In collaboration with
McKinsey & Company

World Economic Forum

Circularity in the Built Environment: Maximizing CO_2 Abatement and Business Opportunities

WHITE PAPER

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Foreword

Fernando Gomez
Head, Resource Systems and Resilience - Centre for Nature and Climate, Member of the Executive Committee, World Economic Forum

Jukka Maksimainen
Senior Partner,
McKinsey & Company

Sebastian Reiter
Partner,
McKinsey & Company

Jörgen Sandström
Head, Transforming Industrial Ecosystems - Centre for Energy and Materials, World Economic Forum

A multitude of complex global challenges, including health crises, geopolitical conflicts and economic difficulties, have inspired the narrative that the world has entered a "new normal", where organizations must deal with crises and focus on resilience by default. Throughout this shifting normality, what has not changed is the urgent need to tackle one of the most prevalent issues of the century: combating climate change and its profound impact on the world.

The built environment holds immense potential for positive change. Buildings and construction account for about 26% of global greenhouse gas emissions, primarily due to their substantial consumption of energy and materials. However, there is an opportunity to transition from current consumption and production patterns to a more sustainable circular approach. By reimagining design processes, embracing cutting-edge technologies and exploring innovative business models, industry players can unlock greater value from existing assets, conserve crucial resources and reduce waste. The urgency of making this shift towards greater circularity cannot be overstated; each passing day without action exacerbates the challenges humanity faces.

This white paper by the World Economic Forum's Centre for Nature and Climate and the Centre for Energy and Materials, in collaboration with McKinsey, embarks on a comprehensive exploration of circularity's potential to revolutionize the built environment and create a sustainable and resilient future. Through careful analysis of value pools and abatement potential, our research serves as a call to action, revealing both environmental gains and significant economic rewards. Here, we share a path towards a more sustainable industry that can abate CO_2 emissions while unlocking economic value.

As the industry begins this transformative journey towards a circular built environment, it is crucial to recognize the pivotal role of lighthouses, which offer breakthrough circularity solutions that demonstrate environmental impact, scalability and financial viability. These pioneers bring together industry leaders to actively drive and accelerate the transition towards circularity, serving as beacons of inspiration and showcasing proactive adoption of circular practices. By embracing circularity, they not only safeguard the planet but also unlock sustainable prosperity.

We thank all community members and Forum initiative leaders for their dedication and invaluable input towards this report. We trust it will offer valuable guidance and perspectives to leaders in both the public and private sectors as we collaboratively chart the course for the built environment's future.

Executive summary

Circularity could abate 75% of embodied emissions from the built environment while creating significant economic value.

This white paper quantifies the potential for carbon dioxide (CO_2) abatement and potential net value gain across nine circularity loops for six key building materials: cement and concrete, steel, aluminium, plastics, glass and gypsum. The circularity loops are assessed through three dimensions: recirculation of materials and minerals, renewable and recovered energy and reducing emissions through carbon capture and storage (CCS) and carbon capture and utilization (CCU).

The results show that circular loops could abate 0.5 to 0.8 gigatonnes of CO_2 (Gt CO_2) in 2030 and between 3.4 and 4.0 Gt CO_2 in 2050. This accounts for 13% of the built environment's embodied carbon emissions in 2030 but approaches 75% in 2050. In 2030, recirculation of materials and minerals and CCS/CCU are each expected to contribute around 40% of total abatement, with CCS/CCU increasing its contribution to more than 50% by 2050. Circularity more broadly also presents substantial economic advantages, with the potential to yield an annual net profit gain of $31-46 billion by 2030 and $234-360 billion by 2050. The recirculation of materials and minerals makes up the great majority of potential net value gain both for 2030 and 2050.

Each building material investigated can be made more circular through specific strategies:

1. Concrete and cement: Concrete and cement contribute 30% of building materials-related CO_2 emissions. Circular strategies such as mineralization technologies and smart crushed aggregates offer substantial value gains, as well as the potential to abate 96% of embodied CO_2 emissions from cement by 2050.
2. Construction steel: Steel is already highly recyclable, and the transition to electric arc furnace (EAF) steel production and increased scrap collection hold promise. These measures can avoid up to 60% of total CO_2 emissions from steel by 2050.
3. Construction aluminium: Opportunities for circularity lie in designing for reuse, increasing recycled material use and adopting alternative fuels. These measures can lead to a reduction in aluminium-related CO_2 emissions of up to 89% by 2050.
4. Construction plastics: Introducing circularity levers, such as designing for reuse and modularity, increasing regrind plastics, and using alternative fuels, can decrease CO_2 emissions from plastics by up to 62% by 2050.
5. Flat glass: Practices such as designing for reuse and modularity and increasing cullet use can abate up to 41% of CO_2 emissions from glass by 2050.
6. Gypsum wallboards: Recycling, downcycling and using renewable energy in the production process can yield significant value gains and CO_2 emission abatement from gypsum of up to 31% by 2050.

In this transformative journey, lighthouses will play a pivotal role. Lighthouses catalyse collaboration, advance circular thinking and disseminate digital technologies. Their industry-leading solutions in the built environment are actively propelling the shift towards circularity and setting the example for others. The built environment must take action, in part by recognizing and highlighting these leading lighthouses to the wider ecosystem.

Introduction

A circular built environment responds to an urgent need and creates wide-ranging opportunity for industry players.

The built environment is a crucial component of daily life, providing essential services that impact every aspect of existence, from housing to transport. In fact, 90% of individuals' time is spent inside buildings, infrastructure and urban ecosystems.[1] This ecosystem accounts for 13% of the world's gross domestic product (GDP) and employs 7% of the working-age population.[2] At the same time, the built environment is a significant contributor to the transgression of planetary boundaries, thresholds for key environmental indicators such as climate change and land system change. The built environment contributes one-third of material consumption and waste generation[3] and approximately 37% of fuel-related carbon dioxide (CO_2) emissions from humans.[4] Around one-third of emissions from new buildings come from embodied sources, meaning from material production and construction, and two-thirds from operational sources.[5] As the population grows and urbanization accelerates, 30 billion square metres of new buildings will need to be constructed in the next 40 years,[6] equivalent to adding a building the size of New York City every 40 days. Most of this growth will occur in residential construction in emerging markets, including Africa, the Middle East and East and South Asia.[7] Overall, 75% of the infrastructure needed by 2050 still needs to be built.[8] Thus, creating a sustainable and resilient built environment is crucial for people's well-being and to stay within safe planetary limits.

Transitioning from a linear to a circular economy aims to decouple economic growth from environmental depletion. In a circular ecosystem, virgin-resource inputs and end-of-life waste are minimized, and value is created without exhausting limited resources. Across all industries, new sources of economic growth are estimated at $4.5 trillion in additional global economic output by 2030.[9] Simultaneously, circular levers contribute significantly to reducing CO_2 emissions.

This white paper showcases the potential for circularity in the built environment to simultaneously create business value and reduce CO_2 emissions. While this industry has significant environmental impacts across various dimensions such as pollution, land use change or biodiversity loss, this white paper specifically addresses the potential for emissions abatement to ensure a thorough quantitative and qualitative analysis. The overall purpose is threefold: first, to illustrate how circularity can contribute to the decarbonization of the sector; second, to quantify both the abatement potential and business value pools across key materials; third, to describe what is needed to capture this potential. This white paper is also a call to action to identify lighthouses for circularity in the built environment as a method to demonstrate environmental impact, financial viability and scalability.

The quantification of value pools and abatement potential is performed across nine circularity loops for six building materials, which largely contribute to the built environment's resource consumption and carbon emissions: cement and concrete, steel, aluminium, plastics, glass and gypsum. The circularity loops are incorporated into a framework exploring circularity across three levers: resource recirculation, resource efficiency and resource utilization, and considering the impact dimensions of materials and minerals, renewable and recovered energy and reducing emissions through carbon capture. The impacts have been quantified through a granular modelling approach, exploring global material flows and the implementation of circular loops at the respective building material level and across different stages of the building and construction value chain.

Within this white paper, "the built environment ecosystem" refers to real estate and infrastructure. It touches all aspects of human life, from homes and offices to factories and highways. Its value chain encompasses a variety of stakeholders, ranging from developers and investors to waste-handling companies.

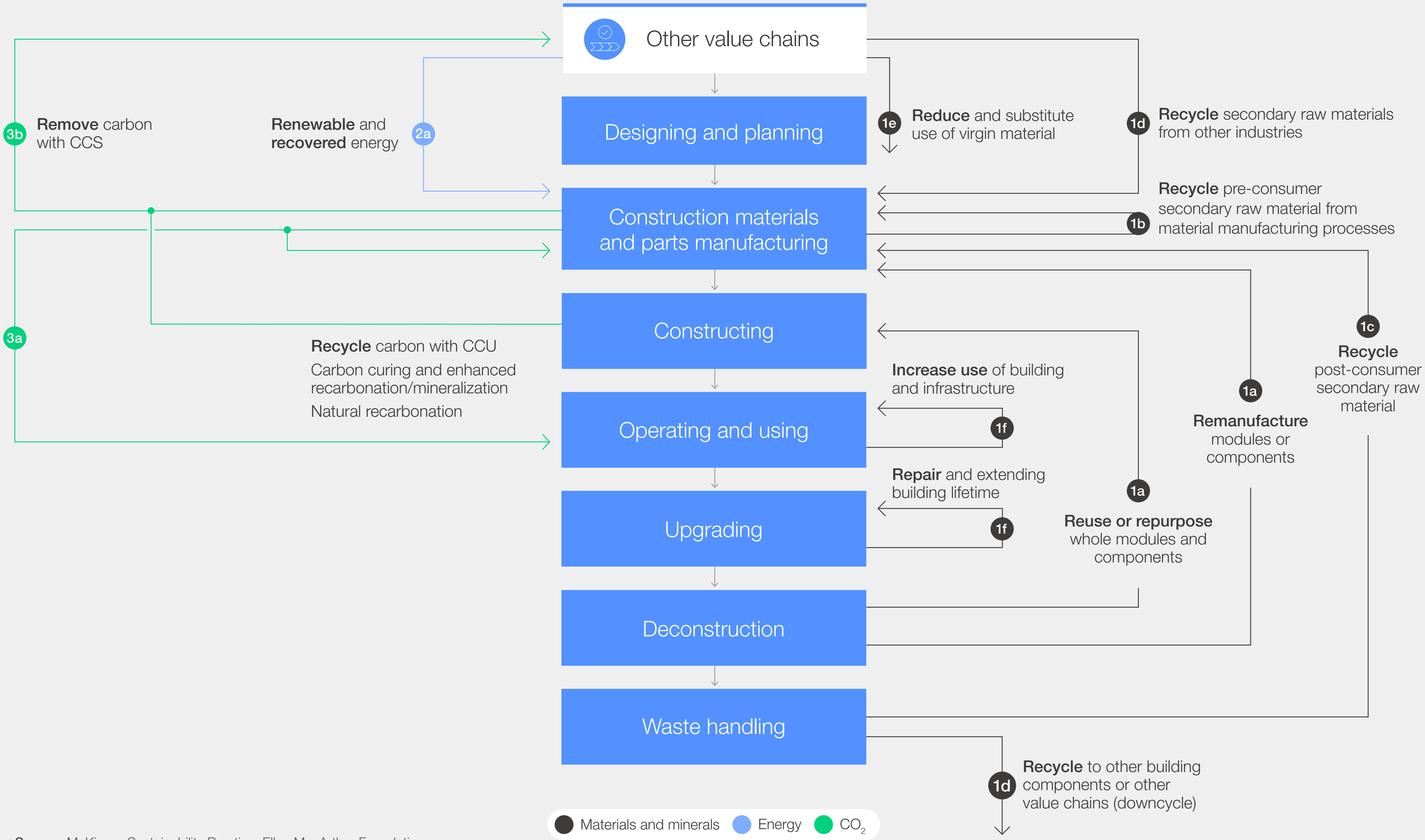
1 Transforming the resource loops in the built environment

True circularity captures new potential value across a variety of flows and resources.

Transitioning from linear to circular systems reveals new opportunities to create value, driven by cost improvements through efficient resource use and new business models. A circular built environment employs resource loops, the flow of resources throughout the value chain, across three key dimensions: resource recirculation, resource efficiency, and resource utilization. The aim is to maximize the recirculation of resources at their highest value to eliminate waste, increase efficiency and reduce the need for new buildings.

Various circularity loops enable those three dimensions (see Figure 1). Increased material recirculation comprises the reuse or remanufacturing of building components or high-value recycling of material in the same or adjacent value chains. To enhance resource efficiency, waste is eliminated by valorizing it as a secondary raw material, as well as by optimizing resource consumption to manufacture a building material or reduce product use per building. To prolong a resource's useful life and maximize its use, spaces and existing buildings can be shared, reused or even repurposed, renovated or refurbished to extend their lifespan.

FIGURE 1 | Nine circularity loops across three dimensions in the built environment



Source: McKinsey Sustainability Practice, Ellen MacArthur Foundation

1.1 Resource recirculation

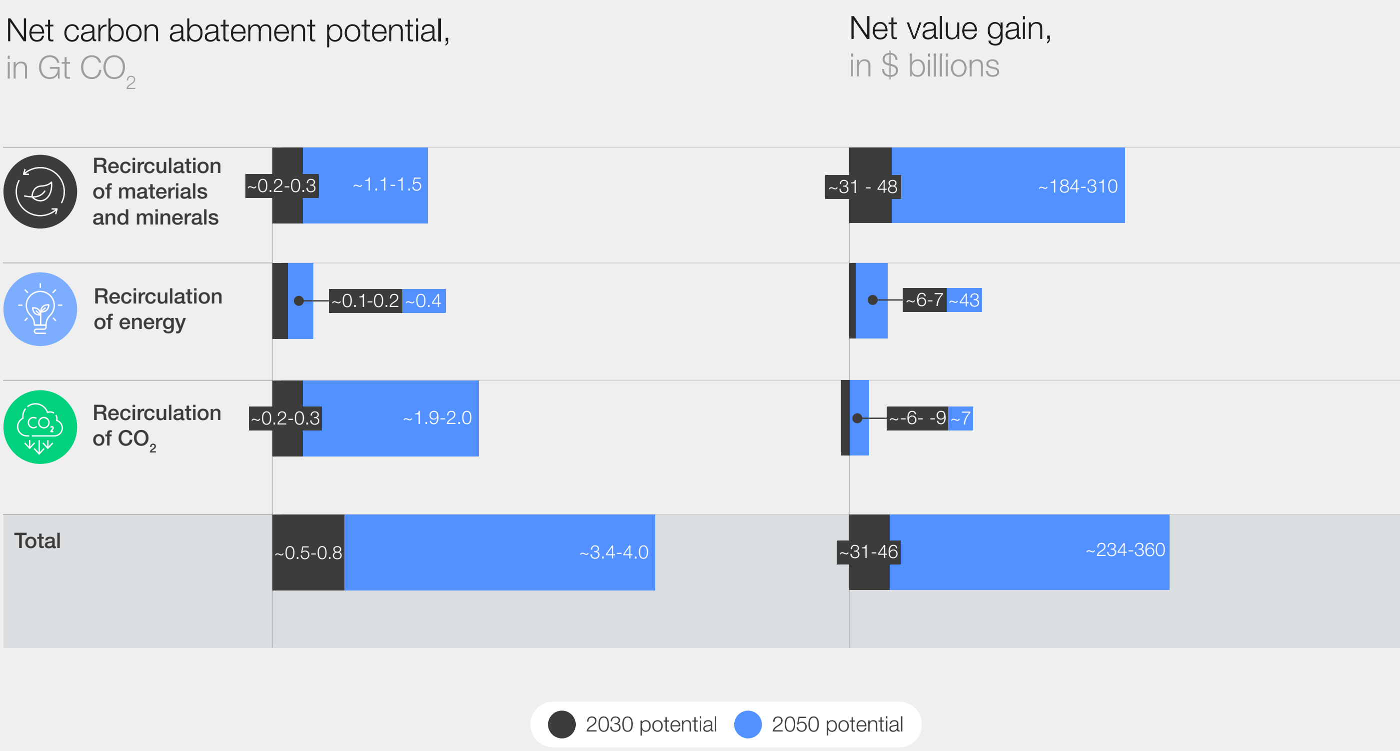
Across construction materials, there are many options to use recycled construction and demolition waste (CDW) as a substitute for virgin raw materials during production. Crushed CDW can also be directly reused in construction, either as crushed concrete for road construction or as a raw material in other value chains, such as lower-quality glass cullet in the production of container glass and fibreglass.

Figure 2 displays an overview of potential net value gain and CO_2 emission savings along the three different dimensions by 2030 and 2050. Overall, the annual net value impact of recirculating materials and minerals is estimated at $31-48 billion and $184-310 billion by 2030 and 2050. The net impact of reusing and remanufacturing is estimated at $6-13 billion and $45-96 billion (2030, 2050), whereas that of recycling materials and minerals (including downcycling) is estimated at a higher value of $25-35 billion and $138-214 billion, respectively, in 2030 and 2050. The abatement potential for these levers amounts to 0.02-0.04 and 0.1-0.2 gigatonnes of CO_2 (Gt CO_2) for reuse and remanufacturing and approximately 0.2 and 1-1.3 Gt CO_2 for recycling, in 2030 and 2050, respectively.

Energy from recirculated resources comprises the use of alternative fuels from waste materials and biomass. This lever is regionally dependent and mainly important in areas with high availability of waste material and biomass supply, such as heated and dried sugar, energy cane or pyrolysed eucalyptus. This lever could unlock a value pool of $6-7 billion by 2030 and approximately $43 billion by 2050 while enabling the abatement of approximately 0.1-0.2 Gt CO_2 by 2030 and 0.4 Gt CO_2 by 2050.

The recirculation of CO_2 from the processing and production of construction materials pertains to capturing CO_2 emissions and reintroducing them back into the value chain with carbon capture and utilization (CCU), including carbon curing and enhanced re-carbonation, mineralization and natural re-carbonation. It can also refer to removing emissions from the value chain altogether via carbon capture and storage (CCS). CO_2-offtake technologies will likely be implemented first in regions with rapid growth in carbon pricing mechanisms, such as Europe or North America and within CCU hubs, where high-emitting industries such as steel and cement are clustered. Removing emissions with CCS or recycling emissions with CCU would abate around 1.9-2.1 Gt CO_2 in 2050 while also generating $7 billion in terms of value gain. By 2030, these would have already contributed to the abatement of 0.2-0.3 Gt CO_2. However, due to the initial investment and upfront costs, an initial loss of $6-9 billion would be incurred in 2030.

FIGURE 2 **Net value gain and carbon abatement potential of circular levers for the recirculation of materials and minerals, energy and embodied emission (CO_2) (2030, 2050)**



Source: McKinsey analysis and calculations based on expert assessment and press research/technology reports

1.2 Resource efficiencies

Efficiency aims at doing more with fewer resources, which ultimately reduces waste throughout the entire process. This involves reusing materials strategically and limiting the need for new resources. Furthermore, by fine-tuning resource consumption in the production process, the overall volume of material required per building can be significantly reduced.[10]

A prime example of this principle is the optimization of building modules. Through design and engineering, it becomes possible to use fewer resources while maintaining or even enhancing structural integrity. This is achieved through approaches that maximize the inherent strength of materials, ensuring that they perform optimally with minimal input. This not only leads to a substantial reduction in the environmental footprint associated with construction but also contributes to a more efficient use of resources in the long term.

The integration of such efficiency-enhancing practices into the construction industry aligns with the principles outlined in the circular economy framework. It encourages a paradigm shift from a linear, “take-make-dispose” model to a circular one, where resources are conserved and perpetually cycled through the system.

1.3 Resource utilization

The utilization dimension aims to increase the number of times or duration a given product or module can be used. Thereby, the used value of a resource can be improved, and its footprint can be reduced. To prolong a resource’s useful life and maximize its use, spaces can be shared, enabled by adaptable and interchangeable building components.

Embracing this paradigm shift in construction practices brings a variety of benefits. It extends the lifespan of resources, maximizing their potential and reducing the need for continuous replacement or replication.

Innovative business models further augment the impact of the utilization dimension. Resource sharing, leasing arrangements and product distribution “as a service” intensify the use of buildings or components. These models promote efficiency in resource allocation and utilization, contributing significantly to the reduction of environmental burdens associated with construction activities.

Proactive maintenance strategies are crucial in prolonging the useful life of building components.[11.] Repair and refurbishment interventions mitigate premature disposal of materials and products, reinforcing the circularity of the construction process. Through such measures, the industry can significantly diminish the environmental impact associated with construction.

2

Building with circular materials

In the built environment value chain, different materials will require different circularity loops and levers.

The value and abatement potential of implementing circularity across the three dimensions for the six building materials are outlined in Figure 3. It displays the modelled net value gain on the left side and the abatement potential on the right. For both dimensions, the potentials for 2030 and 2050 are displayed on the upper and lower part of the figure, respectively. For net value gain, levers concerning the recirculation of minerals and materials, especially recycling, contribute the largest values both in 2030 and 2050. While CCU and CCS levers yield negative (2030) or relatively low net value gains (2050) due to the significant investments required, they contribute a vast amount of abatement potential in 2030 and the majority of total abatement in 2050. In the following section, a detailed analysis is conducted on all six materials displayed in the figure. It covers relevant circular loops, corresponding value pools and abatement potentials for 2030 and 2050, as well as exemplary case studies for selected materials that illustrate strategic options available to players in the field to capture those potentials.

Overview of net CO_2 abatement potential and net value gain of circularity levers per dimension, in Mt CO_2, in 2030 and 2050

Overview net value gain of circularity levers per dimension, $ billions

Dimension	Levers		Cement and concrete	Steel	Aluminium	Plastic	Glass	Gypsum	Total
Recirculation of materials and minerals	1a	Reuse and remanufacture	~1 / ~27	~4 / ~6-17	~0-1 / ~3-10	~1-6 / ~6-36	~0-1 / ~3-6		~6-13 / ~45-96
	1b-c	Recycle (pre- and post-consumer)	~9 / ~61	~5 / ~27-36	~4-6 / ~16-31	~4-12 / ~21-65	~2-1 / ~7-14	~0-1 / ~3-4	~24-34 / ~135-211
	1d	Downcyle	~0	~0			1 / ~4-3	~0 / ~0	~1 / ~4-3
Recirculation of energy	2a	Renewable and recovered energy	~2 / ~27	~0 / ~1-0	~1	~2 / ~11	~0 / ~2	~0 / ~1-2	~5 / ~43-44
Recirculation of CO_2	3a	CCU	~-1 / ~7			~0 / ~0			~-1 / ~7
	3b	CCS	~-1 / ~0	~-5 - -7 / ~0	~0	~0 / ~0	~0 / ~0		~-6- -8 / ~0
Total			~10 / ~122	~4-2 / ~34-53	~5-8 / ~20-42	~7-20 / ~38-112	~3 / ~16-25	~0-1 / ~4-6	~29-44 / ~234-361

2030 potential / 2050 potential

Source: McKinsey analysis and calculations based on expert assessment and press research/technology reports

FIGURE 3 | Overview of net CO_2 abatement potential and net value gain of circularity levers per dimension, in Mt CO_2, in 2030 and 2050 (continued)

Overview net CO_2 abatement potential of circularity levers per dimension, Mt CO_2

	Levers		Cement and concrete	Steel	Aluminium	Plastic	Glass	Gypsum	Total
Recirculation of materials and minerals	1a	Reuse and remanufacture	~40	~20 ~30-80	~0-10 ~20-60	~2-7 ~6-33	~1-2 ~6-9		~20-40 ~100-220
	1b-c	Recycle (pre- and post-consumer)	~30 ~560	~120-130 ~320-440	~50-70 ~90-160	~5-12 ~34-83	~2-1 ~8-23	~2-3 ~4-5	~210-250 ~1,020-1,270
	1d	Downcyle		~0	~0	~0	~0-2 ~8- -1	~0 ~0	~0-2 ~10-0
Recirculation of energy	2a	Renewable and recovered energy	~30 ~240	~10 ~10-0	~50-100 ~110	~5 ~17	~4 ~16	~3-6 ~9-17	~100-160 ~380-400
Recirculation of CO_2	3a	CCU	~80 ~660						~80 ~660
	3b	CCS	~20 ~940	~103-160 ~240-450	~1 ~4-0	~4 ~16	~2 ~9-5		~130-190 ~1,200-1,400
Total			~160 ~2440	~250-320 ~600-970	~100-180 ~220-330	~16-28 ~73-149	~9-11 ~47-52	~5-9 ~13-22	~540-720 ~3,400-4,000

2030 potential 2050 potential

Source: McKinsey analysis and calculations based on expert assessment and press research/technology reports

2.1 Concrete and cement

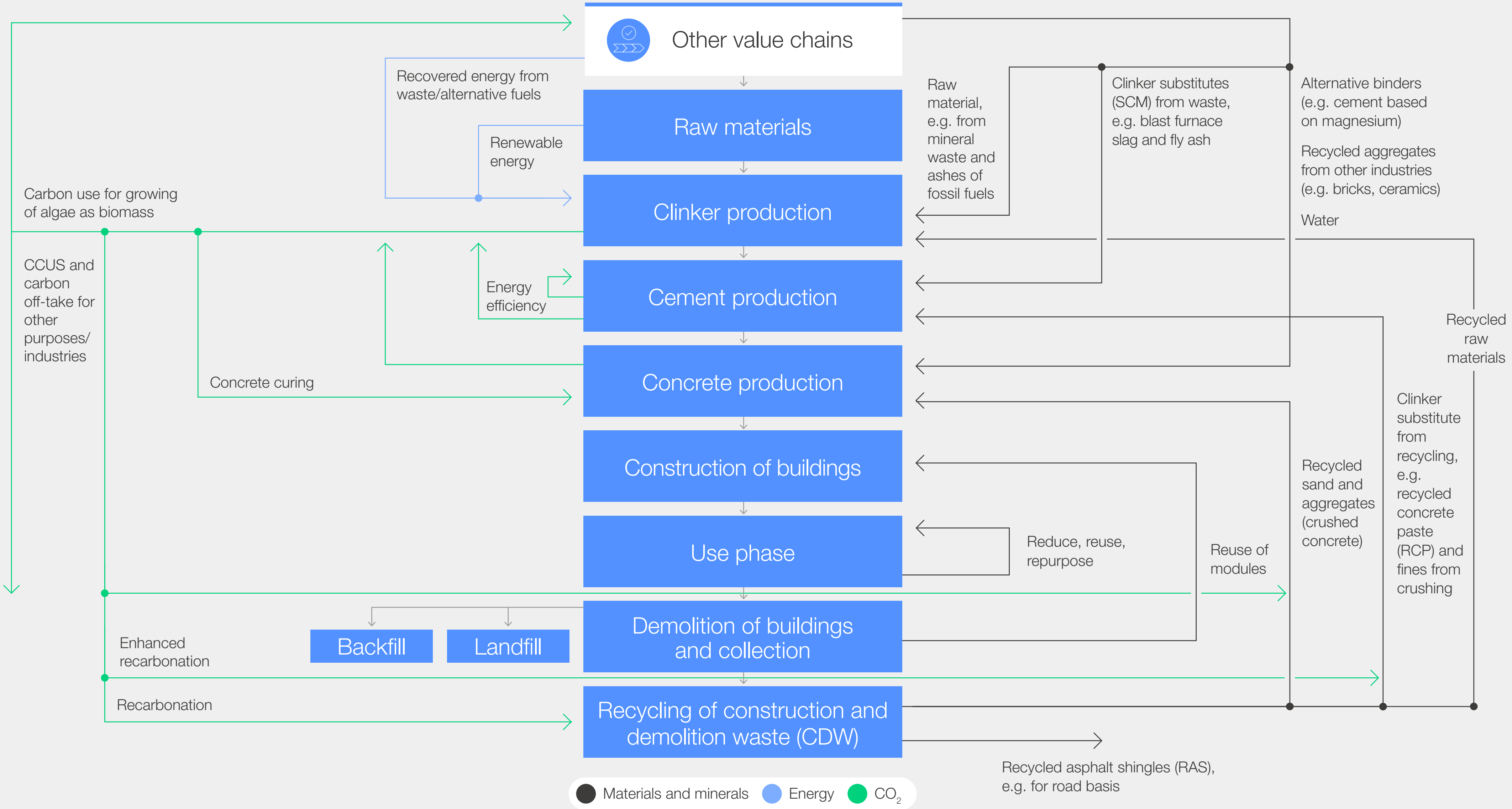
Cement is the largest emitter in the built environment, contributing 30% of building materials-related and 7% of global CO_2 emissions.[12] This sector is particularly difficult to decarbonize due to the high amount of energy required for cement production and the high levels of CO_2 emitted during extraction, processing and manufacturing. It faces several externalities, such as carbon prices[13] and landfill taxes, which will likely increase in the future. Circularity in cement has the potential to create the highest value pool across materials, with an estimated net value gain of $10 billion in 2030 and $122 billion in 2050. These represent 2% and 28% of the estimated market size, respectively.[14] The primary value gain for circularity in cement and concrete will be through mineralization technologies and smart crushed aggregates, with a potential gain of more than $68 billion. Concrete waste can also be recycled and used as an aggregate in concrete production, as a replacement for clinker as a raw material.

Circularity in cement has the potential to create the highest value pool across materials, with an estimated net value gain of $10 billion in 2030 and $122 billion in 2050.

The selected circularity loops overall can abate 0.2 and 2.4 Gt CO_2 emissions by 2030 and 2050, representing an abatement opportunity of 6% and 96% of total emissions, respectively. Carbon curing, enhanced recarbonation and mineralization can significantly help recirculate CO_2. Key technologies include the enhanced recarbonation of connecting devices and workspaces and the mineralization of aggregates from concrete waste or other waste materials. CCS and offtake opportunities offer additional abatement potential. Retrofitting cement plants with CCU and CCS technologies will lead to a total abatement potential of 0.08 and 0.02 Gt CO_2, respectively, in 2030, further increasing to 0.66 and 0.9 Gt CO_2 by 2050. While the annual net value impact of recirculating carbon in the cement and concrete value chain is estimated at a loss of $1.5 billion in 2030, given high upfront costs, a positive gain of $7 billion would be achieved by 2050.

Recirculating energy displays a potential to create a net value gain of approximately $2 billion by 2030, reaching $27 billion by 2050. This would contribute to the abatement of 0.03 and 0.2 Gt CO_2 in 2030 and 2050, respectively. Considering the generation of energy based on alternative fuels from waste and biomass, it is important to note that there are regional differences, and the process is dependent on areas with sufficient supply of waste materials, such as in Latin America and Russia.[15] Each of these technologies are at different levels of maturity and subsequently have a different impact potential.

FIGURE 4 | **Circularity loops along the cement and concrete value chain**



Source: McKinsey & Company, *The circular cement value chain: Sustainable and profitable*, 2023, https://www.mckinsey.com/industries/engineering-construction-and-building-materials/our-insights/the-circular-cement-value-chain-sustainable-and-profitable.

To show how industry players are starting to capture abatement potential and value pools, short case studies using publicly available information have been created for selected materials.

CASE STUDY 1

Concrete and cement

A player in the construction materials industry has started to harness the potential of circularity in cement, concrete and aggregates through its technology platform. By establishing robust operational procedures and accompanying technology for the large-scale recycling and repurposing of construction and demolition waste, the company has strategically positioned itself as a provider of circular materials within the sector. This was possible through a dedicated setup for processing, grinding and recycling these materials, offering an end-to-end circular economy solution encompassing waste collection, transport, processing and the production and distribution of recycled materials. The venture boasts a wide array of applications for reusing waste materials, resulting in 10-100% recycled content in cement, concrete and aggregates, along with the recycling of approximately 6-8 million tonnes (Mt) of construction and demolition materials annually.

2.2 Construction steel

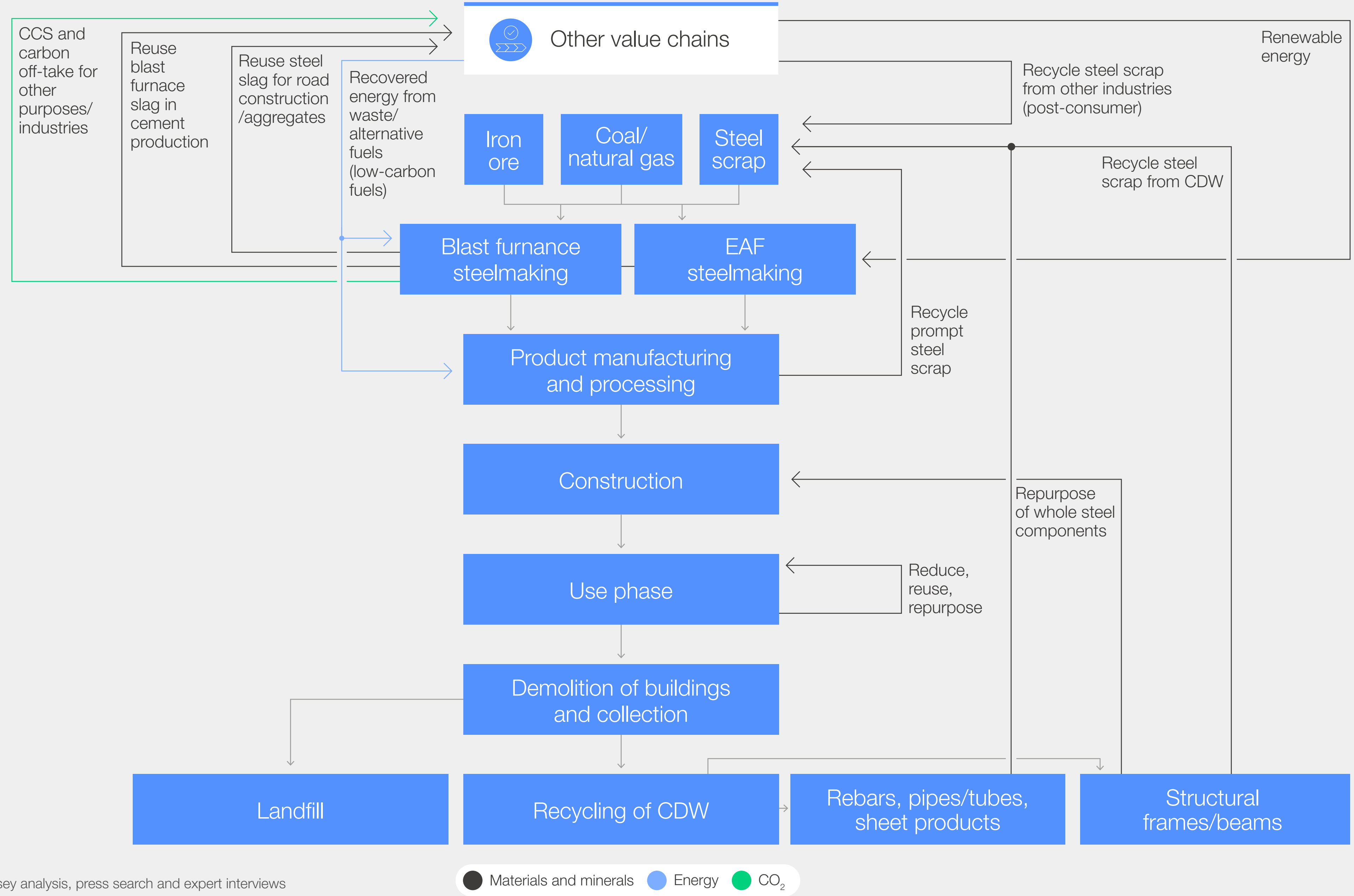
Steel is already highly circular, especially in developed countries, where 70-80% of scrap from construction steel products is recycled and reused in steel production.[16] Additional potential can be captured via transitioning steel production to electric arc furnace (EAF) and increased collection and use of scrap. Overall, increased circularity can avoid an additional 0.2-0.3 Gt CO_2 by 2030, or 18-22% of total CO_2 emissions. This potential increases to 0.6-1 Gt CO_2 by 2050, representing 37-60% of total CO_2 emissions.[17] Circularity levers for steel can create an additional value gain of $2-4 billion by 2030 (1% of the total estimated market), increasing to $34-53 billion by 2050 (9% of the current market size[18]).

Reusing or repurposing whole construction steel components is currently only done at a small scale but has the potential to be expanded. Design for modularity and disassembly are crucial to enable reuse. Steel beams can either be directly reused in new or refurbished buildings or cut into required lengths and rerolled into other steel products. These levers have the potential to generate $6-17 billion by 2050 while abating 0.03-0.08 Gt CO_2. Increased standardization of construction steel products, careful demolition, direct sorting of steel waste and use of material passports for buildings could further increase the potential of reusing and repurposing steel.

Some levers that are already widely implemented can be intensified. Energy can be recirculated in steel manufacturing through EAF steel plants with renewable or green hydrogen energy sources via direct reduced iron (DRI). Steel scrap can also be recycled and remelted as raw material to produce construction EAF steel products. Increasing the collection and upgrading of steel scrap to enable EAF steel production is the most significant lever to increase circularity. Recycling beyond business-as-usual (BAU) has the potential to generate $27-36 billion by 2050, while contributing to the abatement of 0.3-0.4 Gt CO_2 emissions. Strategically securing access to more and better scrap, whether by vertical integration of steel producers and recyclers or closed-loop partnerships between steel producers and steel consumers, will become increasingly important. Using alternative energy sources or fuels, like biomass, in the fuel mix will also contribute to approximately $0.1-0.5 billion value gain and a relatively lower abatement at around 0.01 Gt CO_2 by 2050.

Finally, the recirculation of CO_2 via CCS technologies is especially relevant for the decarbonization of steel production, with an abatement potential of around 0.2-0.5 Gt CO_2 by 2050. This could represent on average 21% of total industry CO_2 emissions based on a BAU scenario. According to this analysis, an integrated blast furnace steel plant retrofitted with a CCS unit can reduce CO_2 emissions by as much as 80%.

FIGURE 5 | **Circularity loops along the steel value chain**



Source: McKinsey analysis, press search and expert interviews

CASE STUDY 2

Construction steel

A steel manufacturer has demonstrated the potential of circularity through a comprehensive overhaul of supply chains, the optimization of production techniques and the replacement of traditional raw materials with organic coke for ferro-chrome production, effectively minimizing waste. Additionally, it launched an initiative to enhance transparency and collaboration in scrap flow management across industries. With intensive R&D in zero-carbon steel and effective integration of value chains, it has achieved an approximate 7-9% reduction in the global steel carbon footprint, maintaining a 100% recycled content for the new product.

2.3 Construction aluminium

Increasing recycled material share from 13% today to up to 50% by 2050 translates to an annual net CO2 decrease of 0.1-0.2 Gt and around $16-31 billion net value gain.

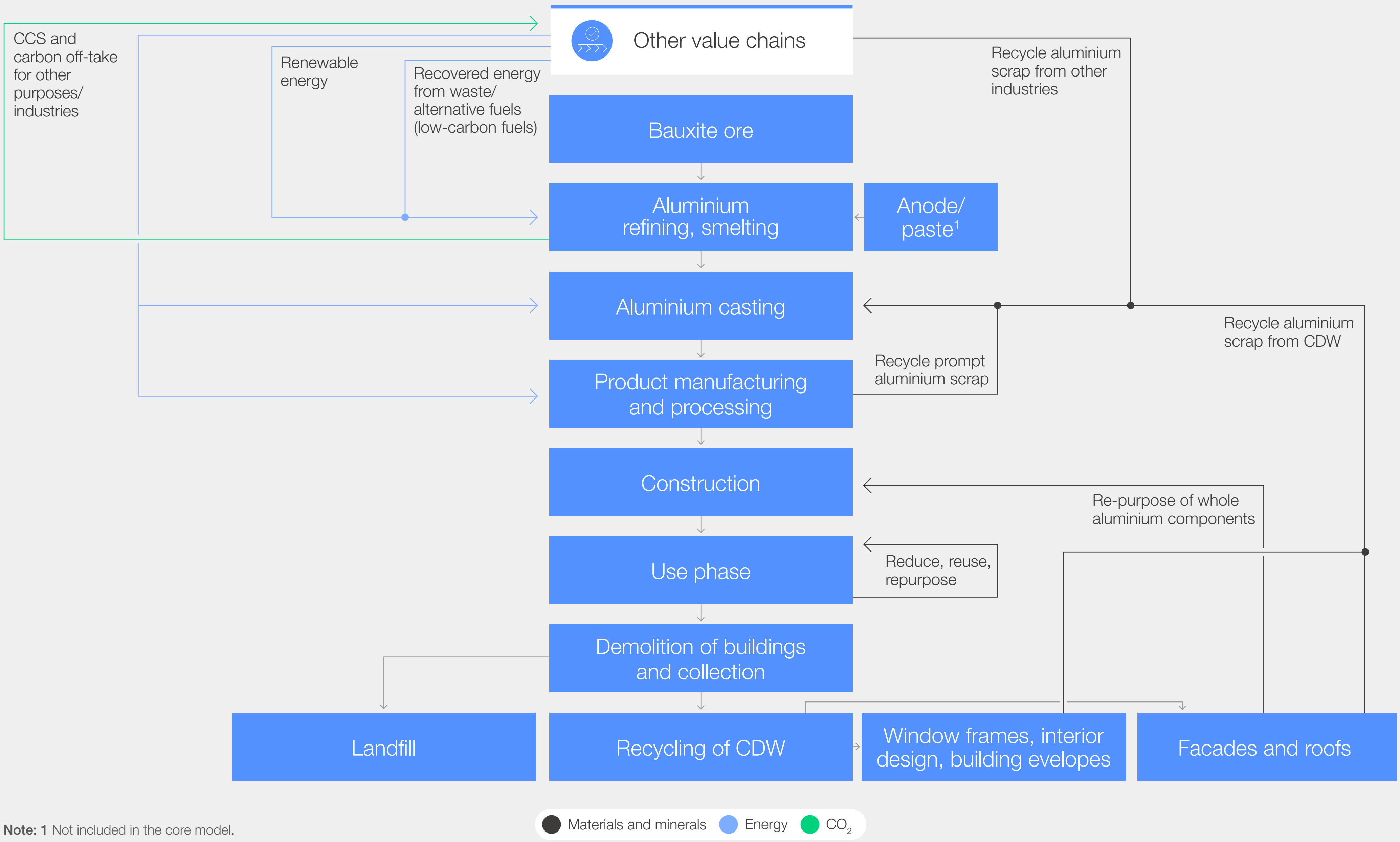
Today, the aluminium chain is already partially circular, with recycling rates of around 30%. However, in construction, the share of secondary material is significantly lower, at only 13%.[19] Even though aluminium offers various circularity levers due to its infinite recyclability without any detriment to its mechanical properties, the variety of alloys and current scrap sorting technologies make increasing recycled content in products or other circularity loops challenging. Current emissions from construction aluminium are around 313 Mt of CO_2 equivalent (CO_2e) and are expected to rise to around 382 Mt by 2050. In total, introducing additional circular aluminium levers can help abate 27-51% (0.1-0.2 Gt) and 62-89% of CO_2 emissions (0.2-0.3 Gt) by 2030 and 2050, respectively. These would also contribute to creating $5-8 billion and $20-42 billion value gains, respectively. This represents around 4-8% and 20-40% of the total market size for aluminium in construction in 2030 and 2050.

The main opportunity for decarbonizing aluminium lies in designing for the reuse of aluminium parts and modules, increasing the use of recycled material and using alternative fuels.

Designing aluminium for reuse and modularity is a lever to act on now with significant impact in the long term (i.e. building life cycle). Reusing aluminium parts and modules, and thereby avoiding costs and emissions from procuring virgin material, could result in an annual net CO_2 decrease of 0.02-0.06 Gt and generate $3-10 billion net value gain by 2050. Increasing recycled material share from 13% today to up to 50% by 2050 translates to an annual net CO_2 decrease of 0.1-0.2 Gt and around $16-31 billion net value gain. The main challenge lies in aluminium's vulnerability to contamination and the impurities of various grades, as well as the difficulty of properly matching materials to different applications. The largest driver for aluminium recycling is post-consumer scrap (95%). However, there is also an important lever regarding pre-consumer scrap in production. Increasing recyclate collection would require collaboration among players across the value chain, such as on-site recycling, standardization and increasing transparency on material flows.

The use of alternative fuels can significantly reduce CO_2 emissions from current electricity use, which make up to 67% of total production emissions. By replacing fossil fuels with biogas or other alternative fuels, aluminium producers can reduce their carbon footprint by up to 30% (0.1 Gt CO_2 in 2050), depending on the availability of alternative fuels. CCS can be a meaningful lever for capturing remaining CO_2 emissions from carbonate releases. However, due to the small share of process emissions in aluminium production, the impact potential is limited.

FIGURE 6 | **Circularity loops along the aluminium value chain**



Note: 1 Not included in the core model.

Source: McKinsey analysis, press search and expert interviews

2.4 Construction plastics

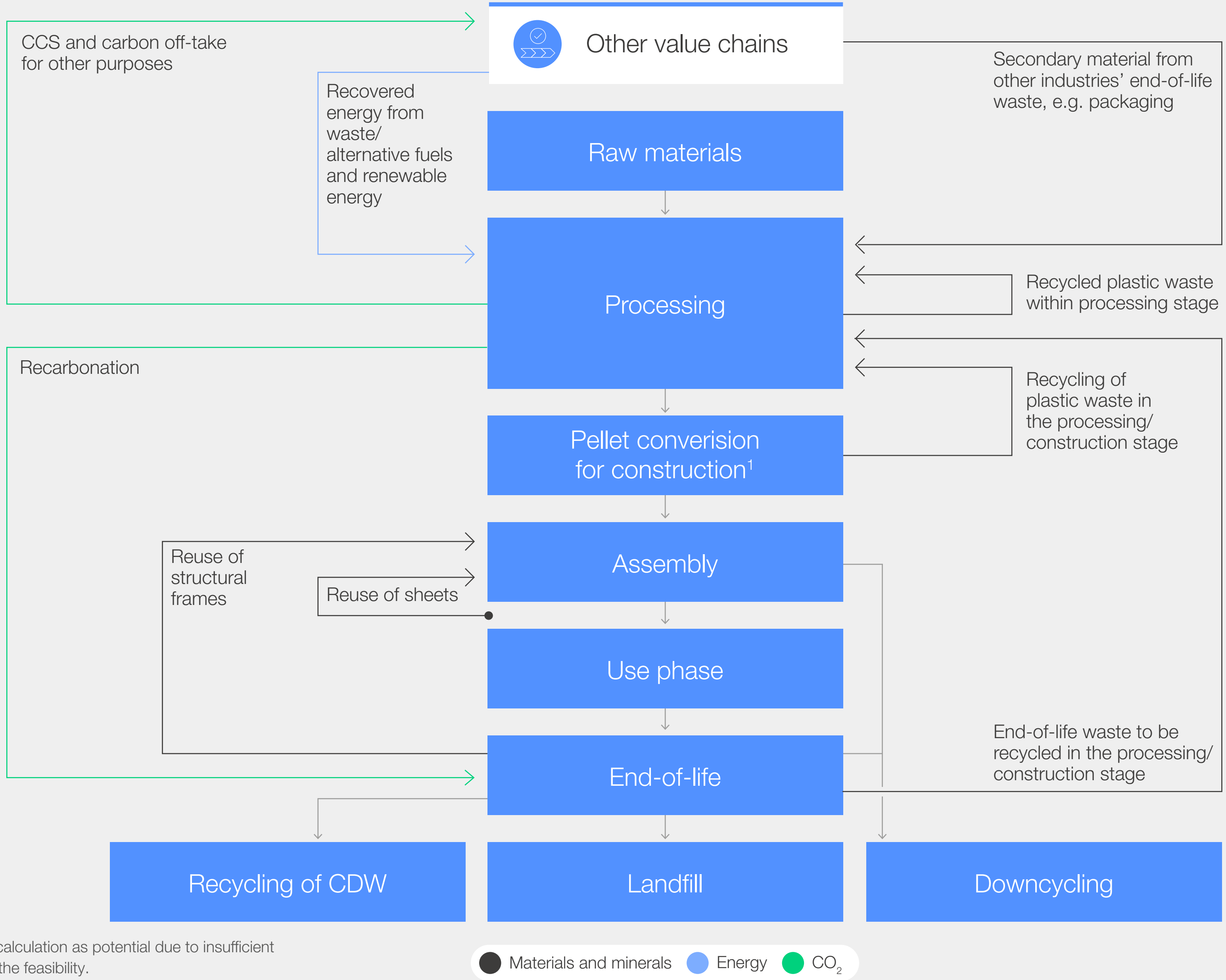
Construction plastics span many applications and polymers, such as polyvinyl chloride (PVC) for applications like flooring and pipes, high density polyethylene (HDPE) sheets for cladding or roofing, and polyurethane (PU) or polystyrene (PS) for insulation.[20] The built environment accounts for 18% of global plastics demand,[21] with plastics currently representing 3% of material volumes (e.g. pipes, bricks with plastics). Due to its high emission factor, emissions due to plastics in the built environment were estimated at 127 Mt CO_2 in 2020, with the potential to reach 288 Mt in 2050.[22] The current construction plastics value chain is mainly linear, with recycling rates as low as 17%, depending on the region. The built environment can serve as a major intake hub for plastics waste, and there is a further opportunity to increase the share of recycled plastics.

The main opportunity for decarbonizing lies in reusing plastics sheets and modules, increasing regrind plastics (i.e. pellets or granules), using alternative fuels and implementing CCS. Respectively, 10-17% and 30-62% of carbon dioxide emissions can be avoided by 2030 and 2050. This represents a decrease of 16-28 Mt CO_2 (2030) and 0.1-0.2 Gt CO_2 (2050). These levers can create net value gains of $7-20 and $38-112 billion in 2030 and 2050, approximately 4-11% and 12-34% of the estimated market size.[23]

According to this analysis, reuse as a circularity lever could result in an annual net CO_2 decrease of 2-7 Mt in 2030 and 6-33 Mt in 2050 while generating $1-6 and $6-36 billion. Increasing regrind plastics – from today's 17% recycling rate to 35% in 2030 and to 61% by 2050 – translates to an annual net CO_2 decrease of 5-12 and 34-83 Mt in 2030 and 2050, respectively. This would unlock $4-12 and $21-65 billion in value. To achieve this, it is crucial to secure a cost-effective supply of waste to recovery facilities, explore alternative business models to retrieve materials, invest in enhanced sorting and waste collection technology and optimize the recyclability of waste by designing for circularity. This should complement sufficient recycling capacity and at-scale (chemical) recycling technologies standardized across products and waste streams.

By replacing fossil fuels with biomethane, bio-naphtha or other alternative fuels, plastics manufacturers can reduce their carbon footprint by 3% and up to 7% of total emissions in 2030 and 2050 while making gains of $2 billion and $11 billion. In addition, the abatement potential of CCS during the cracking process of plastics such as PVC, PU, PS and HDPE can contribute 3% (2030) and 7% of total emissions (2050) of total emissions abatement.

FIGURE 7 | **Circularity loops along the plastics value chain**



1 Not included in the calculation as potential due to insufficient information regarding the feasibility.

Source: McKinsey analysis, press search and expert interviews

2.5 Flat glass

Currently, the flat glass value chain is mostly linear, with low recycling rates of 0-1% and downcycling rates of approximately 40%. Landfill rates are around 60%, depending on the region. Current emissions from the construction flat glass are approximately 64 Mt CO_2, which are expected to rise to as much as 130 Mt by 2050.

Introducing additional circular flat glass levers could help abate approximately 10-11% (around 0.01 Gt) and 36-41% (around 0.05 Gt) of energy-related CO_2 emissions by 2030 and 2050, respectively. It can create net value gains of approximately $3 billion by 2030 (3% of the market size) and $16-25 billion by 2050 (around 14-22% of the total estimated market size).

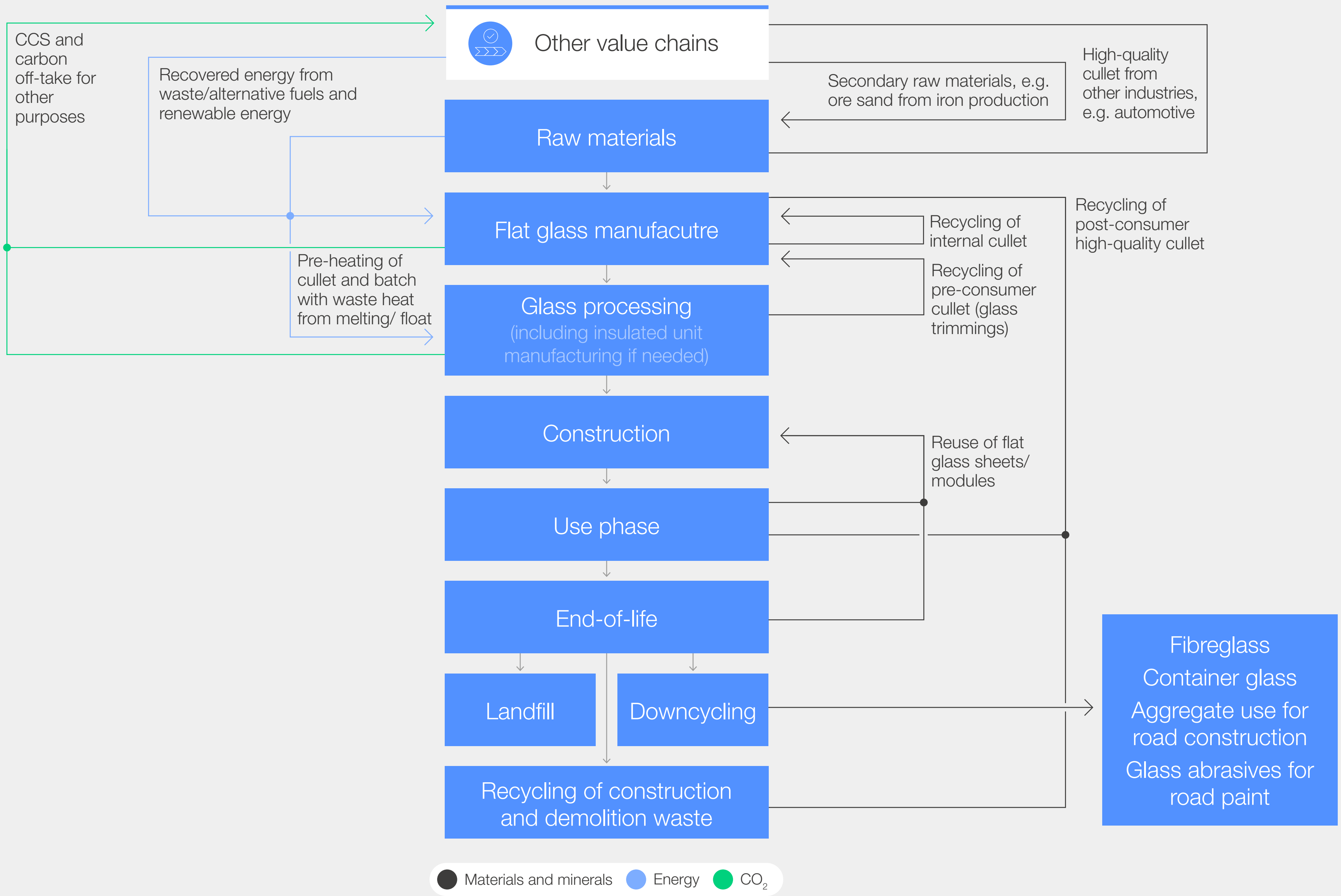
The main opportunity for decarbonizing construction glass lies in reusing glass sheets and modules, increasing cullet use and using sustainable fuels, such as biogas, to decarbonize the production process (especially the heating process). Designing glass for reuse and modularity could have a large impact on the long-term life cycle of a building. In fact, reusing glass sheets and modules could result in an annual net CO_2 decrease of 1-1.5 and 6-9 Mt CO_2 while generating $0.5-0.7 and $3-6 billion in net value gain in 2030 and 2050, respectively. Designing for reuse and reusing glass sheets and modules with circular procurement models, enabling "glass-as-a-service" and vertical consolidation of the market are key levers to increase the circularity of glass.

Moreover, in a circular scenario, increasing cullet use from today around 22% up to 60% by 2050 translates to an annual net CO_2 decrease of 2 Mt in 2030 and 16-22 Mt by 2050. This lever would also unlock approximately $2-3 billion (2030) and $11-17 billion (2050) in potential value. However, ensuring adequate quality of recyclates is key, as one of the main challenges lies in the vulnerability of cullet to contamination and impurities. Moreover, increasing cullet collection requires collaboration among players across the value chain, especially for on-site recycling. Although the collection of pre-consumer cullet needs to be further optimized, the greatest impact lies in recovering post-consumer cullet. Today, almost no cullet is recycled from construction and demolition waste.[24] By incorporating circular practices, it will likely be easier to collect cullet early and ensure a high-quality supply of recycled glass.

Using alternative fuels can significantly reduce CO_2 emissions from combustion, which constitute up to 88% of total production emissions. By replacing fossil fuels with biogas or other alternative fuels (depending on the availability of alternative fuels), with replacement share up to 13% and 25% in 2030 and 2050, glass manufacturers can reduce their carbon footprint by 4 Mt CO_2 in 2030 (4% of total emissions) and 16 Mt CO_2 (13% of total emissions) in 2050. Value gains are at approximately $0.3 billion and $2 billion in 2030 and 2050, respectively.

CCS can also be a meaningful lever for capturing remaining CO_2 emissions from carbonate releases. Its abatement potential is smaller, amounting to 2 Mt CO_2 by 2030 and 5-9 Mt CO_2 by 2050. Supporting measures, such as glass de-specification, can be used to abate residual emissions.

FIGURE 8 | **Circularity loops along the glass value chain**



Source: McKinsey analysis, press search and expert interviews

CASE STUDY 3

Flat glass

A window industry player has developed a take-back scheme for window units, ensuring responsible disposal. These units are transported to specialized dismantling facilities where advanced sorting technology separates components for reuse. The company's approach extends to "as-a-service" and modularized business models.

This shift is enabled by factors like modularization and design for disassembly, specialized dismantling technology, customer-centric education, efficient data management and strategic partnerships. Outcomes include an approximate 30% reduction in CO_2 emissions along the window life cycle.

2.6 Gypsum

Circular gypsum offers an opportunity of $1 billion in annual net value gain by 2030 and $4-6 billion in 2050, representing 1% and 3% of the total market size, respectively.

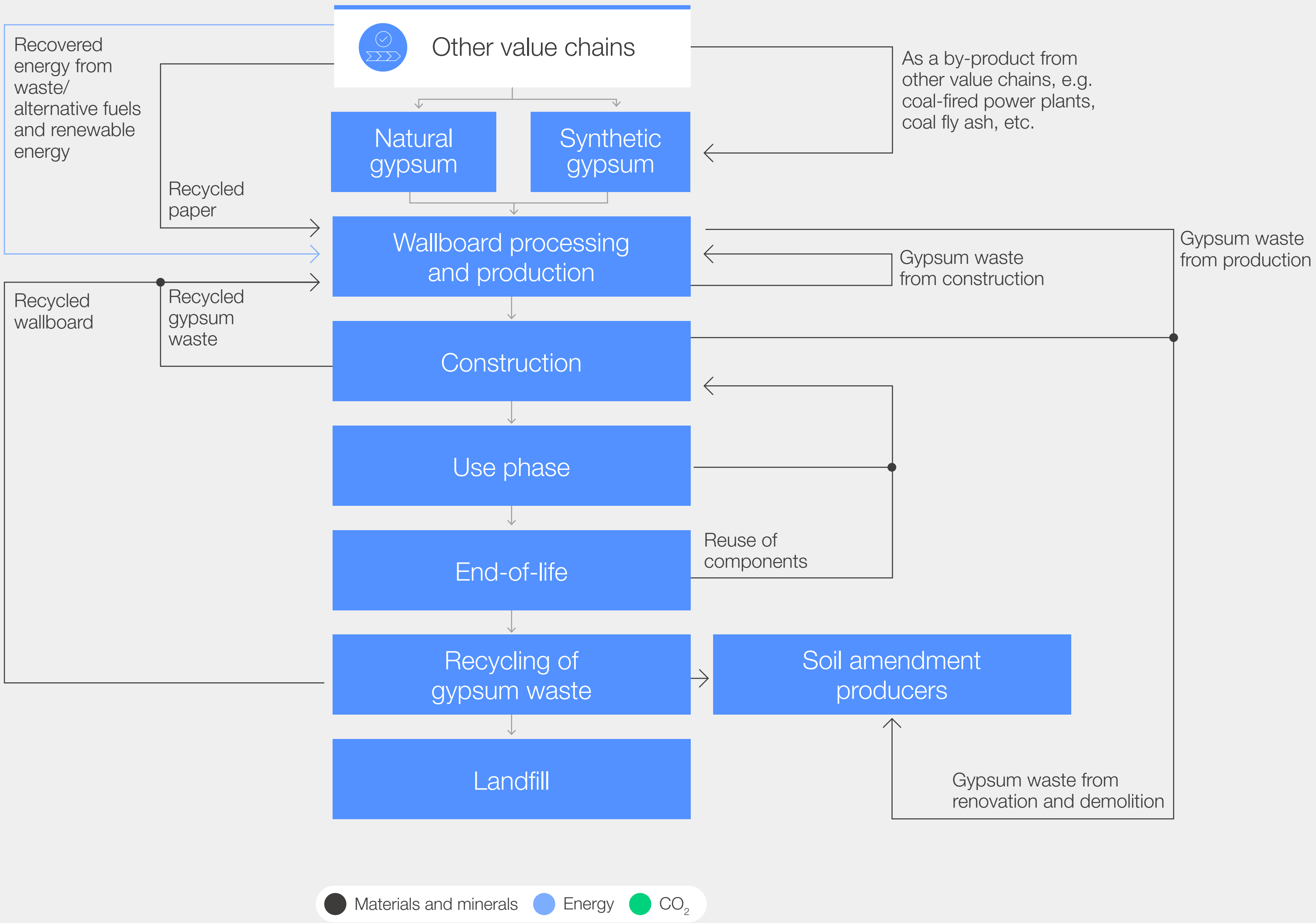
Gypsum is either found naturally in sedimentary rock, produced synthetically as a by-product of various industrial processes or recycled from construction and demolition waste – at a very low share currently. The global gypsum market amounted to around 350 Mt and $33 billion in 2020,[25] with construction being the main consumer of gypsum (around 96% of global demand) given its fire resistance and thermal insulation properties. Gypsum is mainly used in the construction industry to extend the setting time of cement (49%); in drywall (35%) used in walls, ceilings and partition systems; and plaster (12%). Half of the world's gypsum is mined, while the other half is synthetically produced, mostly from flue gas desulfurization (FGD) gypsum. As coal-fired power plants (producing FGD gypsum as a by-product) are phased out and natural resources in some regions are depleting, alternative options for gypsum production are being explored, such as phosphogypsum, gypsum solubilized from natural seawater and recycled gypsum, which is the only alternative option that is technically viable today.

Recycling of gypsum has great potential as it is infinitely recyclable and has a lower carbon footprint than primary gypsum. However, for gypsum to be extracted from cement, that cement needs to be recycled first. Recycling of gypsum plaster is also challenging due to other additives. Therefore, this analysis focused on gypsum boards. The current recycling rate for gypsum boards is only 1-7%, but it is increasing due to the mentioned resource scarcity, landfill regulations and customer demand for green materials.

To increase the circularity of gypsum boards, they can be recycled, downcycled into soil amendments and produced with a greater share of renewable energy in the gypsum drying process. Recycling of gypsum can be made more effective by increasing the use of pre-consumer scrap from production and post-consumer scrap from construction, renovation and demolition, as well as downcycling gypsum waste for use as soil amendment. Overall, circular gypsum offers an opportunity of $1 billion in annual net value gain by 2030 and $4-6 billion in 2050. This represents 1% and 3% of the total market size, respectively. These measures also have the potential to abate 2-3 and 4-5 Mt CO_2 in 2030 and 2050 (3-5% and 6-7% of total market emissions, respectively).

The recirculation of energy results in more moderate gains, namely around $1-2 billion in 2050 (1% of the market size), but has the potential to abate 3-6 and 9-17 Mt CO_2 by 2030 and 2050. This corresponds to 5-10% and 13-23% of total sector emissions. Finally, in addition to these levers, greening transport infrastructure will lead to further savings, as a large part of gypsum emissions can be traced back to transport.

FIGURE 9 | Circularity loops along the gypsum value chain



Source: McKinsey analysis, press search and expert interviews

Conclusion: Driving the circularity transition in the built environment

Key elements to accelerate the circularity transition

There are three clear actions individual players and the ecosystem as a whole can initiate today to capture the displayed potentials: 1) promoting collaboration across the value chain, 2) promoting circular thinking and capability development, and 3) using digital technologies.

1. Collaboration and extensive coordination are essential to address the decentralized nature of the value chain. The built environment is characterized by a highly fragmented landscape where vast coordination is required across a high number of sub-scale players to close resource loops. Moreover, many of these actors do not have relationships from traditional linear supply chains. Stakeholders should actively promote integration, partnerships and standardized requirements for circular materials across assets and regions to ensure smooth recirculation. For instance, material suppliers can collaborate with designers and contractors to develop reusable materials and promote interchangeability. Reverse supply chains between manufacturers and deconstruction or waste handling players can ensure a sufficient supply of secondary material to produce new products. Established collaboration models have successfully facilitated the transition to a circular economy in other industries, such as consumer or automotive, hinting at significant value-capture opportunities in the built environment.

2. Circular thinking and capability development are fundamental to anchoring circularity in built environment organizations. Despite some early adopters increasing circular activities, the built environment is still largely a linear value chain. To address this, formalized ideas and best practices should be disseminated and shared among peers. Particularly, circular mindsets in the early stages of a project and design are critical in determining the environmental impact of a built asset over its lifetime. By the time the construction process begins, most decisions affecting the project's greenhouse gas (GHG) emissions are already locked in. Key design decisions have an impact on emissions for decades to come. When building new, actors should prioritize circular design practices such as designing for disassembly and using modular construction. Relatively easy reuse, repair and recycling should be factored in when selecting products and materials.

3. Digital technologies can create transparency on secondary materials and the overall material life cycle, which, in turn, can promote material exchange and urban mining. Such practices can also reduce uncertainty around lead time or demand-side price spikes as "mining" from cities themselves makes a supply chain more localized. Moreover, digital solutions can tackle the challenge of navigating within the fragmented and multi-level industry structure. Technological enablers include digital material passports, digital twins and technology to track and manage assets. Digital material marketplaces can consume this data for material, product or system resale. Generative design algorithms can optimize new buildings, maximizing reused materials based on what is available locally. Stakeholders can use these technologies, combined with at-scale material testing processes, to implement circular levers earlier on in the planning and construction process.

A call to action to identify circularity lighthouses

The circular economy provides a path to decarbonization but will also shift value pools from the products and players anchored in the traditional, linear economy to the ones driving and accelerating the circularity transition. This white paper has discussed the issue of circularity at a material level, looking at target dates of 2030 and 2050. However, the change is already starting to happen, and the industry ecosystem needs to position itself today to capture the outlined potential in the future.

Circularity lighthouses showcase leadership, demonstrate innovative applications at scale and bring industry actors together to collaboratively accelerate the circularity transition, inspiring others to follow. Lighthouses embrace a disruptive, collaborative agenda, even among traditional competitors or across value chains. They approach the circular transition proactively and develop industry-leading solutions rapidly. They establish new circular business models beyond the traditional value architecture and demonstrate their environmental impact, scalability and financial viability. Industry players developing lighthouses and acting as accelerators will have an advantage in capturing the value behind the circular economy, gaining market share, driving the way forward and locking in partnerships.

A lighthouse-driven approach can be a booster to ensure collaboration, advance circular thinking and capability development, and disseminate digital technologies across a decentralized built environment. The built environment is called to action to identify those leading lighthouses and make them visible to the ecosystem.

Appendix: Modelling assumptions and results calculation

All net value gain and abatement potential values provided are calculated for the circular scenario compared to the business-as-usual (BAU) scenario. For the circular scenario values, ranges represent conservative and ambitious circularity assumptions (lower and upper bound). Abatement and net value gain potential as a share of total sector emissions or market size are calculated considering total estimated emissions and market size in a BAU scenario in the respective years (i.e. 2030 and 2050).

For cost calculations, including carbon price and landfill tax, a CO_2 price of $5.50 and a landfill tax of $20.00 are assumed in 2020. These are estimated to rise to $88.00 and $120.00, respectively, in 2050. Prices are free of inflation. It is assumed that more countries will implement moderate landfill taxes in the range that can currently be observed today. Further, it is assumed that the price of carbon credits will slowly equal CO_2 prices over the long term.

Other costs used in the models, such as the cost of carbon capture technology and carbon storage, fossil fuels, biomass and other alternative fuels (waste excluding biomass), as well as their associated emission factors, are derived from expert assessment based on global market analysis, reports and press research. Given that the modelling considers the impact within the overall value chain (building life cycle), additional or avoided emissions from the transport of products and materials have not been assumed. Moreover, there is uncertainty in modelling these emissions at a global level given the uncertainty in estimating actual distances required, as infrastructure is not fully established yet at scale, and, in a circular economy, the supply chain would be more localized.

Furthermore, assumptions made are generalized for the modelling to be at a global level. In practice, it is acknowledged there might be regional and local differences in the market, regulation, technologies, infrastructure and logistics, hence actual levers potential.

Contributors

World Economic Forum

Fernando Gomez
Head, Resource Systems and Resilience;
Member of the Executive Committee, Better Living, Centre for Nature and Climate

Anis Nassar
Lead, Resource Circularity, Better Living, Centre for Nature and Climate

Jörgen Sandström
Head, Transforming Industrial Ecosystems - Energy and Materials

McKinsey & Company

Maximilian Gebhardt
Consultant

Janice Klaiber
Consultant

Jukka Maksimainen
Senior Partner

Sebastian Reiter
Partner

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Production

Rose Chilvers
Designer, Studio Miko

Laurence Denmark
Creative Director, Studio Miko

Martha Howlett
Editor, Studio Miko

Endnotes

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World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org