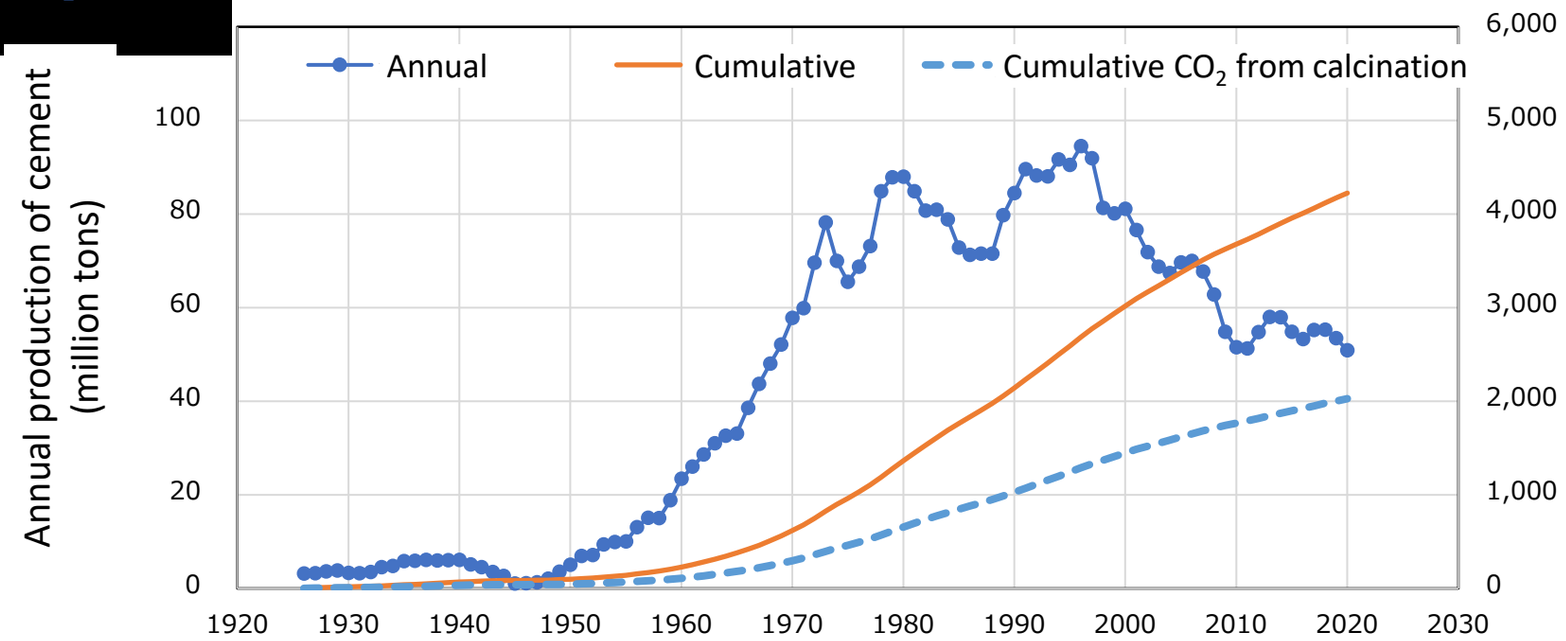
C⁴S Research and Development Project

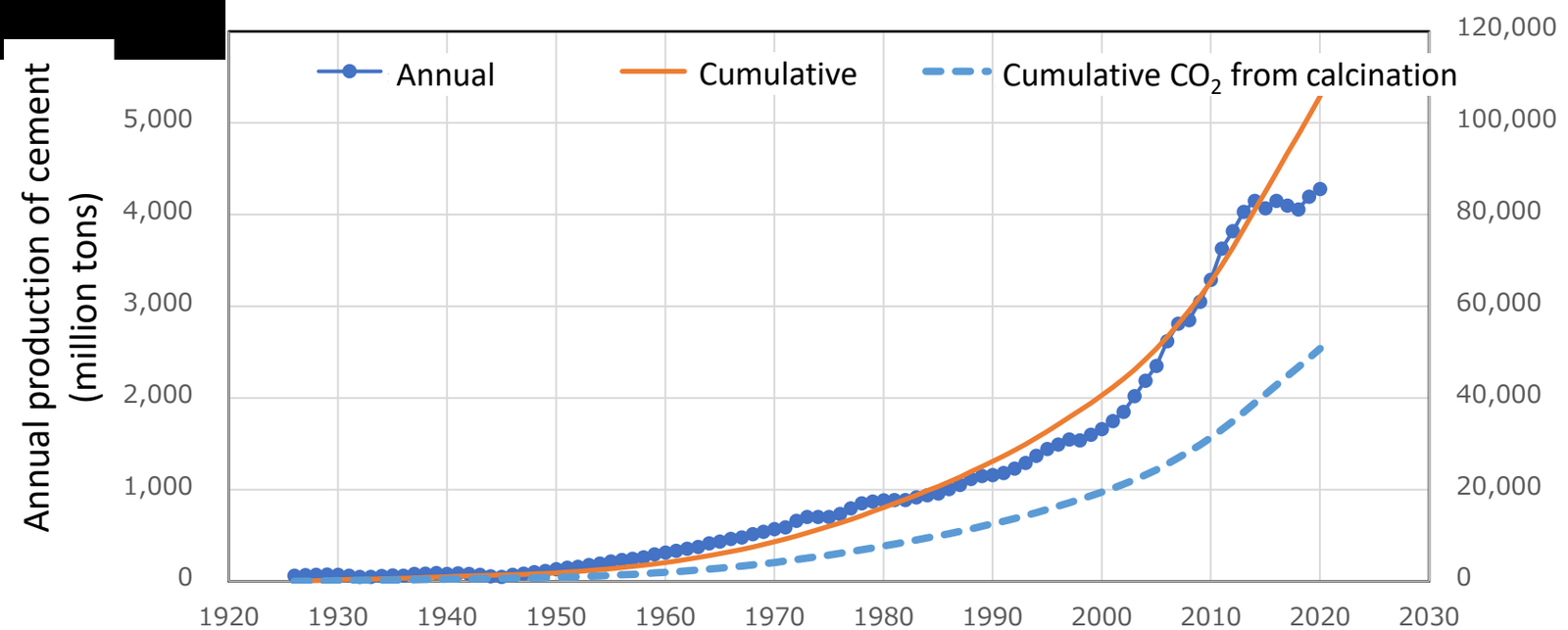
PM: Takafumi NOGUCHI
The University of Tokyo, Professor
PJ constituent organizations
The University of Tokyo, Hokkaido University
Recommissioned organizations
Tokyo University of Science,
Kogakuin University, Utsunomiya University,
Shimizu Corporation, Taiheiyo Cement,
Masuo Recycle

Background (Cement production & CO_2), Objective

Japan



World



■ **Total CO_2 in air**
2.8 trillion tons

■ **CO_2 emission from calcination**

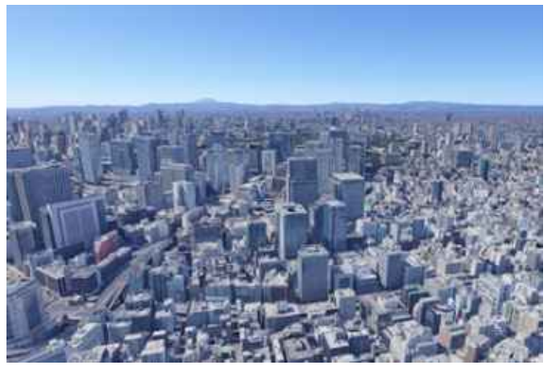
- Cumulative
  - World 55 billion tons
  - Japan 2 billion tons
- Annual
  - World 2.1 billion tons
  - Japan 26 million tons

Capture & Utilization CCUS

Background, Method for CCUS

Extraction of limestone $CaCO_3$ to produce cement, etc.

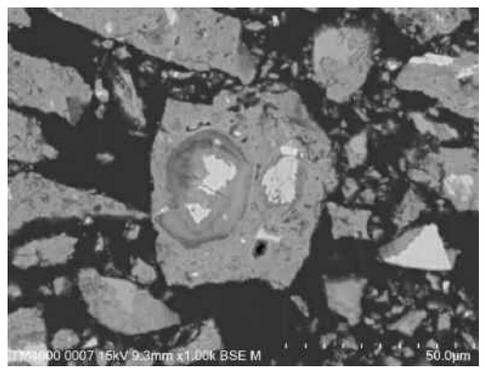
⇒ Always generate CO_2 when using calcium **Ca**



Concrete which is no longer used in cities,
is a valuable source of calcium **Ca**

Crushing waste concrete

Binding CO_2 in the air



Calcium carbonate ($CaCO_3$) formation

CCC

⇒ Production of **calcium carbonate concrete (CCC)** to **capture and fix CO_2**

Project Implementation Structure

Social implementatior (PJ III)

Development of performance evaluation methods, and material and structural design methods
Design of resource recycling scenarios
Establishment of laws and standards
CO_2 emission reduction effect analysis

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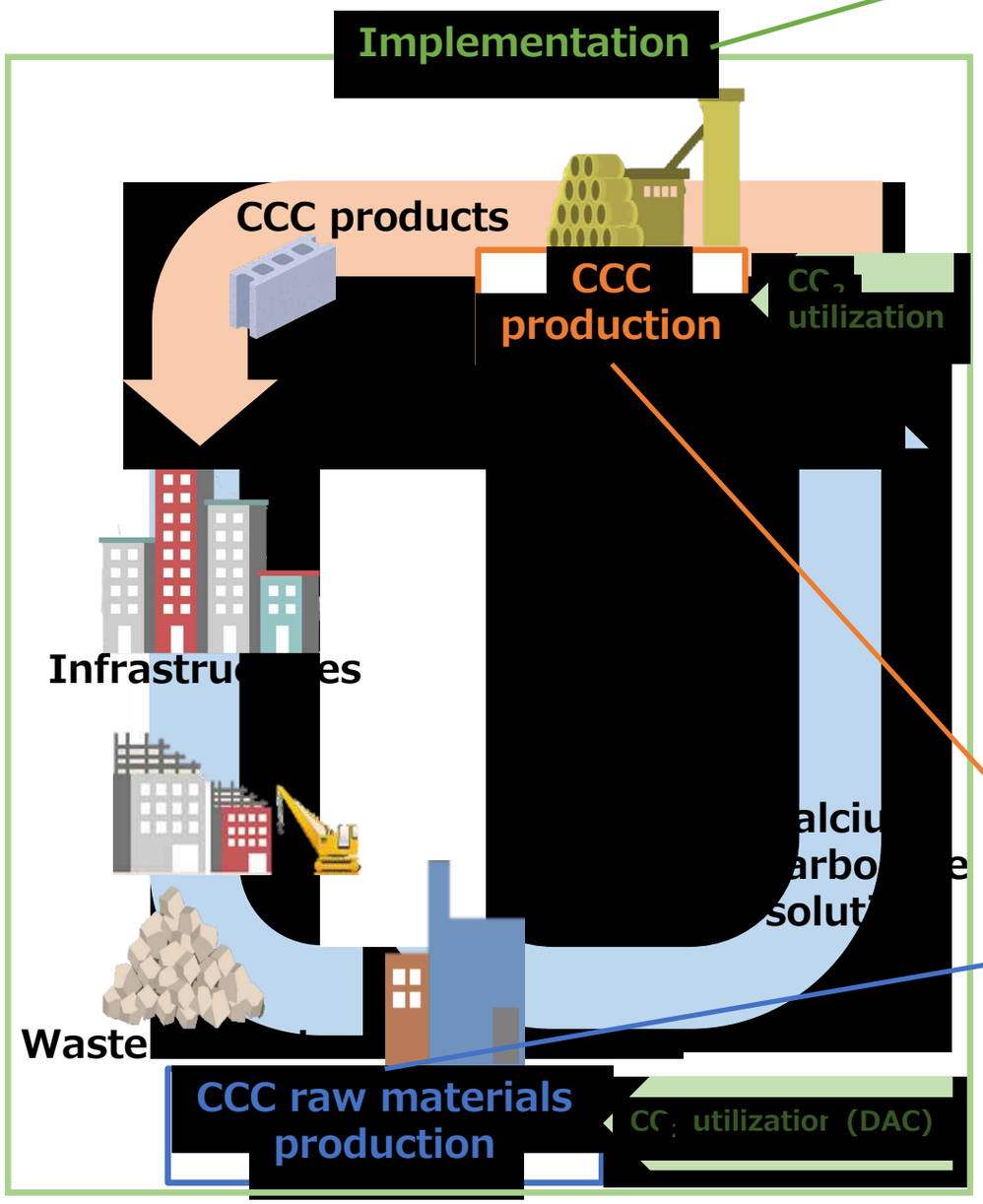
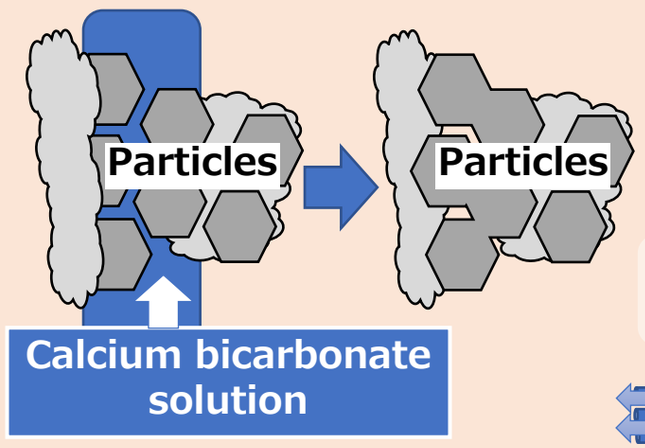
Kogakuir Universitv
Utsunomiva University
Shimizu Corporation



CCC productior (PJ I)



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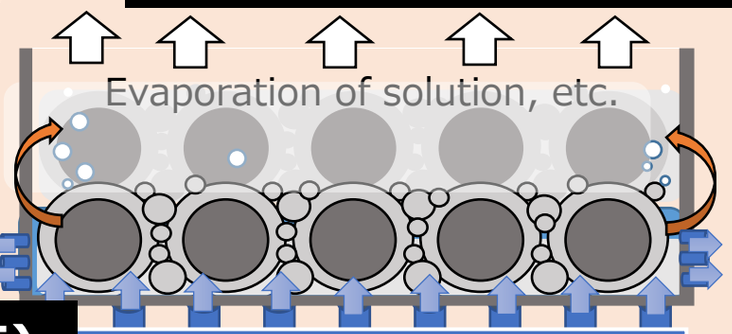
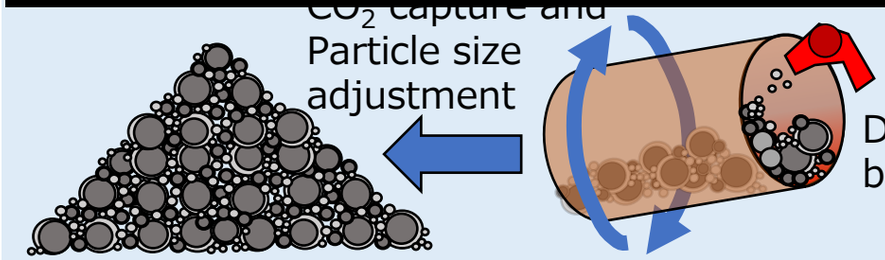
Taiheivo Cement
Tokyo University of Science



CCC raw materials production (PJ II)

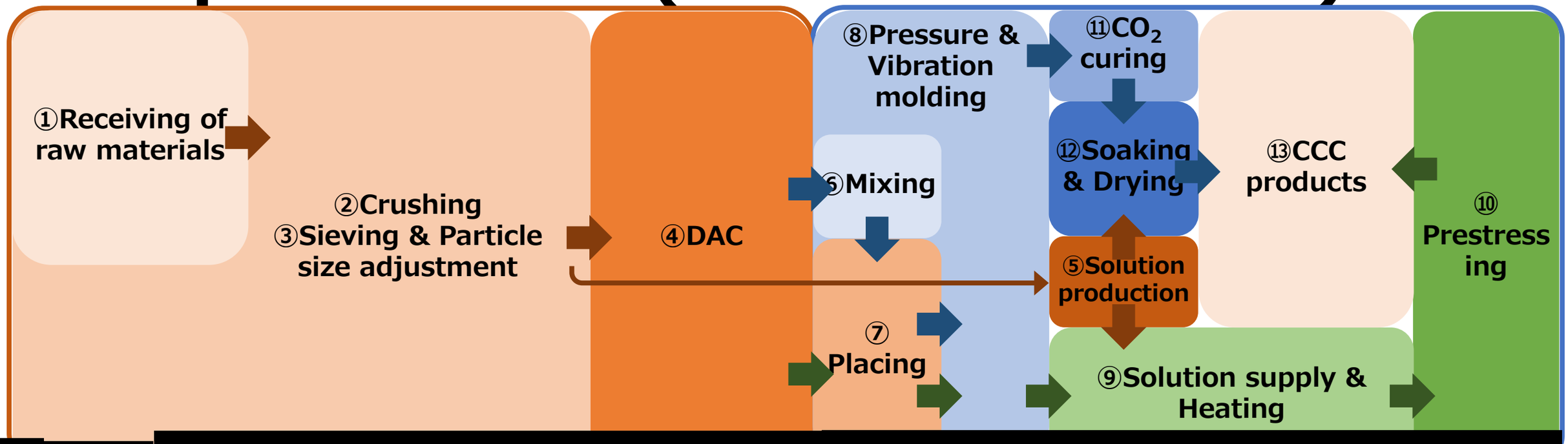
Hokkaido University
Masuc Recycle



Development Schedule, Targets

R&D Items	Target at the end of FY2022 (Interim)	Target at the end of FY2024 (Interim)	Target at the end of FY2029 (Final)
①Development of CCC reaction control technology and component manufacturing principles	**Minimum strength of 12MPa** as specified by the Building Standard Law secured with a test specimen of Φ10x20cm	■Production of structural members with a strength of 12MPa ■Construction of structural frames	■Ensure **strength equal to or greater than conventional concrete** in pilot demonstration
②Development of manufacturing processes for CCC raw materials	**CO₂ absorption time from the atmosphere** be implemented in society	■CCC raw material production capacity of 500kg/hour	■Development of a **2ton/hour** CCC raw material production process
③Development of structural design and performance evaluation methods for CCC structures and social implementation of C⁴S	■Prospect for **contribution to global warming prevention** in LCA ■Drafting of measures to establish a system of **certification by the Minister of LIT**	■Establishment of a schematic material design method ■Establishment of outline of design principles for structural members	■Construction of **two-story buildings** ■Confirmation of **effectiveness of global warming countermeasures** through LCA
④Development and demonstration research of CCC structure design, manufacturing, and construction technologies		■Determination of structure construction method ■Study of construction equipment ■Start prototype design and development	■Confirmation of the realization of construction with **an appropriate construction period and amount of work** in the pilot demonstration

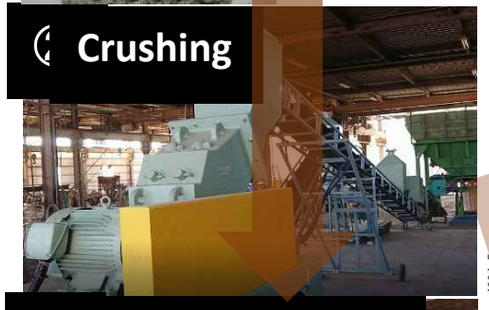
Implementation (Production and Use)



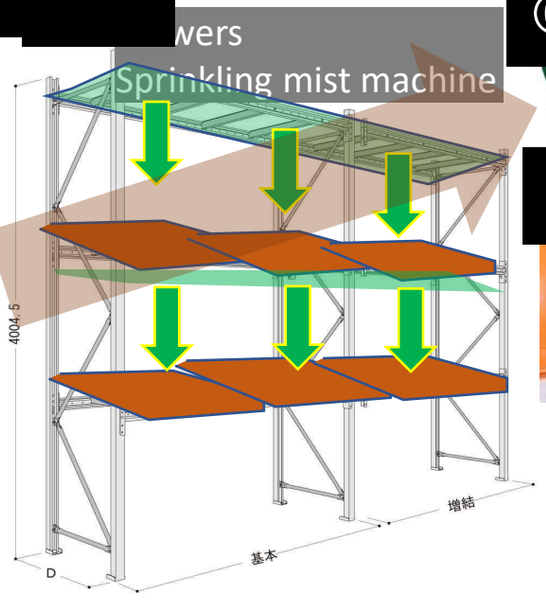
Production of raw materials　CCC production　PCa products)

Receiving

Crushing



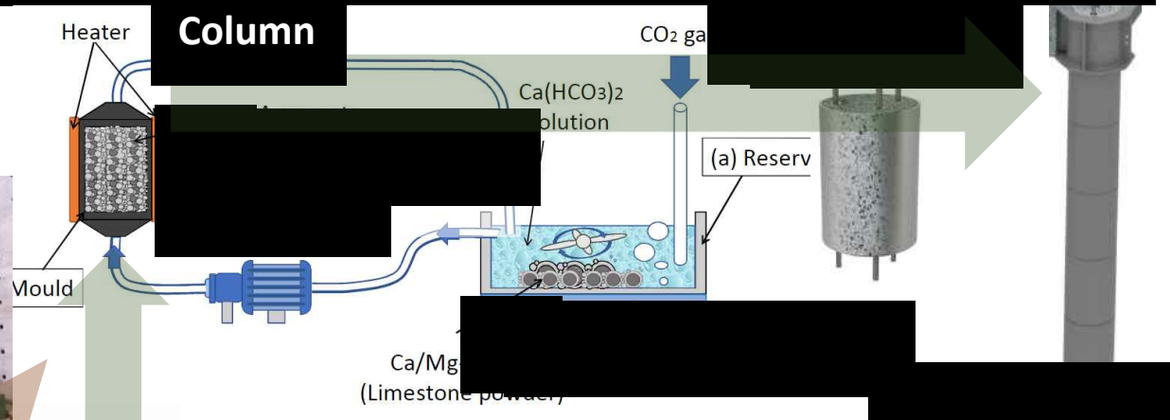
Seiving & Particle size adjustment



Mixing

Pressure

Column



Beam

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Project II: CCC Raw Material Production

CO_2 Capture in Waste Concrete by DAC

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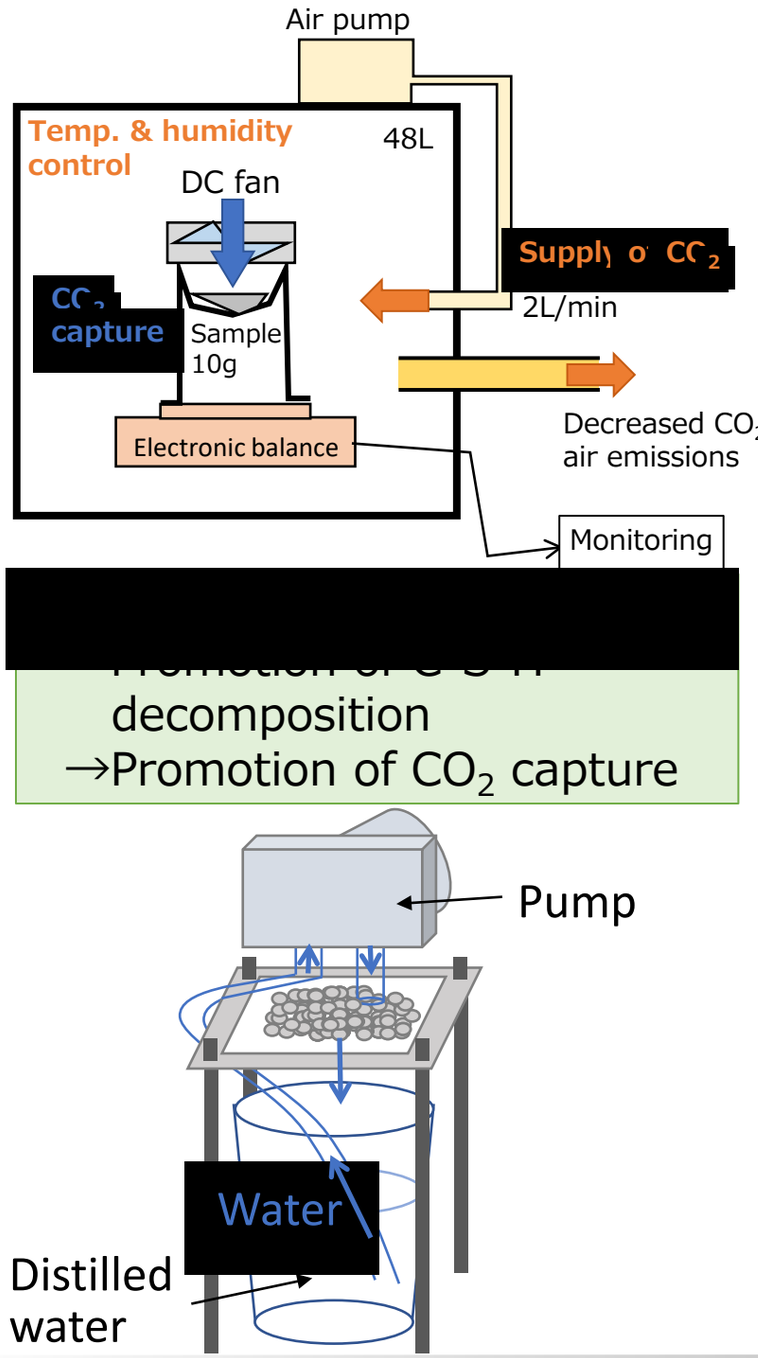
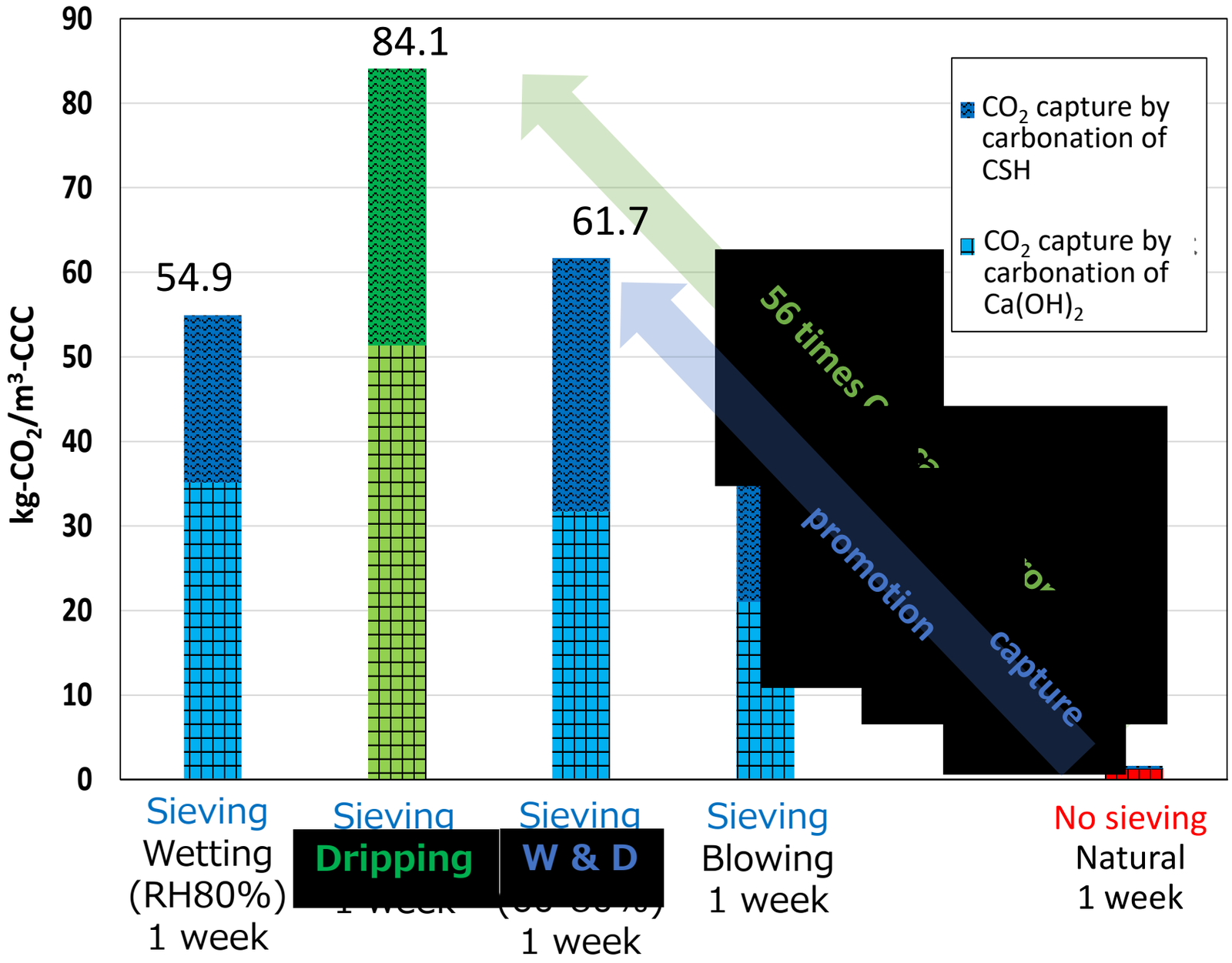
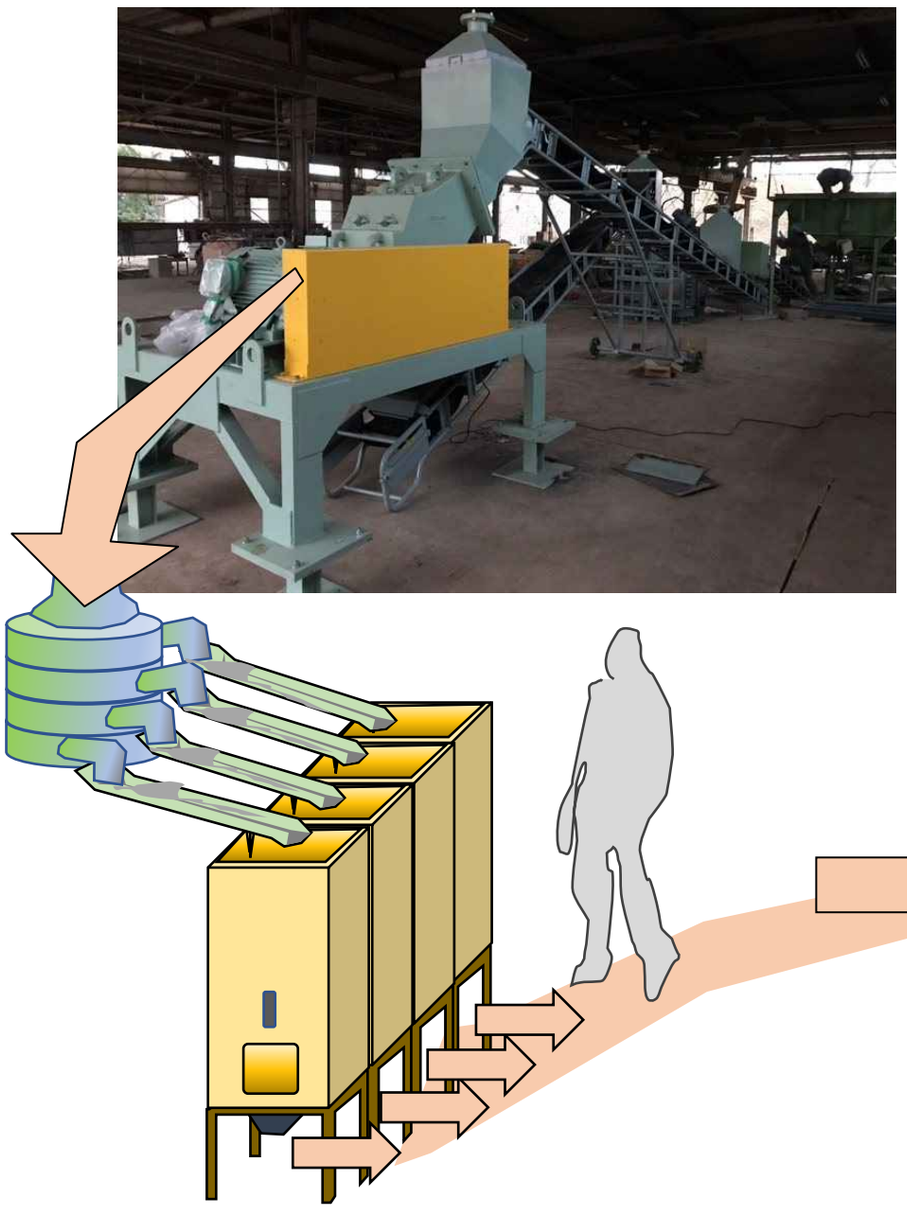


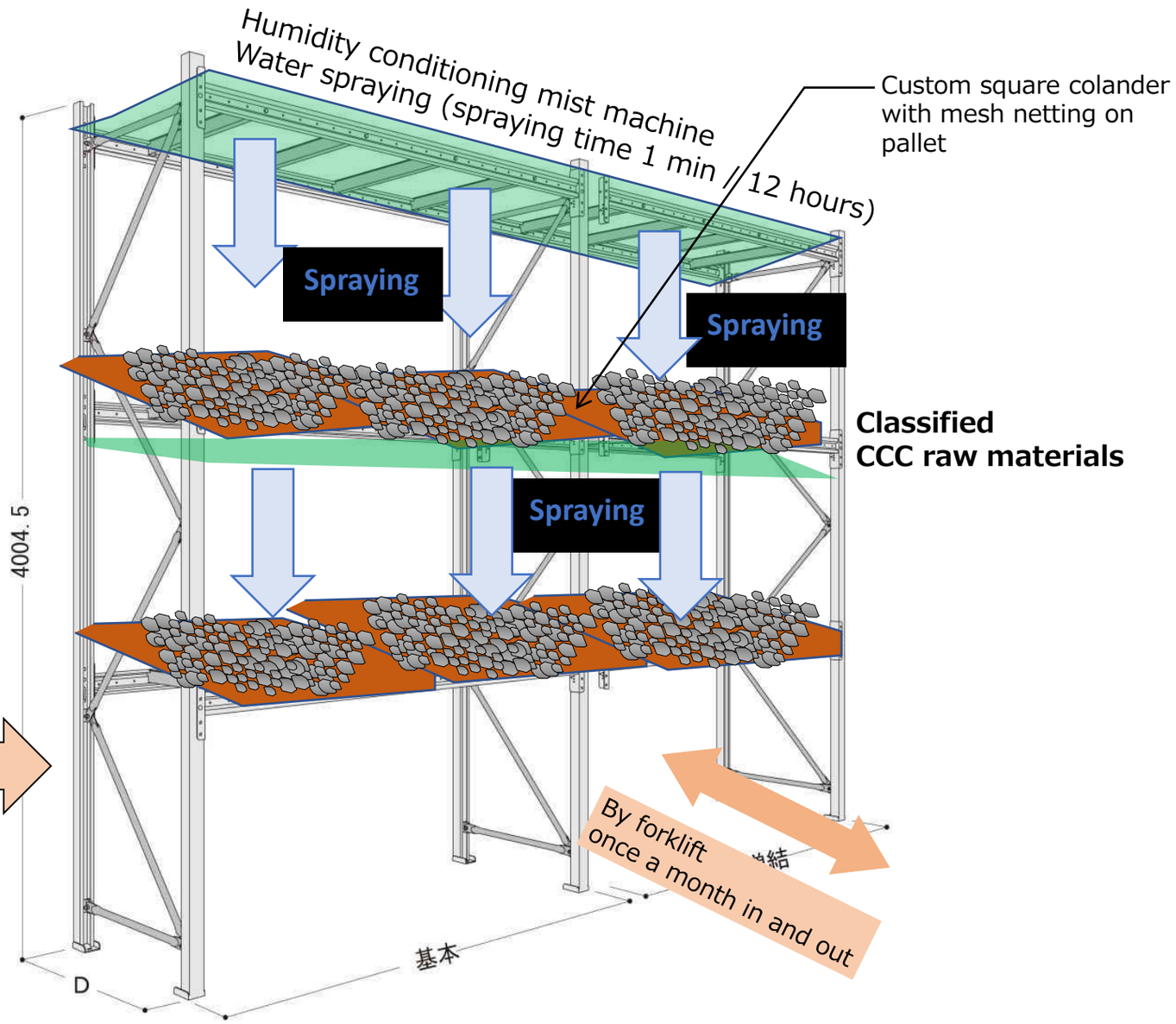
Increase in CO_2 capture by repeated wetting & drying (atmospheric CO_2 utilization)



Production of CCC Raw Materials (Plant)

Main process: **Crushing** only small amount of **mist spraying** (1 time/12 hours)
➡ Low energy consumption ➡ **Low CO emissions** about 10 kg-CO_2/m^3





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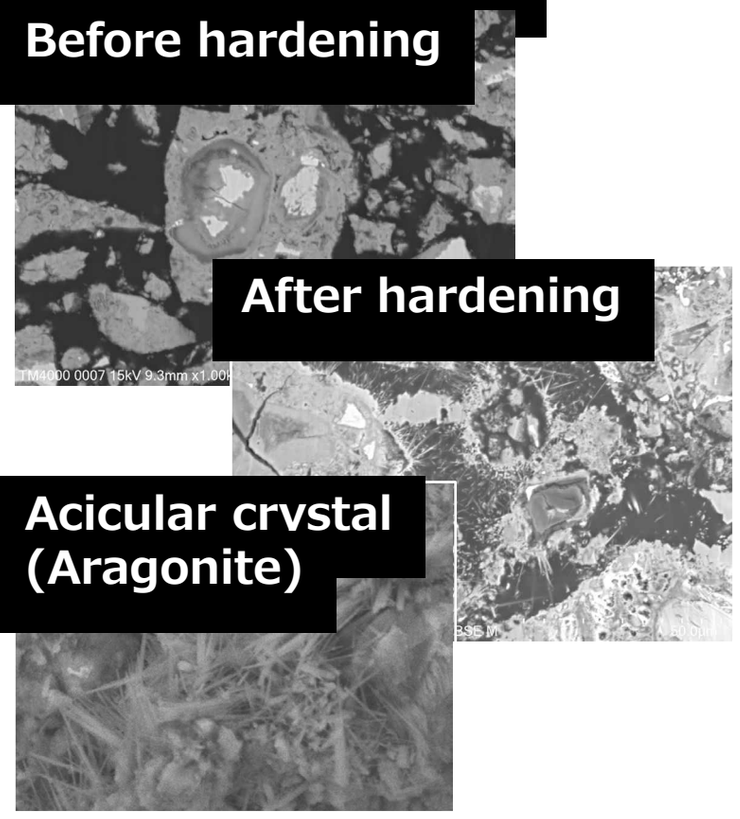
Project I: CCC Production



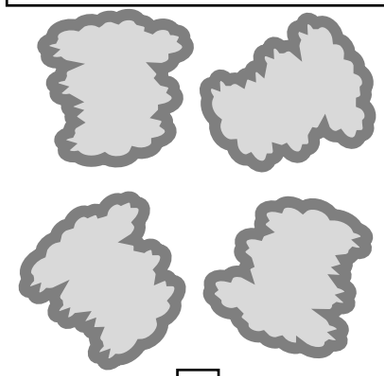
Principle of CCC Production

Strength development strategies for calcium carbonate concrete (CCC)

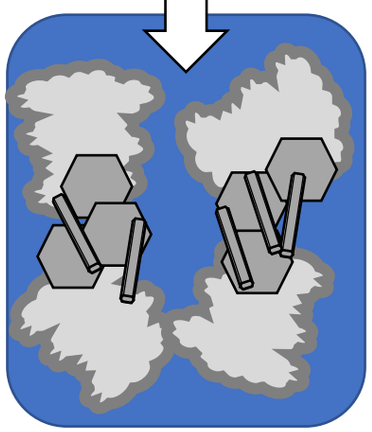
- **Stress transfer by generating calcium carbonate between aggregate particles**
- **Appropriate placement of aggregate particles in the initial stage**

Precipitation
(Passage and precipitation of calcium bicarbonate solution)

Carbonated mortar

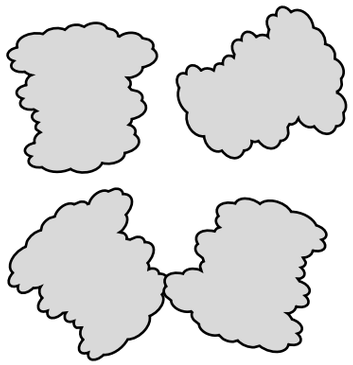


Precipitation by solution supply & temperature change

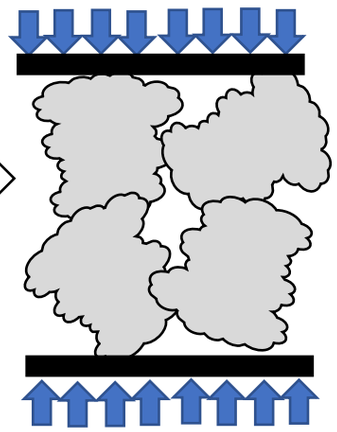


Pressure
(Proximity of aggregate particles under pressure)

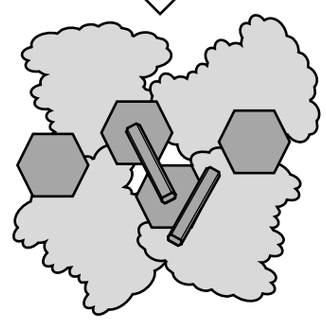
Uncarbonated mortar



Pressure



CO_2 gas curing
$Ca(HCO_3)_2$ aq. soaking and drying



Precipitation Method

Production with particle filling and continuous calcium carbonate precipitation (carbonation rate: 85%)

DAC process

Carbonation

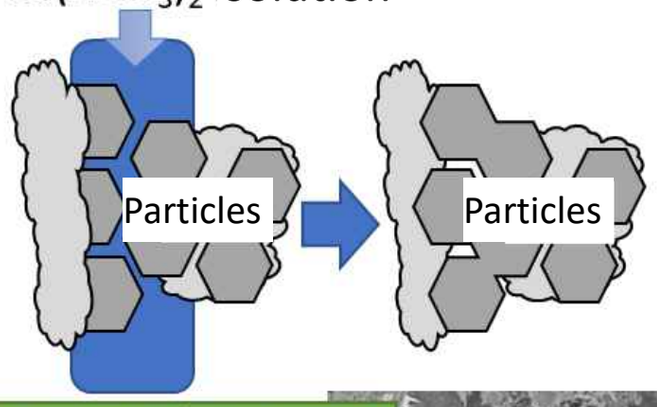
$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

$(CaO)_x(SiO_2)(H_2O) + xCO_2 \rightarrow xCaCO_3 + SiO_2(gel) + H_2O$

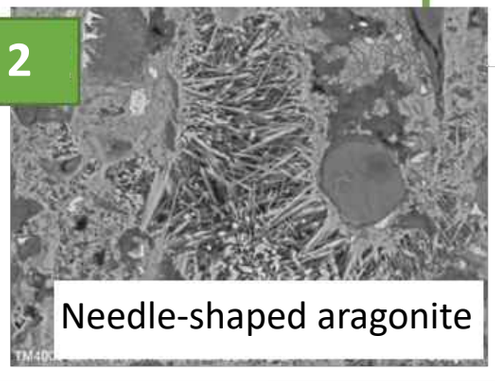
Precipitation reaction

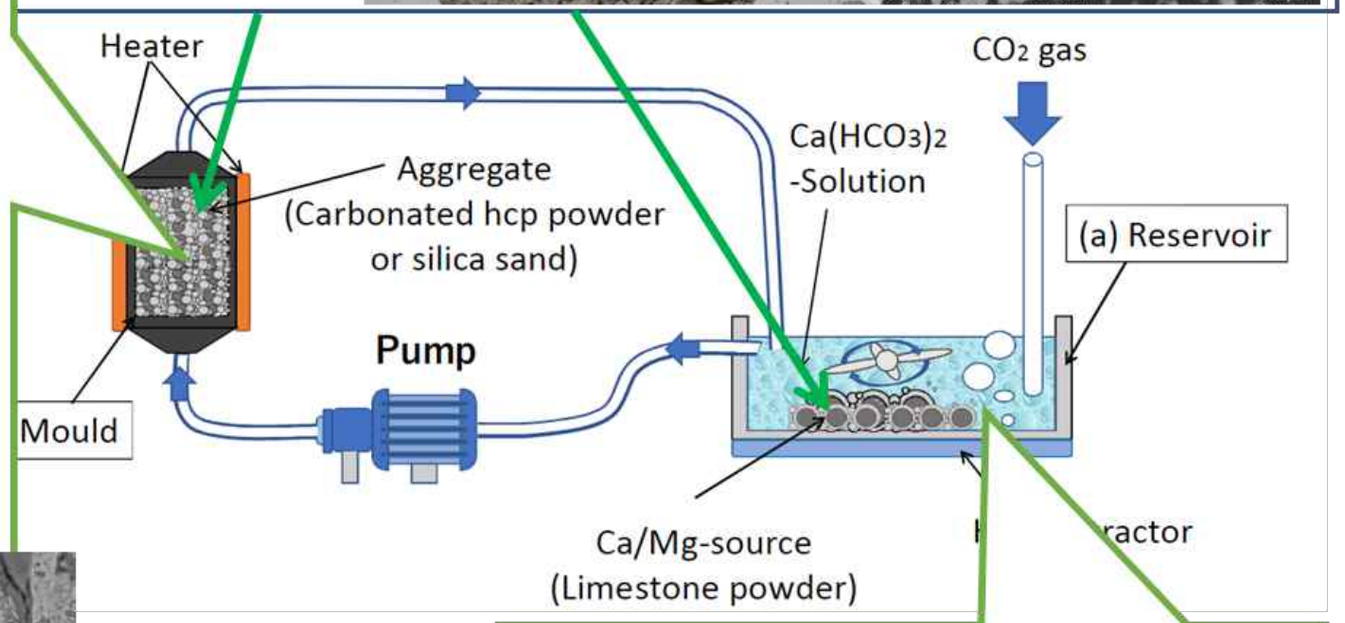
$Ca(HCO_3)_2$ aq. $\rightarrow CaCO_3 \downarrow + CO_2 + H_2O$

$Ca(HCO_3)_2$ solution



Coupling process 2





Calcium bicarbonate solution

$CaCO_3 + CO_2 + aq. \rightarrow Ca(HCO_3)_2$ aq.

Coupling process 1

Pre-loading Method

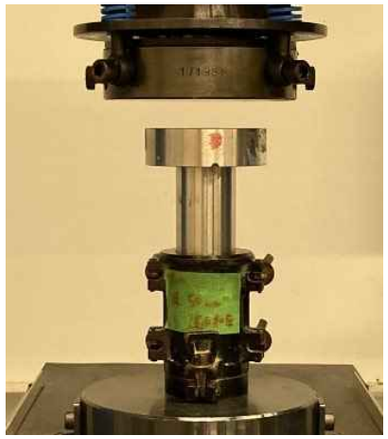
Production by repeated pressure filling, soaking and drying (carbonation rate: 60-70%)

Vibration

Compression

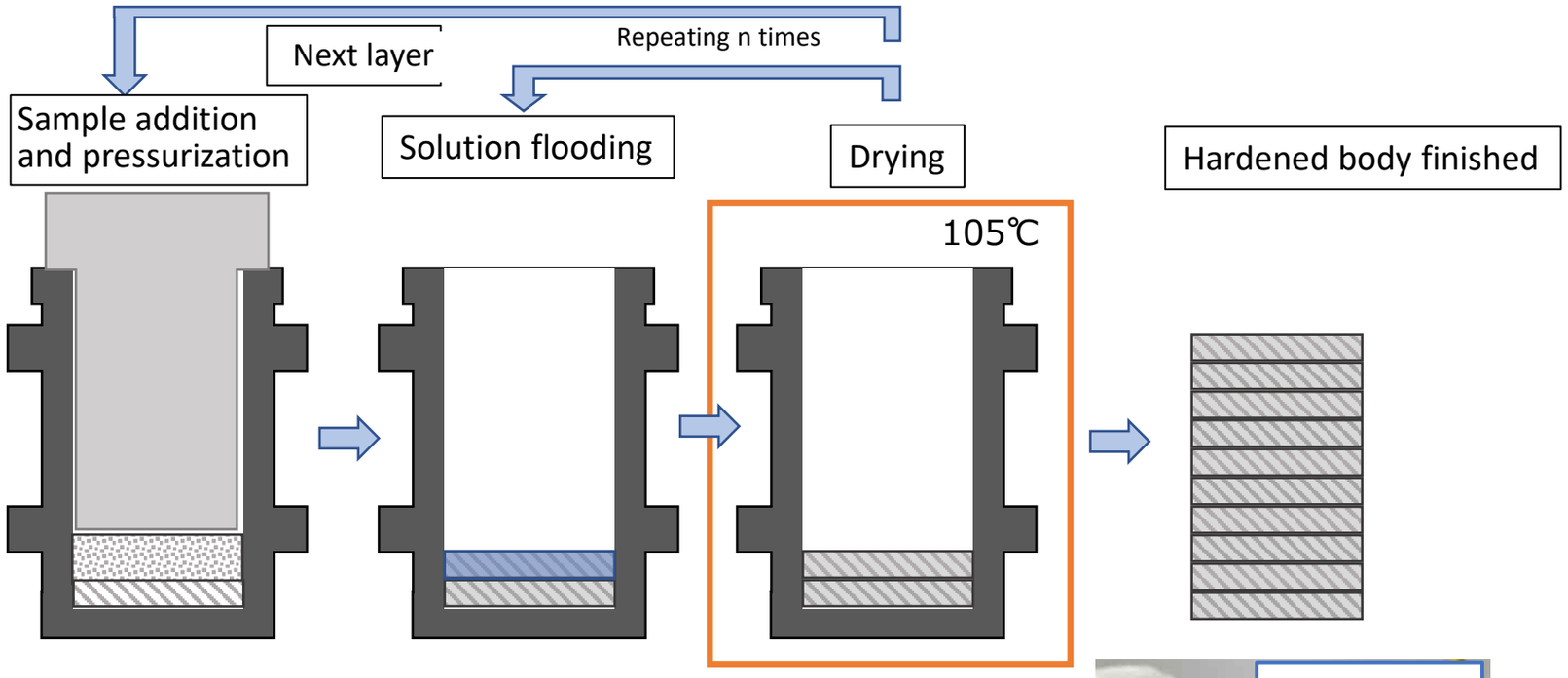
Stacked Pressurization Method

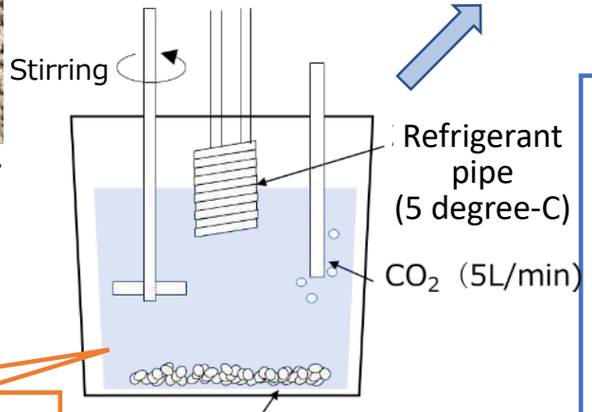
Production by repeated pressure, flooding and drying (carbonation rate: 60-70%)



Pressure molding

Carbonated mortar





DAC process

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$$

Solution production

Coupling process

Precipitation

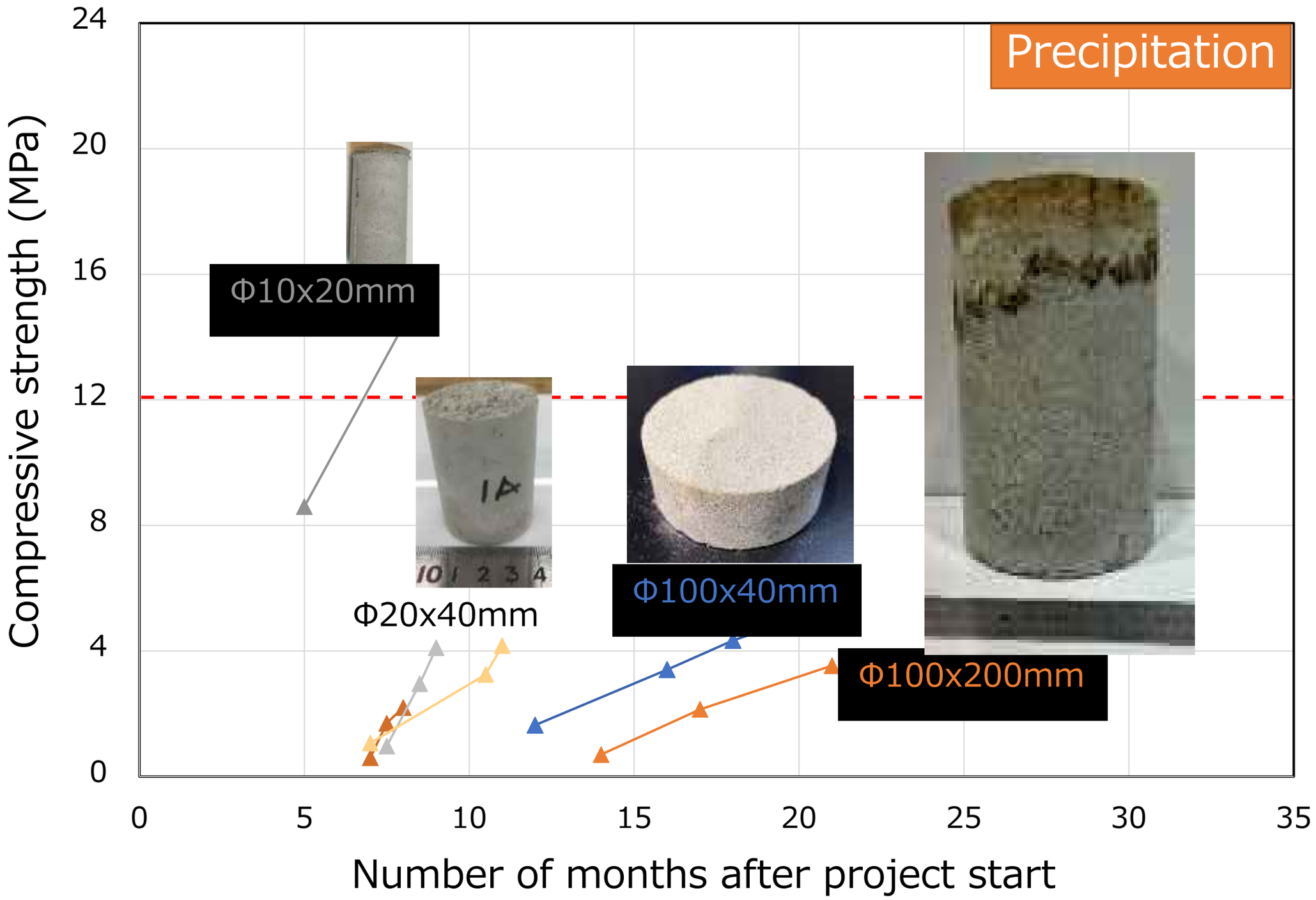
$$Ca(HCO_3)_2 \rightarrow CaCO_3 \downarrow + H_2O + CO_2$$

Carbonation

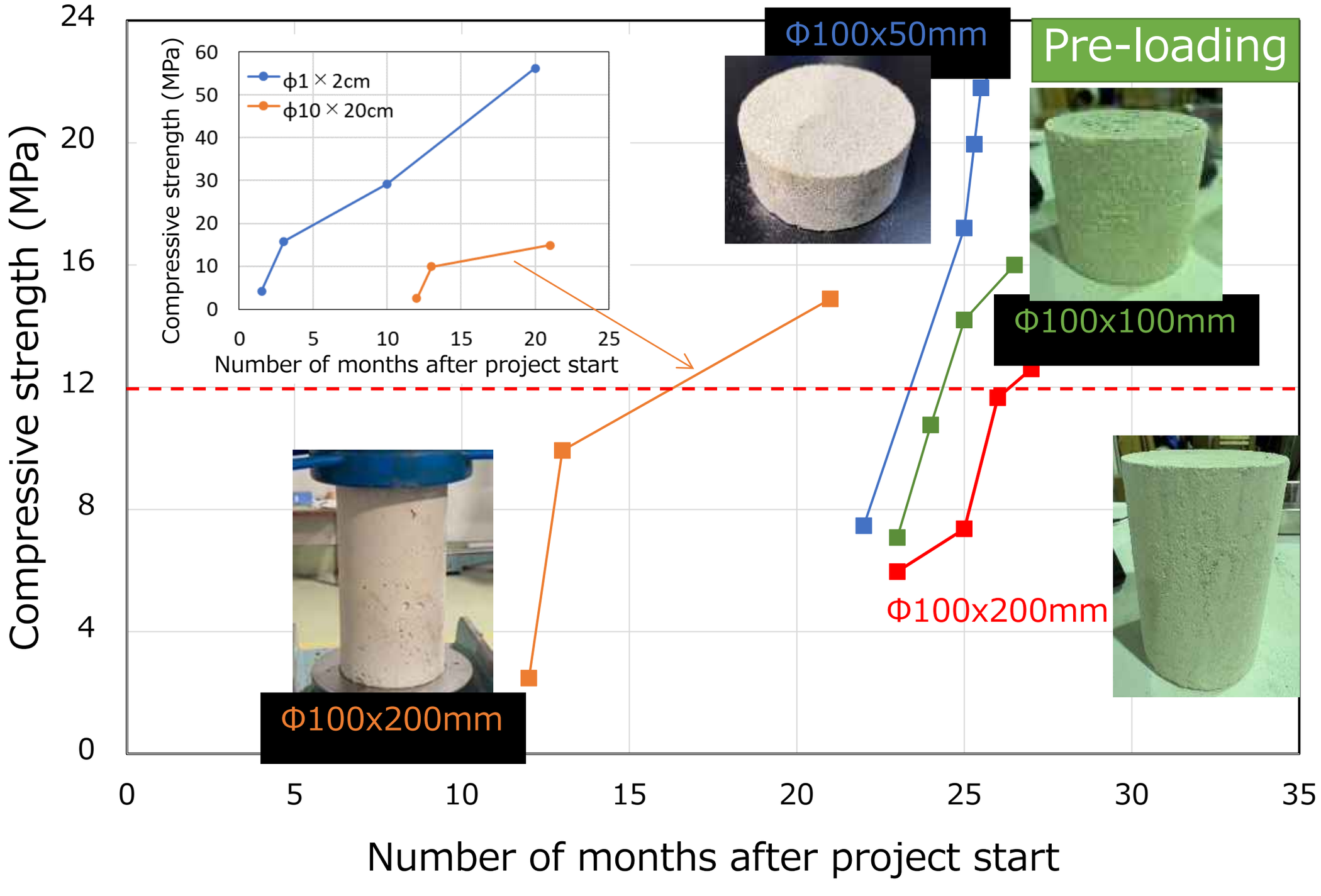
$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

$$(CaO)x(SiO_2)(H_2O) + xCO_2 \rightarrow xCaCO_3 + SiO_2(gel) + H_2O$$

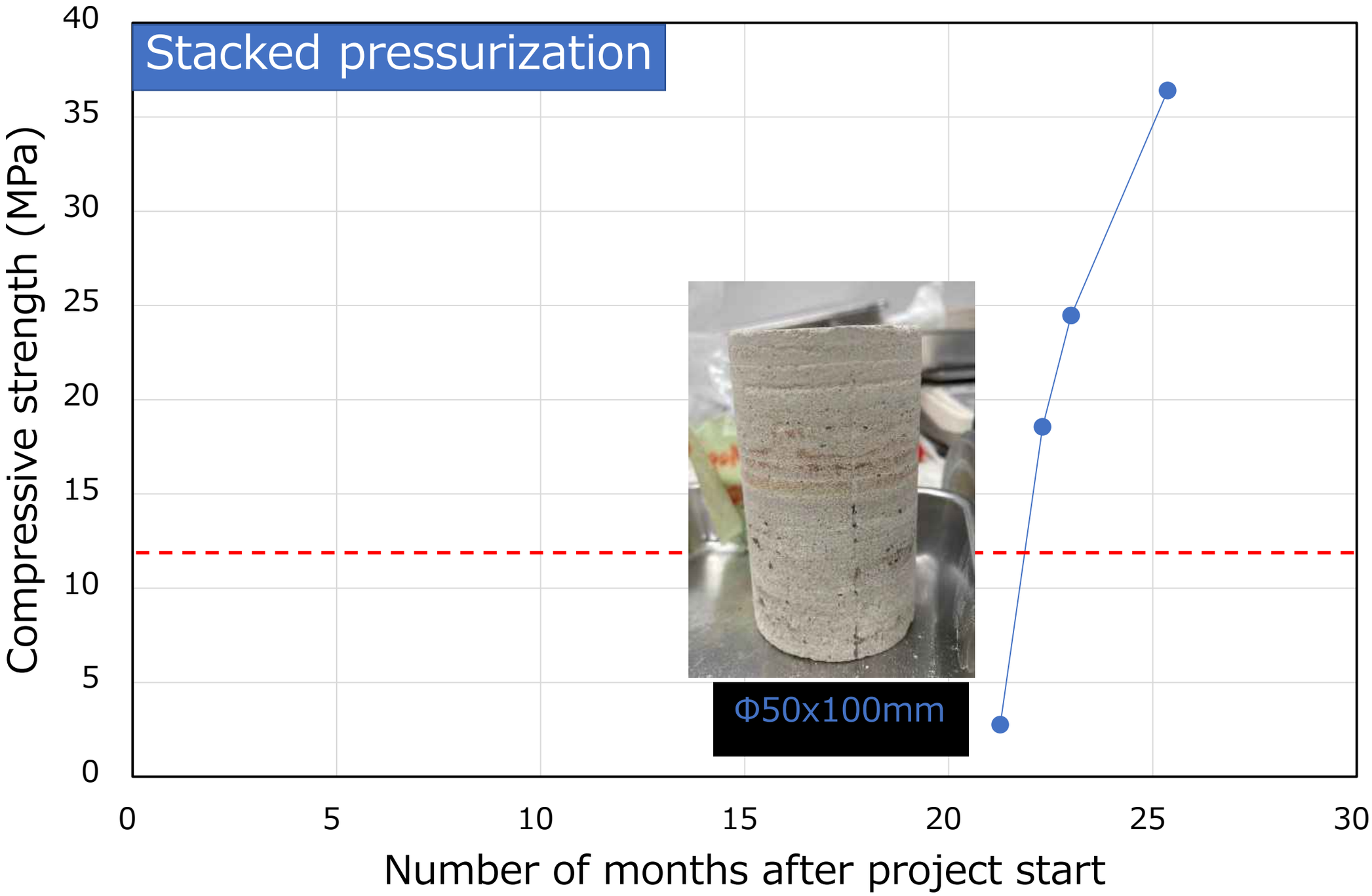
Development Process (Strength & Size)



Development Process (Strength & Size)

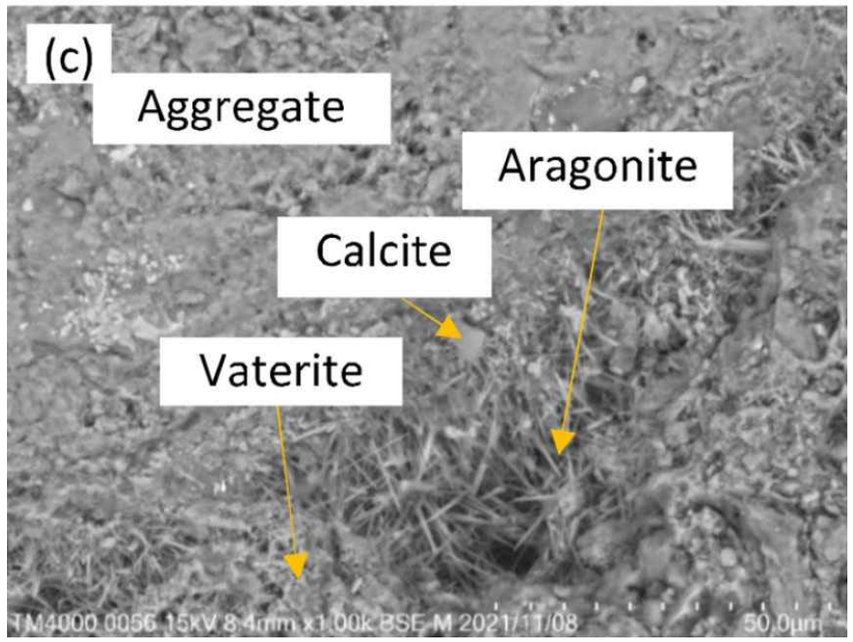


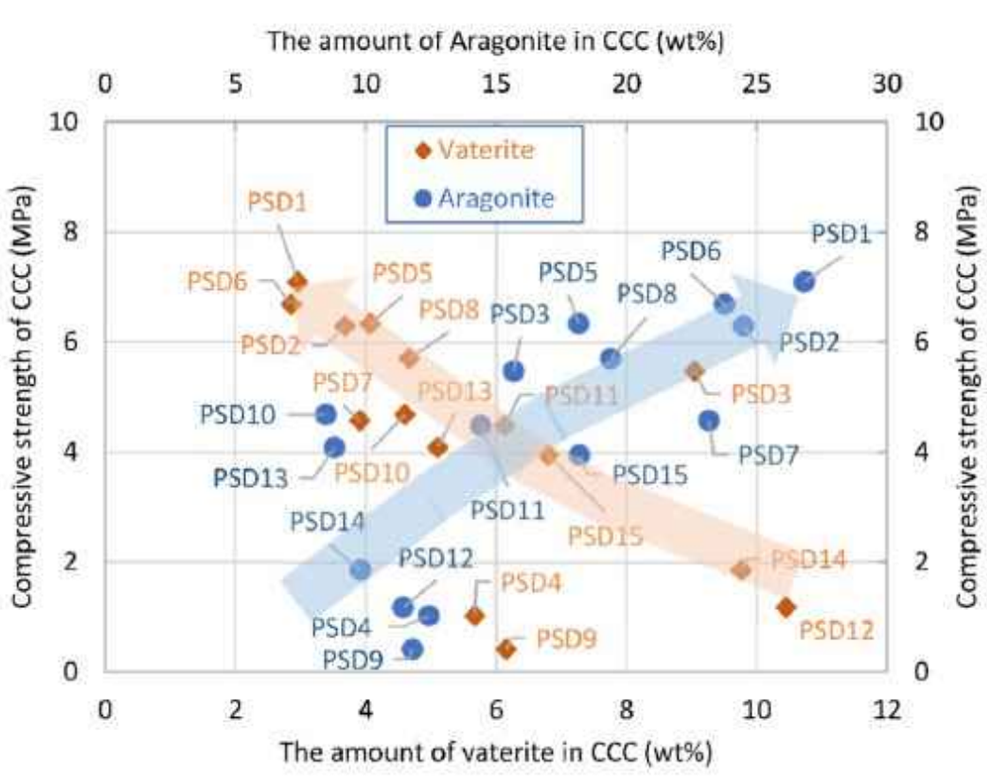
Development Process (Strength)

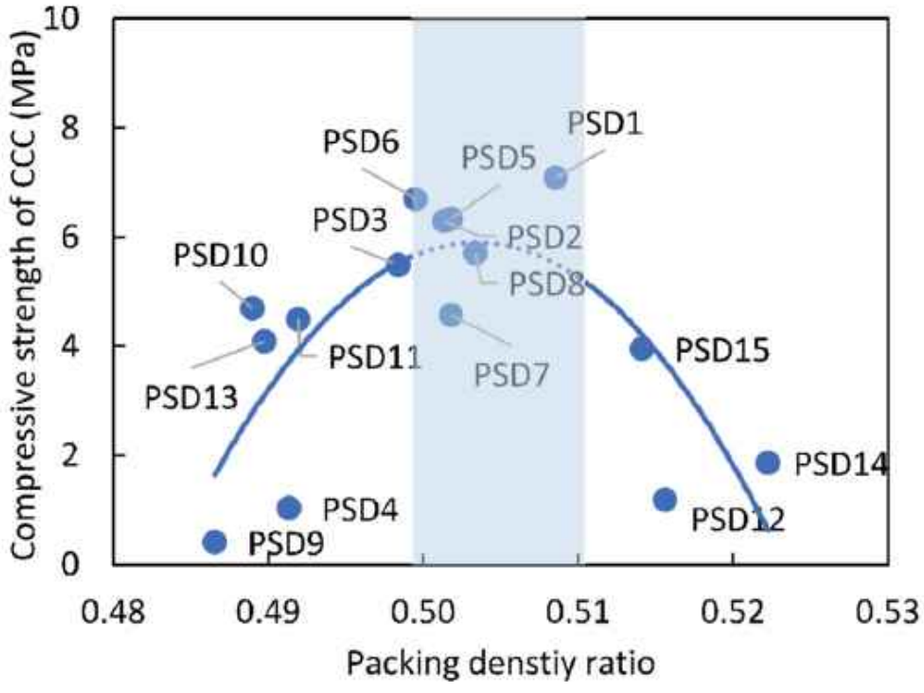


Mechanism of Strength Development

- Initial condition with appropriate particle size distribution is necessary.
- Aragonite in calcium carbonate is necessary for strength enhancement (because the needle-like crystals allow stress transfer between particles).
- Generation conditions at temperatures where aragonite is abundant (70°C) are important.







Mechanism of Strength Development

- Suppression and control of arch action during pressurized filling is important.

- Optimization of particle size distribution
  - ➡ CCC porosity reduction
- Optimization of mixing ratio of aggregate and $Ca(HCO_3)_2$ solution
  - ➡ Proper arrangement of aggregate particles, decrease in porosity of CCC
- Increase of contact area between aggregates
  - ➡ Reinforcement of CCC skeletal structure after pressure molding

➡ Increase in compressive strength

- Drying of CCC at 105°C after pressure molding
  - ➡ Precipitation of calcium carbonate at the aggregate interface
  - ➡ Densification of CCC and binding of aggregate particles
- Immersion in $Ca(HCO_3)_2$ solution and drying (secondary curing)
  - ➡ Further precipitation of calcium carbonate by $Ca(HCO_3)_2(aq.) \rightarrow CaCO_3(s)+CO_2+H_2O$
  - ➡ Further carbonation of uncarbonated Ca in CCC aggregate by CO_2 generated by the reaction

➡ Further increase in compressive strength

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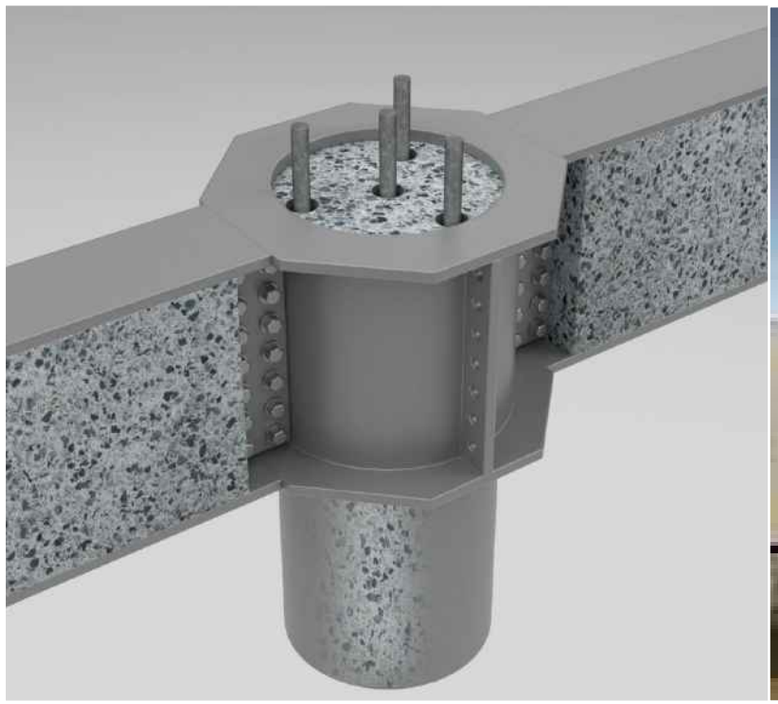
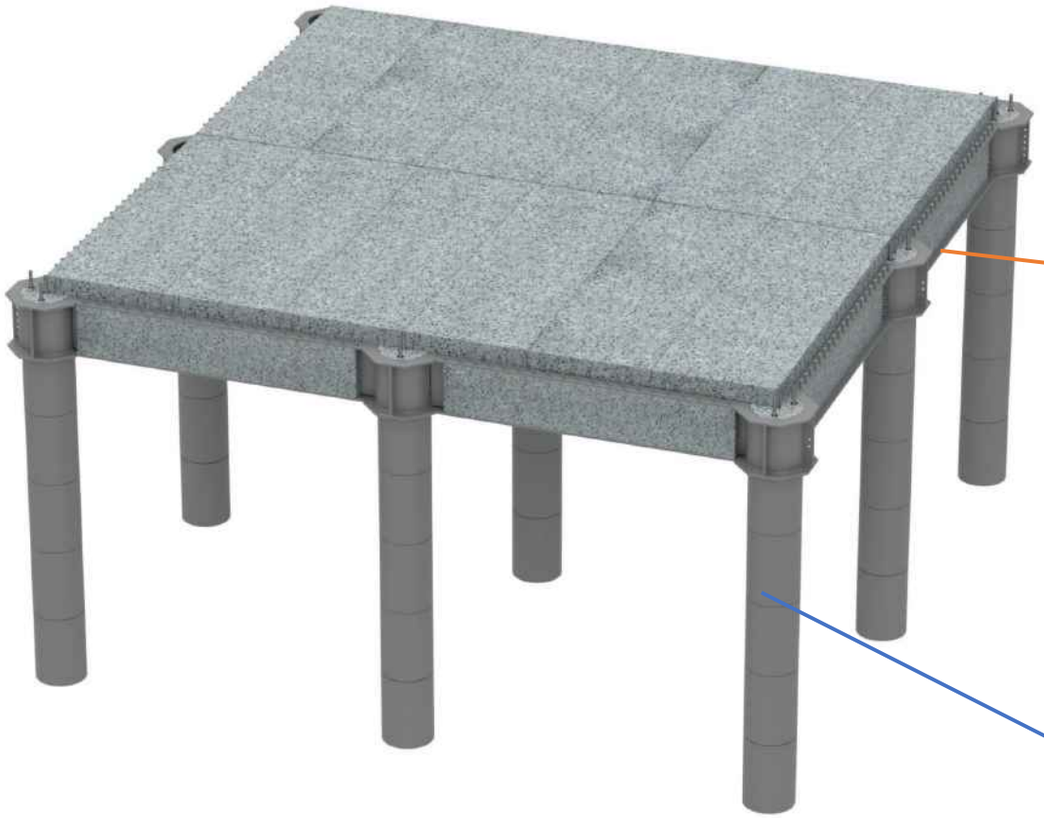
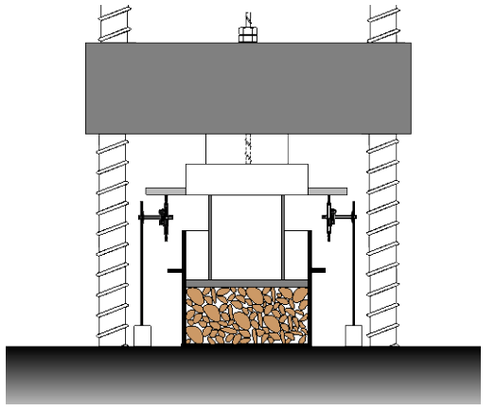
Project III: Implementation of CCC



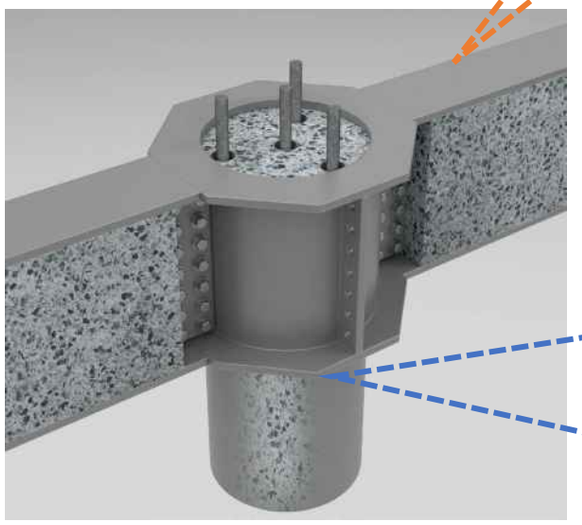
Proposal for Structural Form Using CCC



【Beam: Pressurization】



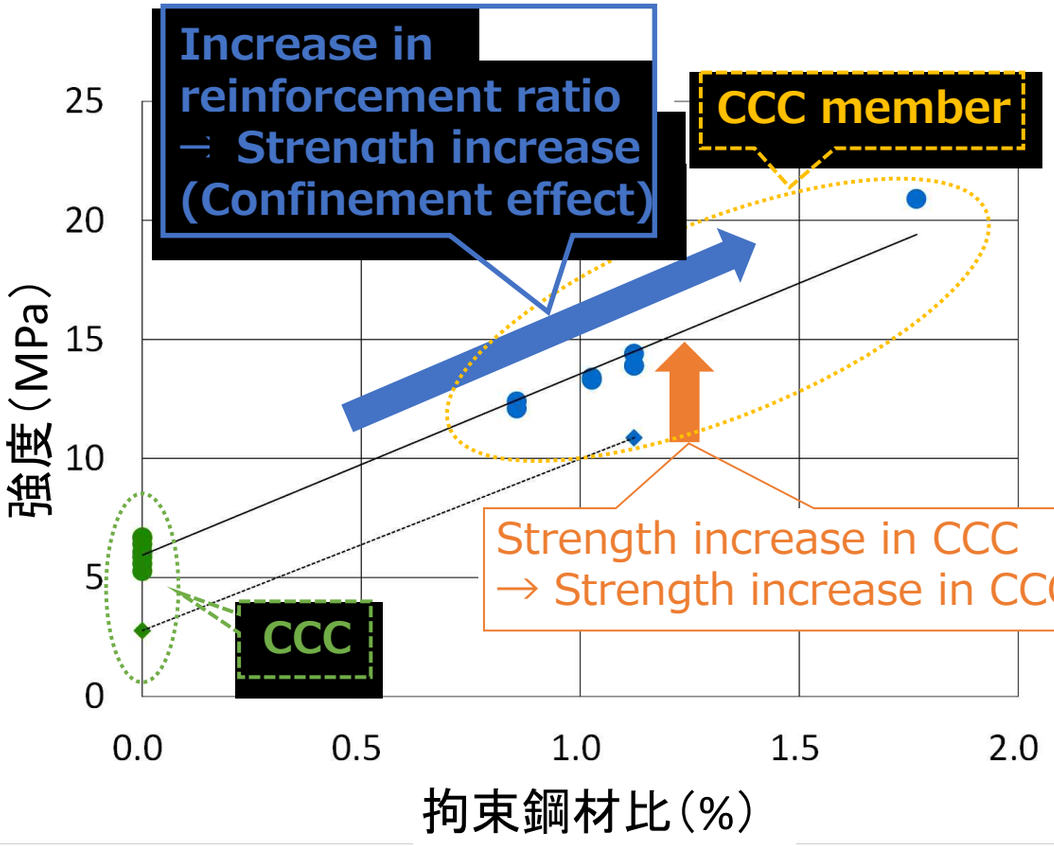
【Column: Pressurization or Precipitation + Prestressing】



Evaluation of Mechanical Performance of CCC Members (Columns)



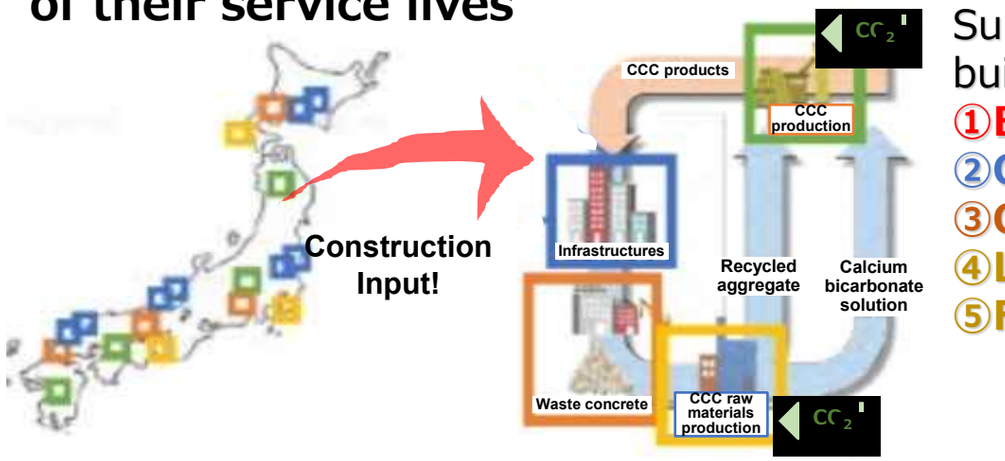




- Confirmation of the **confinement effect** in the low strength range
- Possible to **estimate the strength of simulated CCC members** based on the relationship between the strength of the simulated CCC and the reinforcement ratio
  → Confirmed the possibility of using **CCC as a structural member** of low-rise structures

Accumulation of CCC Raw Materials

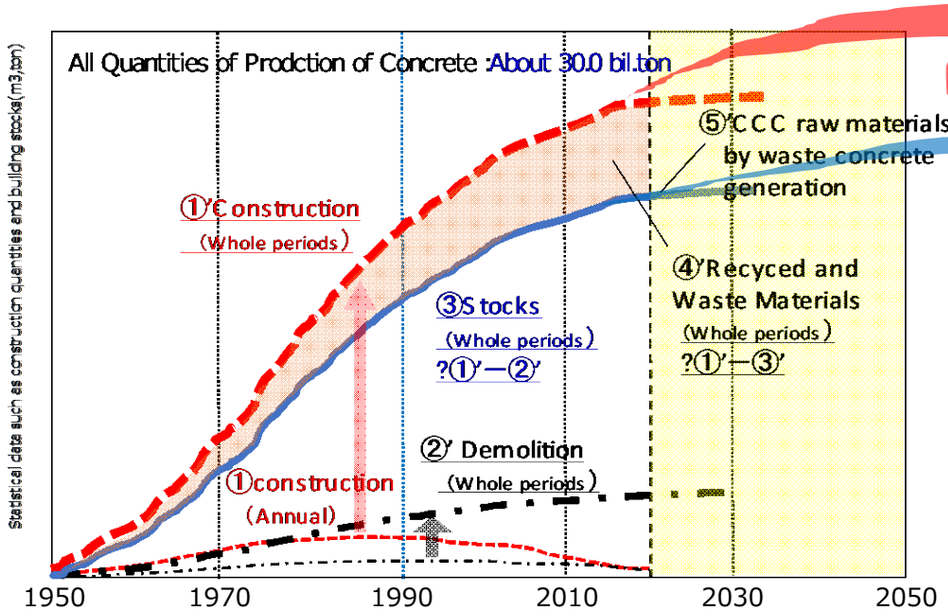
Buildings and civil engineering structures have so far stocked enormous amount of concrete. In the future, they will be demolished and become raw materials for CCC when reaching the end of their service lives

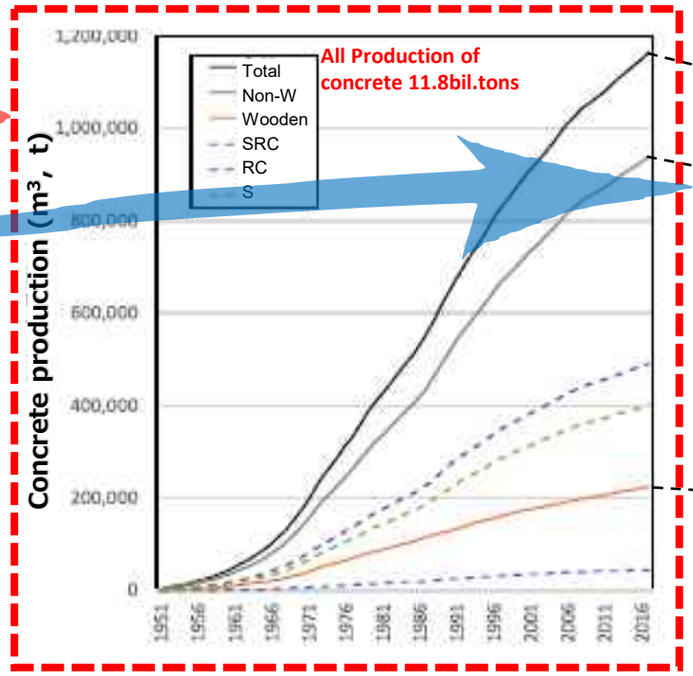


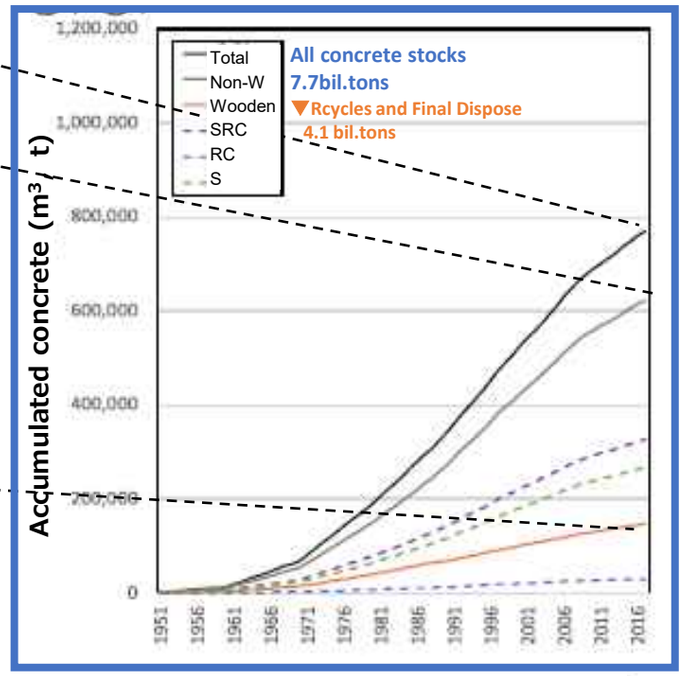
Surveys based on statistical data such as construction quantities and building stocks

①Building construction (m²) and concrete production to date (m³, ton)
②Current building stocks (m²) and concrete accumulation (m³, ton)
③Concrete production and accumulation from the past (m³, ton)
④Life span of buildings (year)
⑤Future amount of concrete waste generated (m³, ton)

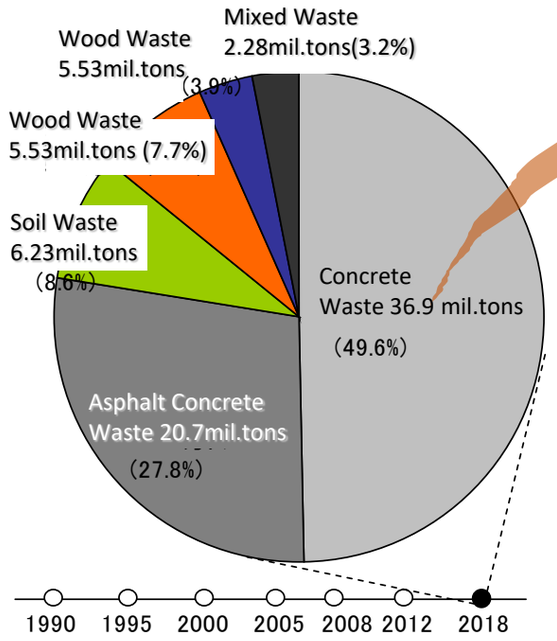
Cumulative concrete production for buildings: 11.8 billion tons
- ■Structure types: RC-38.3%, Steel-33.3%, Wood-19.2%, SRC-8.5%
- ■Area: Tokyo, Osaka, other prefectures (47)
- ■Total concrete production: About 30 billion tons

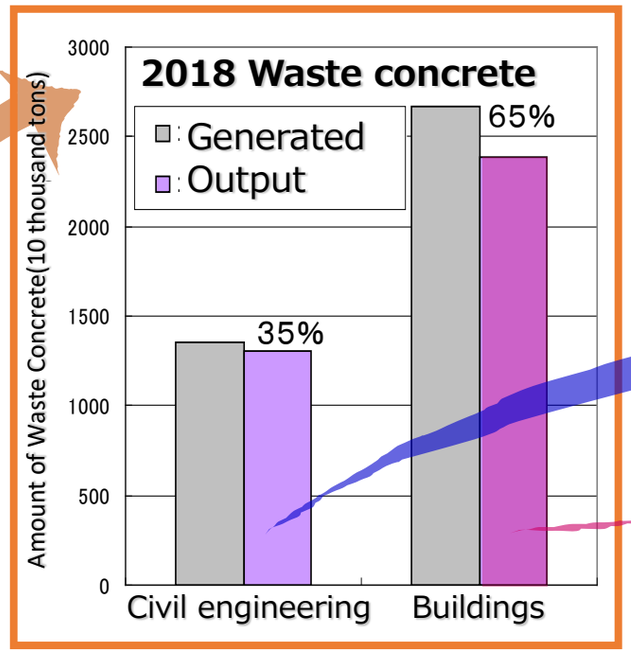






Generation of Waste Concrete





From civil structures (43.8%)

mogeneous)

▼

Recycled aggregate, etc.

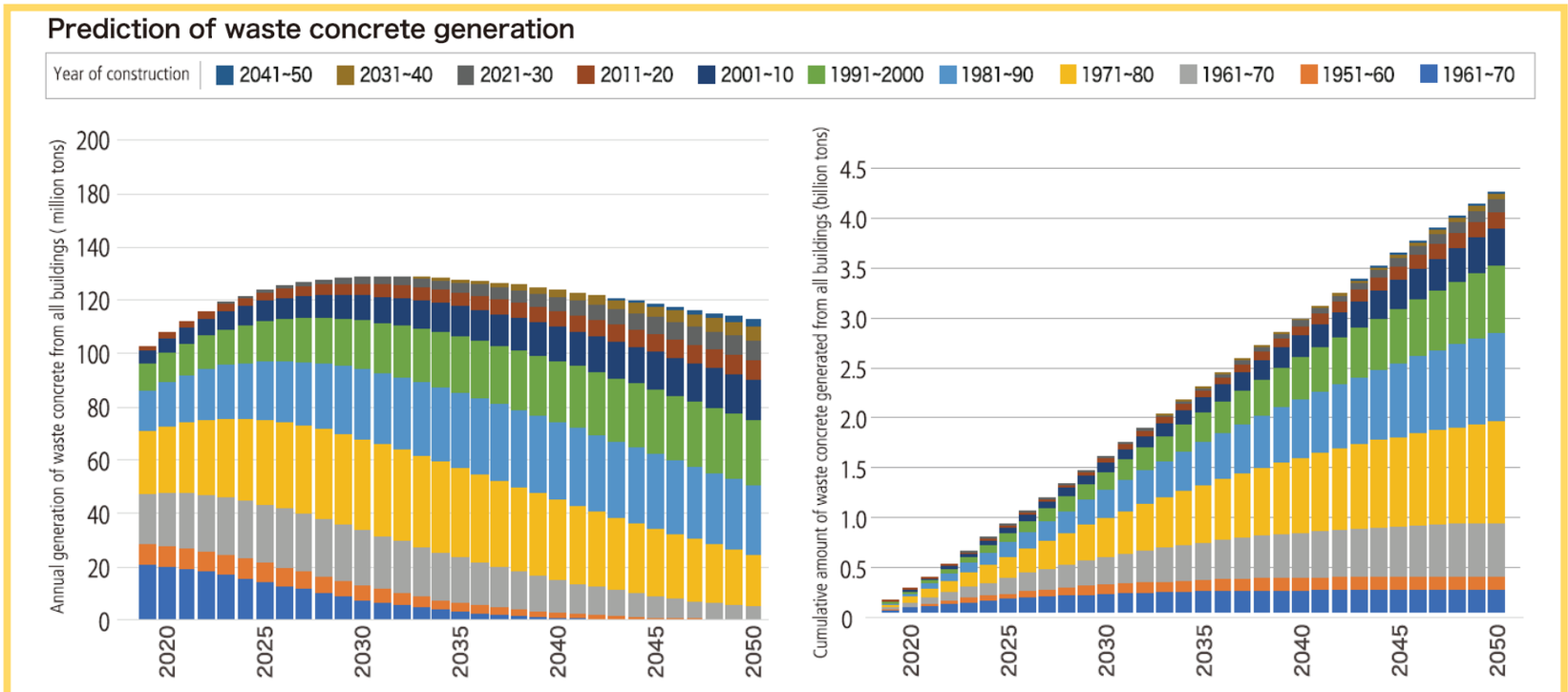
From buildings (56.2%)

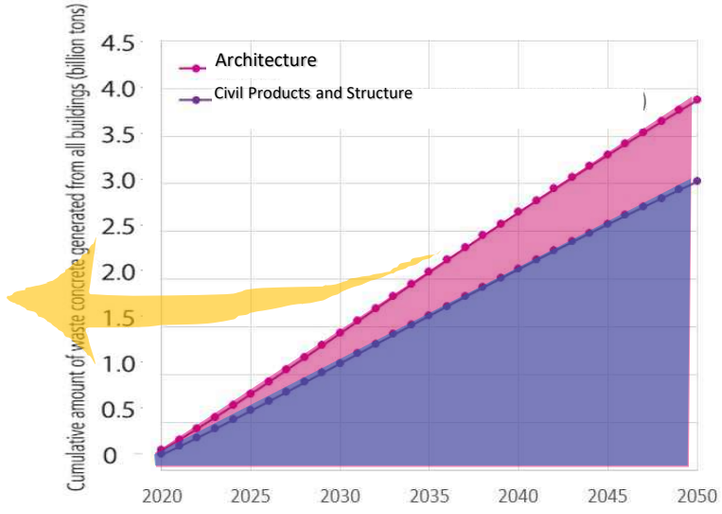
amic tile)

▼

Roadbed, etc.

Comparison in construction waste output between civil engineering structures and buildings (2018)





Waste concrete generated (2020-2050: 30 years)

- **Buildings : 3.9 bil. tons (Ave. 126 mil. tons/year)**
- **Civil structures : 3.0 bil. tons (Ave. 100 mil. tons/year)**

LCA in CCC Production (Boundary setting)

Building demolition → Demolished concrete / Transportation (abbrev. Trans.) → **Intermediate treatment** → Recycled aggregate for roadbed → **Road construction**

NOTE: Some may remain unused for CCC production.
(Not considered at this point)

Building demolition → Demolished concrete → CCC raw material production (crushing・classification) → Trans. → CCC production (heating, cooling, pressing and pumping etc.) → Trans. → Construction of CCC building → **Use of CCC building** → CCC building demolition

Production and execution of reinforcing materials
Production and execution of formwork
→ CCC production

NOTE: Reinforcing and formwork methods and scaled-up production methods are not determined.

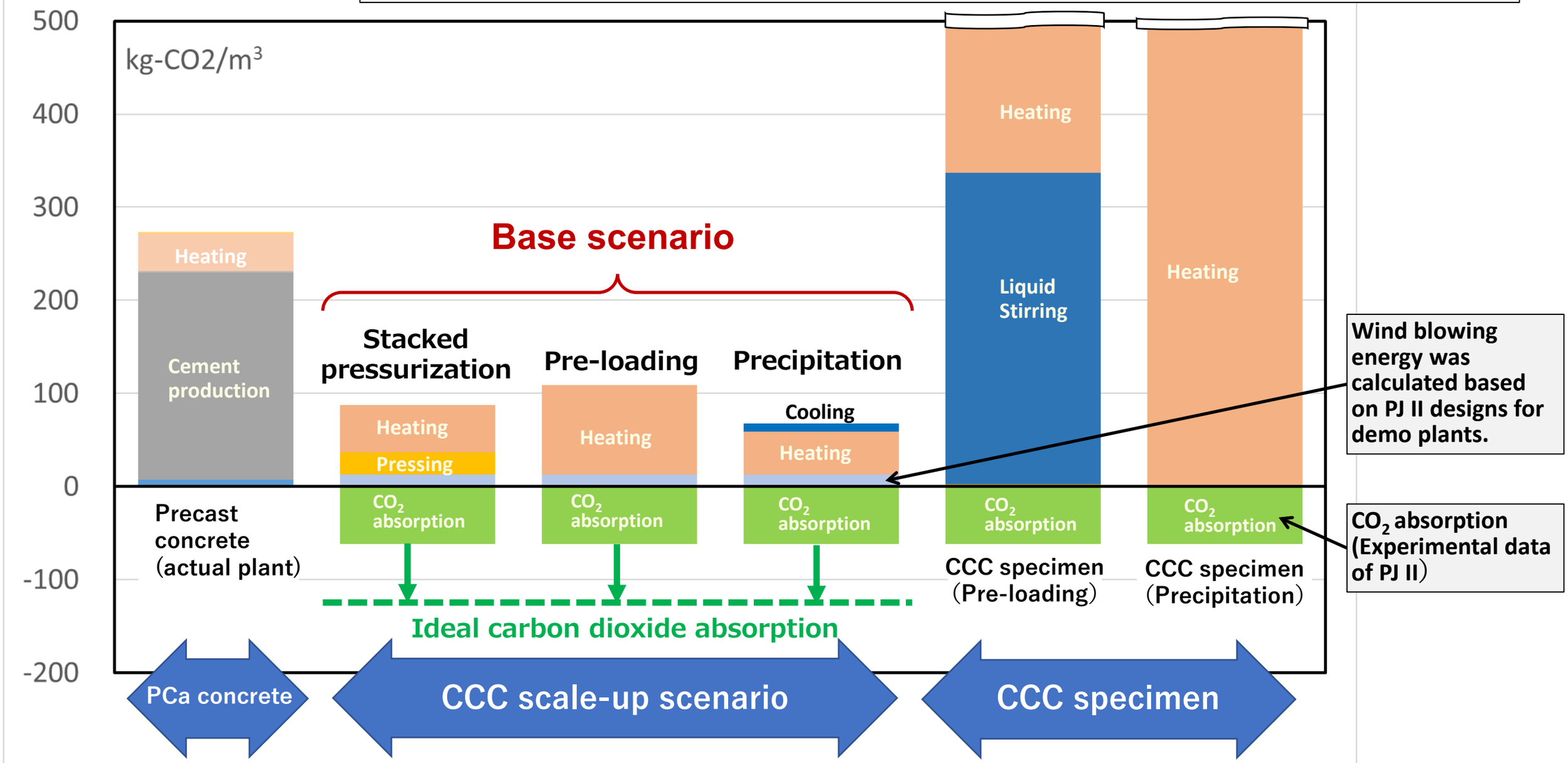
Cement production
Aggregate production
Water production
Chemical admixture production
→ Precast concrete production (mixing, heating etc.) → Construction of PCa building → **Use of PCa building** → PCa building demolition

Production and execution of reinforcing materials
Production and execution of formwork
→ Precast concrete production

Estimation of CO_2 Emission in CCC Production

Base Scenario =

① Standard energy intensity **(kg-CO_2/MJ)** provided by CR2-LCA-WG was used.
② **DAC by air-blowing during CCC raw material production**. CO_2 curing is not used.
③ **100% energy efficiency was assumed** using water consumption data at experiment.



Future Development

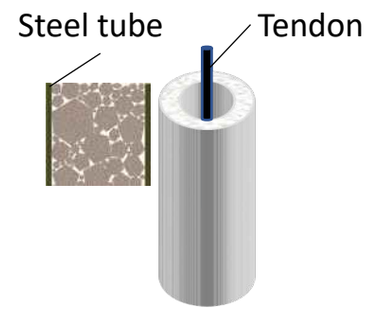
Carbon captured in continental ecosystems
Green Carbon
from land green

Carbon captured in marine ecosystems
Blue Carbon
from ocean blue

Carbon captured in human ecosystems
White Carbon
from human activities

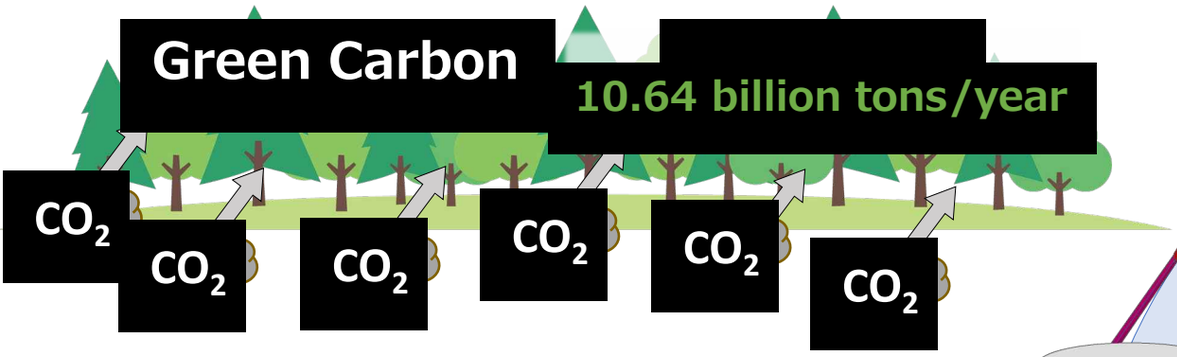
Schedule for Implementation (Concept)

Year	Development & Spreading of CCC	Production of CCC	Enactment & revision of laws and standards CO_2 reduction
2023	Compressive strength of 12MPa legal minimum ent for concrete)	0 ton	
2025	Construction o mockup	100 tons	
2030	Construction of several low rise buildings	2,000 tons	①Certification for a specific project based on ②Establishment of Building Codes & Standard Specifications of Architectural Institute of Japan ③Revision o n Ministry of ④Certification for a specific concrete based on ⑤ ⑥ n Ministry of ⑦Conformity to
2040	**1.725 times increase** every year	0.345 million tons	
2050	**50%** f concrete ures are made of CCC	110 million tons	Japan: **▲26.2 million tons-CO_2/year** World: **▲2.1 billion tons-CO_2/year**



Exhibition at Expo 2025 Osaka

CCC＝White Carbon



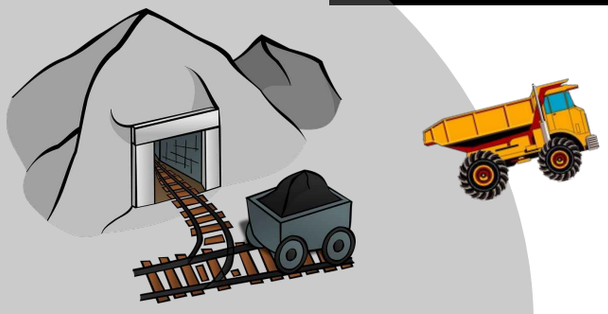
■Total CO_2 in atmosphere　2.8 trillion tons

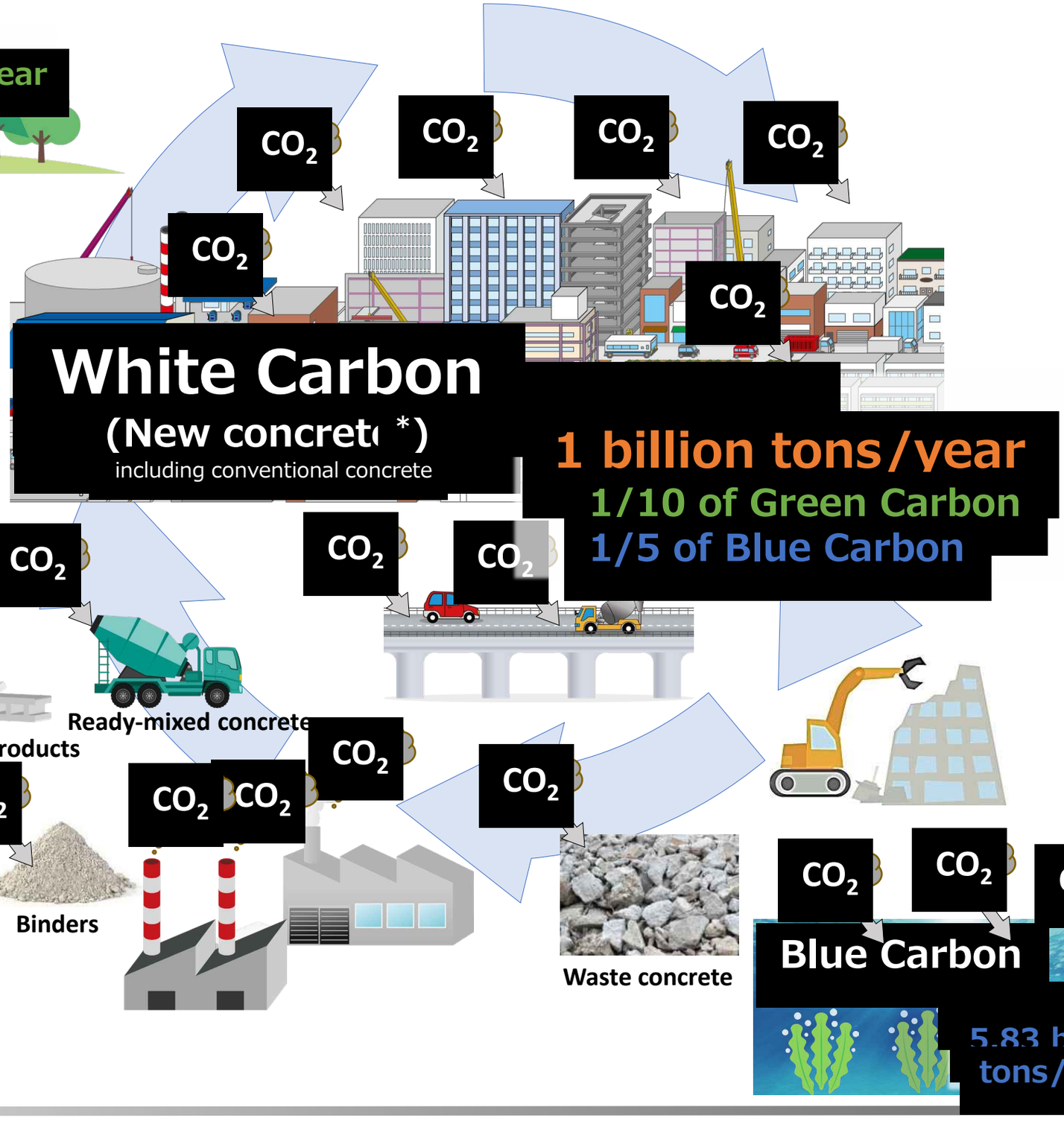
CO_2 emissions by calcination during cement production

➢Cumurative
World　55 billion tons
Japan　2 billion tons

➢Annual
World　2.1 billion tons
Japan　2.6 million tons

Capture of total CO_2 in the atmosphere/ exhaust gas and fixation in concrete





Thank you for your attention.

Our goal for the end of FY 2022 has been achieved.

From now on, all of us will work together to accelerate the study for the social implementation of CCS in order to realize a carbon neutral society in 2050!

Save the Earth!

With CCS!!