SYSTEMIQ

THE CASE FOR CONCRETE RECYCLING IN ROTTERDAM

Could Rotterdam be the first region to close the loop on concrete?

Clean Tech Delta

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ACKNOWLEDGEMENTS

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INTRODUCTION: THE CONCRETE OPPORTUNITY IN ROTTERDAM'S CIRCULAR ECONOMY

This short paper explores the potential in Rotterdam of one economic activity that would significantly reduce emissions while strengthening the economy: **concrete recycling** – an opportunity to turn Rotterdam's largest material flow circular. This paper was written by Systemiq in collaboration with the **Clean Tech Delta**.

Rotterdam is world renowned for its strong industrial sector, as the home of the largest port in the Western world, a major oil and gas cluster and accompanying industrial activity. Its diverse and technically skilled population, its knowledge institutions, culture of action, and solid digital base add to the strong position that Rotterdam currently holds. A downside of Rotterdam's leading position in these industries is that the region is especially exposed to economic stagnation, stranded assets, and lost jobs as a result of the transition away from fossil fuels. Two facts highlight the scale of the issue: today, the area managed by the Port of Rotterdam emits 15% of all greenhouse gas (GHG) in the Netherlands;[i] bringing those emissions down to net-zero by 2050, as both the city and the port have committed to, is a huge operation. The port-industrial area gives rise to 385,000 jobs.[ii] This means that the stakes are high for many families in Rotterdam and the wider region. The challenge is to achieve a swift transition to a new economy, while safeguarding economic activity and employment and keeping Rotterdam a great place to live. The best way to approach the economic challenge is to build on the advantages that make Rotterdam an exceptional place to do business: its scale, its logistical excellence, its people and culture.

The need for a circular economy in Rotterdam

The transition to a net-zero economy can only be called a success if it works for broad groups in society, if it builds social and climate resilience and if it fits in a world that is rapidly digitalizing. Climate neutrality, circularity, resilience and digitalization are often approached in a siloed way – no surprise given the complexity of these challenges. In mid 2022, a vision was published that takes all four themes simultaneously into account. The ***Green and Digital Deal for Rotterdam***, as it is called, makes the case for one integrated approach centered around citizens' needs.[iii] It articulates six missions for Rotterdam *(Exhibit 1)*: missions A, B and C focus on making the city itself resilient; D and E are about future-proofing the economy and F proposes a new perspective on governance.

EXHIBIT 1 | 6 MISSIONS FOR ROTTERDAM

Mission	Sub-missions
A RESILIENT CITY	
A FUTURE-PROOF URBAN INFRASTRUCTURE	**A1** Integrated infrastructure for urban systems **A2** Digitalization of these urban systems
B KNOWLEDGE AND SKILLS FOR THE FUTURE	**B1** Workforce of the future **B2** Equal opportunities for all in a digital and circular world
C VIBRANT COMMUNITIES	**C1** Climate neutral and circular physical environment **C2** Social capital in a network society
A FUTURE-PROOF ECONOMY	
D CLIMATE-NEUTRAL AND CIRCULAR PORT-INDUSTRIAL COMPLEX	**D1** Hydrogen (and biobased) hub **D2** Climate-neutral and circular basic chemicals **D3** Climate-neutral and circular logistics
E NEW CIRCULAR BUSINESS	**E1** Circularity innovation and knowledge hotspot **E2** Circular manufacturing, repair and recycling industry **E3** Circular services (x-as-a-service and commodities trading)
F HOLISTIC, MISSION-DRIVEN GOVERNANCE MODEL	**F1** Policy management based on a broad measure of citizen well-being **F2** Mission-driven and investing government

Concrete recycling, the focus of this paper, touches on both elements of 'future-proofing the Rotterdam economy' (missions D and E). According to the Green & Digital Deal for Rotterdam, these missions entail:

- **Mission D: Making the port-industrial complex and its activities climate-neutral and circular.** This involves a fundamental turnaround of current activities in the port-area. In doing so, Rotterdam can leverage current (scale) advantages such as reliable infrastructure, strategic position near open-sea and inland waterways, and innovation hotspots in and around Rotterdam
- **Mission E: Stimulating new circular value chains including manufacturing, repair, refurbishment, remanufacturing and recycling.** As a central node for transportation, Rotterdam has the key to unlock significant value in a circular economy. Doing so requires fostering innovation, setting up demonstration plants, ensuring off-take for recycled materials and feedstock to recycle.

Transitioning the port-industrial complex towards a carbon-neutral circular future (D) is crucial and necessary, but it may not be enough to maintain the levels of economic activity and employment required to underpin a vibrant and dynamic region. This is where Mission E "New Circular Business" comes in. Turning Rotterdam into the center point of an emerging European circular economy offers tremendous potential to develop new economic activity – perhaps to such an extent that it delivers a 'boost to Rotterdam's economy akin to the opening of the "Nieuwe Waterweg" canal to the sea in 1872 that gave the port its leading position'.[iv]

Why concrete matters in building a circular economy

Developing a circular economy is all about improving resource productivity: how to get more economic and social value per ton of resource (material and energy) used. In defining circular opportunities for Rotterdam, a good starting point is to look at the largest material flows through the city. In the report *Circular Rotterdam*, Metabolic and Circle Economy estimate that end-of-life **concrete represents 25% of the material flows** through the city of Rotterdam, or 200 thousand tons (kt).[v] To this is added 90 thousand tons of concrete (demolition) waste generated in the port-industrial complex, as the report 'Rotterdam: Towards a circular Port" estimates.[vi] Taken together, 290 kt of end-of-life concrete was generated in 2015. This is projected to grow to 390 kt in 2030.[1,vii,viii] This makes concrete the largest material flow in Rotterdam, an order of magnitude larger than e.g. metals (17 kt) and plastics (12 kt). This fact alone makes developing a circular economy around concrete a crucial element of a circular economy in Rotterdam.

Today, nearly all used concrete in Rotterdam is downcycled, typically for use as filler for road construction (*Exhibit 2*).[ix] This means it is not used to make new concrete. Recent technological innovation has made it possible to break down waste concrete and salvage its components: sand, aggregate (gravel), and cement paste. These can be used as input for new concrete, substituting up to half of the materials that are now used to make concrete.[2,x] These technologies are developing rapidly. No city has yet established itself as the hotbed of concrete recycling technology. There is an opportunity for Rotterdam to become a global pioneer in bringing the technology to scale.

As we will see in the next section, concrete is a carbon-intensive material. The combination of large volumes and high carbon-intensity means that **concrete alone accounted for 7% of Rotterdam's carbon emissions** in 2015 (excluding the port).[3,xi,xii,xiii] Recycling represents an important lever to bring these emissions down, especially if virgin concrete can be (partially) substituted by processed end-of-life concrete. For Rotterdam, this could result in an estimated reduction of 15 kt CO_2 of Rotterdam's annual greenhouse gas emissions (0.4%), growing to an estimated 135 kt CO_2 (3.5%) over time,[4] and salvage the economic value of 290 kt of waste.[xiv,xv,xvi]

EXHIBIT 2 | END-OF-LIFE CONCRETE CAN BE DOWNCYCLED, RECYCLED OR RESET

	Current practice **Downcycle**	Focus of this document **Recycle**	Future north star **Reset**
What happens?	Concrete is crushed	Concrete is processed into sand, gravel and clinker substitute	Concrete is (chemically) processed back to original raw minerals
Where is the output used?	Crushed concrete is used as low-value construction material – mainly as foundation for roads	Output products can be used in construction, replacing primary materials	Raw materials can be used for all the same purposes as virgin materials
How developed is the technology?	Fully scaled: most concrete is downcycled at end-of-life	Commercially ready: Sand and gravel Demonstration phase: Clinker substitute	Early (laboratory) development
TRL	10	6-9*	3-4**

** Salvaging sand and gravel is at TRL 9, while salvaging clinker substitute is at TRL 6*
*** Estimated based on own analysis*

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1 Assuming 2018-2030 yoy growth of construction & demolition waste is equal to 2010-2018 growth (2%)
2 Highly dependent on the type of material. Recycled sand can substitute up to 100% of virgin sand, but recycled clinker substitute (cement paste) can substitute 5-35% of virgin clinker depending on local policies and quality of the cement paste
3 Based on the emissions for producing the 225 kt concrete used in the City of Rotterdam in 2015 and an emission factor of 1 t CO_2/t concrete
4 CO_2 emission reduction depends on the composition of concrete waste and how much clinker can be replaced by recycled substitute. Lower end of range based on 290 kt concrete waste (2015) and 5% substitution factor, higher end of range based on 390 kt concrete waste (expected 2030) and 35% substitution factor, assuming emission factor of 1 t CO_2/t concrete

I CONCRETE RECYCLING AS A LEVER TOWARDS A CIRCULAR, NET-ZERO ECONOMY

In the fight against climate change and resource scarcity, addressing the GHG impact and waste flows associated with concrete is a big lever. What we saw for Rotterdam is true for the world. **Concrete production is responsible for ~7-8% of global GHG emissions** and represents the single largest waste flow in the world.[xvii]

Concrete represents significant waste flows and GHG emissions

Concrete is the most used human-made material on earth with an annual production of fourteen billion cubic meters per year.[xviii] For comparison, the concrete industry produces more concrete every two years than the total plastic industry has done over its lifetime of 60 years.[xix] In the Netherlands specifically, end-of-life concrete currently accounts for **~12 million tons of waste** flows annually.[xx] This is half of all building and demolition waste, ~20% of total solid waste and ~50% more than all household waste combined.[xxi]

In addition to exceptionally large volumes of waste, concrete production accounts for **~3 billion tons of CO_2 equivalent** per year, or ~7-8% of global human emitted GHG.[xxii] Advancing circularity in the concrete and cement sector is thus a major lever in the transition towards zero waste and zero emissions.

GHG-emissions in concrete production are hard to abate

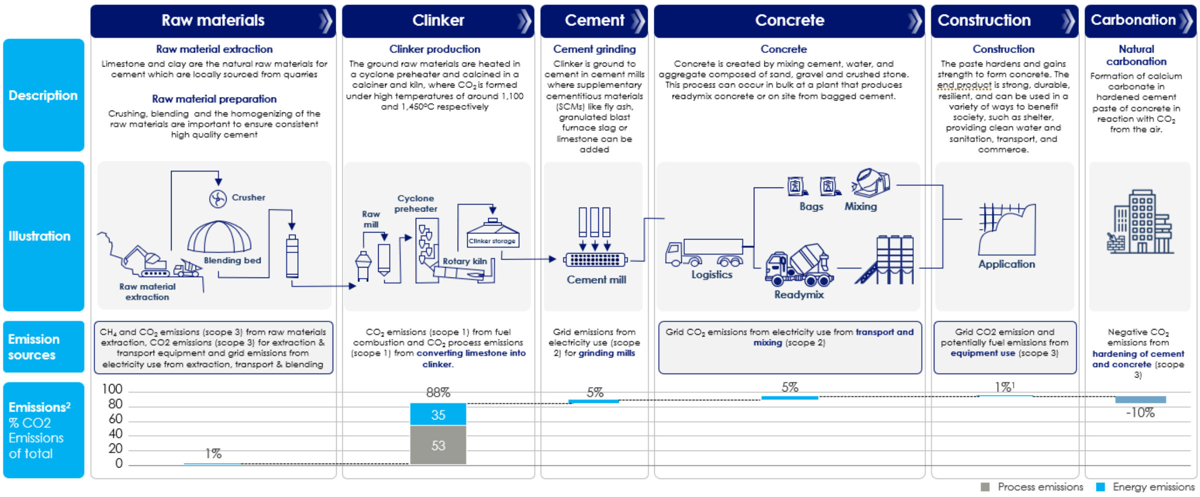
The chemistry of the production process makes it difficult to abate the CO_2 emissions that arise from concrete production (*Exhibit 3*).[xxiii] Per production step:

1. **Extraction and preparation of raw materials**[5] represents only a small part of total end-product GHG emissions (<2%)
2. In contrast, **production of clinker** involves heating ground raw materials at temperatures exceeding >1100 °C. The energy required to achieve such high temperatures accounts for ~35% of total end-product GHG emissions. The chemical process that occurs when clinker is created accounts for another ~50%
3. **Grinding clinker to cement** accounts for ~5% of GHG emissions
4. **Production of concrete** by mixing the cement with other raw materials such as gravel, water and sand (including transportation) adds 5% of emissions
5. **Construction of the building** adds another ~1% of emissions, while natural carbonation after construction reduces lifetime emissions by about 10%

The **bulk of emissions arise during step 2, the clinker making process (85-90%)**. This step is particularly hard to decarbonize. Achieving temperatures of >1100 °C requires high energy density, only achieved through combustion of coal, natural gas or fossil waste. Currently the only proven technology to decarbonize this is using green hydrogen, which is today still low in supply and will not be sensible from a cost-competitiveness and hydrogen-scarcity perspective to use in the cement sector for a long time. Even more difficult is abating the >50% process emissions that occur chemically when producing clinker.

[5] Sand, water and a closely controlled combination of materials including calcium, silicon, iron and aluminium.

EXHIBIT 3 | MOST EMISSIONS IN THE CONCRETE SUPPLY CHAIN RESULT FROM CLINKER PRODUCTION



1 Further analysis needed | 2 Other construction materials are not considered in this analysis
Source: Decarbonisation Pathways for the Australian Cement and Concrete Sector, McKinsey 'Laying the foundation for zero-carbon cement', Material Economics Industrial Transformation 2050, GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete

Recycling is an important lever to reduce GHG emissions and waste flows from end-of-life concrete

As substitutes for concrete[6] are limited, other means to reduce GHG emissions and waste flows are needed. Three main actions are to i) **reduce demand**, ii) **capture GHG** using carbon capture, utilization and storage (CCUS) in production; and iii) **re-use end-of-life concrete** (*Exhibits 4 and 5*).[xxiv,xxv] As shown in Exhibit 5, there are three different methods to re-use end-of-life concrete. This document covers the second one: recycling.

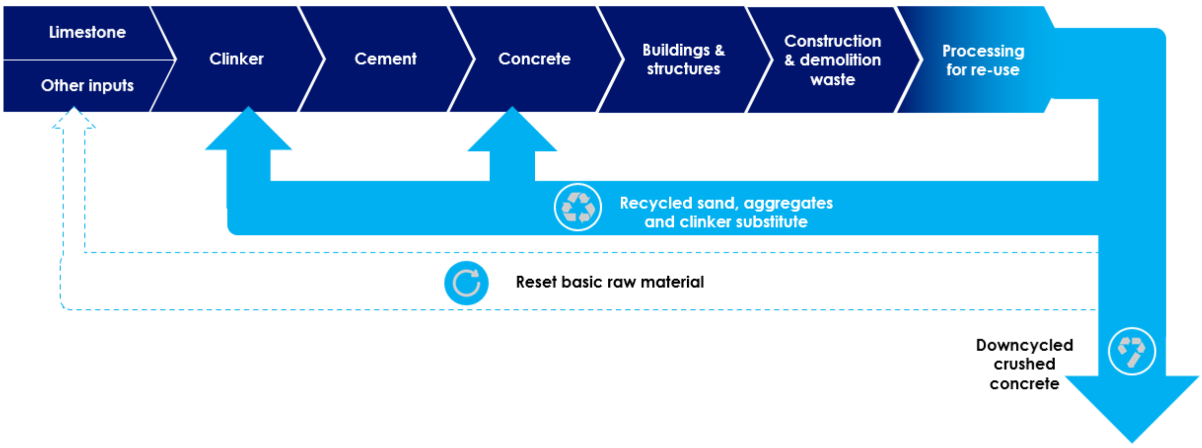
[6] Timber is sometimes mentioned as a substitute, but difficult to scale: if 25% of global annual concrete use were replaced by timber, a land area 1.5 times the size of India would be necessary for the production forest (ETC, Making Mission Possible (2018)).

EXHIBIT 4 | THREE MAIN LEVERS FOR GHG AND WASTE REDUCTION FROM CONCRETE

Strategy	Approach	Potential for Circularity	Potential for Net-Zero
Reduce	Reduce the amount of concrete needed by efficient design & construction	Up to 20% material use reduction at low cost[3]. Waste reduction materializes only at next building and infrastructure lifecycle (~50-100 years)	Up to ~20% of GHG abatement at low cost
	Reduce production losses by using bulk versus bags of cement	No impact	Up to ~ 10% of GHG abatement
	Reduce clinker and cement use and emission intensity of production	No impact	Up to ~20% of GHG abatement through savings in clinker production, already done today
Capture	Leverage CCUS to capture up to ~70-100%[2] of GHG emissions in the clicker making process	No impact	Up to ~35% of GHG abatement at high cost, no commercial scale projects to date
Re-use	**Downcycle** used concrete by crushing it and using the aggregate for road foundations or mixing it with new materials	Up to 100% waste reduction at low cost. Concrete can be fully downcycled, but quality declines	Near zero impact as downcycling does not replace the need for new clinker or cement
	Recycle used concrete into clinker substitute and raw materials (sand and gravel)	Majority of waste suitable for high quality recycling. Recycled materials can replace 5-100% of virgin materials	~5% at current TRL and regulation up to ~35% potential in the future
	Reset *used concrete into basic minerals and raw materials*	*TBD – at TRL 3-4*	*TBD – at TRL 3-4*

Focus of this document

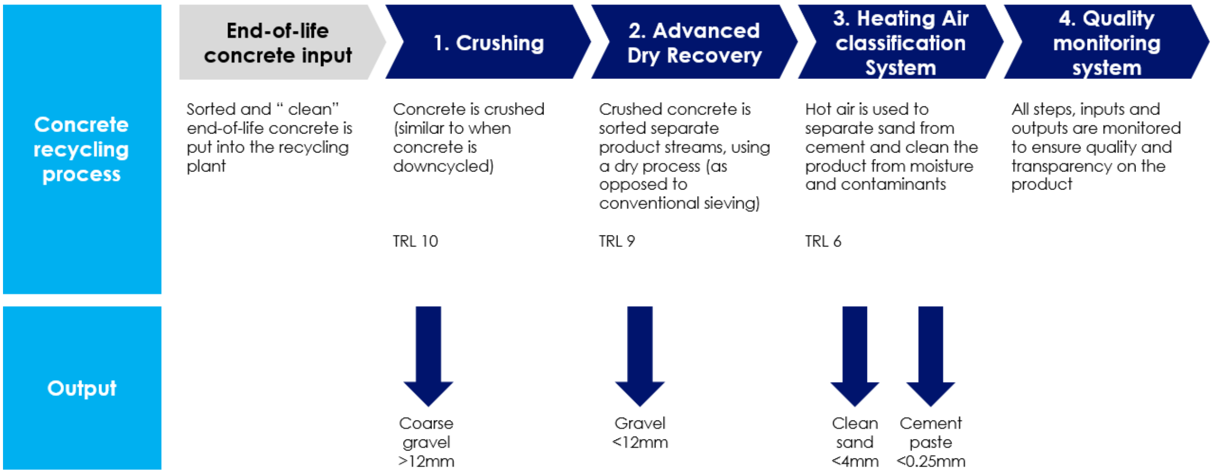
EXHIBIT 5 | THREE PROCESSING METHODS PRODUCE DIFFERENT QUALITY LEVEL MATERIALS FOR RE-USE



Recycling end-of-life concrete is currently nascent but has clear business potential

Start-ups like C2CA, SmartCrusher, and incumbents like Elkon and Sika are disrupting the recycling landscape: with their technologies, **recycling of concrete at high quality has become possible**, albeit still at a small scale *(Exhibit 6)*. Most of their work has been focused on demonstrating the technological feasibility of the recycling process. The next step will be to scale up these technologies.

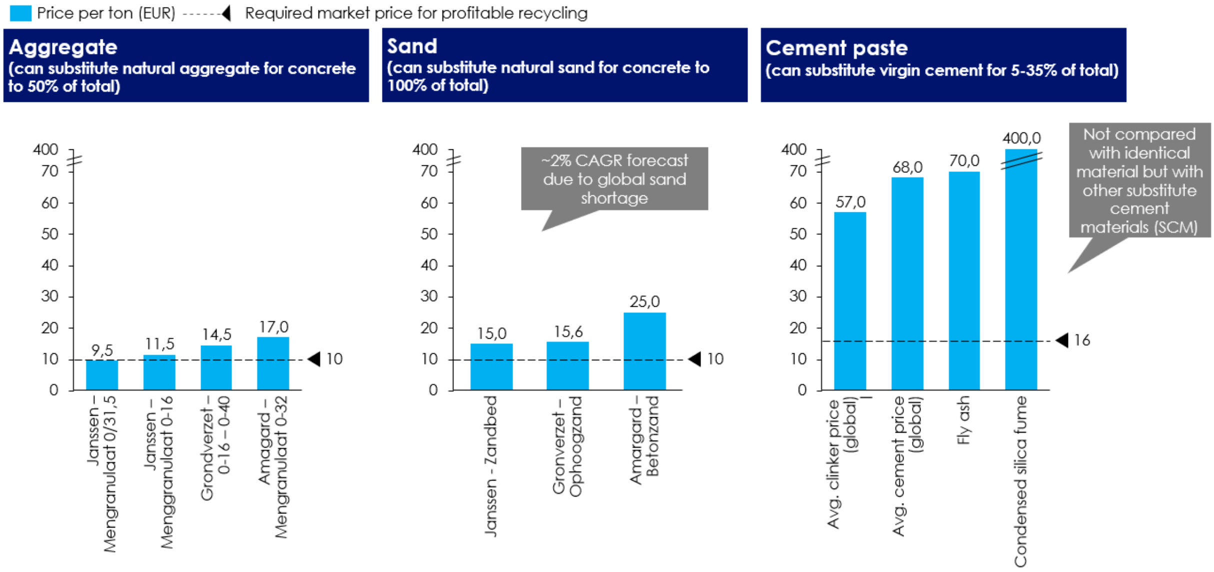
EXHIBIT 6 | EXAMPLE OF A DUTCH CONCRETE RECYCLING TECHNOLOGY



The sand and gravel salvaged from end-of-life concrete can replace 50-100% of virgin raw materials in concrete production. The salvaged cement paste is a supplementary cementitious material (SCM) that can currently substitute ~5% of virgin clinker.[xxvi] This share is expected to grow to up to 35% in the future depending on technological improvement further improving the quality of the cement paste, and government regulations that dictate for each SCM the share of virgin clinker it can substitute. It is important that this share increases in the future, as the replacement of virgin clinker poses the largest reduction in GHG emissions from concrete production.

The business case for recycling concrete is highly dependent on two factors. First is raw materials prices. Recycled outputs (gravel, sand and cement paste) are sold at market price and determine the profitability of the plant. Second is transportation and storage costs. Low value per ton of weight but high costs of transportation and storage can increase total costs of recycling concrete rapidly. Therefore, it is important to build concrete recycling plants close to urban centers (for end-of-life concrete feedstock) and close to waterways (for cost-effective transportation).

EXHIBIT 7 | NEW RECYCLING TECHNOLOGIES ARE COMPETITIVE AT CURRENT MARKET PRICES FOR RECYCLED OUTPUT



Under favorable conditions with regard to the location of the recycling plant, **new recycling technologies should – at scale – already be competitive in the Dutch market under current materials prices** (*Exhibit 7*). Resource scarcity, rising energy prices and a growing global demand for construction are expected to push materials prices up in the future while technology costs of recycling should reduce resulting from further innovation and scale advantages, further improving the business case.

II 3 ROADBLOCKS THAT HAVE PREVENTED CONCRETE RECYCLING FROM TAKING OFF SO FAR

Concrete recycling technologies are currently in the demonstration phase and should soon be ready for commercialization. Through a consultation of stakeholders in the Rotterdam concrete cluster and global experts on cementitious materials, Clean Tech Delta has identified **three major roadblocks** for concrete recycling at scale: i) **lack of transparency** and coordination on (high-quality) material flows, ii) **lack of coordination** throughout the value chain, and iii) **inadequate regulations and standards** (*Exhibit 8)*.

i. **Lack of value chain coordination.** Building a recycling plant for concrete is just one step in a concrete recycling value chain. Both upstream (a supply of cleaned and sorted end-of-life concrete) and downstream (an off-taker of the recycled materials) action is required. Exhibit 8 shows a typical path from financing through utilizing and demolishing a building, a process that involves many stakeholders. Decisions throughout this value chain are made in a fragmented manner, and sometimes years or decades apart. This is problematic because decisions taken early on (construction design, materials used, etc.) have an impact on the recyclability of the building at end-of-life. It is also problematic because incentives to utilize sustainable materials in construction are not consistent across the chain: investments made by one player may result in benefits for another company. At the same time, information asymmetry along the value chain can mean that

that those with the incentive to build greener buildings are not necessarily the ones with the knowledge on sustainability options.

ii. **Lack of transparency on (high-quality) material flows.** To ensure that demand meets supply both for recyclers as well as for builders, insight into material flows and their quality must improve dramatically.
   a. *Availability of recyclable end-of-life concrete.* There is currently no central overview of expected end-of-life concrete flows in the Rotterdam area. This makes it difficult for players to match these flows with planned construction projects. This issue is compounded by the fact that there is a lack of (transparency on) the quality of materials. Current demolition practices often lead to contamination of potentially recyclable concrete with other materials, and there are no adequate collection and sorting hubs available.
   b. *Utilization of recycled input for new concrete.* There is limited monitoring of material quality for recycled products. If the waste processor cannot underwrite the recycled material's quality and technical characteristics, contractors will be hesitant to use it in construction. This is especially the case for clinker substitutes.

iii. **Inadequate regulations and standards.** Construction regulations on the use of recycled materials do not reflect the latest state of concrete recycling technology. For example, NEN-standards prescribe a maximum substitution rate of primary materials by recycled granulate of 20-50%, while experts indicate that safe replacement at higher rates is possible.[xxvii] Current regulations also lead to too little financial incentive along the value chain to recycle concrete. With virgin concrete being comparatively low-cost, value chain players may see too little upside in going through the hassle of setting up a concrete recycling value chain, despite the obvious benefits to society laid out in the previous chapter.

EXHIBIT 8 | ROADBLOCKS FOR CONCRETE RECYCLING ARE PRESENT IN ALL 6 STEPS OF THE CURRENT VALUE CHAIN OF THE CONSTRUCTION AND DEMOLITION OF A BUILDING

	Financing	Planning & design	Construction	Use	Demolition	Waste processing
Stakeholder involved	Investor	Project developer Architect (local) government	Project developer Contractor Suppliers	User	Demolition company	Waste processor
Role in typical building construction process	• Investor decides to finance a project, or developer finds investor for a project • Budget, scope and timeline are decided upon	• Location is selected • Architect designs building • Developer sees to performance • Permits are secured	• Contractor sources materials from suppliers (ensures to meet performance criteria) • Contractor executes building plans	• Building is used	• Building is demolished at end-of-life	• Building waste is processed (landfilling not allowed in NL)
Roadblocks for increased recycling	• Lack of (financial) incentive to use recycled materials • Lack of (financial) incentive to ensure building recyclability	• No overview of available recycled materials • Lack of up-to-date regulation • Public tenders not set up to promote recycling • Design not optimized for recyclability	• Lack of insight in availability and characteristics of recycled materials • Limited experience with integrating recycled materials in construction • Construction not optimized for recyclability		• Demolition not optimized for recovering materials (high contamination) • Lack of financing for increased demolition costs	• No overview of demand for recycled materials • Lack of funding for recycling • Limited monitoring of material quality • Limited scale of recycling operations

III ROTTERDAM'S POTENTIAL TO TAKE THE LEAD ON CEMENT RECYCLING

On balance, Rotterdam is an attractive location for developing a cement recycling hub at scale. If successful, as was pointed out above, concrete recycling can play a central role in Rotterdam's transition towards a circular and net-zero economy.

Four factors favor Rotterdam as a location for concrete recycling: i) its **strategic location** on main logistics routes, ii) a strong **local concrete and recycling expertise** and activity, iii) **material flows** in and around Rotterdam, and iv) **progressive national and local policies**. The main drawback of Rotterdam is that land prices are comparatively high due to its privileged logistical position. This fact has not prevented the emergence of a strong commodities cluster. In other industries, the benefits of scale and low logistics costs have shown to balance out higher costs for land.

EXHIBIT 9 | STAKEHOLDERS IN CEMENT, CONCRETE AND RECYCLING ARE PRESENT IN ROTTERDAM

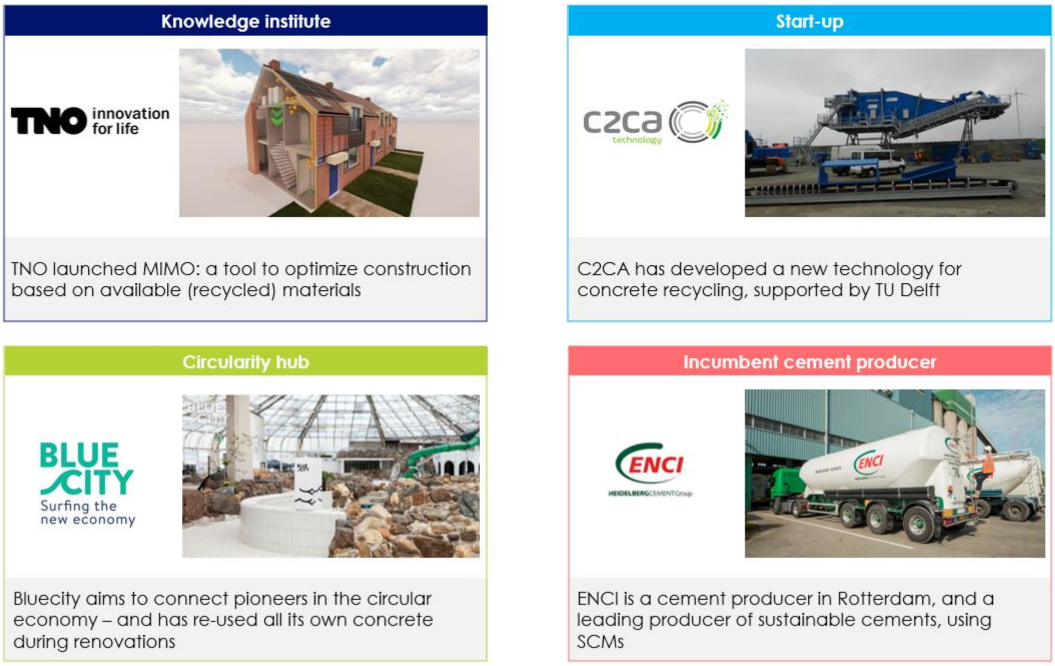
Not exhaustive

1. ENCI Rotterdam (Botlek)- Cement producer (600 kt)
2. PSD Beton – Concrete producer
3. Struyk Verwo Infra- Concrete producer
4. Mebin Rotterdam Brienenoord- Concrete producer
5. DCC – Demolition company
6. Oranje BV- Demolition company
7. REKO Recycling Combinatie- Recycling company
8. Bnext.nl (Beelen)- Recycling company

i) **Strategic location.** Exhibit 9 demonstrates the strategic location of Rotterdam for concrete recycling: the abundance of and proximity to main waterways. This is important because the weight and volume of concrete makes that it can best be transported via water. Both end-of-life concrete waste streams as well as recycled output can as such be economically transported.

ii) **Existing players.** The full value chain of concrete is present in Rotterdam; as well as an extensive recycling sector for other commodities (*Exhibit* 9) – embedded in a strong, triple-helix ecosystem of academia and the wider port-industrial complex. Knowledge institutions in the region are working on key aspects of concrete recycling: Delft University of Technology has a 'Resources & Recycling' research group that studies concrete recycling,[xxviii] and TNO is developing methods to scale the use of recycled concrete in construction.[xxix] Exhibit 10 shows examples of innovation across the ecosystem in the Rotterdam region. Additionally, the large port-industrial complex provides an opportunity for additional synergies with concrete production and recycling: waste streams from power and steel plants can be used as clinker substitutes. Also, from a cluster perspective, the chemical hub present in Rotterdam could play a role in the further development of enhanced absorption of carbon into concrete (recarbonation).

EXHIBIT 10 | EXAMPLES SHOW ROTTERDAM'S ECOSYSTEM IS DRIVING INNOVATION IN CIRCULAR CONCRETE



iii) **Material flows.** For concrete recycling to be economically feasible, sufficient feedstock (end-of-life concrete) needs to be available at proximity, in order to keep transportation costs low. C2CA estimates that one at-scale facility requires about 220 kt of concrete per year to operate at the required utilization rate. This figure compares to an estimated 290 kt of concrete granulate was available for repurposing in 2015, originating from the city of Rotterdam (200 kt) and the Port of Rotterdam (90 kt).[7, xxx, xxxi, xxxii] By 2030, this concrete granulate waste stream could grow to 390 kt.[8,xxxiii]

Additionally, while demand for clinker substitutes will likely grow as decarbonization targets increase, supply of clinker (substitutes) is limited and declining the Netherlands: the Netherlands is one of very few countries with a very limited domestic limestone supply (a key ingredient of virgin clinker). Specifically in industrial regions such as Rotterdam, decarbonization in the power and steel sector will drastically reduce availability of traditional clinker substitutes such as fly ash.

iv) **Supportive policies.** Inadequate regulations were identified as a roadblock in the previous chapter, based on input from Rotterdam stakeholders and international experts. This does not mean that the policy environment in the Netherlands is unfavorable compared to elsewhere. In fact, Dutch government policies are comparatively supportive to concrete recycling. The Dutch government has set ambitious targets to reduce CO2 emissions

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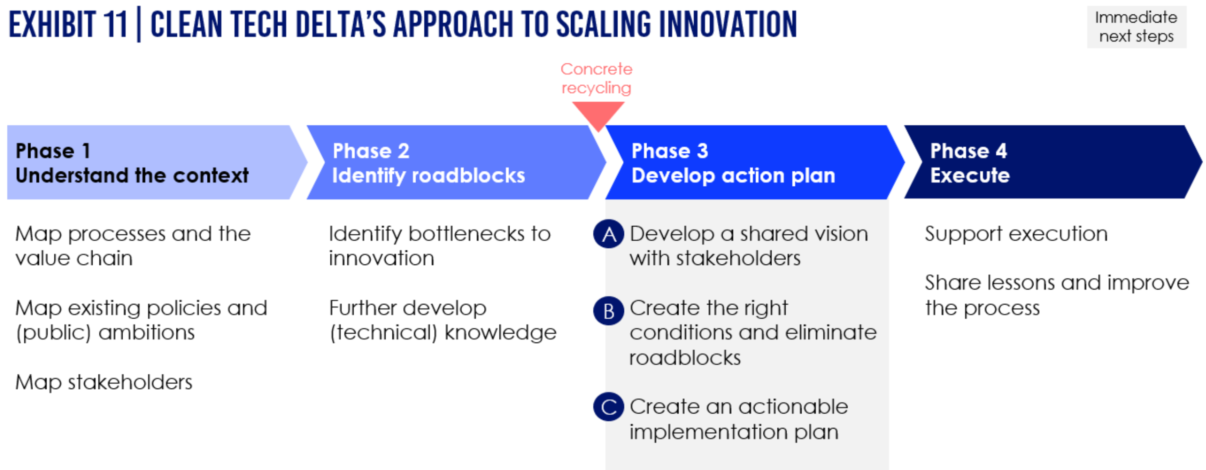
[7]Assuming that 60% of construction & demolition waste is concrete waste, as 60% of material used in buildings is concrete.
[8] Assuming 2018-2030 yoy growth of construction & demolition waste equal to 2010-2018 growth (2%).

by 49% and primary material use by 50% by 2030.[xxxiv,xxxv] It is a co-signatory of the 2018 ‘Concrete Agreement (Betonakkoord)’, which includes 2030 targets for 30% CO_2 reduction, and 100% high-value recycling of concrete.[9,xxxvi] This provides a strong basis to address remaining policy roadblocks. Locally, the municipality of Rotterdam has the additional aim to reduce primary material use by 50% by 2030, as described by the ‘Programma Rotterdam Circulair 2019-2023’.[xxxvii] In this program, the built environment is featured as one of the four key sectors to transform to reach this target.

IV NEXT STEPS FOR ROTTERDAM TO CAPITALIZE ON THE OPPORTUNITY

Clean Tech Delta (CTD) – the triple helix organisation that has commissioned this paper[10] – identifies four distinct phases for developing innovation clusters (*Exhibit 11*). In the first phase, CTD gathers information: it maps the value chain, current policies and stakeholders. In the second phase, CTD identifies bottlenecks and gets an even deeper understanding of the subject. In the third phase, CTD uses its understanding of the cluster to create a shared vision for the future, draft plans for implementation and facilitate the right conditions. The fourth and final phase is about action: the cluster is well underway, with CTD supporting and monitoring in the background.

EXHIBIT 11 | CLEAN TECH DELTA’S APPROACH TO SCALING INNOVATION



Today, concrete recycling in Rotterdam is about to enter the third phase of the innovation cluster process. This would suggest three immediate next steps: A. to develop a shared vision with stakeholders; B. to create an environment conducive to innovation and eliminate roadblocks, and C. to develop an implementation plan.

A. Develop a shared vision with leading parties along the built-environment value chain

Developing a shared vision with leading parties in the Rotterdam built-environment value chain addresses roadblock (i) identified above in section II (‘lack of value chain coordination’). This could take the form of round table sessions in which parties identify what it takes to drive concrete recycling in Rotterdam, and what the roles and responsibilities of each could be. This is not a

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[9] 30% reduction based on 1990 CO2 emissions; agreement contains ambition to reduce further to 49%.
[10] The Clean Tech Delta is introduced in chapter V

matter of ‘the more the merrier’; what counts is that those parties are present that could make an initial recycling facility successful.

The main onus of this shared vision should lie with the private sector. This requires action both from players that produce or have access to demolition waste (e.g. by improving demolition practices to produce higher-quality waste concrete; or providing waste to recycling plants instead of e.g. road construction companies) and from potential offtakers (willingness to sign offtake agreements and pay a premium if necessary[11]). In addition, project developers, architects and contractors should design for future reuse and recyclability.

The main impulse for this vision would need to come from the private sector, but there is a role to play for the City of Rotterdam in bringing parties together and creating enabling conditions.[12] Concrete recycling is a good example of an innovation that would benefit from a governance model centered around public-private partnership, which can identify priority projects and support their implementation. As a starting point for discussion, Exhibit 12 outlines three potential roles for the City of Rotterdam to be involved in the concrete recycling cluster. The second of these roles (‘active enabler’) appears to strike the best balance between ensuring active government support while keeping a clear separation between public and private roles.

EXHIBIT 12 | THREE ROUTES FOR THE CITY OF ROTTERDAM IN THE CONCRETE RECYCLING CLUSTER

☐ Best balance between private & public roles

	City of Rotterdam as facilitator	City of Rotterdam as active enabler	City of Rotterdam as utility-provider
What	✓ Facilitate permits and land-use	**City of Rotterdam as facilitator, PLUS** ✓ Act as launching customer through off-take agreements ✓ Set aspirational minimum recycled concrete target for e.g. 2026 ✓ Advocate for updated regulations to allow more use of recycled materials ✓ Provide land or subsidize gate fees	**City of Rotterdam as market enabler, PLUS** ✓ Operate a demolition waste hub to reduce transportation and storage cost and improve availability ✓ Separate recyclable concrete from non-recyclable material ✓ Manage a digital inventory of planned demolition waste
Why	▪ The City of Rotterdam ensures that permitting does not become a bottleneck in developing concrete recycling	▪ Additionally, the City recognizes that active interventions can accelerate the transition to circular concrete	▪ Additionally, the City of Rotterdam believes that efficiently operating concrete recycling facilities is possible and desirable

Absolute necessity for success — Driving force for change

- **City of Rotterdam as a facilitator.** A minimum requirements for success is a speedy handling of permits and land-use permission to avoid that permitting becomes a bottleneck
- **City of Rotterdam as an active enabler.** In addition to its facilitator role, the Municipality could lend active support to concrete recycling to accelerate the formation of a cluster. Though the Netherlands in general and Rotterdam specifically have comparatively favorable policies in place (Betonakkoord, please refer to chapter V), the City of Rotterdam could increase momentum by taking the lead in achieving circularity goals ahead of time. Our specific proposed policies are:

[11] If there is a premium: some recycled materials are at or below market prices for primary materials.
[12] See for example Mission F of the Green & Digital Deal for Rotterdam

a. Engage/require offtake agreements for procuring recycled cement for its own new buildings, with a focus on clinker substitutes
b. Increase stringency of environmental standards for new buildings across the city, for example by including a minimum recycled concrete target in environmental permits from e.g. 2026 (feasibility to be verified in a separate study)
c. Advocate for updating of safety regulations to allow for higher shares of recycled inputs in new construction
d. Provide incentives either by providing land for a recycling plant or through subsidized gate fees for recycling plants

- **City of Rotterdam as a utility provider**. It is possible for the City to take an even more active role. In addition to its 'facilitator' and 'active enabler' roles, it could get involved directly in the concrete recycling value chain, in some ways akin to the role it plays in managing demolition material from private citizens in its *milieuparken*. This could mean directly operating a demolition waste hub. It could even mean engaging in separating recyclable concrete from non-recyclable materials to improve the quality of material offered to a recycling plant or to operate a digital inventory of when and where demolition waste is likely to become available

B. Create the right conditions for concrete recycling to take off

Chapter II identified two more roadblocks that have prevented concrete recycling from taking off: ii) lack of transparency on material flows; and iii) inadequate regulations & standards. These can be addressed by two actions:

i. Develop a central overview of the (expected) available recyclable and recycled concrete, its quality and potential off-takers.

a. Ensure sufficient availability of recyclable end-of-life concrete and recycled concrete by tracking material flows throughout the Rotterdam region, and closely monitoring material quality during construction, demolition and recycling. In construction, transparency on the quality of the recycled product is key: this transparency can be enhanced by close monitoring during the demolition and recycling process, and initiatives like the materials passport. To increase availability of recycled concrete, demolition companies need to adopt 'clean' demolition practices, and recycling companies need to scale recycling operations.
b. Match construction to demolition and recycling hubs. This also includes a logistical network that ensures end-of-life concrete can be transported to recycling facilities cheaply and that feed-in is scheduled to minimize the need to store large volumes of concrete. (Local) governments can support by creating a (digital) overview and requiring project developers and demolition companies to provide details on the materials they expect to use or provide. Rotterdam has started to implement materials passports; this initiative is a good first step but is not mandatory (yet).

ii. **Update regulations and (tender) standards.** While generally local and national policies favor circularity in concrete, some policy changes can further drive progress to address the remaining roadblocks. The Dutch national government should ensure that standards for cement composition reflect up to date information on new clinker substitutes. For the planning and design stage, support through updated regulations and tender procedures is essential. Facilitating increased recycling of concrete through public tenders can help the market for recycled concrete develop further. The renovation of the 'Afsluitdijk'[13] is a great example of this: the Dutch Ministry of Infrastructure and Water Management is experimenting with several suppliers of low-CO_2 concrete to strengthen the dyke.[xxxviii]

EXHIBIT 13 | CROSS-VALUE CHAIN COORDINATION AND COLLABORATION ARE CRUCIAL TO FACILITATE RECYCLING

Typical steps for building construction	Financing	Planning & design	Construction	Use	Demolition	Recycling
Stakeholder involved	Investor	Project developer Architect (local) government	Project developer Contractor Suppliers	User	Demolition company	Recycling company
Facilitate use of recycled materials	• Insight into cost level recycled materials • Financing use of recycled materials	• Overview of (quality of) available recycled materials • Regulations allowing use of recycled materials • Facilitation of recycling through public tenders	• Insight in quality and characteristics of recycled materials available • Experience with integrating recycled materials in construction		• Application of demolition best practices to harvest material with low contamination • Financing for additional demolition costs	• Overview of potential new applications for materials • Funding for recycling • Monitoring of material quality • Scaling of recycling operations
Ensure future recyclability	• Insight into (added) costs of design for recyclability • Funding for design for recyclability	• Design optimized for future recyclability	• Construction optimized for future recyclability			

C. Kick-start implementation through a pilot

To get at-scale concrete recycling off the ground, it is important to start learning fast. Setting up a pilot program can be a good way to do that.

As a discussion starter, we envision that in 2024, the City of Rotterdam will have **fully closed the circular loop for the demolition of at least one building** in the city. This means that demolition is performed in a way that enables recycling of the waste streams, that waste streams are collected, sorted and prepared for recycling, and that the sorted materials are in fact recycled into new concrete and sold on the market or used in development of new Rotterdam real estate. Closing this loop at least once will help understand where operational bottlenecks are, and which division of roles and responsibilities between private actors and local government is sensible.

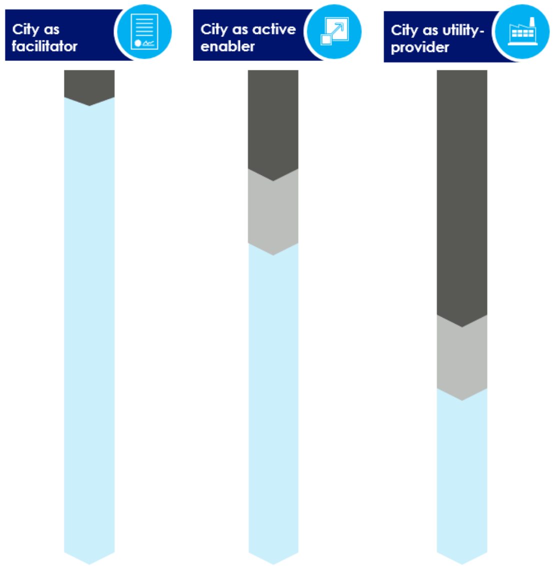
Closing the concrete loop from beginning to end requires action all the way from regulation and market coordination, to logistics, recycling facilities and demolition and construction practices (*Exhibit 13*). Depending on the City of Rotterdam's envisioned role in the concrete recycling cluster, a share of these actions should be taken by the municipality (*Exhibit 14*).

[13] The Afsluitdijk is a 32 km dam that closes off a bay in the center of the Netherlands, completed in 1932

EXHIBIT 14 | THE CITY OF ROTTERDAM CAN TEST 3 INVOLVEMENT MODELS THROUGH A PILOT

Role for City of Rotterdam
Potential role for City of Rotterdam
Role for other stakeholders

Role	Description
Regulation	• Trial requirement for 60% of concrete waste recycled, and/or • Trial requirement for 60% of demolition waste to be delivered 'clean'
Market	• Coordinate supply and demand of demolition waste and recycled concrete • Match construction to demolition • Ensure demand through off-take agreements
Logistics	• Transport end-of-life concrete and recycled concrete • Store end-of-life concrete and recycled concrete
Recycling	• Process end-of-life concrete to recycled output materials
Demolition	• Demolish buildings and deliver clean end-of-life concrete
Construction	• Use recycled concrete in construction projects



When the Municipality acts as a **facilitator**, it could support concrete recycling by granting permits and clearing any land-use related hurdles. All other key actions to increase recycling would be executed by other stakeholders, possibly incentivized by regulation.

When the City of Rotterdam acts as an **active enabler**, it could set targets for recycling and the delivery of clean concrete waste at building/demolition sites it directly owns. Additionally, the city could facilitate the market by coordinating supply and demand and matching the material flows from demolition projects to construction projects. Developing neighborhoods (such as in Merwe-Vierhavens or Wielewaal) could be used as testing grounds for coordination of supply and demand: local matching of projects is optimal.

When the City acts as a **utility-provider**, it could facilitate the logistics for recycling in addition to its regulatory and coordinating roles. This could include developing a central hub for circular concrete, including operating space for a recycling company, and managing transport of the materials. To kick-start the market for recycled concrete, the Municipality could also function as a first off-taker and use the materials for new construction projects in its own portfolio. The first step for this pilot is to find a suitable location, ideally located near main waterways and construction centers. Then, Rotterdam could select upcoming demolition projects to participate in the hub, as well as a recycling company.

V THE ROLE FOR CLEAN TECH DELTA IN CONCRETE RECYCLING

Clean Tech Delta's role: bring sustainable business ideas to the project phase

The purpose of Clean Tech Delta (CTD) is to **close the implementation gap between an idea and a sustainable business** in the province of South Holland. It collaborates with its members and partners in a cluster set-up (triple helix: knowledge institutes, companies and local governments) on repeatable and scalable clean tech initiatives. It believes that the cluster set-up is necessary and justified especially on issues that that require cooperation along the entire value chain, without one clear owner. It forges new coalitions between stakeholders that wouldn't exist otherwise and in doing so it accelerates innovation. CTD is characterized as a 'transition broker' by University of Utrecht researcher J.M. Cramer who mapped.[xxxix] From a neutral position, transition brokers play a crucial role in bringing together all relevant parties in circular projects. They can provide interfaces between the different leading actors. This enables CTD to motivate companies and other organizations to participate in circular initiatives and make connections between them. CTD's approach has already brought numerous innovative and sustainable ideas to commercial scale, providing positive impact to the Rotterdam region.

Clean Tech Delta as an innovation broker for concrete recycling

The complexities involved in concrete recycling (stakeholder, logistics, regulations, technology, etc.) are well-suited to CTD's cluster approach. CTD has a track record in coordinating similar circular projects in South Holland and is well-positioned to do this for concrete recycling:

- Clean Tech Delta has already completed phases 1 and 2 of its innovation scaling approach (see beginning of chapter IV) for a recycling cluster in the Rotterdam area. This includes a mapping of stakeholders, context and value chains, identifying bottlenecks and developing and sharing knowledge. Selected insights from these initial phases are found in this document, as well as an overview of next steps for phase 3: developing a shared vision on concrete recycling in the Rotterdam region, creating an implementation plan and create a conducive environment for execution.
- Clean Tech Delta has co-managed the project 'Circular Dordrecht', in which circular value chains in Dordrecht were developed together with a broad set of local and regional stakeholders and with a strong focus on the construction sector.
- Clean Tech Delta has a strong network in academia, business, and government in the Rotterdam area. It has close ties with TU Delft, Hogeschool Rotterdam, Erasmus University and TNO, collaborates closely with start-and scale ups as well as large corporations in the region, and historically has close ties with local government.
- Clean Tech Delta has deep expertise in industry, having spent the last decade working on circularity and clean industries in the Rotterdam region.

CTD will focus on the next step in the process towards a circular concrete hub in Rotterdam: to develop a shared vision with the most important stakeholders in the Rotterdam region.

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