MATERIAL IMPROVEMENTS

BUILDING A BETTER WORLD WITH LOWER-CARBON MATERIALS

SYSTEMIQ

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Briefing note – August 2024

MAIN INSIGHTS

This paper presents the latest thinking around embodied emissions and construction material decarbonisation, one of the three main levers to bring the built environment to net-zero alongside reducing operational energy demand and decarbonising the energy supply.

Main insights from this paper

1. Embodied emissions in the built environment – emissions arising from the construction and renovation of buildings and infrastructure – have a **major impact on climate change.** They represent 13% of energy-related greenhouse gas (GHG) emissions, but receive comparatively little attention from policy makers and the public.

2. Global **demand for construction materials will remain strong** in the coming decades, due to continued population growth, the need to adequately house a rapidly expanding middle class, especially in Asia, and the infrastructure demands of the energy transition. Given its impact on climate, nature and human health, the sector needs to change the way it works to meet this continued demand with a more regenerative way of working.

3. **Concrete and steel are the focus of this paper**. They are the most important building materials today in terms of volumes and GHG emissions (60%) and will likely remain so. Among the strategies to reduce GHG impact, **decarbonising the production process** of these materials is projected to have the most significant long-term effect. This can be accomplished by introducing new technologies and by capturing, using and storing any remaining carbon emissions.

4. However, there is no realistic scenario where large amounts of low-carbon concrete and primary steel will be available globally before 2030. A **step-up is required today** to make sure there will be enough affordable supply post-2030, by prioritising availability at scale and effective cost parity. Leverage points are long-term demand signals and transparency on carbon performance (market players in the lead), updated building and zoning rules, mandated use of low-carbon building materials, carbon pricing and subsidies (governments in the lead).

5. As developers and asset owners cannot rely on the large-scale availability of 'green' concrete and steel to meet their 2030 targets, they are left with two other decarbonisation strategies – **material efficiency** and **substitution with lower-carbon alternatives** such as wood – as the main levers to lower embodied emissions this decade. Both are substantial and largely available today. Developers, investors and policy makers must act on them without delay.

    a. Material efficiency, which includes more **material-efficient designs and applications, re-use and recycling**, has the potential to reduce demand for primary materials substantially in the short run. Other material efficiency levers, such as space-efficient urban planning and some regulatory changes require more time to implement

   b. Substitution with **sustainable timber** offers lifetime carbon benefits and efficiencies in application. However, it is less straightforward as a way to lower embodied emissions than often assumed. Supply from sustainably forestry is limited globally and opinions diverge on how to account for timber's climate impact.

6. Despite many promising initiatives, embodied emissions are not coming down fast enough to meet the sector's own ambition of net-zero by 2050. **Five barriers** specific to the built environment are holding back progress: a) low awareness and weak demand signals; b) lack of widely agreed net-zero metrics; c) (perceived) challenging economics; d) supply chain fragmentation; and e) technology gaps.

7. All players in the built environment supply chain need to take action individually and collectively, including materials manufacturers, developers, investors and policy makers.

   a. Cement and steel companies need to accelerate their efforts to **make lower-carbon materials available on a large scale** and markets where most growth is projected to take place (today 80% of green cement initiatives are concentrated in Europe, a continent with ~4% of global demand).

   b. Investors, and developers (including governments commissioning buildings and infrastructure) need to send clear long-term **demand signals** for low-carbon materials, to enable the producers to invest. Buyers' clubs and public procurement initiatives are effective ways to achieve this.

   c. Developers need to double down on the levers available to them today: **material efficiency and substitution** (where proven effective).

   d. Policymakers need to provide an **enabling policy environment**, including updated building and zoning rules; mandated use of low-carbon building materials; carbon pricing and subsidies.

   e. The sector as a whole needs to come together to fill in **remaining knowledge gaps** (e.g. on timber); raise **awareness** and translate the above into **collective action.**

8. None of this is easy, but the scale of the built environment and its importance in people's daily lives mean that there is a **huge upside for society** in meeting the challenges described. In some senses, lowering embodied emissions is more straightforward than the net-zero pathways of other sectors. The leverage points are well known (4 and 7 above). This transition can take place largely 'in the background', as it does not require conscious action from millions of individual households, unlike e.g. home insulation, electric mobility and the dietary transition. The built environment sector is notoriously fragmented and difficult to mobilise. But great rewards await the planet, society and ultimately the businesses themselves if the sector brings down its embodied emissions. Those rewards alone should make this transition eminently possible.

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ABOUT THIS PAPER

This paper provides an overview of the latest thinking from the Systemiq on reducing embedded emissions in the built environment[i] to net zero. It covers the expected developments in the coming decades, decarbonisation strategies, barriers to overcome and required interventions. Cement, concrete, steel and major alternatives such as timber are the focus of this paper as they represent 60% of GHG emissions. The paper builds on earlier work by Systemiq, Mission Possible Partnership (MPP) and the Energy Transitions Commission (ETC), deeply diving into the dynamics at play. Other construction materials represent the other 40% of emissions, and while important, will not be covered in this paper in detail.

This paper concentrates on greenhouse gas impact, as this is the focus of the MPP and ETC work this paper uses as main sources. No less important, but outside the scope of this paper is the impact the built environment has on other aspects of nature and society. This includes biodiversity loss,[1] the impact that construction waste has on its surroundings (35% of EU waste is from demolition),[2] the human health impact of particulate emissions, dangerous working conditions (construction accounts for 1 in 5 work-related deaths in the European Union),[3] wage theft and lack of legal protections[4] etc.

This paper is intended for people looking to understand the big picture on construction materials decarbonisation and the main strategies to achieve that. We imagine that this paper is especially relevant for private developers and governments in both their developer and regulating role, as the manufacturers of materials already have a rich body of sectoral literature available to them. Its purpose is to inform and spark a debate.

ACKNOWLEDGEMENTS

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[i] This paper uses the terms 'reducing emissions from construction/building materials' and 'reducing embodied emissions' interchangeably. In scope are both buildings and infrastructure

I THE NEED TO REINVENT THE BUILDING MATERIALS INDUSTRY

Buildings, infrastructure, and the materials they are made of are foundational to life as we know it. The built environment industry, and its subsector the construction value chain, deserve credit for huge worldwide improvements in quality of housing, sanitation and infrastructure over the past 50 years. The sector's scale and production methods have led to untenable greenhouse gas impact that require nothing short of a reinvention of how the sector operates. With construction materials becoming critical in new ways in the coming decades, opportunities await forward-looking players willing to reinvent their way of doing business.

What lies ahead for the sector

Building materials: foundational to our way of life

Construction materials have been **foundational to our way of life** over the past 5,000-10,000 years. The neolithic revolution – one of the biggest steps in human development – is often described as the moment mankind began farming. It can also be seen as the point at which our ancestors started living in permanent settlements. From early times, quality of life has depended on the performance, availability and affordability of building materials.

Until the early to mid-20th century, **building materials were often local**. This explains why Paris is coloured with the warm cream grey of the limestone from the quarries below its surface; why the Dutch live in homes built in brick made from the clay of the delta they inhabit;[5] and why the traditional architecture of Sumatra and Java uses teak wood – a tree once abundant on these islands.

The 20th century saw a gradual shift away from these quintessential local materials towards reinforced concrete, supported by steel beams for tall buildings, even if brick, natural stones and wood remain in use to this day. **Concrete and steel** were high-performing, abundant and sufficiently low-cost to provide billions of people with new homes. This development went hand-in-hand with extraordinary **improvements in quality of life**: today, 6.2 billion people (78%) live in adequate housing, up from 50% in 1970.[6] A parallel expansion in roads, rails, pipelines, electricity cables and other forms of infrastructure took place. This too consumed increasing volumes of concrete and steel and delivered benefits to billions of lives: 67% of people now have access to clean sanitation[7] and 50% have access to public transport.[8]

Critical for the transitions of the 21st century

Four megatrends are expected to put substantial new demands on the built environment in the decades ahead.[9] As growth in the number of households outpaces population growth, building floor space is projected to increase by 50% by 2040,[10] fuelled in particular by **growth in the middle-class**, which is set to expand by 63% between 2016 and 2028. 88% of the expansion is projected to take place in Asia, including 38% in India and 35% in China.[11] The **transition to net-zero** will require USD 9.2

trillion worth of infrastructure per year between now and 2050, up from USD 3.5 trillion today.[12] **Climate adaptation** will require USD 3.3 trillion in financing between now and 2035 in developing countries alone, of which 25% is needed to build infrastructure resilience in energy and transport sectors.[13] Finally, **digital transformation**: global data centre construction capex alone could be close to USD 50 billion annually in 2030.[14]

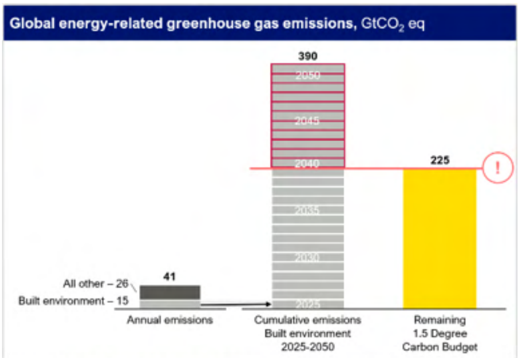
Implications for the operating model of the sector

To seize the opportunities that come with this increased demand, the (various) real estate and infrastructure supply chains **cannot continue on the path** they have been on for the past decades, for the climate impact has become too big to ignore.

Greenhouse gas emissions

At 40% of the global total, the built environment is the largest end-use sector in terms of energy-related **greenhouse gas** (GHG) emissions.[15] It is also the fastest-growing consumer of materials.[16] 88% of the growth is in emerging markets. Without action, emissions from the built environment alone would use up the world's entire remaining carbon budget by the late 2030s.[17] Decoupling emissions from growth is the only viable way to meet climate and societal goals.

Figure 1: **Built environment emissions compared to the world's carbon budget**



Note: Buildings account for 37% (=15 Gt CO2eq) of the total greenhouse gas emissions in 2021. Assuming no action is taken this accounts for a total of 390 Gt CO2eq (=15 Gt CO2eq * 26 years) up to 2050. The built environment alone will therefore have exceeded the remaining 1.5 degree carbon budget of 225 Gt CO2eq.
Source: IEA (2022), Global Energy Review: CO2 Emissions in 2021; Global Alliance for Sustainable Buildings and Construction (2022) 2022 Global Status Report for Buildings and Construction; MCC (2024), That's how fast the carbon clock is ticking

Leaders of the Urban Future (LOTUF), a group of real estate investors with USD ~0.5 trn of assets under management, convened by Systemiq, has identified three main courses of action to bring GHG emissions down in the built environment and has adopted these as its North Star. The third of these actions, 'build and renovate smarter', is the topic of this paper. For many infrastructure assets, building and renovating smarter is the main lever to reduce GHG emissions, as they typically have no or very low operational emissions.

Figure 2: **LOTUF North Star**

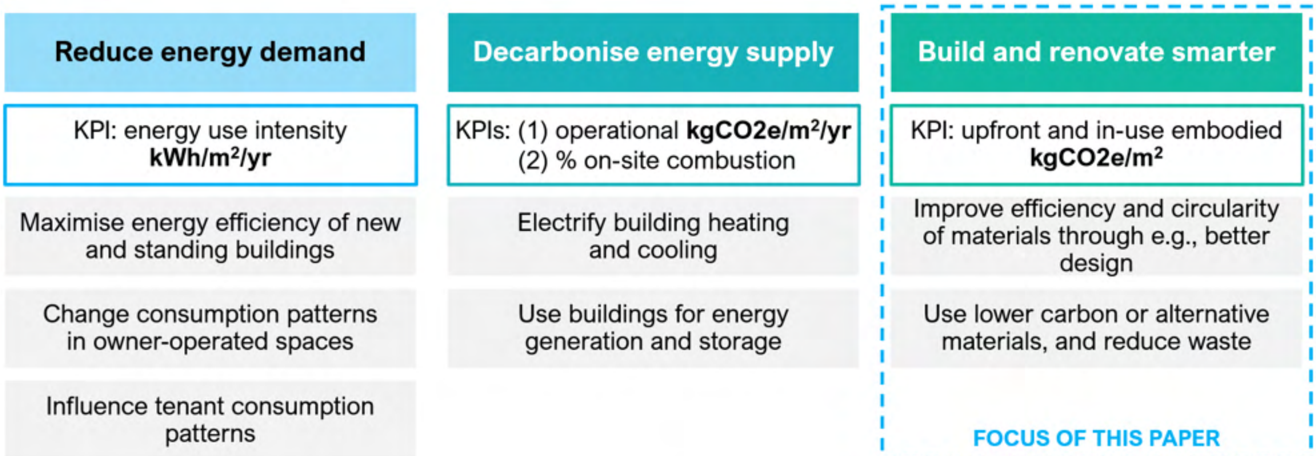
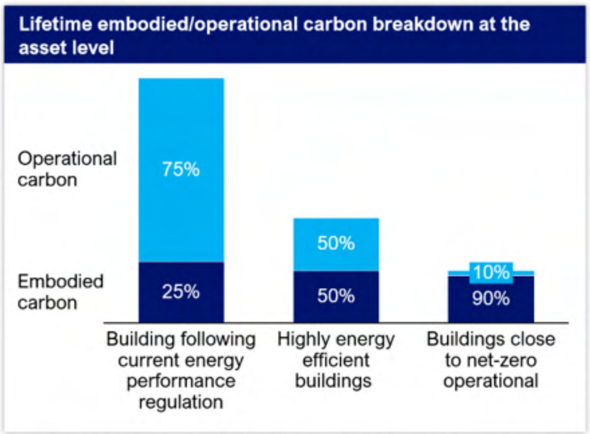


Figure 3: **Embodied carbon to overtake operational as buildings get more efficient**



Source: Leaders of the Urban Future based on M. Rock. 2020. Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation. Applied Energy. Volume 258, 114107

Embodied emissions, those arising from the manufacturing and transport of materials and construction, represent 13% of global GHG, compared to 26% for operational emissions.[18] (Figure 4) As the world decarbonises and improves the efficiency of electricity and heat, this balance will shift: about half of the carbon footprint of the buildings that will be built between now and 2050 is embodied.[19] This is largely due to the difference in timing and pathways between operational and embodied decarbonisation technologies; many countries are targeting to decarbonise power and heat by the middle of the 2030s – this is not yet the case for steel and cement.

Concrete and steel represent >60% of material emissions for buildings, and more for infrastructure.[20] These emissions are so high because of the **high temperatures** required to produce the main ingredients of cement and steel: ~1400°C for clinker and ~2000°C for iron. These temperatures are typically achieved by burning fossil coal, emitting vast quantities of CO_2. To make things worse, clinker and ironmaking also emit CO_2 as a byproduct of their chemical **processes** (Box 1). Combine this high carbon intensity with very large volumes – by mass, concrete is the most-used material after water; steel also makes the top-5[21] – and it is clear why these materials emit such great amounts of greenhouse gases.

Box 1: **Process emissions: the chemistry**

The chemical processes currently used to make iron and clinker directly emit CO_2. The iron used to make primary steel, is typically made by reacting iron ore and fossil coal to form iron and carbon dioxide, which is released into the atmosphere:

$$2Fe_2O_3 + 3C \longrightarrow 4Fe + 3CO_2$$

Steel used in construction is often a mix of primary and recycled (scrap) steel, with primary steel ratios higher in e.g. load-bearing beams. The lower-grade steel used to reinforce concrete is produced via a different method and contains more recycled steel, especially in mature markets.

Clinker making involves several chemical reactions acting on the components of limestone. One of them is calcium carbonate, decomposing to free lime and carbon dioxide:

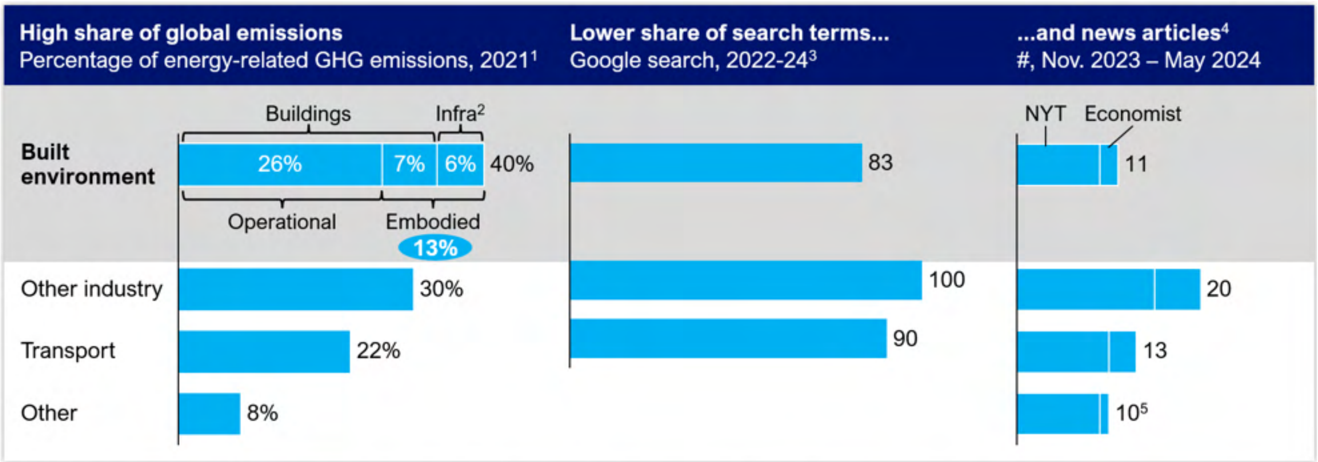
$$CaCO_3 \rightarrow CaO + CO_2$$

By grinding and mixing in other ingredients, clinker is made into cement; and cement into concrete.

Flying under the radar

Compared to its share in GHG emissions, the decarbonisation of the built environment receives **comparatively little attention** from citizens and the news media, as suggested by two sets of indicative statistics in Figure 4.

Figure 4: **Sectors' GHG share compared to some indicative measures of public and media attention about their climate impact**



1 ETC and Architecture 2030 based on IEA statistics
2 Includes other emissions related to the built environment; operational emissions from infrastructure such as for running trains or electricity networks are counted in other categories e.g. transport
3 Google Trends, based on global search between 1 January 2022 and 5 May 2024, score based on combinations of "sustainable"/"carbon"/"climate" and top-3 search terms related to the built environment ("buildings", "heating", "infrastructure"), other industry ("industry", "steel", "industrial") and transport ("transport", "cars", "travel"); index other industry = 100
4 New York Times articles tagged 'sustainable development' (150 in total; of which 94 are climate-related; 17 on food / non-energy-related emissions and 34 on general climate change) and Economist articles listed on www.economist.com/climate-change (39 in total; of which 10 were on adaptation; 2 on food / non-energy-related emissions and 16 on general climate change)
5 Mostly about consumer goods

Within the built environment, the **impact of embodied emissions is particularly overlooked**. A factor could be the 'false perception that embodied carbon is relatively insignificant compared to operational emissions over the lifecycle'.[22] That large objects appear small when they are contrasted with even larger objects is a known optical illusion:[23] the reason why New Guinea seems small next to Australia, despite being the world's largest island after Greenland.

It is not a sensible strategy for the sector to count on this illusion staying intact. Embodied emissions represent too big a share of greenhouse gas emissions to evade attention forever. Forward thinking players are starting to act; they are right. Capital investments and skill building take time, the sector cannot afford to wait.

II WHAT IT TAKES TO DECARBONISE BUILDING MATERIALS

180 businesses, governments and other organisations have agreed on 2050 as the year by which the total decarbonisation of buildings needs to be complete, under the auspices of the World Green Building Council.[24] Separately, 30 built environment players and suppliers have committed to using 50% low-emissions steel by 2030 as part of the SteelZero initiative by the Climate Group.[25] The Mission Possible Partnership (MPP) has quantified on a global level what it would take for the cement & concrete, steel and aluminium sectors to reach net-zero by 2050.[26] These sector transition strategies were developed with and endorsed by the leading corporates from each sector. They show that while complex, the transition to net-zero is possible from both a technical and economic perspective.

The Energy Transitions Commission (ETC) is working on an overall quantification for net-zero building materials. This chapter summarises the impact that three decarbonisation strategies can have for bringing cement & concrete and steel to net zero, based on the MPP reports: material efficiency, substitution with lower-carbon alternatives and lowering the emissions of producing the remaining cement and steel. As the leading substitute, timber will also be discussed, based on ETC work.[27]

Material efficiency

Efficient use of concrete and steel can avoid that a substantial share of these materials needs to be produced at all. There are three main material efficiency strategies: to avoid use, to reuse and to recycle. Together, MPP estimates they can reduce carbon emissions of concrete and cement by 22%[28] and demand for steel by 41% by 2050.[29]

Every tonne of material **use avoided**, is one that emits no carbon whatsoever. Estimates show that material-efficient design can reduce material use by 30% in Europe.[30] The upside is likely higher elsewhere, given relatively high material efficiencies in Europe compared to high-growth countries in e.g. the Global South.

- **Improving space use,** for example by building at medium instead of suburban densities, can save 45% of GHG emissions on a neighbourhood level, with the biggest lever being the need for less roads and pipes because people live closer to each other.[31]
- **Improving efficiency in design and construction** can reduce carbon emissions through leaner designs and by casting concrete in a factory instead of at the construction site. Because this pre-casting process is easier to control, it can save on materials use and lower the carbon-intensity of the materials used without compromising quality. The related practice of modular construction, where building elements are prefabricated off-site, can reduce costs by 20%.[32] Decisions about efficient use of material should always be based on lifecycle analyses that take the impact on both embodied and operational carbon into account, as there are many cases where the extra embodied carbon of using a bit more construction material is more than offset by lower operational carbon, e.g. due to better insulation.[33]
- **Extending the lifetime** of buildings was estimated to be the second-most effective strategy to avoid building material use in Europe, at 277 million tonnes of materials savings until 2050.[34] That this holds in Europe is notable, as this continent is known for its long building lifespans compared to e.g. Japan, where the effect of this lever is expected to be higher. Here too,

lifecycle analyses can reveal whether the carbon savings of lifetime extension indeed weigh up to the foregone reduced operational carbon that new buildings often bring.

Re-use of building materials, such as wooden and steel beams or even concrete elements, is an important lever, but the effect of avoided emissions only takes place at end of life, which can be decades in the future for new buildings. The buildings that are deconstructed today were typically not designed for re-use, leading to less than a percent of emissions reduction potential until 2060.[35]

When it comes to **recycling**, steel and concrete are very different. In both cases the GHG reduction of recycling compared to producing virgin materials is substantial: ~80-85% less emissions per tonne of steel.[36] Recycling scrap steel is very common: scrap steel covers ~60% of EU iron demand, with the percentage higher for steel used in construction. Increasing scrap usage is an important lever that can reduce demand for primary steel by 8.9% in 2050.[37] This requires scrap collection from e.g. construction sites to be improved. In contrast to steel, concrete recycling is still in its infancy. The first products are starting to come onto the market.[38]

Substitution with lower-carbon alternatives

The dominance of concrete and steel as construction materials is relatively recent. Going back to bricks and natural stone can be a viable alternative in regions where the resources are available, but for many applications they are unable to match the structural performance and cost of concrete and steel. Traditional **brick** manufacturing is relatively carbon-intensive, again due to high temperatures, though it does not have the process emissions of clinker and coal-based ironmaking. **Natural stone**, if quarried efficiently with low-carbon equipment, can be a low-carbon alternative in locations close to a quarry. Unfortunately, availability is limited to specific regions and natural quality variations can lead to high levels of waste.[39]

In contrast, **wood** has seen a revival of sorts in the past 20 years, in particular with the rise of several types of mass timber, including cross-laminated timber. It is largely uncontroversial that timber has lower overall GHG emissions than traditional concrete and steel in regions with ample sustainable forestry – but exactly how high is contested and traceability is poor. The harvesting equipment and method used, the (sustainable) forestry practices of the replanted tree, the period over which the timber is used and the end of life treatment all have significant impact on the net lifecycle GHG emissions from timber, and therefore the question whether it has higher or lower emissions than (decarbonised) concrete and steel.

Timber is supply-constrained: if timber were to replace concrete and steel on a large scale, it would require a vast expansion of timber production. It is clear that timber is a good substitute in many cases, but that full substitution is not feasible or even desirable. It is much less clear where the boundary lies between desirable and undesirable timber substitution. Complicating matters is the presence of strong views on either side of the debate and the fact that the subject is approached from very different fields of expertise (forestry, construction materials, carbon accounting) that don't speak each other's language. This is an active debate that requires swift resolution. Appendix B summarises the terms of the debate.

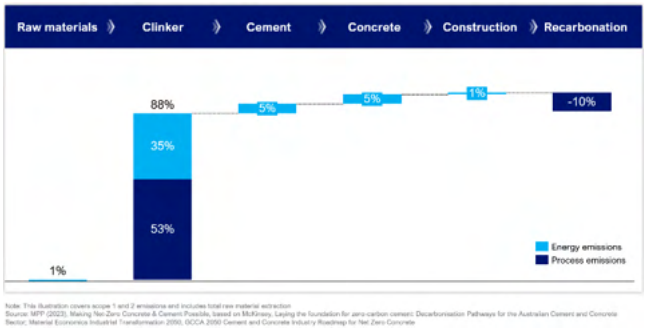
Lowering the emissions of producing the remaining concrete and steel

Material efficiency and substitution strategies can make a significant dent in embodied emissions. However, given the demands on the sector in the coming decades, it is inevitable that concrete and steel use will continue to be used extensively. MPP estimates that the largest lever in terms of GHG impact is to lower emissions of the production process of the remaining concrete and steel.

For **concrete**, 88% of the CO_2 emissions arise in clinker making. There are two main levers to reduce clinker emissions: lowering the amount of clinker that goes into the final product; and using less and cleaner energy. MPP estimates that 25% of the total GHG reduction of concrete can come from reducing clinker usage in the final product.[40] This can be done in three ways:

- By using **less clinker per unit of cement** by using supplementary cementitious materials (SCMs) that emit less carbon
- By using **less cement per unit of concrete** by increasing the effective strength of cement and industrialising the concrete production process
- By bringing **alternative low or zero carbon chemistries** to market such as alternative binders[ii] and decarbonated raw materials

Figure 5: **CO_2 emissions per step in the conventional concrete production and application process**



Lowering high-carbon energy use can save 16% of GHG.[41] This entails switching from coal to e.g. fuels made from waste,[iii] hydrogen or green electricity, or by improving energy efficiency.

MPP expects that cement will continue to be produced in a way that emits GHG inherent in the chemistry of the production process. The **steel** sector, however, has initiated a switch to an alternative way of making virgin steel, using hydrogen to directly reduce iron without the use of coal. (See Box 1 in Section I to compare with conventional steelmaking). It is possible to produce hydrogen without carbon emissions by splitting water (H_2O) molecules into hydrogen and oxygen through electrolysis using renewable electricity. Steel produced using **zero-carbon hydrogen** could account for 35%–45% of primary steel production in 2050.[42] The same production process can be fuelled by natural gas, which is expected to play the role of transition fuel until the transition to hydrogen is complete. Combined with steel production using natural gas and biomass, CO_2 emissions from steelmaking can be reduced by 47% in 2050.[43] This has the potential to substantially reduce emissions from applications that use primary steel – often ones that require higher grade steel such as structural steel.

After applying all previous levers, the production of cement and steel is projected to emit substantially less carbon than today. Yet around 39% of cement and concrete and 27% of steel emissions are projected to remain.[44] To bring emissions to net-zero, the remaining carbon needs to be captured and used or stored (**CCU/S**) before it reaches the atmosphere. Different links in the capture, transport and storage chain remain at immature technology readiness levels. The MPP sector transition strategy for cement and concrete contains a section with the state of play of CCU/S as of 2023.[45]

[ii] E.g. replacing calcium carbonates with calcium silicates as a raw material

[iii] Such as oil made from household waste, charcoal, biomethane, waste-derived syngas, etc.

Who needs to make this change

Of the parties involved in the construction of a building or a work of civil engineering, some have more direct influence on embodied emissions than others. First among these are the **cement and steel companies** involved in manufacturing basic construction materials, as this is where most GHG emissions arise. They can only lower GHG intensity with sufficient market demand. At least as important, are **investors and developers**, as they have the most direct influence over what gets built and with which materials, which should put them in the lead for substitution and most material efficiency strategies. For real estate investors, those focusing on new developments over retrofits are especially important. In infrastructure value chains, the role of investor can be played by both governments and for-profit entities. Developers are understood to include both private-sector parties (e.g. developing a residential neighbourhood) and public bodies (e.g. tendering an offshore wind park). They are often the ones who can leverage innovation and tech for example in the space of modular construction and software to improve efficient material use during design and construction. **Policy makers and regulators** also play a pivotal role, especially those who have the power to set spatial plans and building codes – influencing space use – and incentivise low-carbon materials in both buildings and infrastructure. One advantage of this transition is that can take place largely 'in the background'; it does not require conscious action from hundreds of millions of individual households, unlike home insulation, electric mobility and the dietary transition. That said, the global built environment sector is notoriously fragmented and difficult to mobilise.

A more regenerative built environment

Interventions by investors, supply chain players and regulators are ultimately what matters, but there is a risk they stay in the paradigm of 'doing less harm' as opposed to switching to a model that can meet the demands of the coming decades with much fewer downsides for climate, nature and society. There are signs that an alternative, more **regenerative** business model (Box 2) is emerging for the built environment. Governments are changing their planning requirements, regulations and procurement. The built environment industry is innovating along the length of its value chain. Financial institutions are developing new financing models, including innovations in redistributing value and new metrics that aim to capture longer-term, broader sources of value. And users are getting their voice heard through more regenerative corporate commitments and citizen empowerment.[46]

The shift towards a more regenerative model resonates with the way executives talk about the leading **industry trends** of 2024, as reported by PriceWaterhouseCoopers and the Urban Land Institute.[47] They indicate that relations across the real estate sector are being redefined to increase flexibility and ESG performance; and that there is an increased focus on embedding buildings in their local ecosystems. While these practices may not be fully regenerative yet, they indicate that a more holistic, flexible and cooperative way of working creates value and is increasingly practiced.

Box 2: **Four characteristics of a regenerative approach to the built environment**

EVOLVING OVER TIME

Regenerative approaches do not aim to deliver outcomes by strict time deadlines. Rather they are designed to include feedback loops giving them the flexibility to adapt continuously to their ever-changing economic, social and environmental circumstances. Home.Earth's model in Copenhagen is designed to give residents a stake in their housing complexes by distributing 15% of profits to tenants, giving them a real stake in the property and potentially leading to lower churn.

PEOPLE CENTRIC

The ultimate purpose of built structures is to meet the needs of their users for shelter, security, comfort, creativity, connectivity, or enterprise. Putting the needs and wishes of users at the centre of the planning and design process can create structures that uplift and improve human beings' daily experiences. The Phoenix neighbourhood in Sussex, UK has won planning permission for the largest timber constructed residential scheme in the country primarily on the basis of its extensive and elaborate community engagement and consultation efforts.

ROOTED IN PLACE

Urban environments that regenerate lives and livelihoods deepen the sense of connection between people and the places in which they live, work and play. They are informed by an intimate understanding of the local history, ecology, and culture so they reflect the unique essence of their place. In the Nairobi informal settlement of Kibera, community-led initiatives rooted in the area have improved 125,000 lives at much lower cost than the conventional "raze and replace" approach to developing informal settlements.

INTEGRATED WITH NATURE

Restoring the connections between people and their natural surroundings regenerates their health and wellbeing. Regenerative places originate from living systems thinking, which respects planetary boundaries and favours nature-based solutions. "Sponge cities" in Hainan, China, draw on the natural properties of their coastal environment to integrate flood accommodation zones, wetlands, parks and coastal habitats in a single "sponge system". This nature-based solution boosts local climate resilience and avoids the need for hard coastal defences.

Source: Systemiq & Holcim, *Unleashing a regenerative revolution for the built environment*, 2024

III THE BARRIERS TO OVERCOME

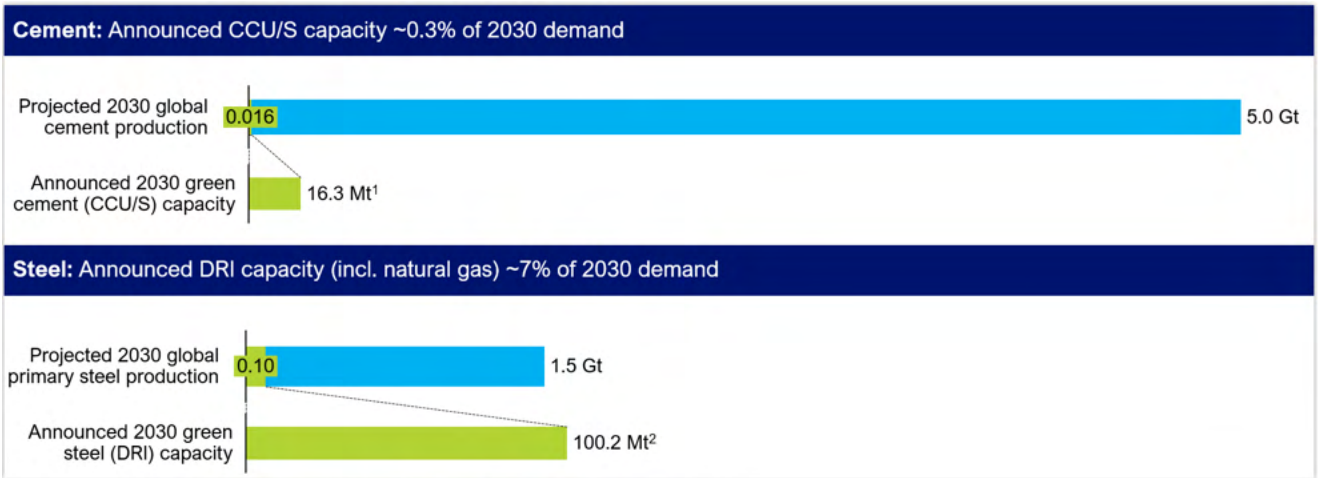
The decarbonisation gap

There is a large gap between where the sector stands today and where it needs to be to be on track for its 'total decarbonisation' goal by 2050. Initiatives exist across each of the levers described in Section II, but the collective progress is underwhelming, in particular in the markets in the Global South where most of the growth in floorspace and infrastructure is projected to take place.

This gap can best be illustrated by looking at the largest lever to bring embodied emissions to zero: the decarbonisation of the manufacturing process of cement and steel, for which the leading technologies are CCU/S for green cement and hydrogen-enabled DRI for green steel. Both have seen a flurry of investment announcements in recent years, but no examples exist today of plants using these technologies that work at full commercial scale.

Even if all announced projects reach commercial scale by 2030, they would represent a very small percentage of projected 2030 primary demand: about a third of a percent for cement and ~7% for steel. (As mentioned in Section II, much of the steel used in construction can incorporate high percentages of recycled steel, which this statistic does not account for.) It is notable that these announcements are heavily skewed towards Europe: about 80% for cement, whereas Europe represents only ~4% of global 2022 demand.[48]

Figure 6: **2030 demand compared to announced green capacity**



1 Cement carbon capture and CCUS announced by industry for 2030; Leadit Green Cement Tech Tracker as of November 2023
2 Additional direct reduced iron capacity announced for 2030; Mission Possible Partnership

Five barriers

Five interlinked barriers help explain why the sector is still far from a path to net-zero GHG emissions: low awareness and weak demand signals, a lack of commonly agreed metrics, (perceived) challenging economics, supply chain fragmentation and technology gaps. Of these, boosting demand is the core leverage point. This can be done by increasing awareness and transparency and by (artificially) improving the economics through government interventions, including carbon pricing and subsidies and through better supply chain coordination. Stronger demand will then in turn improve performance on these same points and increase pressure to close the remaining technology gaps.

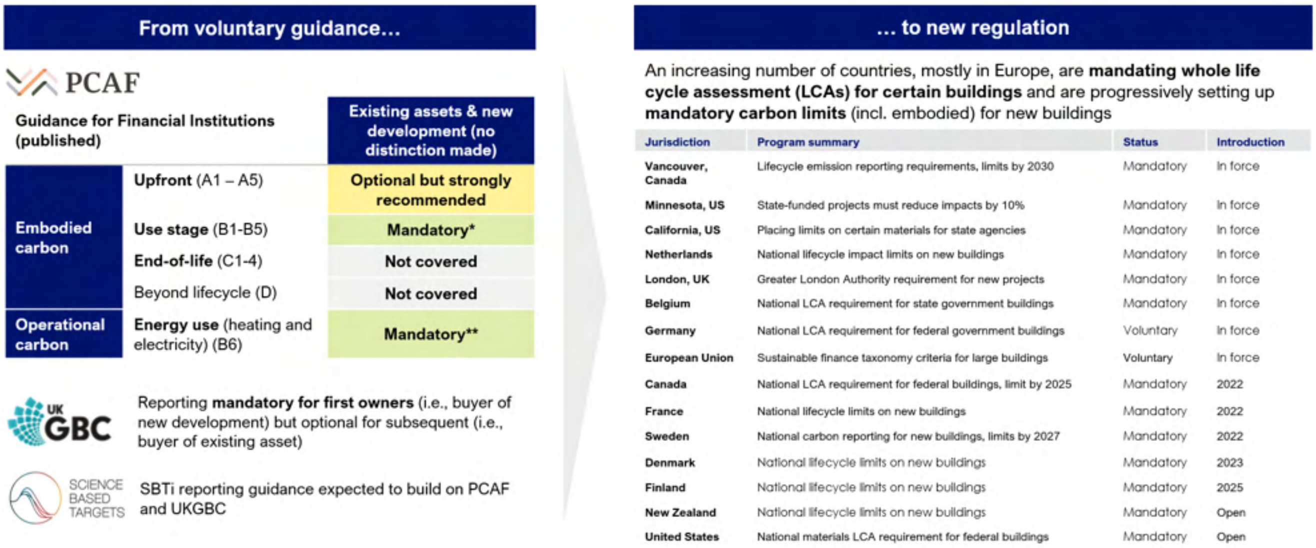
A. Low awareness and weak demand signals

Emissions in the built environment, particularly embodied emissions, receive less public attention than their share of total emissions would merit. This lack of awareness is paired with a lack of know-how of material efficiency and substitution strategies and a low felt urgency in the value chain – much lower than, for example, the pressure consumer goods companies face over plastic pollution, or electricity producers over coal. Low awareness likely results in limited support for policy measures or subsidies aimed at lowering embodied emissions; and in end users less willing to pay a green premium. In fact, whether a building has high or low embodied emissions often has no effect on its price in the sales or rental market. This makes embodied emissions different from operational emissions where investments in low carbon are starting to result in somewhat higher real estate prices.

B. Lack of widely agreed net-zero definitions and transparency

Closely linked to weak demand signals is the fact that the sector lacks transparency on carbon and energy performance. This means that market signals such as price and demand are not coming through. Built environment players and external valuers lack the evidence to reflect carbon in their models. Although numerous frameworks and certification schemes exist, such as LEED and BREEAM, they all have significant gaps.[iv] The LOTUF project has developed its north star (Figure 2 in Section I) into an underpinning of net-zero definitions and standards.

Figure 7: **Guidance and regulation are picking up pace on disclosure of embodied carbon**



Jurisdiction	Program summary	Status	Introduction
Vancouver, Canada	Lifecycle emission reporting requirements, limits by 2030	Mandatory	In force
Minnesota, US	State-funded projects must reduce impacts by 10%	Mandatory	In force
California, US	Placing limits on certain materials for state agencies	Mandatory	In force
Netherlands	National lifecycle impact limits on new buildings	Mandatory	In force
London, UK	Greater London Authority requirement for new projects	Mandatory	In force
Belgium	National LCA requirement for state government buildings	Mandatory	In force
Germany	National LCA requirement for federal government buildings	Voluntary	In force
European Union	Sustainable finance taxonomy criteria for large buildings	Voluntary	In force
Canada	National LCA requirement for federal buildings, limit by 2025	Mandatory	2022
France	National lifecycle limits on new buildings	Mandatory	2022
Sweden	National carbon reporting for new buildings, limits by 2027	Mandatory	2022
Denmark	National lifecycle limits on new buildings	Mandatory	2023
Finland	National lifecycle limits on new buildings	Mandatory	2025
New Zealand	National lifecycle limits on new buildings	Mandatory	Open
United States	National materials LCA requirement for federal buildings	Mandatory	Open

Source: Leaders of the Urban Future

C. (Perceived) challenging economics

A major obstacle to adopting lower-carbon solutions is their low economic viability: low or no willingness to pay a green premium and higher costs than business as usual. Figures 8 and 9 illustrate that low-carbon production methods are generally more expensive when compared tonne-for-tonne with traditional cement and steel. This is always the case when they involve CCU/S. The solutions that do come out cheaper – e.g. using SCMs to lower the clinker factor in cement and using more scrap

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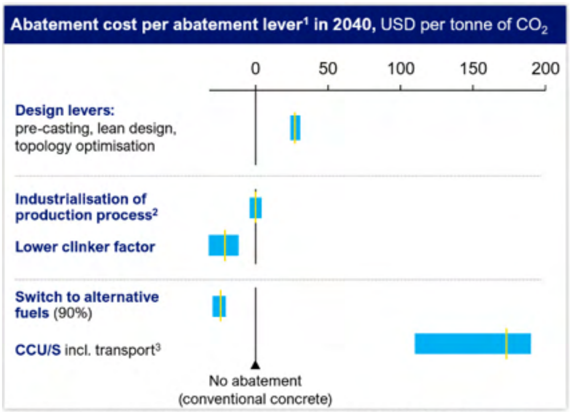
[iv] An overview of various certification schemes is contained in Appendix A3 of Leaders of the Urban Future (2024), *Seeing is Believing: Unlocking the Low-Carbon Real Estate Market* in partnership with Systemiq

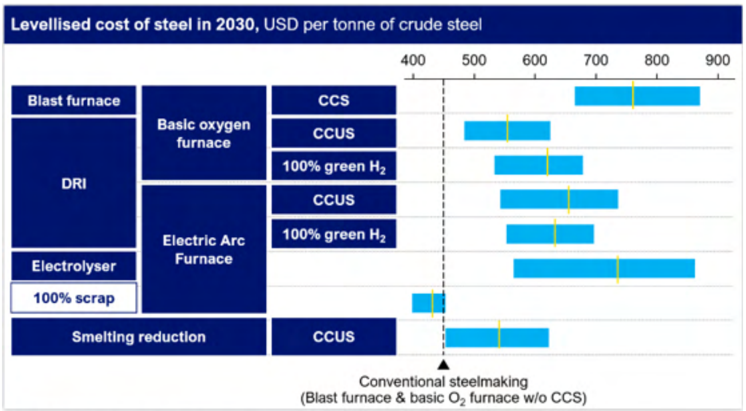
steel in electric arc furnaces – are unable to bring the sector fully to net-zero, but they can make a difference for embodied emissions.

Figure 8: **Abatement cost comparison of concrete decarbonisation levers**



1 Figures depend on regional circumstances, in particular the average abatement costs are higher if some of the measures have already been successfully implied
2 Industrialization investments in ready mix plant to large extent offset by reduction in labour costs
3 Average Levelized Cost of Clinker making for post combustion and oxyfuel capture technology
Sources: MPP (2023), Making Net-Zero Cement and Concrete Possible; GCCA (2021) Roadmap and ECRA experts

Figure 9: **Product cost comparison of different green steel production methods**



Note: MPP Steel STS Carbon Cost Scenario; assumes a plant with a capacity of 2.5 Mt/y and a capacity utilization factor of 80%
Source: MPP (2022), Making Net-zero Steel Possible

The unfavourable economics of 'low-carbon' vs. 'conventional' building materials are the main economic barrier holding back progress as long as there is no mandate for companies to follow a net-zero aligned decarbonisation pathway. However, tonne-by-tonne cost comparisons are not the only way to understand the economics of decarbonisation. From a societal perspective, the main concern is not whether green steel is cheaper than high-carbon steel, but rather how to achieve net-zero emissions quickly in a fair and cost-effective manner. This requires comparing the costs of decarbonising cement and steel with alternative pathways to net-zero and the knock-on effects that solutions in one sector can have elsewhere in the economy. In *The Breakthrough Effect*, Systemiq and its partners use this logic to identify technologies that can provide large-scale decarbonisation at comparatively low cost to society.[49] So far, there are no studies known to the authors that put the costs of building material decarbonisation in the context of other decarbonisation pathways.

D. Supply chain fragmentation

The supply of low-carbon building materials is held back by a lack of confirmed long-term demand, and demand is, to a lesser extent, held back by a lack of supply. Unlike in other sectors, the supply chain coordination that is needed to overcome this, has yet not led to actual demand pooling, even though several initiatives provide hopeful signs (Box 3 in the Section IV). The structure of the industry plays an important role in how difficult it is to pool demand; the built environment sector is more local and fragmented than, say automotive, making it harder to coordinate a large enough group to reach necessary demand volumes for steel. It is less clear if this logic holds for cement. Cement suffers from the same built environment supply chain fragmentation, but this is partially offset by the small range in which it operates of about 150-200 km. This may make it easier to coordinate to achieve a critical demand volume locally.

E. Technology gaps

Many solutions are ready to be implemented, but some are not. This is especially the case for interventions in the production process, with CCU/S being the most prominent solution that still needs several years of development to be able to capture high rates of CO_2 from mixed sources, such as the exhaust of a clinker or steel plant at commercial scale and reasonable cost (current TRL[v]: 6-7).[50] Hydrogen use in cement production and electrified kilns are still in the small prototype stage (TRL 4)[51] For steel, the electrolysis – EAF route is projected to have a TRL of 9 in 2035.[52]

The MPP reports give a detailed overview of the state of play.[53]

[v] The level of maturity a certain technology has reached from initial idea to large-scale, stable commercial operation. The International Energy Agency reference scale is used, with 11 TRL increments grouped into six categories: concept (TRL 1–3), small prototype (TRL 4), large prototype (TRL 5–6), demonstration (TRL 7–8), early adoption (TRL 9–10), and mature (TRL 11)

IV NEXT STEPS TO BRING BUILDING MATERIALS TO NET ZERO

Section II identified materials manufacturers, developers and policy makers as the key players to accelerate the decarbonisation of construction materials. The actions that materials manufacturers need to take are extensively covered in the MPP sector transition strategies and will not be detailed here.[54] This section focuses in turn on investors and developers – by which we mean both private companies developing for example a residential area, and public agencies charged with developing infrastructure or e.g. social housing – on supply-chain level interventions and on policy interventions.

Interventions by investors and developers

Decarbonising the production process of cement and steel should have top priority as this is the lever with the highest long-term GHG impact. Yet, today, there is no realistic scenario where large amounts of low- or zero-carbon concrete and primary steel will be available globally by 2030. This has two implications. Firstly, a serious step-up is required to accelerate the availability of these materials. Investors and developers can play their part by giving off long-term **demand signals**. Secondly, investors, developers and asset owners cannot rely on the large-scale availability of 'green' concrete and steel to meet their 2030 targets and should therefore **double down on the strategies available to them today**: material efficiency and substitution

Long-term demand signals

Investors and developers can play a crucial role in enabling the manufacturing industry to make long-term investments in green production capacity. They can give comfort to producers and their financiers by giving off clear **long-term demand signals**, the most effective of which are long-term agreements with green premiums or tenders where sustainability metrics are heavily weighted in the

Box 3: **Examples of supply chain coordination initiatives around green procurement**

Name	Membership	Goal/achievements
First Movers Coalition (FMC) by World Economic Forum, supported by BCG	Players across aviation, shipping, trucking, steel, cement & concrete, aluminium, and chemicals	Made commitments to buy near-zero-emission products worth an estimated USD 12 billion in total. Partnered with H2Global to ramp up green hydrogen
SteelZero by Climate Group & ResponsibleSteel	44 companies in the steel value chain: automotive, machinery, building materials, real estate	Public commitments to use, procure and specify 100% net zero steel by 2050 with an interim commitment of using 50% responsibly produced steel by 2030
Sustainable Aviation Buyers Alliance (SABA) by RMI and Environmental Defense Fund, supported by Neoteric	Banks, consultancies & tech companies as offtakers; airlines, OEMs and logistics companies, as 'providers'	First collective procurement early 2023; certificates bought for nearly 850k gallons of high-integrity SAF helping to fuel a commercial flight. Currently working on the second
Zero Emissions Maritime Buyers Alliance (ZEMBA) by coZEV, supported by Aspen Institute	Cargo owners including Amazon, Patagonia and Tchibo	Request for Proposal for zero-emissions shipping services to be delivered in 2025; seeking ocean shipping services for over 600,000 twenty-foot containers
Zero Emissions Port Alliance (ZEPA) by APMT and DP World, supported by Systemiq	OEMs, ports and container terminal operators	Making battery-electric container handling equipment affordable and accessible
Industrial Deep Decarbonisation Initiative (IDDI) by United Nations Industrial Development Organisation	UK and India (co-leaders); Canada, Germany, Japan, Saudi Arabia, Sweden, UAE, USA	Encouraging governments and the private sector to buy low carbon steel and cement; sourcing and sharing data for common standards and targets

evaluation. Such commitments are typically made on an offtaker-by-offtaker basis, but coordination can play an important role to avoid that first movers find themselves at a disadvantage. Box 3 gives some examples of such initiatives in this and related sectors. These experiences are relevant for the built environment industry, because its fragmentation makes it difficult for any single player to generate enough demand to support an industrial-scale plant for low-carbon building materials.

Public developers, public bodies that commission the construction or renovation of buildings or infrastructure, have another tool available in addition to giving off offtake commitments, which is to set the terms of **public tenders** in a way that reduces embodied emissions. While their share of buildings is smaller than that of the private sector – even in Copenhagen which has the highest public (30%) and cooperative (19%) ownership of housing stock among large European cities[55] – they can play an important role in catalysing innovation. In infrastructure development the role of the public sector is much more important. Box 4 explores how public procurement can be used strategically to trigger tipping points.

Box 4: **Public sector in its developer role: using public procurement to create local tipping points**

Construction companies in Europe tell Systemiq they want to use lower-carbon materials in their bids, but tenders do not sufficiently reward them for this effort, even if they include 'green' provisions. Public procurement is a powerful policy tool that can encourage technological breakthroughs in reducing embodied emissions. Bid teams usually stick closely to the requirements in order to win the tender.

National, regional, and local governments underuse procurement as a tool to meet their climate goals. Cities in particular struggle to meet their GHG goals; partially because they have at best partial control over major emission sources. Procurement is a lever they do have direct control over. Large cities spend billions each year on built environment-related procurement. This could be enough to trigger local tipping points, especially for cement, that could then spill over to other regions. (See also Box 5). In a similar vein, international financial institutions are under-using their power to move sectors in a greener direction, e.g. by attaching stricter conditions to loans and grants in countries they provide financing to.

Double down on what can be done today

Because of their pivotal role in the value chain, developers need to raise the bar for the companies they work with, from architects to construction companies, when it comes to **material efficiency**: material-efficient designs with re-used or recycled materials, refurbishments rather than new construction if more efficient from a lifetime carbon perspective; and substitution with timber or other biobased materials in regions where the carbon benefit over alternatives is clear. In addition, there are technological interventions in the production process that are in the money and don't have long lead times, such as supplementary cementitious materials (Box 5). Either via buyer's clubs, by teaming up with local government procurement organisations or otherwise, developers have the potential to create a market for these (partial) alternatives to clinker. Similarly, while the availability of low-carbon building materials remains limited, these materials are coming onto the market and forward-thinking developers should see it as their duty to purchase these materials.

Box 5: **Supplementary cementitious materials**

Supplementary cementitious materials (SCMs) are among the few cement decarbonization technologies that are already in the money (Figure 8 in Section III). They are available in many regions globally and easily applicable in existing processes. SCMs reduce the ratio of clinker in a cement or concrete mix, thereby directly reducing process and energy emissions from a clinker plant – a lever with the potential to reduce cement and concrete emissions by 25%.

Two SCMs are expected to gain importance as the transition progresses: natural pozzolans and calcined clays. Natural pozzolans, such as volcanic ash, are available in volcanic regions, while calcined clays are abundant worldwide, especially in regions that lack limestone deposits – the principal ingredient of clinker. According to the European Cement Research Academy, the production cost of calcined clay is ~25% lower than the cost of clinker making due to the lower temperature needed for calcination (~800°C vs ~1,400°C). Natural pozzolans and calcined clay are expected to gradually replace fly ash and ground granulated blast-furnace slag, the most common SCMs today. As byproducts created in coal and blast furnaces, their availability is expected to decline with the phasing out of these processes. Large stockpiles ensure they will remain significant in the medium term.

It is desirable to accelerate the adoption of natural pozzolans and calcined clay given their low emissions and favourable economics. The regional nature of the cement industry may make it possible to bring these SCMs to scale in one megacity or a cluster of cities. Once a regional tipping point has been triggered, the adoption of these SCMs may spill over to other regions through positive feedback loops.

Several factors are holding back widespread adoption so far. These include unfamiliarity and lack of expertise on the side of industry, including inadequate surveying of potential deposits, lack of market trust in the performance of these SCMs and not-yet-widespread knowledge on how to mix and deploy lower-clinker ratio cements. On the regulatory side, structural and building codes often do not allow for adoption of alternative binders such as these SCMs. Despite already having favourable economics, key technologies such as calciners for calcined clay are still at the beginning of their learning curve, with further cost reductions expected over time.

Switching to **alternative building materials** such as timber is another thing that can be done today in regions with enough sustainably forested supply. More on that below and in Appendix B.

Policy interventions

To enable private-sector action, the transition needs **supporting regulation and subsidies** by government. These fall into three categories. The first are those to simply **allow innovation** to take place: too often building codes and zoning regulations stand in the way of progress, for example by disallowing cement mixes with a lower clinker content or by disallowing higher building density. The second is to **stimulate the transition through regulation**, for example by mandating use of green materials by a fixed date, comparable to blending mandates for fuels, starting with government projects. France, Germany, the Netherlands, California, New York and Oslo[56] are positive exceptions. Official accreditation of low-embodied carbon buildings is another way to stimulate the transition through regulation (examples in Figure 7 in Section III). Finally, governments can **proactively change the economics** through both 'sticks and carrots', such as carbon pricing and subsidies to offset the cost difference between low- and high-carbon. A major challenge is that most new building will occur in parts of the world with weaker policy ambitions and institutional capacity.

Supply chain level interventions

Individual players and regulators can take many actions on their own and make a difference, but some barriers can only be overcome by coming together as a supply chain.

Completing the picture

As Section II showed, the overall direction of travel for the sector is clear. This is especially true for the materials manufacturing component, which has been covered in depth by MPP.[57]

Four areas remain for which the picture is not yet complete:

1. **Timber**: there is no alignment yet about some of the largest questions surrounding the use of timber as a building material (Appendix B outlines the terms of the debate). One comprehensive vision is needed that brings together insights from forestry, the built environment and materials science.

2. **Nature**: most reports cover climate and largely neglect other planetary boundaries, especially those related to nature; a comprehensive global study is needed to bring to the fore which priorities and trade-offs exist.

3. A global, quantified **roadmap from the user/developer perspective**. Sector transition strategies exist for individual construction materials, but none has been made that brings these insights together into comprehensive roadmaps for the materials side of the buildings and infrastructure supply chains. Such roadmaps would be more than simple sums of the parts, as they would offer a deeper, consistent perspective on material efficiency and substitution between building materials and give developers and policy makers a clear roadmap on which to base their materials strategies. On the buildings side, the ETC will contribute by bringing together the insights from the cement and steel sector transition strategies (e.g., from MPP) together with a wider discussion on the additional levers to reduce embodied carbon, as well as to decarbonise operational energy in buildings. This work is also needed for infrastructure.

4. Construction material decarbonisation **compared to the decarbonisation pathways that other sectors offer**, answering the question that ultimately matters most for society – and for companies that have committed to net-zero emissions: 'how to get to net-zero in the quickest, fairest, most cost-efficient way'. This work would offer a new economic perspective that goes beyond the costs of low-carbon vs. high-carbon building materials. It would explicitly take **breakthrough effects** into account: the exponential growth and cost reduction that can occur when a new technology reaches a tipping point. MPP's Green Market Making initiative works on boosting the availability of green commodities by scaling up market intermediaries that overcome the green premium by bridging market failures.

Philanthropic organisations, governments and multilateral organisations are best suited to fund this work. Substantial involvement from supply chain players and academics are requirements for success.

Raising awareness

Broad outreach is needed to put embodied emissions on the agenda of policy makers and the public at large. This is a role for the private sector, for committed public officials and both mainstream and more activist non-profit organisations.

Increasing transparency on carbon performance

Tenants, investors and the financial players they interact with (e.g. lenders, external valuators, and fund managers) need to demand transparency in carbon and energy performance of buildings and infrastructure to better inform their assessments of buildings and portfolios. This requires a set of commonly agreed standards, based on 1.5°C pathways, as well as certifications and rating schemes that embody these standards. Public reporting on the carbon and energy performance of rated buildings and portfolios is important to increase transparency in the market. Policymakers should support the development of this market by introducing ambitious, performance-based regulations. These regulations should drive transparency and data-sharing and establish simple, clear targets for energy use intensity, operational carbon, and embodied carbon.[58]

APPENDIX A: HOW SYSTEMIQ SUPPORTS THIS TRANSITION

Systemiq's **built environment team** accelerates the system-play market, focusing on transparency, investments and shared incentive systems

Shifting capital towards sustainable placemaking, with a focus on urban regeneration

- Establishing the evidence for the commercial upside of urban regeneration and placemaking
- Developing tools for strategies and aligning stakeholder incentives (e.g. cities and investors/developers)
- Help build the market by working with players across the system (from investors to designers)

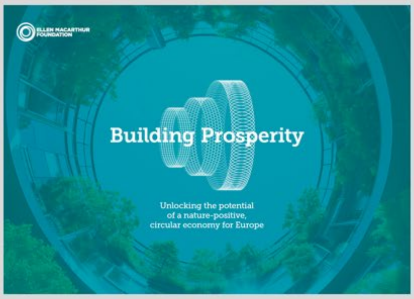
Optimising Built Environment transition for Nature and Land Use, alongside carbon

- Building the demand side for nature- and carbon-positive real estate, with a focus on investor barriers
- Working with frontrunning developers, landowners and constructors who are moving past disclosure and marginal improvements

Driving Green Innovation Districts as catalysts for the climate and urban transition

- Unpacking the market and impact potential of innovation districts, for investors and cities
- Helping innovation district developers leverage their full potential forgreen innovation

Box 6: **Selected publications by the Systemiq built environment team**



For the Ellen MacArthur Foundation
Building Prosperity - Unlocking the potential of a nature-positive, circular economy for Europe

With Holcim
Unleashing a Regenerative Revolution for the Built Environment

For Leaders of the Urban Future, with ATP, BlackRock, HOOPP, Ivanhoé, Norges Bank, Pictet, Urban Partners and Vicory
Seeing is Believing: Unlocking the Low-Carbon Real Estate Market

With the Laudes Foundation
Efficient and Balanced Space Use: Shaping Vibrant Neighbourhoods and Boosting Climate Progress in Europe

For the City of Rotterdam
A Green & Digital Deal for Rotterdam: a systemic mission-driven approach for implementation of the European Green Deal

With Clean Tech Delta
The Case for Concrete Recycling in Rotterdam: Could Rotterdam be the first region to close the loop on concrete?

Systemiq's Energy Platform supports and undertakes related research to specify global and national pathways to net-zero as well as positive tipping points to get there. This includes the sector transition strategies by MPP and the vision-setting work of the ETC on volumes of electricity, low-carbon hydrogen, sustainable bioenergy, carbon capture, carbon dioxide removals and low-carbon finance required for a transition to mid-century. The ETC recently updated its view of sectoral decarbonisation pathways in its 2023 work *Fossil Fuels in transition*, to understand the implications of sector decarbonisation on fossil fuel demand by mid-century.[59] The ETC is now undertaking a deep-dive on the global buildings sector.

The ETC has set up regional Breakthrough Steel Forums that bring together stakeholders from across the regional steel value chain, ranging from upstream suppliers to final users of steel and government in order to discuss which levers could and should be pulled to make green steel investable in the region.[60]

Box 7: **Building materials sector transition strategies developed by MPP, Systemiq and ETC teams**

Fully quantified sector transition strategy developed with the Global Cement and Concrete Association, acknowledged by 19 leading companies

Fully quantified sector transition strategy developed with industry, endorsed by 15 leading companies

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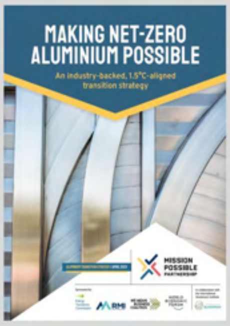
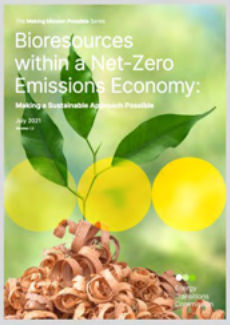


Fully quantified sector transition strategy developed with the International Aluminium Institute, endorsed by 28 leading companies

Pathways to circular, net-zero plastics in Europe. Contains deepdives on decarbonising plastics used in construction (21% of plastics use)



Quantified perspective on the role of bioresources in a net-zero economy. Includes timber alongside e.g. biofuels

APPENDIX B: THE DEBATE AROUND TIMBER

This appendix intends to give insight in the debate surrounding the sustainability of using timber as a building material. Opinions range widely: many experts see increasing the share of timber as far as feasible as a desirable long-term outcome. Others consider timber more as a transition material that can play a valuable role until net-zero cement and steel are mainstream – the "natural gas" of building materials. For yet others, large-scale deployment of timber is not a desirable part of the global mix now or in the future. Underlying these disagreements is a complex and nuanced multi-disciplinary debate. This deepdive attempts to summarise this debate and propose a few steps the sector can take to bring clarify and alignment around the main points. An important resource is the ETC report *Fossil Fuels in Transition* that looks in depth at various aspects of this topic, including sustainable forestry.[61]

A commonly held view is that timber is a desirable substitute for concrete and steel across several regions and applications, even if it cannot replace all use of concrete and steel in buildings and infrastructure. Precise, region-specific guidelines that help draw the line between 'desirable' and 'undesirable' are not yet available.

Points of agreement

There appears to be consensus or no major controversy about a number of key points.

Supply is limited.[62] Today, only 11% of timber is certified as sustainably harvested.[63] 86% of this is from Europe, North Asia and North America. These figures include the 35% of sustainable timber that have recently lost access to the market due to Russia's 2022 invasion of Ukraine.[64] Given competing uses for land and long lead times, rapid expansion is unrealistic in temperate zones: in the European Union, the sustainable timber supply can only realistically be expanded by 10-21%.[65] Expansion in tropical forests – closer to growth markets and beneficial in principle as trees grow faster in the tropics – is limited by the strength of institutions and competing demands for land use.

Timber is a viable substitute only for certain applications. Despite some innovation in the field, application of timber mostly suited for low- and mid-rise residential and commercial buildings, which represent ~40% of total demand for building materials.

Timber has benefits in application that make it more material-efficient than concrete and steel. Prefabrication allows for more efficient production which can shorten production time by up to 20%. Due to the look and feel of timber, less additional material is needed (plaster, paint, drywall), which can save up to 5% in material and labour costs. Mass timber has high insulating capabilities, requiring less use of insulation materials. Construction cost savings of up to 15% have been reported.[66]

Contested and unclear points

Two main points are contested, one is unclear.

Carbon intensity. Lifetime carbon savings from substituting concrete by cross-laminated timber range from 10-15%[67] to 60%[68]. Box 8 gives some insight into the type of arguments used on either side of the debate.

Time dimension. Timber's favourable lifecycle emissions come from carbon sequestration by the replanted tree. These gradually make up for the carbon emitted at harvest over the space of several decades. Some argue that lifecycle emissions are the correct way to assess timber's impact. Others argue that more focus should be placed on the upfront emissions, as the carbon sequestration that takes place over the decades to come will not help bring down emissions in the short run.

Box 8: **Arguments used in the debate around the carbon and nature impact of mass timber**

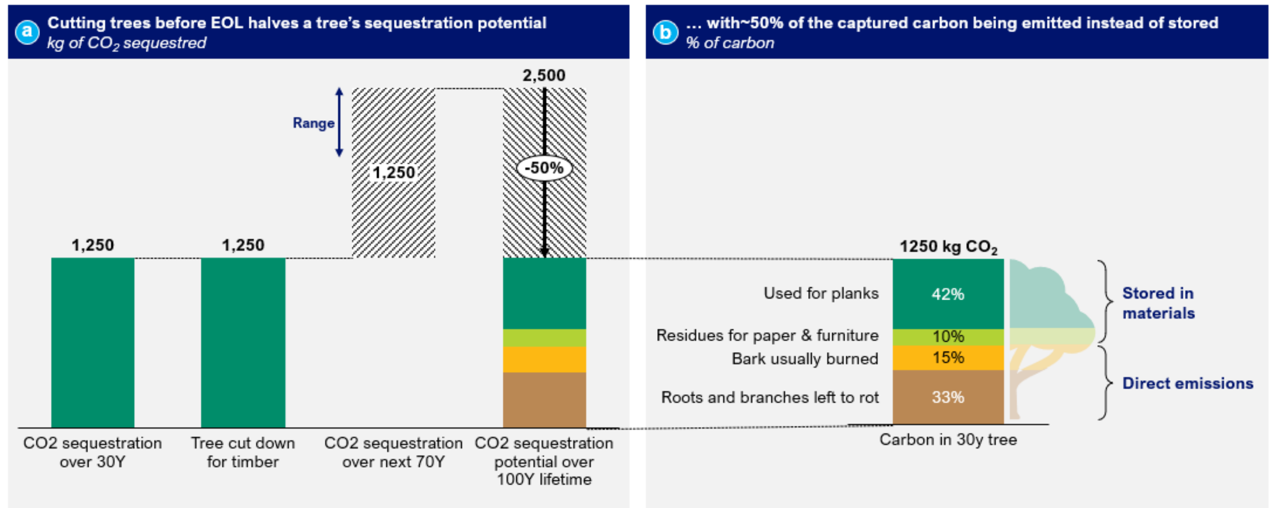
Mass timber is environmentally neutral/positive[1,2]

- Wood has a **short carbon-cycle**, hence only embodied carbon sequestrated in the past 50-100 years (no fossil carbon) will re-enter the atmosphere
- Carbon stock in **sustainably managed forests** is maintained level (the growth of a forest is harvested), hence no additional emissions enter the system
- Mass timber **substitutes other uses of wood** (e.g., paper), hence taking carbon out of the air for a longer period (lifetime of a building exceeds lifetime of paper)[3]
- Increasing demand for mass timber will **increase forest plantations**, with additional carbon stored in the ecosystem[4]

Mass timber is environmentally negative

- **Incorrect accounting,** as the share of tree that cannot be used for timber (roots, bark, branches) will be burned or left to rot (up to 30-50% of embodied carbon) is currently excluded from embodied carbon of (mass) timber
- Conversion of carbon sinks (e.g., grassland, standing forests) into production forests can lower biodiversity and disrupt existing carbon stores
- Forests sequester less carbon when harvested and replanted than if they are kept standing, as saplings absorb less carbon than grown trees.[6]
- It takes 40-100 years for the carbon stock of a forest to restore via reforestation after conventional logging[5]

1. WRI paper 2. Lippke et al. (2011), Ganguly et al. (2020) 3. Smyth et al. (2020) and Xu et al. (2018) 4. (Lippke et al. 2004), 5. Schlamadinger and Marland (1996), Keith et al. (2014) Ingerson (2009), Hudiburg et al. (2019), Law et al. (2018), Skytt et al. (2021) 6. Grassi et al. (2021)



Source: WRI 2023 (adapted from Churkina et al 2020).; assuming tree sequesters 50% in first 30 years

ENDNOTES

1 For a discussion of embodied biodiversity impacts in the context of the United Kingdom: Expedition Engineering and Institution of Civil Engineers (2023), *The Embodied Biodiversity Impacts of Construction Materials*
2 European Commission, Internal Market, Industry, Entrepreneurship and SMEs, *Buildings and construction*
3 Eurostat, Accidents at work statistics, extracted October 2023
4 European Trade Union Confederation (2024), *Enough is enough: zero accidents at work now*, press release
5 Maikel Kuijpers (19 February 2024), 'De baksteen: een anker voor de toekomst', *De Correspondent*
6 Michail Moatsos (2021), *Global Extreme poverty: Present and past since 1820*
7 Ibidem
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9 Systemiq and Holcim (2024), *Unleashing a regenerative revolution for the built environment*; see also: PriceWaterhouseCoopers and Urban Land Institute (2024), *Emerging Trends in Real Estate Global Outlook 2024*
10 International Energy Agency (2017), *Global Status Report 2017*, prepared for the Global Alliance for Buildings and Construction
11 Homi Kharas (2017) *The unprecedented expansion of the global middle class*, Brookings Institute Global Economy & Development Working Paper 100
12 Three quarters of the USD 9.2 trillion is for new construction vs a quarter for e.g. maintenance of existing infrastructure; McKinsey (2022), 'Reducing embodied carbon in new construction', *Voices on Infrastructure*, Global Infrastructure Initiative
13 Global Center on Adaptation (2021), *State and Trends in Global Climate Finance 2023*
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