Low-Carbon Concrete for Myanmar

Practical Technologies, Performance Challenges and Future Opportunities

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19 September 2026

Function Hall, Fed. MES, Yangon

Speaker Profile

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PROFESSIONAL OVERVIEW

Civil engineer and concrete material researcher
Experience in concrete durability and low-carbon concrete technologies

CORE EXPERTISE

- Low-carbon concrete technologies
- Alternative binder systems and CO_2 utilization
- Moisture transport into concrete and durability of concrete

ACADEMIC BACKGROUND

Doctor of Engineering in Material Science
Nagaoka University of Technology, Japan.

Master of Engineering in Civil Engineering
Nagaoka University of Technology, Japan.

Bachelor of Engineering in Civil Engineering
Yangon Technological University, Myanmar

Why This Topic, Why Now?

GLOBAL CHALLENGE

Climate change and pressure on natural resources

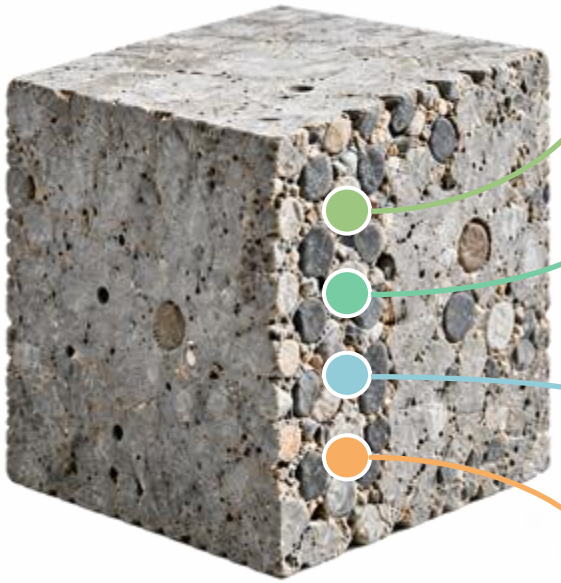
MYANMAR CONTEXT

Continue construction, strengtherning, repair, or reconstruction

MATERIAL SIGNIFICANCE

Concrete will remain essential

Presentation Objective



01 UNDERSTAND

Where concrete-related carbon emissions organiate

02 REVIEW

Practical and emerging low-carbon concrete technologies

03 EVALUATE

Performance benefits, limitations and implementation challenges

04 CONSIDER

Locally avilable materials and realistic production conditions

Presentation Structure

1. Introduction & Scope

2. Concrete Carbon Fundamental

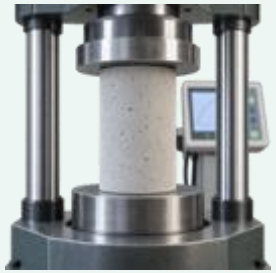
3. ACI Framework & Current Practice

4. Calcined Clay & LC^3

5. Alkali-Activated Concrete

6. Carbon Utilization Technologies

7. Performance and Implementation Challenges



8. Potential Directions and Conclusions

SESSION 2

Concrete carbon fundamentals

Four questions for an engineering comparison

1. Where does CO_2 originate?
2. Which boundary is reported?
3. What reference is used?
4. Does performance remain equivalent?

Concrete Carbon Fundamentals

Where CO_2 arises during clinker production

$CaCO_3 \rightarrow CaO + CO_2$

Raw materials | Heating and clinker formation | Clinker

PROCESS CO_2
Carbonates in the raw material release CO_2 during heating.

ENERGY CO_2
Fuel provide klin heat; electricity also has a foodprint.

Understanding Cement GPW

WHAT IS GPW?

Global Warming Potential compare the warming effects of greenhouse gases on a common scale:
CO_2 equivalent (CO_2e)

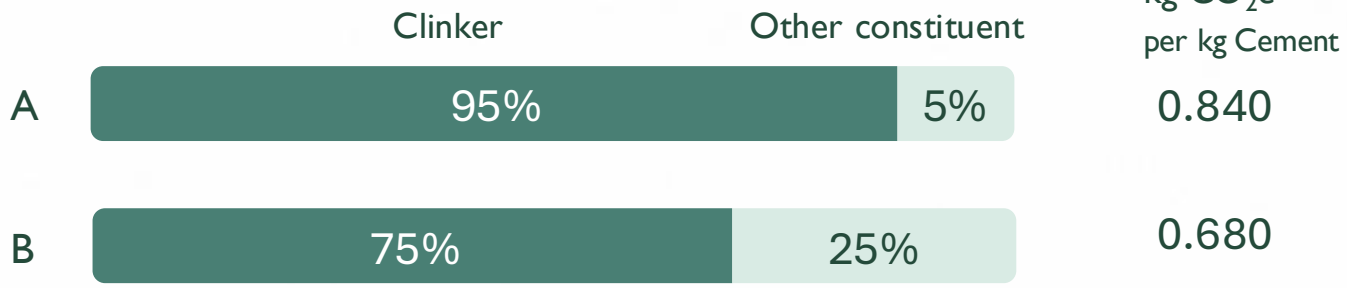
WHY ACCOUNT FOR IT?

To identify emission souces and compare production choices using a consistant measure.

HOW IS CEMENT GWP ESTIMATED?

Clinker factor : mass fraction of clinker in cement
EF (emission factor) : kg CO_2e per kg of material produced

CEMENT COMPOSITION (BY MASS)



	kg CO_2e per kg Cement
A	0.840
B	0.680

Example for B:

Illustrative Efs

Clinker : 0.85 kg CO_2e / kg clinker
Other constituent : 0.05 kg CO_2e/ kg material
Grinding : 0.03 kg CO_2e/ kg cement

Cement B = (0.75 x 0.85) + (0.25 x 0.05) + 0.03
= 0.680 kg CO_2e / kg cement

Note: Use verified product EPD values for project calculations

What Counts in Concrete GWP?

A1–A3 PRODUCT STAGE

A1 Raw-material supply › **A2** Transport to batching plant › **A3** Concrete production ›

Materials, inbound transport and production

A4–A5 CONSTRUCTION PROCESS STAGE

A4 Delivery to site › **A5** Concrete casting

Include when required by the stated assessment scope

ILLUSTRATIVE SITE CALCULATIONS

A4 Delivery logistics

Concrete mass × distance × transport EF

2.4 t/m³ × 50 km × 0.10 kg CO_2e/(t·km)

A4 = 12.0 kg CO_2e/m³

If distance is reduced to 30 km:

A4 = 7.2 kg CO_2e/m³ **Reduction = 40%**

Control: plant selection and delivery planning

A5 Site operations

Pumping diesel	0.60 L × 2.70 = 1.62
Site electricity	2 kWh × 0.60 = 1.20
Concrete wastage	2% × 280 = 5.60

A5 total = 8.42 kg CO_2e/m³

If wastage is reduced to 0.5%:

A5 = 4.22 kg CO_2e/m³ **Reduction ≈ 50%**

A4 and A5 can be reported and improved separately. Compare results only when the unit and included stages match.

Illustrative factors only. Actual vehicle, payload, return-trip method, site energy, wastage and waste treatment must follow the selected assessment rules.

Cement GWP vs Concrete GWP

Product emission intensity and dosage act together

	Cement GWP		Dosage		Contribution
MIX A	**0.820 kg CO_2e/kg**	×	**300 kg/m^3**	=	**246 $kg\ CO_2e/m^3$**
MIX B	**0.650 kg CO_2e/kg**	×	**360 kg/m^3**	=	**234 $kg\ CO_2e/m^3$**

Cement product GWP reduction	**21%**	Cement contribution reduction	**5%**

Material Selection

Choose suitable material with lower verified GWP.

Mix Design

Optimize cement and other material quantities per m^3.

Required Performance

Achieve the specified strength, workability and durability without unnecessary overdesign

Production and Delivery

Reduce avoidable energy use and transport emission.

Reading A Concrete EPD

An EPD reports environmental impacts under defined rules and a stated boundary.

EPD = Environmental Product Declaration

CHECK	WHAT TO LOOK FOR	WHY IT MATTERS
Product and unit	Concrete type; GWP per 1 m^3, for example	Establishes what the number describes
GWP and modules	Reported indicator; A1–A3, A4, A5, etc.	Sets the impact and its boundary
PCR and standard	Applicable product category rules and standard	Shows which calculation rules apply
Data and validity	Geography, data period and validity dates	Shows how representative and current it is
Verification	Programme operator and verification statement	Shows independent review

An EPD reports impacts. Structural suitability requires separate engineering assessment.

Concrete GWP Calculation

Illustrative calculation for 1 m^3 of concrete

CONSTITUENT	QUANTITY	EF (kg CO_2e/kg)	kg CO_2e/m^3
Cement	300 kg	0.82	246.00
GGBS	100 kg	0.08	8.00
Aggregates	1,750 kg	0.005	8.75
Water	175 kg	0.0003	0.0525
Admixture	4 kg	2.0	8.00
Plant energy	per m^3	direct	10.00

Total = 280.8025 ≈ 280.8 kg CO_2e/m^3

Baseline Sensitivity

The same proposed mixture can yield different percentage reductions.

PROPOSED MIX DESIGN	$280.8\ kg\ CO_2e/m^3$

REFERENCE	GWP ($kg\ CO_2e/m^3$)	REDUCTION	DESCRIPTION
A	320	**12%**	Efficient reference mix
B	355	**21%**	Project baseline
C	400	**30%**	High-cement reference

Reduction = (reference GWP − proposed GWP) / reference GWP

Report the reference definition and absolute GWP with every percentage claim.

Equivalent Concrete Preformance

A lower GWP figure is meaningful only for concrete serving the same purpose.

FUNCTION

Same intended application and structural requirements

PERFORMANCE

Same specified strength and test age; suitable workability

EXPOSURE

Same durability requirements and intended service life

ACCOUNTING

Same unit, assessment boundary and data basis

Then compare the GWP per m^3 of the qualifying mixtures.

When is a Carbon Comparison Fair?

Three checks before interpreting a lower GWP value or percentage reduction

01	**Same function**	Comparable specified performance and application
02	**Same boundary**	Matching units and included life-cycle stages
03	**Credible data**	Representative constituent and production information

Next: How can these principles be applied in specifications?

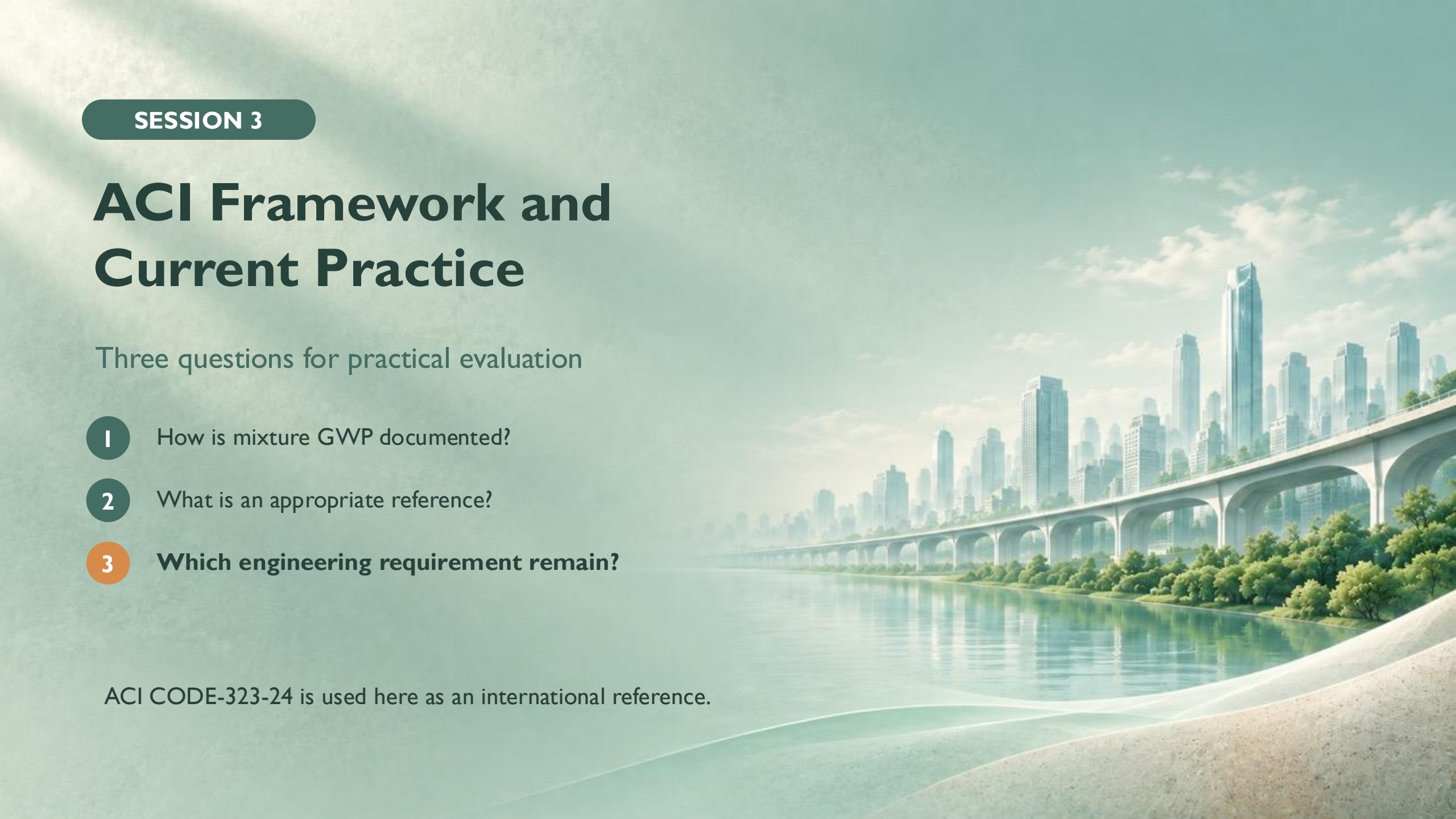
SESSION 3

ACI Framework and Current Practice

Three questions for practical evaluation

1. How is mixture GWP documented?
2. What is an appropriate reference?
3. **Which engineering requirement remain?**

ACI CODE-323-24 is used here as an international reference.



Scope of ACI 323-24: Low-Carbon Concrete

A model code for specified reductions in concrete GWP

Covered	Cast-in-place concrete with design strengths from 2,500 to 8,000 psi (about 17–55 MPa).
Excluded	Precast concrete, tremie concrete, auger-cast concrete, grout, shotcrete, pavers and masonry units.
Repair work	The code also applies to concrete repair and rehabilitation within its scope.

ACI CODE-323-24 provides a useful framework for evaluating and specifying lower-carbon concrete, with principles that can inform professional practice in Myanmar.

How the Code Works

Project type and size determine the compliance path

Tier 1	**Large projects**	Define and meet a weighted project GWP limit relative to a local benchmark.
Tier 2	**Medium projects**	Calculate the corresponding Tier 1 limit and document reduction strategies.
Tier 3	**Small projects**	Document mixtures and reduction strategies.

The code sets GWP performance requirements; it does not prescribe specific mixture properties or constituent materials.

Documenting Mixture GWP

The number needs a product, unit and assessment boundary

Mixture identity

Identify the supplier, concrete mixture and intended application.

GWP result

Report kg CO_2e per m^3 and identify which life-cycle modules the value includes.

Evidence

Use an applicable environmental product declaration or other data permitted by the project rules.

An EPD reports environmental impacts. It does not establish structural suitability.

Choosing a GWP Benchmark

A benchmark gives the comparison a relevant reference

Project mixture GWP versus **Local reference GWP**

Location

Material supply, energy and transport differ from place to place.

Like for like

Match the concrete application and the basis used to calculate GWP.

Benchmark applicability should reflect local materials, production and supply conditions.

Weighted Project GWP

Concrete volume gives each mixture its share in a project result

MIXTURE	VOLUME	GWP PER m^3	CONTRIBUTION
A: early strength	300 m^3	320 kg CO_2e/m^3	96,000 kg CO_2e
B: general use	700 m^3	240 kg CO_2e/m^3	168,000 kg CO_2e

Weighted average **(96,000 + 168,000) / 1,000 = 264 kg CO_2e/m^3**

Engineering Requirements Remain

A carbon target adds to the project's existing performance requirements

Structural

Specified strength, safety and serviceability remain project requirements.

Construction

Workability, setting and strength development must suit construction.

Durability

Evaluate exposure conditions and the intended service life.

Assess proposed mixtures for their intended use before comparing GWP.

Practical Reduction Options

Choose a mixture that meets the application before claiming a GWP benefit

Binder	Evaluate lower-clinker cements and suitable supplementary cementitious materials.
Mixture	Optimize binder content and aggregate grading; verify required fresh and hardened properties.
Specification	Avoid unnecessary early-age strength or prescriptive limits where design permits.

Compare qualifying mixtures using the same unit and assessment boundary.

Questions for Current Practice

What would we need to apply this approach responsibly?

Data	Can suppliers report comparable GWP values for local concrete mixtures?
Reference	Who would establish a credible Myanmar project or regional benchmark?
Design	Which strength, exposure and construction requirements must each mixture meet?

Next session: technologies that may lower mixture GWP while meeting these requirements.

SESSION 4

Calcined Clay and LC^3

Four questions for practical evaluation

1. What is calcined clay?
2. How is clay made reactive?
3. What made LC3 different?
4. **Could Myanmar resources be used?**

Why Look Beyond Fly Ash and Slag?

Conventional SCM supply follows other industries, not cement demand.

Fly ash

Depends on coal-fired power generation

Supply and quality vary

Slag

Depends on iron production

Concentrated near steel plants

Calcined clay

Produced from suitable clay resources

Potentially broader geographic supply

Calcined clay can expand the SCM resource base where fly ash and slag are limited.

Source: Scrivener et al. (2018), Cement and Concrete Research 114, 49–56.

Why Consider Calcined Clay?

Lower clinker content becomes possible with a deliberately produced SCM.

- Suitable clays occur more widely than many industrial by-product SCMs.
- Calcination generally uses a lower temperature than clinker production.
- The material can support binary cement or limestone–calcined-clay systems.
- Local value depends on resource quality, energy, transport and production control.

The opportunity comes from reducing clinker while maintaining verified performance.

Source: Scrivener et al. (2018).

What is Calcined Clay

Thermal treatment converts suitable clay minerals into a reactive supplementary cementitious material.

RAW CLAY → CONTROLLED HEATING → REACTIVE SCM

Calcined clay is a family of processed materials, not one uniform product.

Thermal treatment and reactivity depend on clay mineralogy and associated minerals.

Calcined Clay IS Not One Material

Natural clay deposits contain different clay minerals and non-clay constituents.

Clay minerals

Kaolinite, illite, smectite

Associated minerals

Quartz, feldspar, carbonates

Colouring phases

Iron-bearing minerals

Deposit variability

Layers, locations and extraction faces

Mineralogy and variability influence calcination, water demand and cement performance.

Source: Fernández et al. (2011), Cement and Concrete Research 41, 113–122.

Calcined Clay and Other SCMs

Origin, processing and reaction differ across supplementary cementitious materials.

Material	Origin	Additional processing	Primary behaviour
Fly ash	Coal combustion	Classification may be required	Pozzolanic
Slag	Iron production	Drying and grinding	Latent hydraulic
Calcined clay	Suitable natural clay	Calcination and grinding	Pozzolanic

Material selection must consider availability, processing needs and concrete performance.

General comparison based on ACI and peer-reviewed SCM literature.

Clay Minerals and Reactivity

Different layer structures respond differently to heat.

Kaolinite

Often the most predictable source of high reactivity

Illite

Can develop useful reactivity, but response varies

Smectite

Thermal response and water demand require careful study

The mineral structure matters more than the word "clay" alone.

Source: Fernández et al. (2011).

Kaolinite to Metakaolin

Controlled dehydroxylation disrupts the crystalline structure and creates a reactive aluminosilicate.

Kaolinite

Ordered layered clay mineral
$Al_2Si_2O_5(OH)_4$

HEAT

Metakaolin

Disordered and reactive aluminosilicate

In cement

Reacts with calcium hydroxide and contributes additional hydrates

Kaolinite is the principal example, but calcined-clay technology is broader than metakaolin.

Source: Fernández et al. (2011); Scrivener et al. (2018).

Can Other Clay Be Used?

Useful reactivity is possible beyond high-purity kaolinite, but the response becomes more material-specific.

Potentially useful materials

Lower-grade kaolinitic clay
Illitic clay or shale
Mixed clay deposits
Clay-rich overburden or stockpiles

Questions to resolve

Activation temperature
Reactive fraction
Grinding and water demand
Strength and durability contribution

A lower-grade clay can be valuable when its processed performance is suitable.

Source: Cordoba et al. (2022), ACI Materials Journal 119(1), 134–144.

Composition Alone Is Not Enough

Similar oxide totals can conceal different minerals, crystallinity and reactivity.

XRF

Measures elemental oxide composition

Useful for chemistry and impurities
Does not identify the full mineral structure

≠

Cement suitability

- Mineralogy and crystallinity
- Thermal behaviour
- Reactivity after calcination
- Water demand and concrete performance

Use XRF together with mineralogical, thermal and performance testing.

Source: Fernández et al. (2011); Avet et al. (2016).

How Calcination Activate Clay

Heating removes structural hydroxyl groups and disrupts the ordered mineral structure.

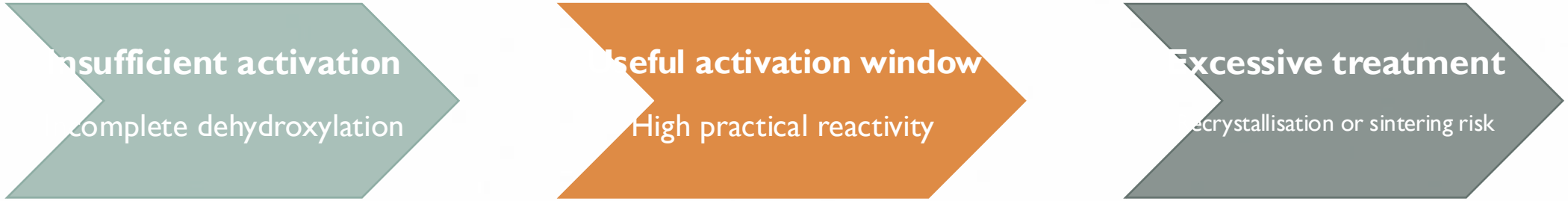
1. **Heat the prepared clay**
2. **Drive dehydroxylation**
3. **Create a disordered reactive phase**
4. **Cool and grind for cement use**

Activation changes mineral structure; it does not melt the clay into clinker.

Source: Irassar (2019), ACI Materials Journal 116(3).

Finding the Calcination Window

The useful temperature and residence time depend on the mineral assemblage and equipment.



Increasing thermal treatment

Do not present one universal calcination temperature as suitable for every clay.

Typical kaolinitic clay ranges often fall near 700–850°C; optimisation remains material-specific.

Processing Affects Performance

The same deposit can produce different SCM performance under different processing conditions.

1. **Selective extraction**
2. **Drying and size reduction**
3. **Controlled calcination**
4. **Cooling**
5. **Grinding or classification**
6. **Blending and storage**

Production controls

Temperature profile • residence time • fineness • moisture • homogeneity

Resource quality and process control must be evaluated together.

Source: Scrivener et al. (2018).

How is Reactivity Evaluated?

Screening narrows the candidates; mortar and concrete trials confirm engineering value.

1. **Mineralogy**
   XRD
2. **Thermal response**
   TGA / DSC
3. **Trial calcination**
   Temperature and time
4. **Reactivity**
   R^3 or equivalent
5. **Performance**
   Mortar and concrete

A screening result supports selection; it does not replace concrete validation.

Source: Avet et al. (2016), Cement and Concrete Research 85, 1–11.

What Does LC^3 Mean?

The name describes a limestone–calcined-clay cement system.

L + C^3

The superscript 3 represents three words beginning with C. It is not a chemical formula.

Limestone Calcined Clay Cement

L = Limestone
C^3 = Calcined + Clay + Cement

LC^3 names the cement concept; LC^3-50 identifies a formulation with about 50% clinker.

Source: Scrivener et al. (2018).

What Is Inside LC³?

Four controlled constituents form the cement system.

Clinker

Main hydraulic phase

Calcined clay

Reactive aluminosilicate

Limestone

Carbonate and filler

Gypsum

Controls early reactions

The constituents must be proportioned, ground and sulfated as one cement system.

Source: Scrivener et al. (2018).

LC^3 and Ordinary Cement

LC^3 reduces clinker and gains performance from complementary reactions.

Aspect	Ordinary Portland cement	LC^3
Main binder	Predominantly clinker	Clinker + calcined clay + limestone
Reaction	Mainly clinker hydration	Hydration + pozzolanic + carbonate interaction
Clinker content	Generally high	Lower; formulation-dependent
Fresh behaviour	Established local practice	May need water/admixture optimisation
GWP	Strongly linked to clinker	Potentially lower with verified performance

LC^3 contains clinker; it is a lower-clinker cement rather than a clinker-free binder.

Comparison based on Scrivener et al. (2018).

Why added Limestone?

Reactive alumina from calcined clay interacts with carbonate from limestone.

Calcined clay

Reactive alumina
and silica

+

Limestone

Carbonate source
and particle filling

Combined system

Carboaluminate phases
Space filling
Improved phase assemblage

Limestone contributes to the reaction system; it is not only an inert diluent.

Source: Antoni et al. (2012), Cement and Concrete Research 42, 1579–1589.

How LC3 Develps Performance

Several mechanisms operate together as the cement hydrates.

Clinker hydration

Produces strength-forming hydrates and calcium hydroxide

Pozzolanic reaction

Calcined clay consumes calcium hydroxide and forms additional hydrates

Clay–limestone interaction

Aluminate and carbonate form carboaluminate phases

Particle packing

Fine particles fill space and support microstructural refinement

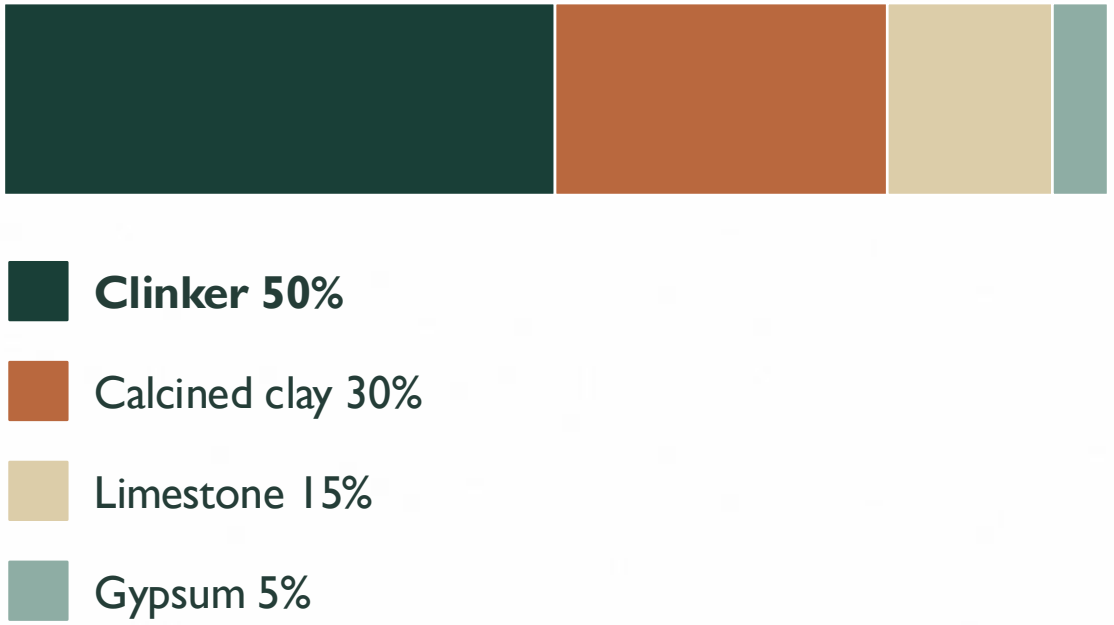
Performance comes from a coordinated cement system, not from one constituent alone.

Source: Antoni et al. (2012); Scrivener et al. (2018).

LC3 Is a Family of Cements

LC³-50 is a widely studied reference formulation, not a mandatory universal composition.

LC³-50



The final formulation must match the raw materials, performance needs and applicable standard.

Reference composition: Scrivener et al. (2018).

Strength Development

Strength depends on the complete material and mixture system.

1 Clay mineralogy

Reactive fraction after calcination

2 Cement formulation

Clinker, clay, limestone and sulfate balance

3 Fineness

Reaction rate and water demand

4 Concrete mixture

Water–binder ratio, dosage and admixture

5 Curing

Temperature, moisture and testing age

Equivalent strength must be demonstrated for the specified age and application.

Sources: Scrivener et al. (2018); Dhandapani et al. (2018).

Fresh Concrete Behaviour

Calcined clay can change water demand, rheology and admixture response.

- High surface area can increase water demand.
- Slump retention may differ from conventional cement.
- Adding water alone can weaken strength and durability.
- Trial mixtures should optimise superplasticizer type and dosage.
- Confirm pumping, placing and finishing under site conditions.

Control workability through mixture optimisation, not uncontrolled water addition.

Source: Ferreiro et al. (2017), Cement and Concrete Research 101, 1–12.

Durability Performance

LC³ can refine the pore structure, but each exposure condition needs verification.

Chlorides	Strong potential from pore refinement
ASR	Calcined clay can reduce expansion
Sulfates	Performance depends on formulation and exposure
Carbonation	Evaluate like other lower-clinker cements
Reinforcement	Confirm transport and corrosion-related performance

Published results support potential, but they do not replace project-specific durability assessment.

Sources: Cordoba et al. (2022); Scrivener et al. (2018).

Benefits and Practical Challenges

A credible assessment considers carbon, performance, production and implementation together.

Potential benefits

Lower clinker content
Potentially lower cement GWP
Broader possible SCM resource base
Strength and durability potential
Reduced dependence on imported SCMs
Possible use of lower-grade clay

Practical challenges

Variable clay mineralogy
Calcination and grinding investment
Water and admixture demand
Sulfate balance and quality control
Colour variation
Standards and market acceptance

The best option depends on local materials, energy, logistics and required concrete performance.

Balanced assessment based on Scrivener et al (2018) and ACI literature.

From Cement to Concrete

Cement formulation and concrete mixture design involve different responsibilities.

1 Cement manufacturer

Formulates clinker, calcined clay, limestone and gypsum

Controls calcination, grinding, blending and cement conformity

2 Concrete producer

Proportions cement, water, aggregates and admixtures

Conducts laboratory and production trials

3 Project engineer

Specifies required strength, exposure and durability

Reviews evidence and accepts the mixture

No single worldwide code provides a complete LC³ concrete mix-design formula.

General proportioning: ACI PRC-211.1. Cement examples: IS 18189; ASTM C595/C1157; ASTM C618 for separate pozzolan.

Could Myanmar Produce LC³?

Reported clay and kaolinite occurrences indicate potential, but cement suitability remains unconfirmed.

What appears possible

Myanmar has diverse geology, clay occurrences and an existing cement industry.

What remains unknown

Deposit quantity and consistency; mineralogy; reactivity; processing energy; concrete performance and commercial feasibility.

Reported clay occurrence provides a reason to investigate, not proof of an LC³-ready resource.

Myanmar context source: UN ESCAP (1996), Geology and Mineral Resources of Myanmar.

A Practical Evaluation Pathway

Local evidence should progress from the deposit to a full concrete demonstration.

1. **Geological review**
2. **Representative sampling**
3. **Mineral and thermal characterisation**
4. **Calcination and grinding trials**
5. **Cement formulation**
6. **Concrete and GWP validation**

Calcined clay and LC³ offer a credible clinker-reduction opportunity for Myanmar when local resources and performance are verified.

Next step: identify candidate materials and build an evidence-based trial programme.

Core references: Scrivener et al. (2018); Fernández et al. (2011); Antoni et al. (2012); Cordoba et al. (2022).

SESSION 5

Alkali-Activated Concrete

Four questions for an engineering comparison

1. What is alkali activation?
2. How does the binder develop?
3. How does it differ from the ordinary concrete?
4. **What evidence support practical use?**

Why Consider Alkali Activation?

A different binder route can reduce reliance on Portland clinker.

Opportunity

Use reactive aluminosilicate or calcium-rich materials as the main binder source.

Potential benefit

Lower process emissions may be possible when clinker use falls.

Engineering condition

Performance, safety, availability and verified GWP still govern selection.

Alkali activation is a material platform, not an automatic low-carbon guarantee.

Reference: Provis (2018), Cement and Concrete Research 114, 40–48.

What Is Alkali-Activated Concrete?

An alkaline environment activates a suitable precursor to form a hardened binder.

Precursor

Fly ash, slag, metakaolin or another suitable reactive material.

Activator

A controlled alkaline solution or solid activator initiates dissolution and reaction.

Concrete

Binder paste combines with aggregates, water and admixtures to form concrete.

The precursor and activator must be designed as one binder system.

Reference: Provis (2018).

Alkali-Activated and Ordinary Concrete

The aggregates may be similar, but the binder chemistry and production controls differ.

Ordinary concrete

Portland cement hydrates with water. Local design methods and supply chains are well established.

Alkali-activated concrete

A precursor reacts in an alkaline environment. Activator chemistry and curing become additional design variables.

Compare equivalent structural and durability requirements, not binder names alone.

Reference: Provis (2018); ACI 318 performance requirements as applicable.

Alkali-Activated or Geopolymer?

The terms overlap, but they are not always interchangeable.

Alkali-activated materials

Broad family of binders produced by alkaline activation.

Geopolymer

Often used for low-calcium aluminosilicate systems with a three-dimensional alkali-aluminosilicate network.

Hybrid binders

May include Portland cement or other calcium sources with alkali activation.

Use “alkali-activated concrete” as the broad session term.

Reference: Provis and van Deventer (eds.), Alkali Activated Materials, 2014.

What Is Inside the Binder?

Binder behaviour comes from the interaction of precursor, activator and curing.

Solid precursor

Controls available silicon, aluminium and calcium.

Alkaline activator

Controls alkalinity, soluble silicate and liquid content.

Curing regime

Controls reaction rate, early strength and practical production.

Changing one component can alter setting, strength, shrinkage and durability together.

Reference: Provis (2018).

Common Precursor Materials

Each precursor brings different chemistry, reactivity and supply constraints.

Low-calcium fly ash

Often slower at ambient temperature; heat curing may assist early reaction.

Ground slag

Calcium-rich and often suitable for ambient curing; rapid setting can occur.

Metakaolin

Reactive and comparatively consistent; cost and availability can limit volume.

Blended precursors

Combine materials to balance reaction rate, workability and performance.

A precursor name does not define performance without source-specific testing.

Reference: Provis (2018).

Common Alkaline Activators

Activator selection affects both reaction and environmental burden.

Hydroxides

Provide high alkalinity; concentration and handling require strict control.

Silicate solutions

Supply soluble silicate and commonly improve reaction development; production can carry notable GWP.

Carbonates and sulfates

Lower-hazard options for some systems, but reaction rate and applicability differ.

Solid activators

Enable one-part systems after dry blending; moisture protection remains important.

Select the activator for performance, safe production and verified environmental impact.

Reference: Provis (2018); Luukkonen et al. (2018), Cement and Concrete Research 103, 21–34.

One-Part and Two-Part Systems

The activator can enter the process as a dry constituent or a prepared liquid.

One-part system

Dry precursor and solid activator are supplied together. Water starts the reaction at mixing.

Two-part system

Prepared alkaline solution is dosed into the mixer with the other constituents.

One-part systems simplify site handling, while two-part systems offer direct solution control.

Reference: Luukkonen et al. (2018).

How the Binder Develops

Dissolution, transport and precipitation produce the hardened binding phases.

1 Dissolution

Alkalinity releases reactive silicon, aluminium and calcium from the precursor.

2 Reorganisation

Dissolved species move and form intermediate structures.

3 Precipitation

Reaction products form, connect particles and refine the pore structure.

The simplified sequence supports understanding; real reactions can overlap.

Reference: Provis (2018).

Reaction Products Depend on Chemistry

Calcium content strongly influences the principal binding phases.

Low-calcium systems

N-A-S-H-type alkali aluminosilicate gels commonly dominate.

Calcium-rich systems

C-(A)-S-H-type calcium aluminosilicate hydrates commonly dominate.

Blended systems

Mixed gels and secondary phases can develop together.

These labels simplify complex, composition-dependent phase assemblages.

Reference: Provis (2018).

Curing Controls the Reaction

Temperature and moisture influence early reaction, strength and dimensional change.

Elevated-temperature curing

Can accelerate low-calcium fly-ash systems; best suited to controlled precast production.

Ambient curing

More practical for cast-in-place work; slag or other calcium sources often support early reaction.

Moisture control

Prevents drying from being confused with chemical or self-desiccation effects.

A curing method proven for one binder may not suit another.

Reference: Provis (2018).

Case Study: Heat-Cured Fly-Ash Concrete

A 2006 ACI study shows one controlled route, not a universal formulation.

Binder

Alkali-activated fly ash concrete.

Curing

Approximately 85°C for about 20 hours.

Testing

Compressive and flexural strength, modulus, bond and shrinkage.

Interpret the results within the materials and curing conditions used in the study.

Reference: Fernández-Jiménez, Palomo and López-Hombrados (2006), ACI Materials Journal 103(2), 106–112.

Reported Engineering Performance

The heat-cured fly-ash concrete developed useful strength and bond.

Compressive strength

Approximately 45–50 MPa at the early reported test ages.

Elastic modulus

Approximately 12–17 GPa, lower than many ordinary concretes of similar compressive strength.

Bond and flexure

The study reported structural-response indicators suitable for further evaluation.

Strength alone does not establish equivalence in stiffness, cracking or durability.

Reference: Fernández-Jiménez et al. (2006). Values are study-specific.

Limits of the Case Study

The experiment answers specific questions and leaves others open.

Supported conclusion

Heat-cured fly-ash concrete can achieve substantial early compressive strength.

Important limitation

Post-curing shrinkage measurements did not capture deformation during heat curing.

Transferability

Local fly ash, activator, aggregates, scale and curing may change the result.

Use the paper as evidence for one system, not as a universal design guide.

Reference: Fernández-Jiménez et al. (2006).

Why Slag Supports Ambient Curing

Calcium-rich slag generally reacts faster than low-calcium fly ash at room temperature.

Benefit	Trade-off	Control need
Faster ambient strength development can support conventional construction schedules.	Higher slag content can shorten setting time and increase workability loss.	Activator dose, temperature and admixture compatibility require trials.

Ambient curing improves practicality, but the faster reaction must remain manageable.

Reference: Provis (2018).

Balancing Slag and Fly Ash

Blending can adjust reaction rate and fresh-concrete behaviour.

More fly ash

Often improves working time but may slow early strength under ambient curing.

Balanced blend

Can combine usable setting, strength development and reduced heat-curing demand.

More slag

Often increases early strength but may increase rapid setting and shrinkage concerns.

The useful balance depends on the actual materials, activator and construction method.

Reference: Provis (2018).

What Controls the Mixture?

Alkali-activated concrete needs performance-based proportioning and laboratory trials.

Precursor variables

Type, source, fineness, glass content and chemical composition.

Activator variables

Alkali dose, silicate modulus, concentration and liquid content.

Concrete variables

Binder content, water, aggregate grading, admixture and curing.

No single universal mix-design procedure covers all alkali-activated systems.

Reference: RILEM TC 247-DTA state-of-the-art reports; Provis (2018).

Setting and Workability

Fresh behaviour can change quickly as temperature and chemistry vary.

Observe

Slump or flow, setting time, temperature rise and loss of consistency.

Adjust

Precursor blend, activator composition, liquid content and compatible admixture.

Confirm

Mixing sequence, transport duration, placement method and finishing window.

A laboratory strength result has limited value if the concrete cannot be transported and placed reliably.

Reference: Performance-based project trials are required.

Strength and Stiffness

Compressive strength does not predict every structural property.

Compressive strength

Can develop rapidly in slag-rich systems or after heat curing.

Elastic modulus

May differ from ordinary concrete at the same compressive strength.

Tensile response

Splitting strength, flexure and fracture behaviour need direct evidence.

Structural design needs the properties used in analysis, not compressive strength alone.

Reference: Fernández-Jiménez et al. (2006); system-specific testing required.

Self-Desiccation and Autogenous Shrinkage

Internal water consumption can reduce pore humidity without external drying.

Mechanism

Ongoing reaction consumes internal water and lowers internal relative humidity.

Result

The paste contracts even when moisture does not escape to the environment.

Sensitivity

Low water content, rapid reaction and slag-rich binders can increase concern.

Measure autogenous and drying components separately when shrinkage matters.

Reference: AAM shrinkage literature; verify for the selected binder.

Self-Desiccation and Autogenous Shrinkage

Measured free shrinkage is only one part of the cracking assessment.

Strain development

Magnitude and rate of autogenous, drying and thermal deformation.

Restraint

Member geometry, reinforcement, subgrade and connections restrict movement.

Stress resistance

Tensile strength, modulus, creep and relaxation control stress development.

Evaluate restrained cracking under relevant temperature and moisture histories.

Reference: Performance-based testing is recommended for unfamiliar binders.

Bond and Structural Behaviour

Reinforced-concrete behaviour depends on the interface and member response.

Bond

Confirm development and splice behaviour when the binder or curing differs from established practice.

Serviceability

Check stiffness, cracking, deflection, creep and shrinkage.

Member tests

Use structural-scale evidence where material-property relationships remain uncertain.

Ordinary-concrete empirical relationships should not be assumed without evidence.

Reference: Fernández-Jiménez et al. (2006); applicable structural code requirements remain governing.

Durability Requires Exposure Evidence

Performance varies with binder chemistry, curing and the test method.

Chloride exposure

Assess transport properties, cracking and reinforcement protection.

Sulfate or acid exposure

Identify likely reaction mechanisms and appropriate test conditions.

Thermal and wetting cycles

Consider field moisture, temperature and dimensional stability.

Alkali-related reactions

Do not infer aggregate compatibility from the binder name alone.

Select durability tests from the actual exposure and failure mechanism.

Reference: Provis (2018); performance-based durability guidance.

Carbonation and Reinforcement Protection

Carbonation response cannot be judged from compressive strength alone.

Pore solution

Binder chemistry controls alkalinity and buffering capacity.

Transport

Pore structure, curing, moisture and cracking govern gas penetration.

Corrosion assessment

Carbonation depth, cover, exposure and reinforcement condition must be considered together.

Use exposure-relevant testing before specifying reinforced alkali-activated concrete.

Reference: Bernal et al., alkali-activated material durability literature.

Is It Always Low Carbon?

GWP depends on the complete binder and production route.

Potential reductions

Lower Portland-clinker use and suitable local precursors can reduce emissions.

Major contributors

Activator production, precursor processing, transport, curing energy and binder dosage.

Fair comparison

Use the same declared unit, boundary and required concrete performance.

Calculate GWP for the actual mixture; do not assign a benefit from the material name.

Reference: Provis (2018); ISO 21930 principles.

Production and Standards Readiness

Implementation depends on controlled supply, safe handling and project acceptance.

Production

Stable precursor quality, calibrated activator dosing and documented batching.

Site practice

Training, storage, PPE, emergency procedures and workable placement time.

Qualification

Trial batches, performance testing, quality control and approval under the governing project requirements.

Start with applications where production control and verification can be maintained.

Reference: Applicable local regulations and project specifications govern use.

Opportunity and Limitations

Alkali activation can expand binder options when evidence supports the application.

Opportunity

Use locally suitable precursors and reduce clinker dependence.

Limitations

Variable materials, activator handling, shrinkage, durability evidence and standards readiness.

Engineering decision

Compare GWP and performance using representative materials, production and exposure conditions.

Progress depends on material characterisation, controlled trials and transparent evidence.

Reference: Session synthesis based on the cited literature.

SESSION 6

Carbon Utilization Technologies

Four questions for an engineering comparison

1. How can captured CO_2 enter concrete production?
2. Which utilization routes are different?
3. How much CO_2 remains stored?
4. **Does the complete route GWP?**

Capture, Utilization and Storage

The terms describe different steps and destinations for captured carbon dioxide.

Capture

Separate CO_2 from an industrial process or another source.

Conditioning

Purify, compress or liquefy it to meet transport and process requirements.

Utilization

Use CO_2 as an input to make or process a product.

Storage

Retain CO_2 permanently in minerals or geological formations.

Concrete technologies generally rely on mineral storage within a product or constituent.

Reference: IPCC (2005), Carbon Dioxide Capture and Storage; National Academies (2019), Gaseous Carbon Waste Streams Utilization.

CO_2 Addition During Mixing

A controlled dose enters fresh concrete during batching and reacts with calcium-bearing phases.

1 Controlled dosing

Specified CO_2 mass enters through calibrated equipment.

2 Rapid reaction

CO_2 reacts during mixing and forms finely distributed carbonate.

3 Mixture verification

Trials confirm fresh behaviour, strength and any cement reduction.

Injected CO_2 provides limited direct storage; larger GWP savings may depend on verified mixture optimization.

Reference: Monkman and MacDonald (2017), Journal of Cleaner Production 167, 365–375; Ravikumar et al. (2021), Nature Communications 12, 855.

Mineralization Mechanism

Carbon dioxide can react with calcium-bearing phases and form stable carbonate minerals.

Available calcium

Calcium-bearing hydrated or unhydrated phases provide reactive Ca^{2+}.

+

Captured CO_2

CO_2 dissolves in pore solution and supplies carbonate species.

→

Stable carbonate

Calcium carbonate forms as a solid mineral within the treated material.

Simplified reaction: $Ca^{2+} + CO_3^{2-} = CaCO_3(s)$

Reaction extent depends on calcium availability, moisture, particle size, CO_2 concentration and time.

Reference: National Academies (2019), Chapter 5; Zajac et al. (2022), Materials and Structures 55, 149.

CO_2 Curing of Precast Products

A controlled chamber exposes formed products to carbon dioxide before normal service.

Factory process

The producer controls CO_2 concentration, pressure, humidity, temperature and exposure time.

Suitable applications

Blocks, pavers and selected precast products can fit a sealed curing operation.

Verification

Confirm uptake, early strength, later hydration, durability and production consistency.

Carbonation curing suits controlled factory production more readily than open cast-in-place construction.

Reference: Zhang, Ghouleh and Shao (2017), Journal of CO_2 Utilization 21, 119–131.

Carbonated Recycled Aggregates

Accelerated carbonation can store CO_2 in attached cement paste and modify aggregate properties.

Feed material

Crushed concrete contains natural aggregate and residual hydrated cement paste.

Treatment

Controlled moisture and CO_2 exposure promote mineralization in the residual paste.

Concrete use

Reassess absorption, density, grading, fresh behaviour, strength and durability.

Carbonation can improve some aggregate properties, but source quality and concrete validation remain essential.

Reference: Luo et al. (2024), Carbon sequestration by preparing recycled cement and recycled aggregates, open-access research.

Carbonated Industrial Residues

Calcium-rich residues can react with CO_2 before use as aggregates, fillers or binder constituents.

Possible feedstocks

Steel slag, cement kiln dust, incineration residues and other alkaline materials.

Pretreatment

Grinding, classification, moisture adjustment or impurity removal may be required.

Mineralization

Process conditions control reaction rate, uptake and product stability.

Concrete qualification

Check leaching, volume stability, strength contribution, durability and applicable limits.

Waste classification alone cannot establish suitability for concrete.

Reference: Pan et al. (2012), Aerosol and Air Quality Research 12, 770–791; material-specific testing is required.

Carbon Accounting for Utilization

Stored carbon must exceed the additional emissions created by the utilization route.

Illustrative contribution per 1 m³ of concrete

Verified CO_2 stored	**8.0 kg CO_2**
Capture and purification	**1.2 kg CO_2e**
Compression and transport	**0.8 kg CO_2e**
Treatment energy and losses	**1.0 kg CO_2e**
Net contribution of utilization route	**–5.0 kg CO_2e/m³**

Do not double count

If the verified product GWP already includes uptake and process emissions, do not subtract stored CO_2 again.

Complete comparison

Compare the proposed and reference concretes using the same declared unit, life-cycle boundary and required performance.

This example explains the accounting logic; project values require verified process and EPD data.

Accounting principle: ISO 21930 and applicable product category rules. Illustrative numbers only.

Opportunities and Limitations

Carbon utilization can contribute to lower GWP when the full process and concrete performance are verified.

Potential opportunities

Permanent mineral storage within products or constituents

Possible support for mixture optimization

Use of selected recycled materials or industrial residues

Compatibility with controlled precast production

Important limitations

Stored quantity may be small relative to total concrete GWP

Capture, conditioning and transport require energy and infrastructure

Material performance and durability remain product-specific

Claims require measurement, boundaries and independent verification

Select the utilization route by local CO_2 supply, production control, verified GWP and engineering performance.

Session synthesis based on cited literature and ISO 21930 accounting principles.

SESSION 6

Performance and Implementation Challenges

From laboratory evidence to reliable construction

1. What must remain equivalent?
2. What changes in the field?
3. Which tests support a project decision?
4. **How can production risk be controlled?**

How the Technologies Differ

The technologies reduce carbon through different changes to materials and production

COMPARISON	Ordinary Portland cement	Calcined-clay cement / LC3	Alkali-activated cement	CO_2 utilization
What changes?	Conventional clinker-based binder	Part of the clinker is replaced by calcined clay and limestone	Reactive binder materials combine with an alkaline activator	CO_2 enters mixing, curing or constituent production
How carbon is reduced	Optimize clinker factor, cement content and concrete mixture	Use less Portland clinker	Reduce or avoid Portland clinker	Store CO_2 and, in some systems, reduce cement demand
Main production issue	Improve efficiency without increasing dosage	Control clay quality, sulfate balance and admixture demand	Control activator handling, mixing and curing	Provide CO_2, equipment, monitoring and complete GWP accounting

CO_2 utilization is a production pathway, so it may be combined with different binder systems

General Engineering Performance

Typical tendencies help screening, but project testing confirms actual performance

PROPERTY	Ordinary Portland cement	Calcined-clay cement / LC3	Alkali-activated cement	CO_2 utilization
Fresh concrete	Familiar workability and setting	May need more water or superplasticizer	Sensitive to binder and activator chemistry	Often comparable when the process is controlled
Strength development	Established early- and later-age behaviour	Early strength may fall; later strength can recover	Strongly affected by materials, activator and curing	Comparable strength is possible after mixture optimization
Structural behaviour	Established modulus, bond and design values	Often close to conventional concrete; verify	Modulus, shrinkage and bond may differ at equal strength	Usually governed by the base concrete; verify changes
Durability	Extensive standards and service history	Can improve some properties; depends on clay and mixture	Varies with binder system and exposure	Confirm for the specific process and exposure

General tendencies only: materials, mixture proportions, production and curing determine the project result

Concrete Performance Requirements

Low GWP matters only when the concrete still meets its intended function

1 **Fresh concrete**

Transport, placing, compaction and finishing

2 **Strength development**

Early-age and specified-age strength

3 **Structural behaviour**

Stiffness, flexure and reinforcement bond

4 **Dimensional stability**

Autogenous and drying shrinkage

5 **Durability**

Resistance suited to the exposure

6 **Production control**

Repeatability from plant to site

A lower-carbon mixture requires the same level of engineering verification as any other concrete

Compressive Strength Is Only One Result

Mixtures with equal strength can behave differently in service

COMPRESSIVE STRENGTH

Elastic modulus

Requires separate evidence

Shrinkage

Requires separate evidence

Reinforcement bond

Requires separate evidence

Transport properties

Requires separate evidence

Use strength to confirm one requirement, then select additional tests for the member and exposure

Fresh Concrete Behaviour

Construction success begins before the concrete hardens

- **Workability**

  Can the mixture be mixed, transported and placed?

- **Slump retention**

  Does consistency remain acceptable during delivery?

- **Pumpability and finishing**

  Can site equipment place and finish it without segregation?

- **Setting time**

  Does the available working time suit the construction sequence?

Water and admixture adjustments must remain within the approved mixture-control procedure

Alkali-Activated Binder Rheology

The proportions of calcium, water and activator change flow behaviour

1

Higher C/S ratio

Spread generally decreased

2

Higher water/binder

Spread generally increased

3

Higher Na_2O dosage

Spread generally increased

4

Molar modulus

Best flow near 1.5; lower at 2.0

These trends describe the tested binder systems; trial mixtures remain necessary for local materials

Source: 19-056(1), Influential Parameters in Rheology of Alkali-Activated Binders

Setting and Workability

Different low-carbon systems create different site-control needs

CO_2 admixture concrete

Comparable slump and air content

Calcined-clay cement

May increase water or superplasticizer demand

- **Sulfate balance**

  Can affect early reaction and workability retention

- **Local trial**

  Confirm admixture compatibility and setting time

Sources: 21-463(1) and 25-171(1)

Strength Development and Curing

The required strength must be available when the project needs it

1. **Mixing**
2. **Placement**
3. **Formwork removal**
4. **Specified age**
5. **Service**

- **Temperature sensitivity**

  Some systems develop strength slowly at ambient temperature

- **Curing method**

  Heat, moisture and duration can change the result

Specify the age and curing condition used to verify strength

Heat-Cured Fly-Ash Concrete

High early strength depended on an elevated curing temperature

Reported compressive strength

≈85°C

elevated curing used in the study

Room-temperature strength gain was much slower

Application suitability depends on whether the required curing regime can be delivered consistently

Source: 103-M12(1), Engineering Properties of Alkali-Activated Fly Ash Concrete

Calcined-Clay Cement Strength

Early strength may decrease while later strength recovers

30% calcined clay + 15% limestone met ASTM C595 strength requirements in most regional groups studied

Sources: 25-171(1) and 20-398(1)

Calcined-Clay Cement Strength

Member response depends on more than cylinder strength

- **Elastic modulus**

  Controls stiffness and influences deflection

- **Flexural response**

  Important for slabs, pavements and beams

- **Reinforcement bond**

  Transfers force between steel and concrete

- **Failure mode**

  Test observations can reveal brittle or unexpected behaviour

Use property values measured for the proposed material when design assumptions may change

Modulus and Bond Results

One heat-cured fly-ash system showed lower stiffness but strong bond

Elastic modulus

Reported ranges: OPC 28.3–34.5 GPa; AAFA 10.7–18.4 GPa

15.4–17.7 MPa

reported reinforcement-bond strength

Some 8 mm bars fractured before bond failure

The result supports material-specific structural testing; it does not define a universal AAFA design value

Source: 103-M12(1)

Shrinkage and Cracking

Volume change becomes a problem when restraint creates tensile stress

Autogenous shrinkage

Internal moisture consumption during reaction

Drying shrinkage

Moisture loss to the surrounding environment

Assess shrinkage together with member size, reinforcement, joints, curing and exposure

Contrasting Shrinkage Results

Different binder systems and test methods produced very different values

STUDY A

Heat-cured fly-ash mortar

<0.025%

at 90 days

OPC mortar ≈0.09% at 70 days

STUDY B

Ambient-cured slag/fly-ash paste

5,644 → 2,168 µm/m

when fly ash increased from 20% to 40%

OPC paste: 505 µm/m

Do not rank the systems directly: materials, specimens, curing and measurement conditions differ

Sources: 103-M12(1) and 20-200(1)

Durability Evaluation

Select tests from the actual exposure and deterioration mechanism

1

Chlorides

Reinforcement corrosion

2

Sulfates

Expansion and cracking

3

Alkali–aggregate reaction

Internal expansion

4

Carbonation

Loss of steel protection

5

Freeze–thaw

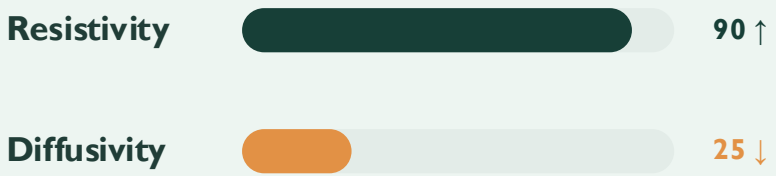
Scaling and internal damage

A durability claim needs a defined exposure, test method, age and acceptance criterion

Chloride Exposure Results

Strength gain and transport resistance did not follow the same pattern

Very-high-strength concrete



With age: resistivity increased and diffusivity decreased

25% calcined illitic shale

No significant change

in the 28-day chloride diffusion coefficient

Measure the transport property needed for the exposure; compressive strength cannot replace it

Sources: 15-065(1) and 20-398(1)

Calcined Illitic Shale Durability

A single addition affected each deterioration mechanism differently

ASR: high/moderate-alkali cement	**Expansion reduced**
ASR: low-alkali cement	**Slight later increase reported**
Sulfate exposure	**Expansion reduced**
Chloride diffusion at 28 days	**No significant change**

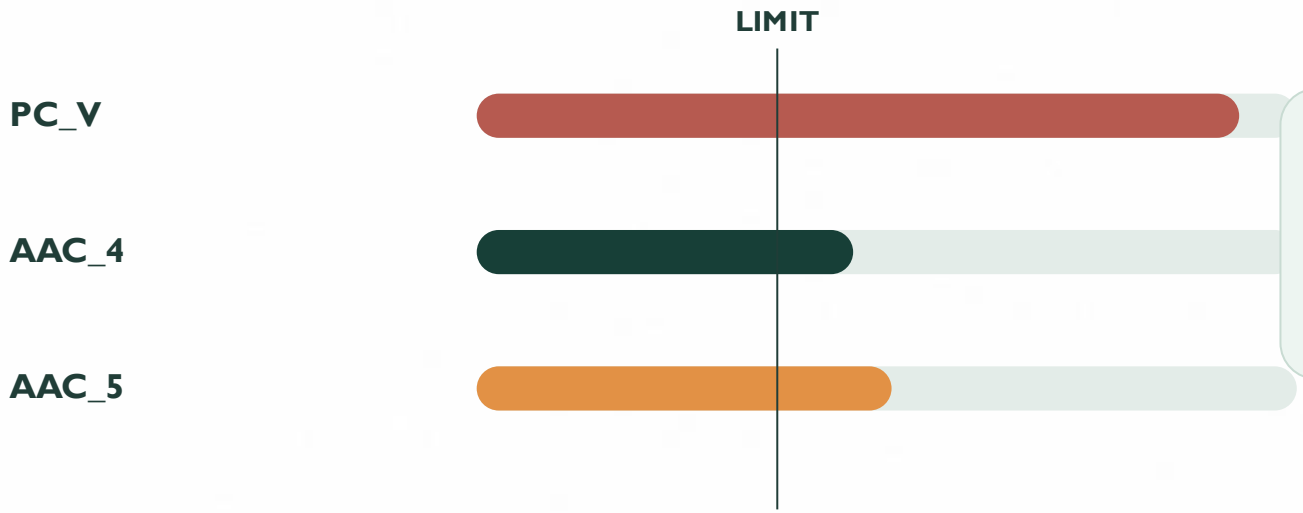
Durability must be evaluated property by property; one favourable result cannot support every exposure

Source: 20-398(1), Durability Performance of Blended Cement with Calcined Illitic Shale

Alkali–Aggregate Reaction Results

The tested alkali-activated cements remained below the expansion limit

Relative expansion against the study limit



No macroscopic fissures and little reaction gel were reported for AAC_4 and AAC_5

Source: 20-528(1), Alkali-Activated Cement Subject to Alkali-Aggregate Reaction

CO_2-Admixture Concrete Results

A controlled cement reduction maintained the measured fresh and hardened properties

Cement content

≈7% reduction

Slump and air

Comparable

7- and 28-day strength

Comparable

Cement efficiency

8–9% improvement

Environmental ind

2.6–6.0% redu

The study reported no adverse effect on the durability indicators evaluated

Count the complete CO_2 supply and processing system when calculating net GWP

Source: 21-463(1)

Material Variability and Scale-Up

Laboratory success must survive changes in materials, equipment and production

1	**Source and chemistry**	Binder reactivity, composition and contaminants
2	**Fineness and moisture**	Powder handling and effective water content
3	**Admixture compatibility**	Workability, retention and setting
4	**Batching sequence**	Dispersion, mixing energy and timing
5	**Plant and weather**	Temperature, storage and delivery duration

Define allowable material ranges and process controls before routine production

Evidence Required for Project Use

Qualification moves from material data to controlled site production

1 **Material characterization** → 2 **Laboratory trial mixtures** → 3 **Performance testing** → 4 **Plant trial** → 5 **Site trial** → 6 **Production control and GWP records**

Project acceptance should identify the required performance, test methods, responsibility and documentation

SESSION 8

Potential Directions and Conclusions

Moving from promising technologies to locally verified applications

1. Which options are closer to present practice?
2. What local evidence is needed?
3. How can projects evaluate alternatives?
4. **What conclusions should guide future work?**

Main Carbon-Reduction Pathways

The technologies act at different points in the concrete value chain

1

Reduce clinker

Use blended cement, calcined clay and limestone

2

Use alternative binders

Activate suitable slag, fly ash or metakaolin

3

Improve concrete efficiency

Match cement content and strength to project requirements

4

Utilize captured CO_2

Store CO_2 in concrete or mineral constituents

Projects may combine more than one pathway when materials, performance and production remain compatible

Technology Readiness

Readiness depends on the technology, local supply chain and intended application

Closer to current practice

- Mixture optimization
- Available lower-clinker cement
- Improved cement efficiency

Project-specific qualification

- Locally developed LC3
- High calcined-clay replacement
- Alkali-activated concrete

Supporting infrastructure required

- CO_2 curing systems
- CO_2 mineralization systems
- Specialized activator supply

This is a screening framework, not a ranking. A technology may move between categories as local capability develops

Potential Opportunities for Myanmar

Local investigation can identify which pathways are technically and practically suitable

1. **Candidate materials**

   Characterise suitable clay, limestone and available supplementary materials

2. **Concrete efficiency**

   Review cement dosage, strength requirements and mixture optimization

3. **Local GWP data**

   Develop representative material and production information

4. **Demonstration projects**

   Connect laboratory evidence with plant and site trials

Opportunities should be established through local material data and engineering verification

Local Evaluation Sequence

A staged process limits risk before routine production

1 **Material screening**

Availability, consistency and supply volume

2 **Laboratory characterization**

Chemistry, mineralogy, fineness and reactivity

3 **Concrete trials**

Workability, setting and strength development

4 **Performance verification**

Structural properties, shrinkage and durability

5 **Plant and site trials**

Batching, delivery, placement and curing

6 **Monitoring and wider use**

Production records, GWP and field performance

Move to the next stage only when the required evidence and controls are defined

Engineering Decision Framework

A lower GWP value is one part of the project decision

1 **Carbon**

How much GWP reduction is demonstrated?

2 **Materials**

Are supply and quality sufficiently consistent?

3 **Structure**

Does the concrete meet structural requirements?

4 **Durability**

Is performance suitable for the exposure?

5 **Construction**

Can the plant and site control production reliably?

6 **Practicality**

Are cost, scale and schedule acceptable?

The preferred option satisfies the project requirements while reducing environmental impact

Roles in Implementation

Reliable application requires information to move across the project team

1 **Material suppliers**

Provide consistent materials and technical data

2 **Researchers and laboratories**

Characterise materials and test performance

3 **Concrete producers**

Develop mixtures and control production

4 **Designers and consultants**

Define performance and acceptance requirements

5 **Contractors**

Confirm placing, curing and site control

6 **Owners and project teams**

Set project objectives and support monitoring

Clear responsibilities and shared data reduce the gap between laboratory results and site performance

Five Principal Conclusions

Carbon reduction and engineering performance must be considered together

1. **No single technology suits every project.**
2. **Reducing clinker and unnecessary cement demand offers an important near-term direction.**
3. **Local materials require local characterization and concrete trials.**
4. **Compressive strength alone cannot confirm equivalent engineering performance.**
5. **GWP, constructability, durability and service requirements must be evaluated together.**

Progress depends on verified evidence, repeatable production and performance suited to the application

CONCLUSION

A Practical Direction for Myanmar

Combine locally appropriate materials with verified engineering performance and realistic production conditions.

Discussion and questions

Thank you