

Role of Coal Ash in Producing Low Carbon Cements of the Future

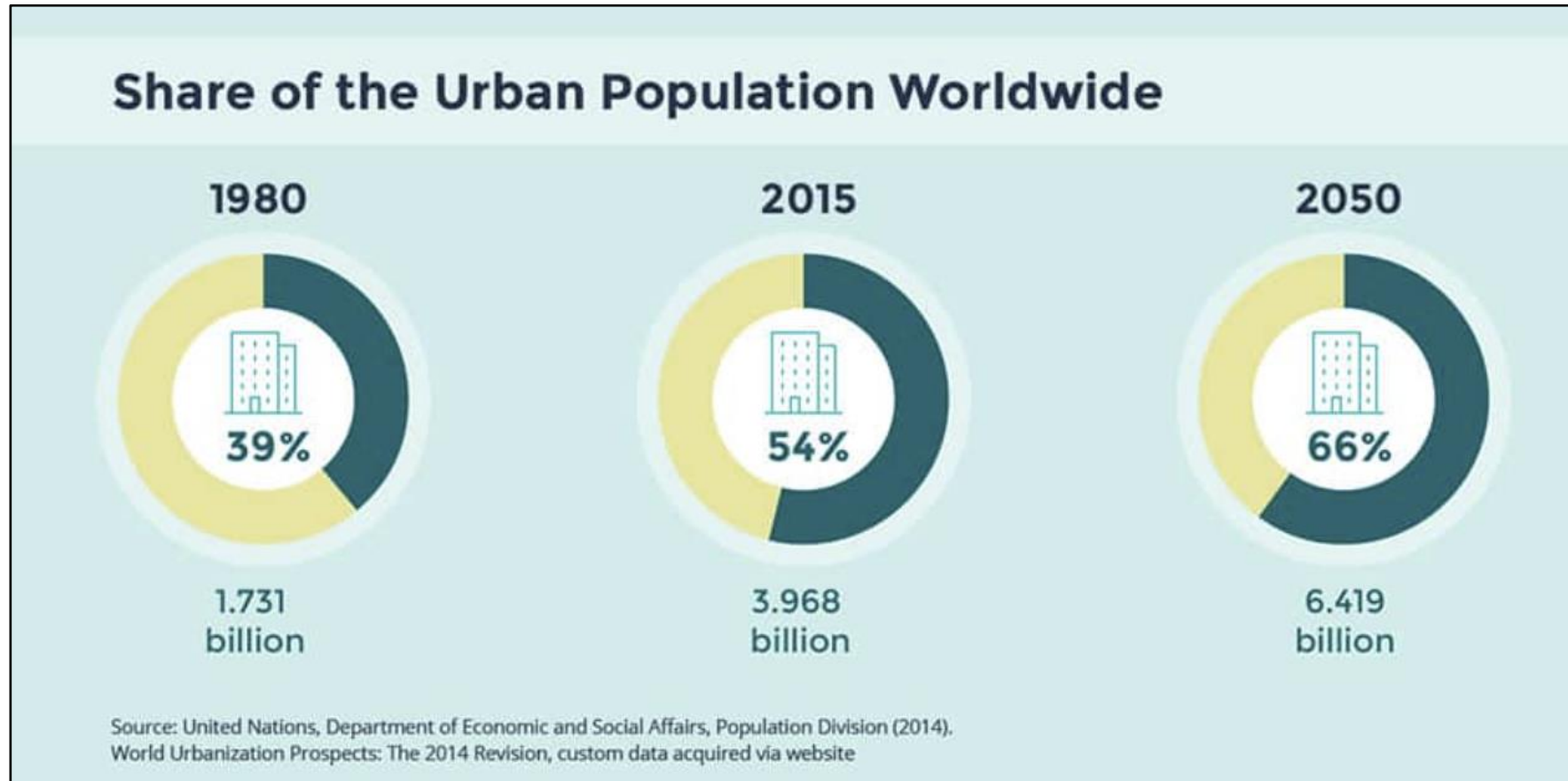
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THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE



Globalization



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The Material Impact of GLOBAL URBANIZATION

The global population living in cities and towns is expected to rise 80% by 2050. With the expansion of cities, the material consumption is expected to grow from **41.1 billion tonnes in 2010** to **88.8 billion tonnes by 2050**.

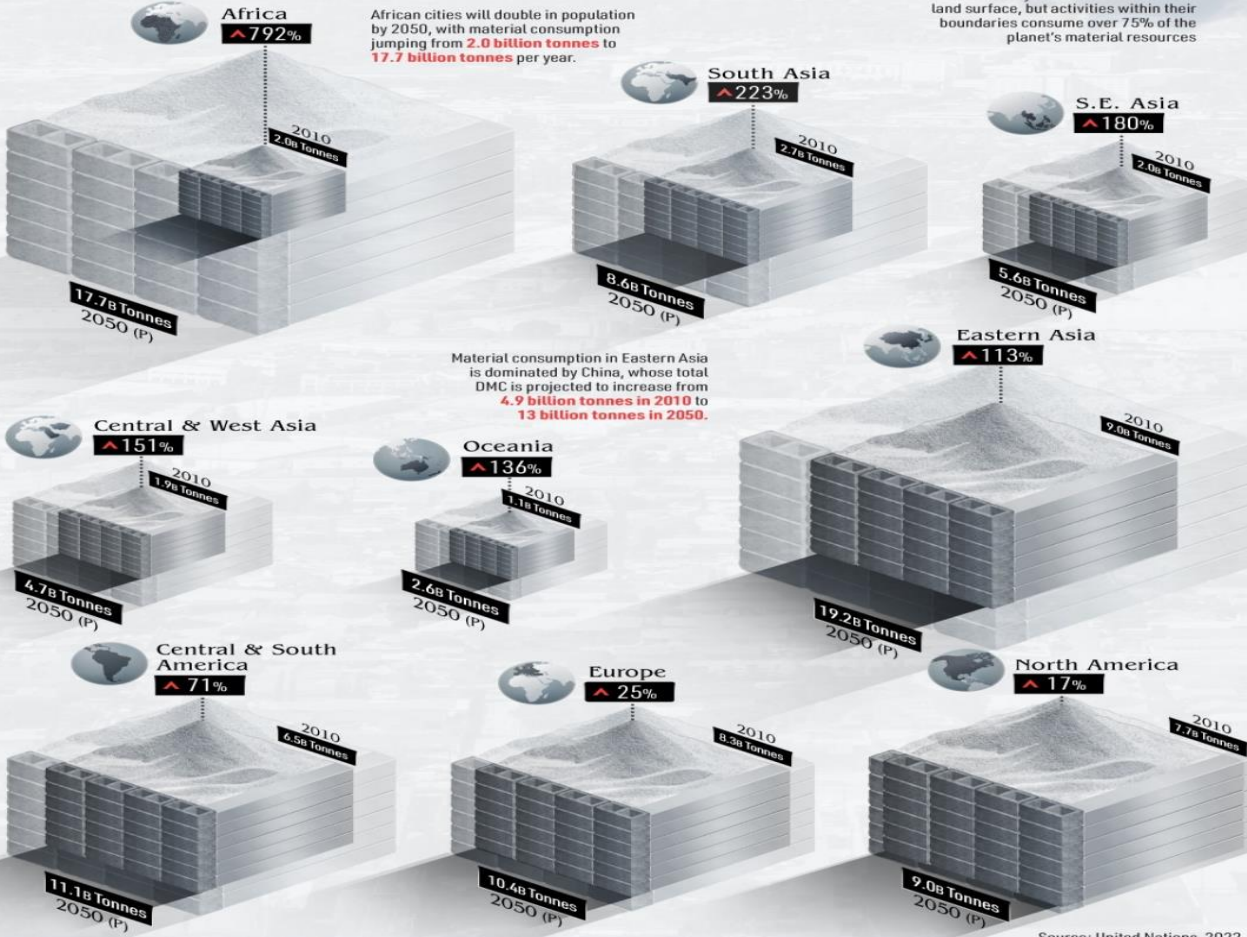


Domestic Material Consumption (DMC)
DMC = Raw materials extracted from the territory per year + All physical imports - All Physical Exports

Steel Cement Sand



People Living in Cities
Cities only cover 2% of the world's land surface, but activities within their boundaries consume over 75% of the planet's material resources



Source: United Nations, 2022.

ELEMENTS

Percentage changes in consumption may not match due to rounding.

ELEMENTS.VISUALCAPITALIST.COM

Impact of Globalization

- The shift in population densities will lead to ever expanding megacities, which in turn will lead to immense pressure on already strained supply of construction materials
- Domestic Material Consumption is expected to double by 2050

Domestic material consumption (DMC) is the total amount of materials used in an economy, including materials extracted domestically and imported, minus materials exported. It's measured in metric tons per capita.

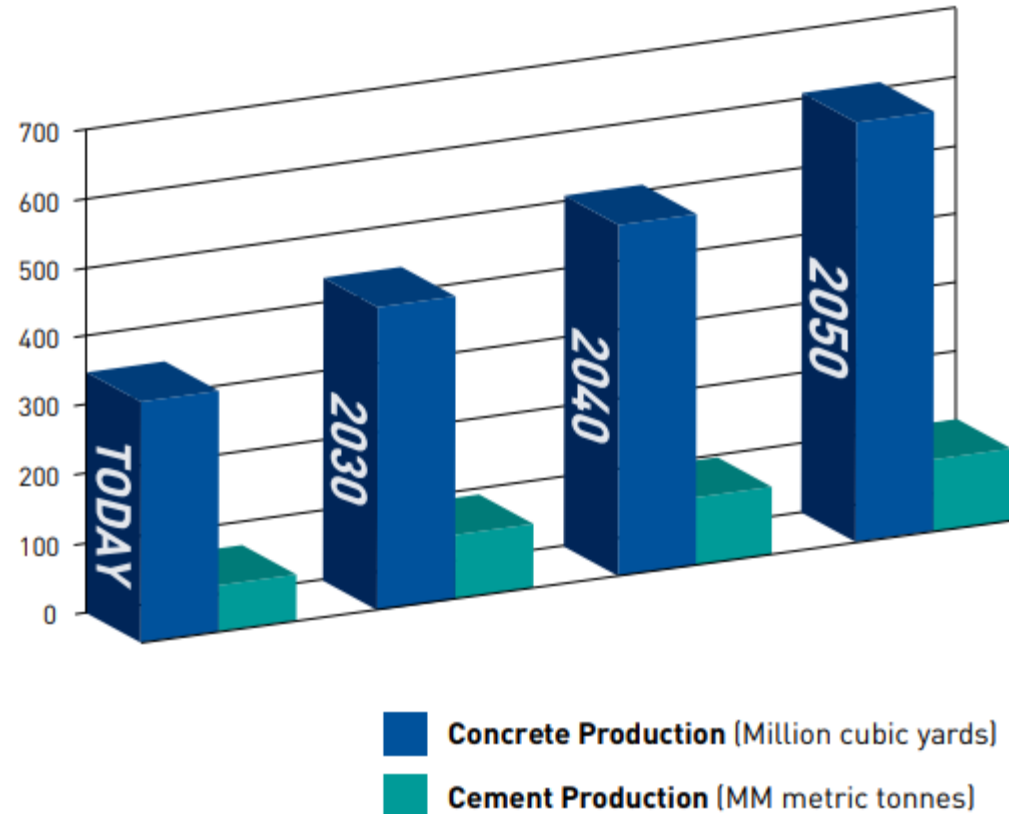


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Impact of Globalization

GROWING CITIES MEANS THE DEMAND FOR CEMENT AND CONCRETE CONTINUES AND INCREASES OVER TIME



(PCA Roadmap to Carbon Neutrality)

- PCA roadmap agrees with the U.N. report on doubling the DMC, concrete production is estimated double by 2050

Material	U.S.	Worldwide
Concrete (Million Cu. Yd.)	350	5000
Cement (Million tons)	88	4000

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Cement GHG

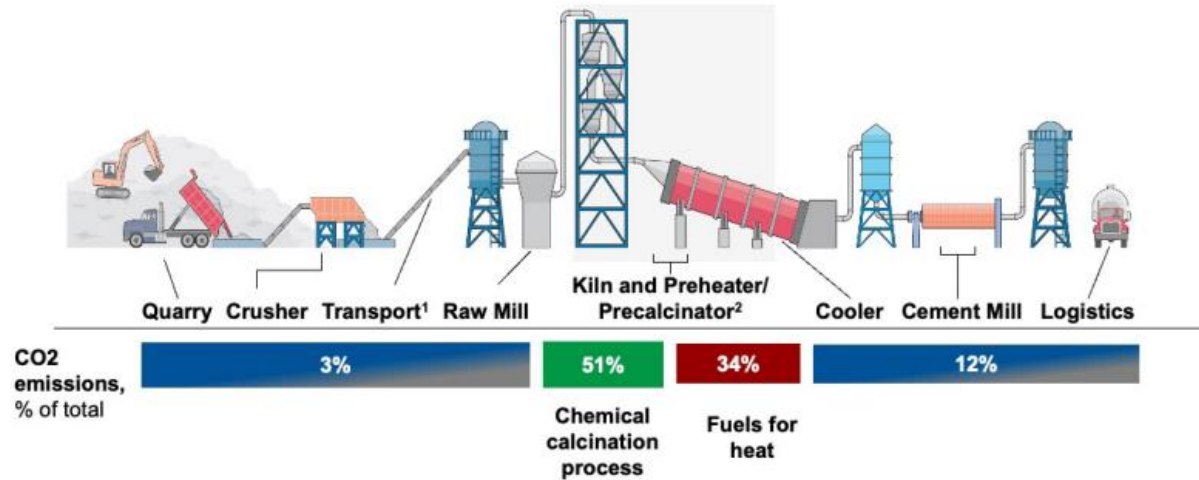
Emissions in the cement production process

■ Industrial heat ■ Process ■ Electric power ■ Other

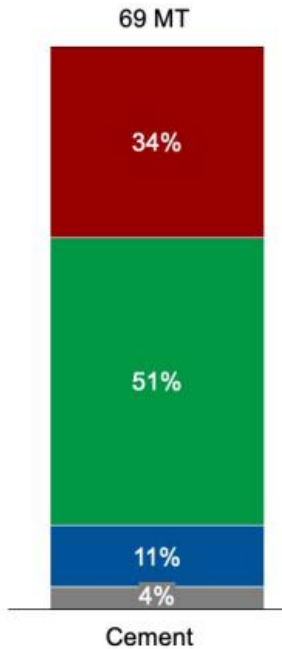
Raw materials, energy
and resources

Clinker and cement manufacturing

Downstream



Emissions breakdown¹, CO₂e



- While concrete production is expected to double by 2050, cement production will only see a marginal increase ~ 15%
- This is because of GHG emissions associated with cement production; 1 MT of cement ~ 0.7 MT of CO₂

How will cement industry support doubled concrete production



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(U.S. DOE Pathways to Commercial Liftoff: Low-Carbon Cement)

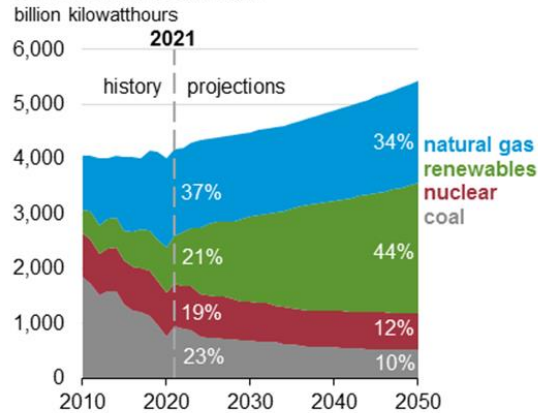
Sustainable Cement Solutions

Cements	Clinker Content (%)	GHG (MT of CO ₂ Eq.)
ASTM C150	95	0.7
ASTM C595 Limestone	80	0.6
ASTM C595 Ternary	60	0.5
ASTM C 1157 Performance	40	0.3

- One of the ways the cement industry is preparing to meet the increased demand is by reducing the clinker content by SCM substitution **AKA blended cements**
- Blended cements, in addition to meeting demand will also aid in GHG reductions **AKA more greener cements with less clinker**
- When it comes to voluminous SCMs, we tend to think of fly ash followed by slag (GGBFS). However, the same 2050 Net-Zero goals that led to cement GHG strategies are leading to supply shortages in fly ash and slag

Net-Zero Impact on SCMs

U.S. electricity generation from selected fuels
AEO2022 Reference case



Source: US Energy Information Administration, Annual Energy Outlook 2022 (AEO2022)

Coal capacity retirements by year (MW)



Data compiled Jan. 20, 2022.
Planned retirements include those approved by regulatory bodies, and those announced for closure but still pending regulatory approval. Also includes company announcements of broader coal capacity phaseouts.
Announced retirements are compiled on a best-effort basis.
Source: S&P Global Market Intelligence

Shutdown of power plants = Less Fly Ash

To meet the GHG emission goals, coal fired power plants and blast furnace steel makers are having to retire or transition to natural gas and other less energy intensive processes

Greenhouse Gases EAF VS BOF



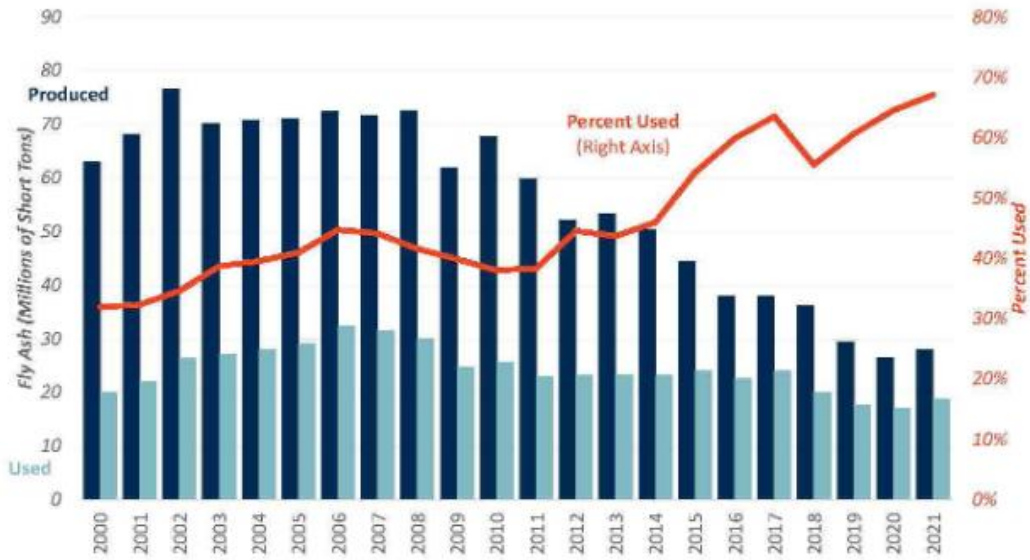
Sources: 2019 study of EAF Greenhouse Gas Emissions, 2019 study of Blast Furnace Greenhouse Gas Emissions

Conversion to EAF = Less GGBFS

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Net-Zero Impact on SCMs

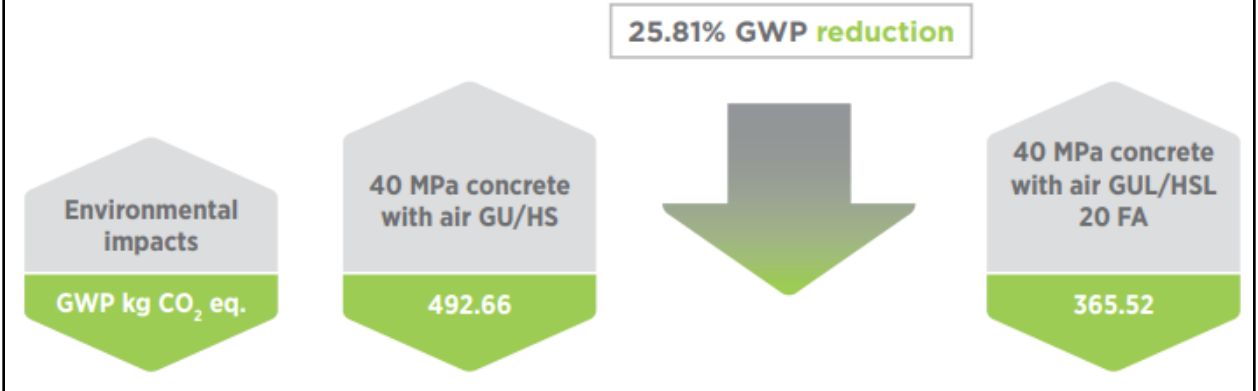
FLY ASH PRODUCTION AND USE



Source: ACAA 2022 Production and Use Survey

GU VS. GUL + FLY ASH

Alberta IA EPD report



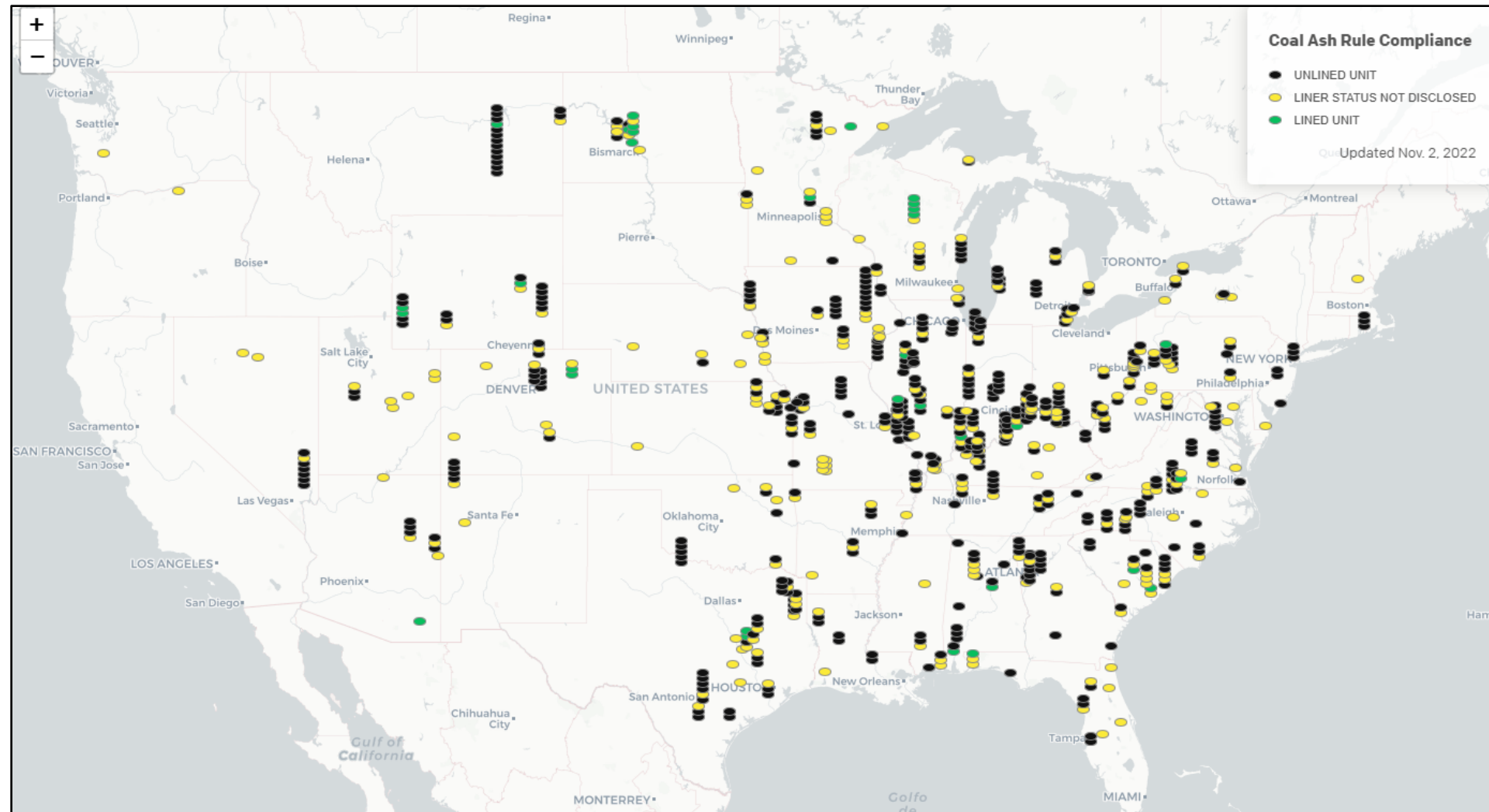
(A guideline for specifying low carbon ready mixed concrete in Canada)

While supply is getting constrained, demand is on the rise again, due to GHG reduction strategies

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Harvesting of Coal Ash



In the U.S., there are **over 740** coal ash storage sites with **over 2 billion tons** of material



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(Coal ash sites in the U.S. per Earthjustice)

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Harvesting of Coal Ash

- In situations where the storage sites are not contaminated and are in the region of influence of a big city with lots of construction, ash harvesting appears to be the solution for high quality coal ash
- Currently, both CSA and ASTM specifications have approved harvested coal ash as mainstream SCMs, and in some cases harvested ashes may contain ground bottom ash, which is also accepted under the specifications
- ASTM went a step further and established guidelines for characterizing (ASTM E3355) and harvesting CCR (ASTM E3183) buried in storage cells



CSA A3000:23

Cementitious materials compendium

*Harvested ash can be considered to fall under the definition of **Fly ash** provided it is tested at the frequency outlined in this Standard and that it conforms to the requirements outlined in this Standard. See the definition for **Harvested ash**.*



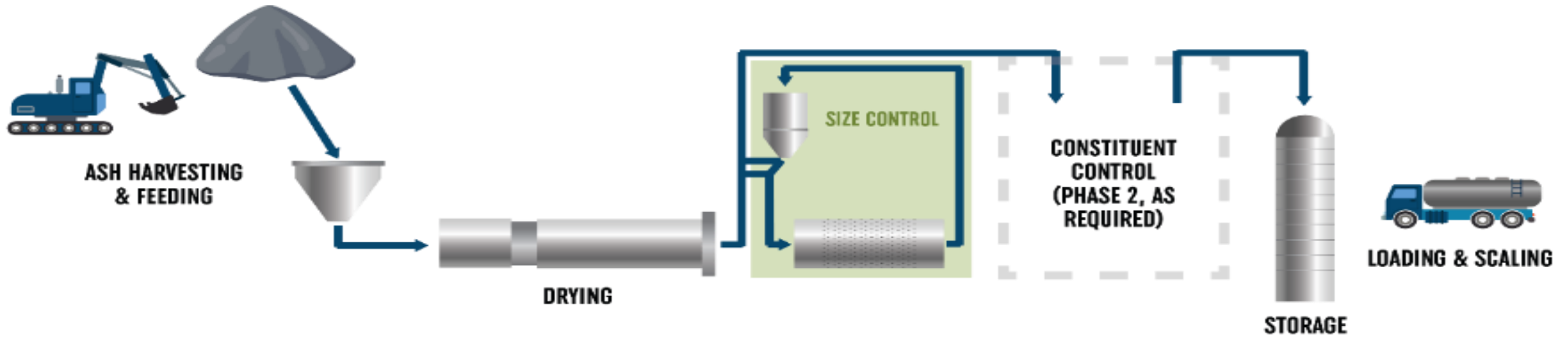
Designation: C618 – 23^{e1}

Standard Specification for
Coal Ash and Raw or Calcined Natural Pozzolan for Use in
Concrete¹

3.2.1 *coal ash, n*—fly ash and bottom ash resulting from the process of combustion of ground or powdered coal obtained either from current power plant production or harvested from landfills or impoundments.



Harvesting – in a “nutshell”



Essentially, there are Five stages in CCR harvesting

1. Reclaiming and feeding (Site engineering and permitting, CCR excavation and hauling, and feed bin)
2. Drying (generally natural gas aided)
3. Size control (vertical mill, ball mill, attrition)
4. Carbon reduction (extraction units or burn off units)
5. Storage and distribution (Silos)

Example of Harvested Coal Ash and its Performance

Ashcor's BR RAM Ash

	Avg. of Annual Composites			CSA A3001		
Chemical Analysis	2022	2023	2024	Type F	Type CI	Type CH
SO ₃ %	0.2	0.2	0.3		5 max	
CaO %	6.0	6.2	6.8	≤15	>15 - ≤20	>20
Moisture %	0.3	0.3	0.3		3 max	
LOI %	2.3	2.4	2.4	8 max	6 max	6 max
Physical Analysis						
Fineness % Ret.	13.6	17.6	20.5		34 max	
Strength Activity 28 Day - % Cont.	85.0	80.8	83.7		75 min	
Soundness %	0.1	0.1	0.1		0.8 max	
Alkali Aggregate Reactivity %	0.1	0.1	0.1		0.1 max	

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Ashcor's BR RAM Ash

BR RAM ash in concrete with 3 different GULs and 3 levels of replacement

Cement Used	GUL 1			GUL 2			GUL 3		
% Replacement	100% Cement	10% FA	25% FA	100% Cement	10% FA	25% FA	100% Cement	10% FA	25% FA
7d MPa	30	29	24	45	39	31	34	29	26
28d MPa	43	38	36	57	51	45	44	41	34
56d MPa	46	42	41	62	57	51	48	45	38
90d MPa	50	46	46	67	60	57	51	48	43
120d MPa	52	48	46	69	61	59	53	50	45
365d MPa	55	51	55	71	68	63	58	55	50

BR RAM Ash at both 10% and 25% replacement levels exceeded target strength requirements

1-year concrete strengths with ash replacements are close to controls

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Ashcor's BR RAM Ash

BR RAM ash in Accelerated Mortar Bar with 3 different GULs and 3 levels of replacement

Cement Used	GUL 1			GUL 2			GUL 3		
% Replacement	100% Cement	10% FA	25% FA	100% Cement	10% FA	25% FA	100% Cement	10% FA	25% FA
ASR AMB (%)	0.4	0.3	0.1	0.4	0.4	0.1	0.4	0.3	0.1

Samples with BR RAM Ash replacement at 25% show high resistance to ASR

Ashcor's BR RAM Ash

BR RAM ash in RCPT with 3 different GULs and 3 levels of replacement

Cement Used	GUL 1			GUL 2			GUL 3		
% Replacement	100% Cement	10% FA	25% FA	100% Cement	10% FA	25% FA	100% Cement	10% FA	25% FA
RCPT 56d Coulombs	2862	2572	1508	1953	1473	999	2318	1985	1193
Bulk Resist 56d $\Omega \cdot m$	82	91	173	108	145	210	127	142	256

BR RAM Ash replacement at 25% significantly reduced chloride permeability and improved bulk resistivity

Ashcor's BR RAM Ash

BR RAM ash in Sulfate resistance test with 3 different GULs and 3 levels of replacement

Cement Used	GUL 1			GUL 2			GUL 3		
% Replacement	100% Cement	10% FA	25% FA	100% Cement	10% FA	25% FA	100% Cement	10% FA	25% FA
Sulphate Resistance (6 months)	0.12	0.11	0.04	0.20	0.09	0.04	0.07	0.04	0.04
Sulphate Resistance (12 months)	0.68	0.33	0.07	0.85	0.30	0.05	0.22	0.10	0.05

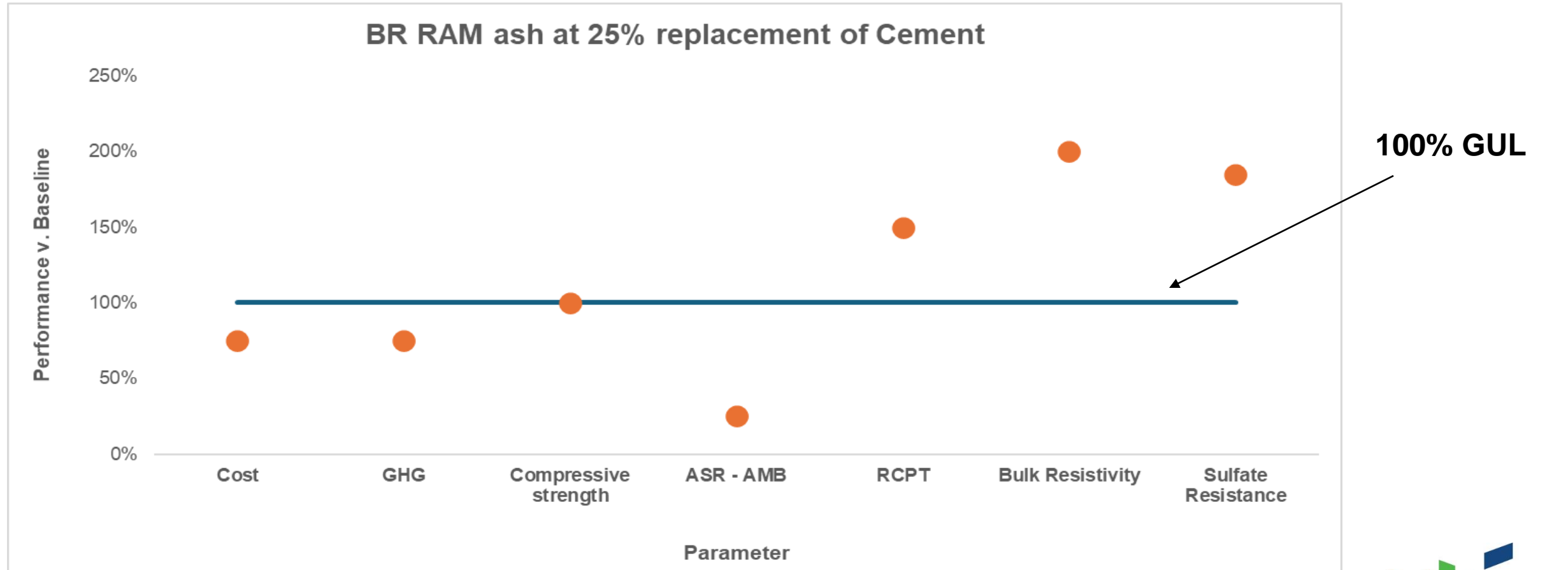
Samples with BR RAM Ash replacement at 25% shows high sulphate resistance

Waiting on Freeze/Thaw and ASR Test Results

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Ashcor's BR RAM Ash



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Summary

- Irrespective of the political landscape, the “2050 Net-Neutrality goals” are not going away
- All studies point towards increased demand for concrete and sustainable construction materials
- To meet the demand for low carbon cements, industry is adapting by reducing the clinker content
- Consistent supply of harvested coal ash is one of the keys to providing sustainable cementitious materials for construction





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