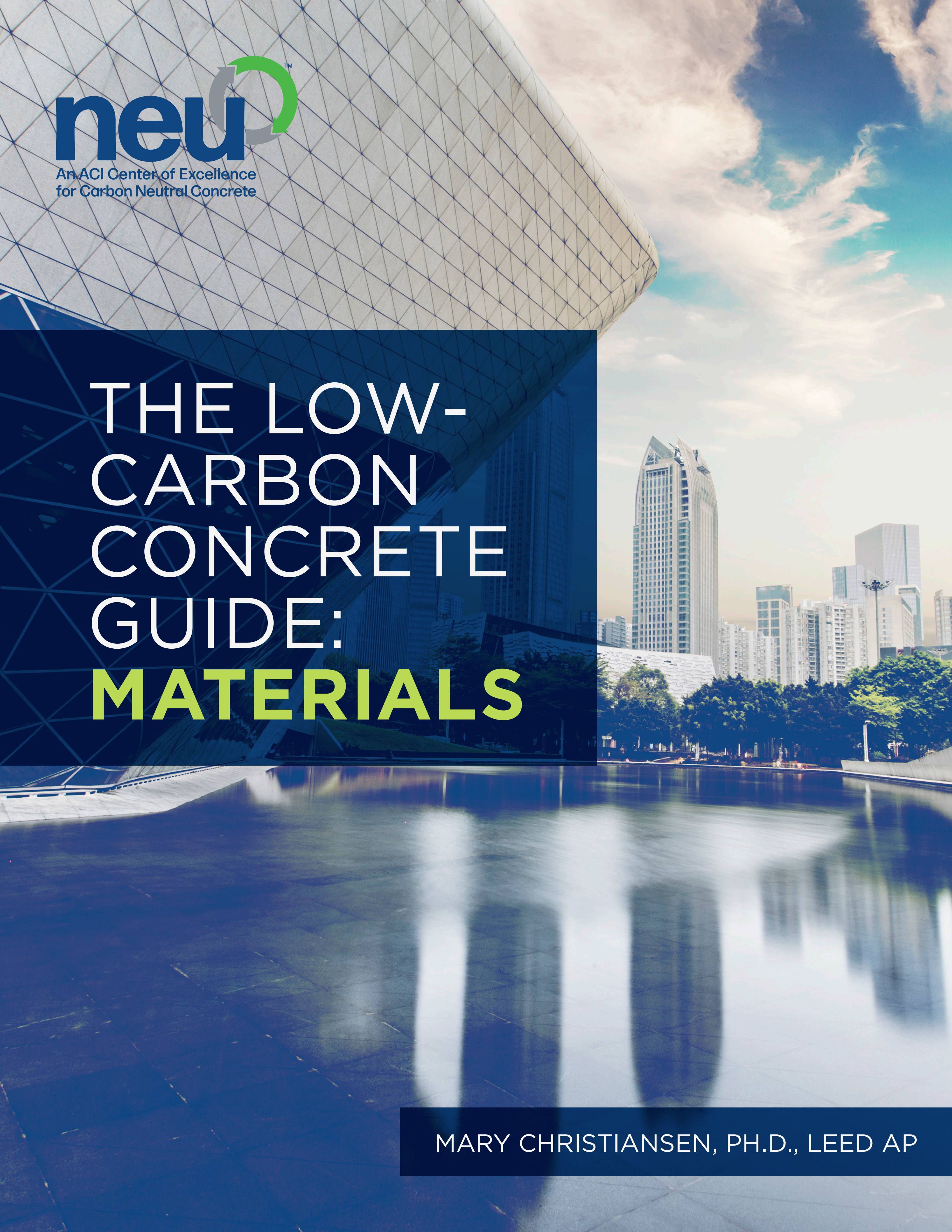

An ACI Center of Excellence for Carbon Neutral Concrete

THE LOW-CARBON CONCRETE GUIDE: MATERIALS

MARY CHRISTIANSEN, PH.D., LEED AP

The Low-Carbon Concrete Guide: Materials

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Author's note: The development of low-carbon concrete materials and technologies is advancing rapidly, with new products and approaches emerging across research and practice. This guide provides a snapshot of the field based on the best information currently available. Every effort has been made to capture the range of materials, technologies, and perspectives shaping low-carbon concrete and to present them as clearly and accurately as possible.

Variations in data availability and maturity across different technologies can make direct comparisons difficult, but the principles and context presented here are intended to serve as a foundation for interpreting and applying concepts in low-carbon concrete. This work is a living document and will be updated as new information and technologies emerge.

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LIST OF ABBREVIATIONS

IL	Portland-limestone cement
IP	Portland-pozzolan cement
IS	Portland-slag cement
IT	Portland-ternary cement
AAC	Alkali-activated cement
AACC	Alkali-activated calcined clay
AAFA	Alkali-activated fly ash
AAS	Alkali-activated slag
AASHTO	American Association of State Highway and Transportation Officials
AC	Alternative cement
ACA	American Cement Association
ACAA	American Coal Ash Association
ACBFS	Air-cooled blast furnace slag
ACC	Accelerated carbon curing
ACI	American Concrete Institute
ADP	Adiabatic depletion potential
AEA	Air-entraining agent
AHJ	Authority having jurisdiction
AI	Artificial intelligence
AMF	Aggregate mineral filler
AP	Acidification potential
APC	Advanced process control
APC	Air pollution control
ASR	Alkali-silica reaction
ASTM	ASTM International
BCSA	Belitic calcium sulfoaluminate
BET	Brunauer-Emmett-Teller
BF-BOF	Blast furnace – basic oxygen furnace
BFRP	Basalt fiber reinforced polymer
BFSA	Blast furnace slag aggregate
BOF	Basic oxygen furnace
BSE	Backscattered electrons
BYF	Belite-ye'elimite-ferrite
CAC	Calcium aluminate cement
CBA	Coal bottom ash
CC	Carbonated cement
CCR	Coal combustion residue
CCS	Carbon capture and storage
CCU	Carbon capture and utilization
CCUS	Carbon capture, utilization, and storage
CEN	European Committee for Standardization
CFA	Coal fly ash
CFC	Chlorofluorocarbon
CFRP	Carbon fiber reinforced polymer
CIS	Commonwealth of Independent States
CKD	Cement kiln dust
CLSM	Controlled Low-Strength Material
COP	Conference of the parties
CRGA	Coarse recycled glass aggregate
CSA	Calcium sulfoaluminate cement
CSA	Copper slag aggregate
DAC	Direct air capture
DE	Diatomaceous Earth
DOE	Department of Energy
DOT	Department of Transportation
DRI-EAF	Direct reduced iron – electric arc furnace
EAF	Electric arc furnace
ECC	Engineered cementitious composites
EN	European Norm (European Standard)
EP	Eutrophication potential
EPA	Environmental Protection Agency
EPD	Environmental product declaration
f'c	Specified compressive strength of concrete, psi
FA	Fly ash
FAO	Food and Agriculture Organization
FBE	Fusion-bonded epoxy
FFI	Fossil fuel industry
FGD	Flue gas desulfurization
FHWA	Federal Highway Administration
FRC	Fiber-reinforced concrete
FRGA	Fine recycled glass aggregate
FRP	Fiber-reinforced polymer
GCC	Ground calcium carbonate
GCCA	Global Cement and Concrete Association
GE	E-glass ground glass pozzolan
GFRP	Glass fiber reinforced polymer
GGBFS	Ground granulated blast furnace slag
GGP	Ground glass pozzolan
GHG	Greenhouse emission
GPS	Global positioning system
GS	Soda-lime ground glass pozzolan
GU	General use
GWP	Global warming potential
GWP100	Global warming potential over 100 years
HCFC	Hydrochlorofluorocarbon
HDPE	High-density polyethylene
HE	High early strength
HFC	Hydrofluorocarbon
HPC	High-performance concrete
HPGR	High-pressure grinding roll
HRWR	High-range water reducer
HS	High sulfate resistance
HSC	High-strength concrete
HVFA	High-volume fly ash
IBC	International building code
IEA	International Energy Association
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ITZ	Interfacial transition zone
LA	Los Angeles
LCA	Life cycle assessment
LCC	Low-carbon concrete
LCCA	Life cycle cost analysis
LC^3	Limestone calcined clay cement

LH	Low heat of hydration
LOI	Loss on ignition
LULUCF	Land use, land-use change, and forestry
LWA	Lightweight aggregate
MCP	Manual of Concrete Practice
MEA	Monoethanolamine
MH	Moderate heat of hydration
MICP	Microbiologically induced calcium carbonate precipitation
MK	Metakaolin
MOC	Magnesium oxychloride cement
MOS	Magnesium oxy-sulfate cement
MPC	Magnesium phosphate cement
MS	Moderate sulfate resistance
MSW	Municipal solid waste
NGO	Non-governmental organization
NIST	National Institute of Standards and Technology
NMIC	National Minerals Information Center
NP	Natural pozzolan
NR	Not reported
NREL	National Renewable Energy Lab
NRMCA	National Ready-Mixed Concrete Association
NEU	An ACI Center of Excellence for Carbon Neutral Concrete
ODP	Ozone depletion potential
PC	Portland cement
PCA	Portland Cement Association
PCC	Portland cement concrete
PCE	Polycarboxylate ether
PCR	Product category rule
PE	Polyethylene
PET	Polyethylene terephthalate
PLC	Portland limestone cement
PM	Particulate matter
POCP	Photochemical ozone creation potential
POFA	Palm oil fuel ash
PP	Polypropylene
PRC	Polymer reinforced concrete
PSD	Particle size distribution
psi	Pounds per square inch
PV	Photo-voltaic
PVA	Polyvinyl alcohol
QA	Quality assurance
QC	Quality control
RCA	Recycled concrete aggregates
RDF	Refuse-derived fuel
RHA	Rice husk ash
RMI	Rocky Mountain Institute
S-LCA	Social life cycle assessment
SAI	Strength activity index
SAP	Superabsorbent polymer
SCA	Slag Cement Association
SCBA	Sugarcane bagasse ash
SCC	Self-consolidated concrete
SCM	Supplementary cementitious material
SEM	Scanning electron microscope
SE	Secondary electron
SF	Silica fume
SFA	Silica Fume Association
SFRC	Steel fiber-reinforced concrete
SSA	Specific surface area
SSC	Super-sulfated cement
TGA	Thermogravimetric analysis
UFS	Used foundry sand
UHPC	Ultra-high performance concrete
UNFCCC	United Nations UN Framework Convention on Climate Change
VOC	Volatile organic compound
WAP	Water absorbing polymer
WBCSD	World Business Council for Sustainable Development
WHR	Waste heat recovery
XRD	X-ray diffraction
XRF	X-ray fluorescence

LIST OF CHEMICAL FORMULAS

Oxides

Al_2O_3	Alumina, aluminum oxide
$CaCO_3$	Calcium carbonate, calcite
CaO	Calcia, calcium oxide, lime
Fe_2O_3	Iron oxide
H_2O	Water
K_2O	Potassium oxide
MgO	Magnesium oxide, magnesia, periclase
Na_2O	Sodium oxide
Na_2O_{eq}	Sodium oxide equivalent
SiO_2	Silica, silicon dioxide
SO_3	Sulfate

Major Portland Cement Phases and Gypsum (Cement Chemist Notation)

C_3A	Aluminate, tricalcium aluminate, $3CaO{\cdot}Al_2O_3$
C_2S	Belite, dicalcium silicate, $2CaO{\cdot}SiO_2$
C_3S	Alite, tricalcium silicate, $3CaO{\cdot}SiO_2$
C_4AF	Ferrite, tetracalcium aluminoferrite, $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$
CH_2	Calcium sulfate, gypsum, $CaSO_4{\cdot}2H_2O$ (set regulator)

Portland Cement Hydrates

AFm	Monosulfate, C_4AH_{12}, $4CaO{\cdot}Al_2O_3{\cdot}SO_3{\cdot}12H_2O$
AFt	Ettringite, $C_6A_3H_{32}$, $6CaO{\cdot}Al_2O_3{\cdot}3SO_3{\cdot}32H_2O$
C_3AH_6	Hydrogarnet, $3CaO{\cdot}Al_2O_3{\cdot}6H_2O$
C_6AFH_{12}	Aluminoferrite hydrate, $6CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3{\cdot}12H_2O$

CH	Calcium hydroxide, portlandite, $Ca(OH)_2$
C-S-H	Calcium silicate hydrate, $3CaO{\cdot}SiO_2{\cdot}8H_2O$ (variable stoichiometry)

Alternative Cements

C_4A_3	Ye'elimite, $4CaO{\cdot}3Al_2O_3{\cdot}SO_3$
CA	Monocalcium aluminate
CAH	Calcium aluminate hydrate
$CaMg(CO_3)_2$	Dolomite
C-A-S-H	Calcium aluminate silicate hydrate
KOH	Potassium hydroxide
K_2SiO_3	Potassium silicate
$MgCO_3$	Magnesite
$Mg(OH)_2$	Magnesium hydroxide, brucite
Mg_2SiO_4	Olivine
$Mg_3Si_2O_5(OH)_4$	Serpentine
M-S-H	Magnesium silicate hydrate
Na_2CO_3	Sodium carbonate
Na_2SiO_3	Sodium silicate
NaOH	Sodium hydroxide
N-A-S-H	Sodium aluminate silicate hydrate

Environmental/Emissions-Related Compounds

CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
N_2O	Nitrous oxide
NO_x	Nitrogen oxides
SF_6	Sulfur hexafluoride
SO_x	Sulfur oxides

Figure 1 Concrete arches along the Almería seawall in Spain. Like passing through successive arches, reducing the carbon footprint of concrete requires many coordinated steps over time. *Photo courtesy of Najeeb Jindeel.*