCA: a broader, more holistic evaluation of emerging technologies
  - Cost? Market(s) and time-to-market? Resource? Societal risks?
  - How to quantitatively balance/optimize different impacts and risk factors? Where is the trade-off point?