مجلس قطر للأبنية الخضراء
QATAR GREEN BUILDING COUNCIL

"Green Concrete“

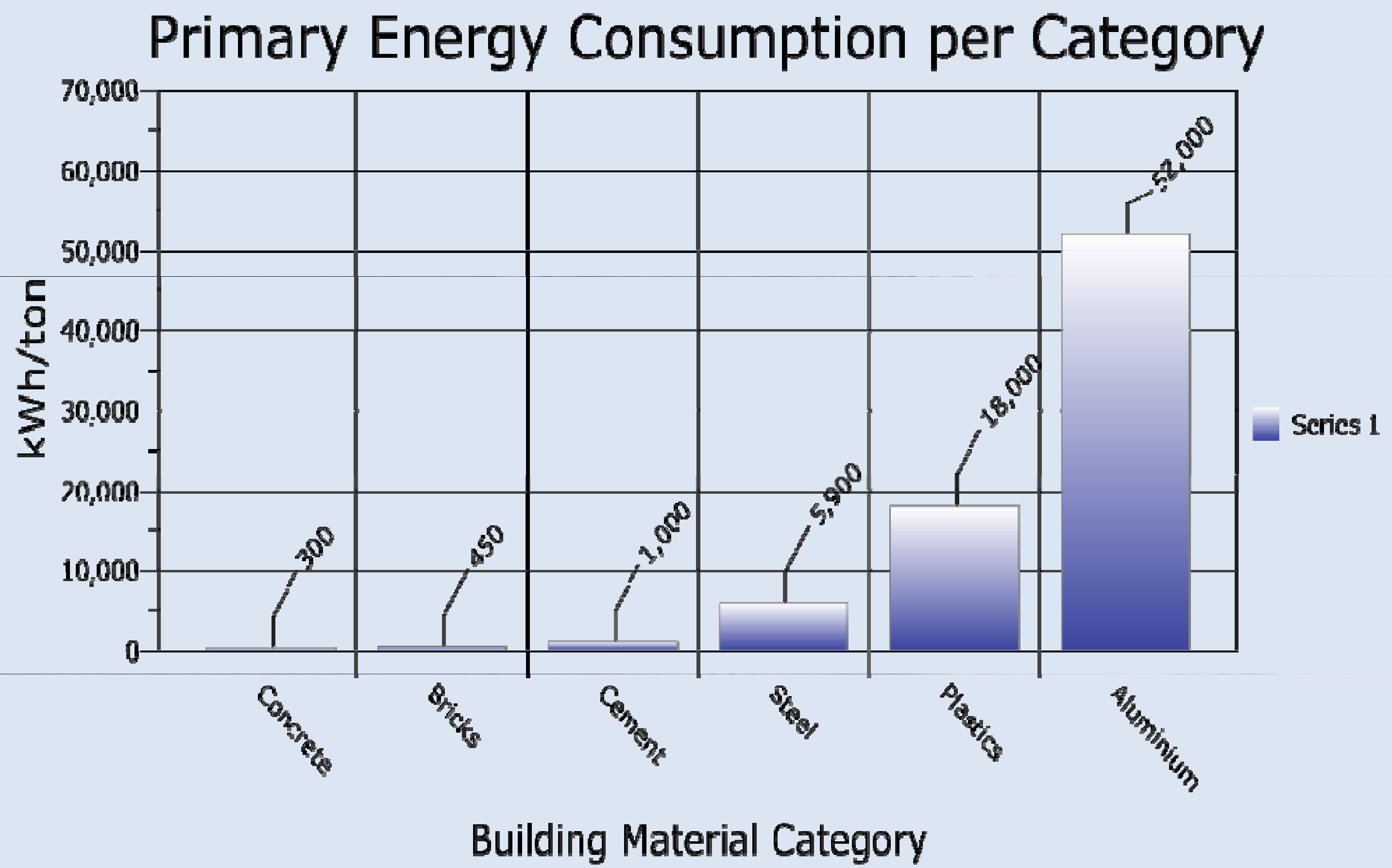
A Guide to Sustainable Concrete Production: From Cement & Aggregate Substitutes to Sustainable Production Methods

International Concrete Sustainability Conference- 13-14 December 2010- Dubai, UAE

Courtesy of: Mobil-Baustoffe GmbH

Sustainable Properties of Concrete

- fully recyclable
- good insulating properties (> steel; < wood)
- good energy storing properties → large thermal mass



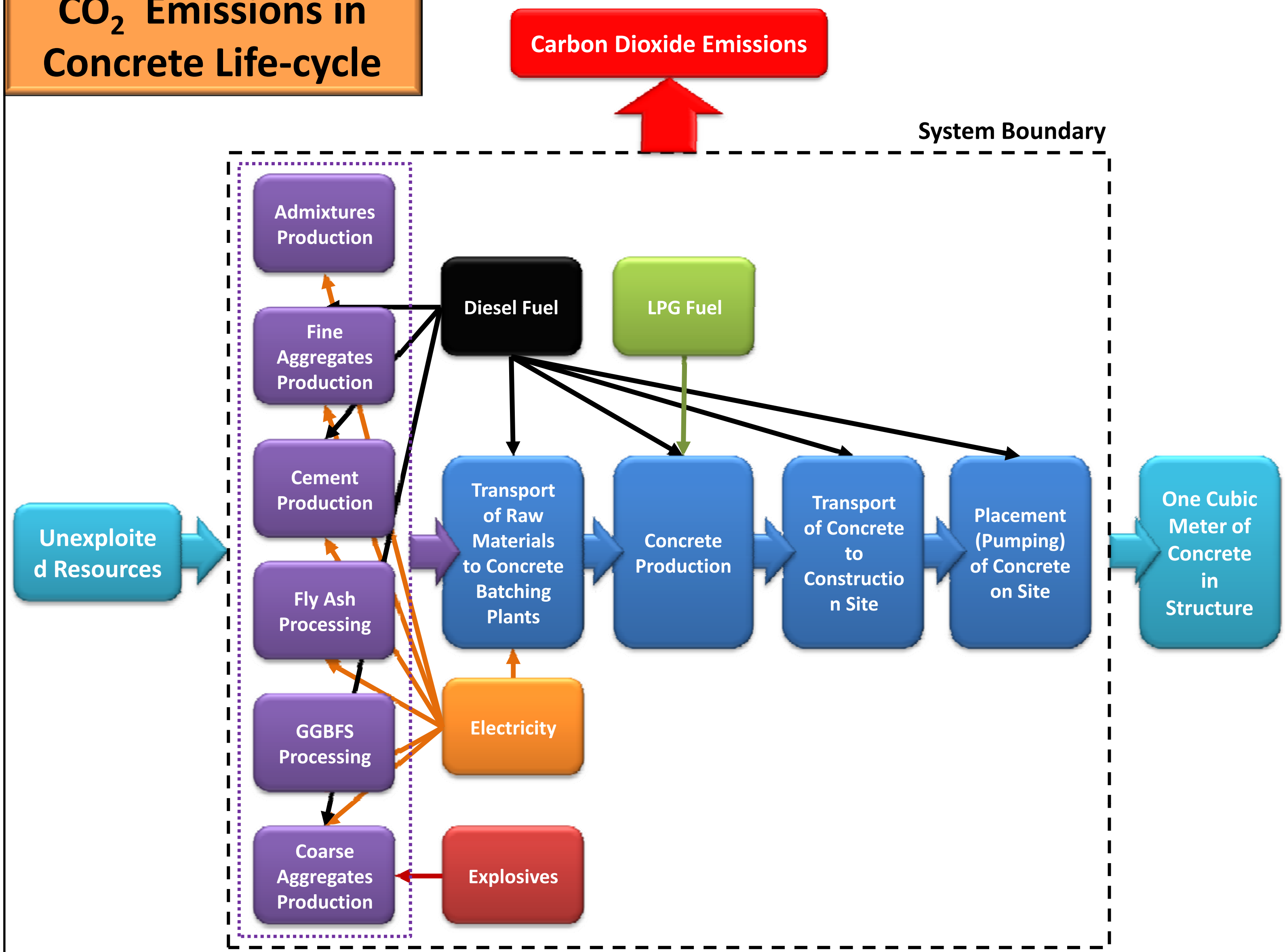
	Concrete	Bricks	Cement	Steel	Plastics	Aluminium
Series 1	300	450	1,000	5,900	18,000	52,000

PRIMARY ENERGY vs. COMPRESSIVE STRENGTH

Material	Compressive Strength	E-Module	Primary Energy Consumption
	N/mm^2	N/mm^2	kWh/to
Brick Work	5	5,000	450
Concrete	50	30,000	300
Aluminum	450	70,000	52,000
Steel	500	210,000	5,900

Material	CO_2 embodied in traditional concrete			
	kg per m^3 of concrete	% per m^3 of concrete	kg of CO_2 emitted per ton produced	kg of CO_2 emitted per m^3 of concrete
Cement	320	13.34	930	297.6
Coarse aggregate	1,100	45.72	2.8	3.08
Fine aggregate	800	33.33	3.4	2.72
Admixture	5	0.12	150	0.76
Water	180	7.49	0	4
TOTAL	2,402.5	100	NA	>308

CO_2 Emissions in Concrete Life-cycle

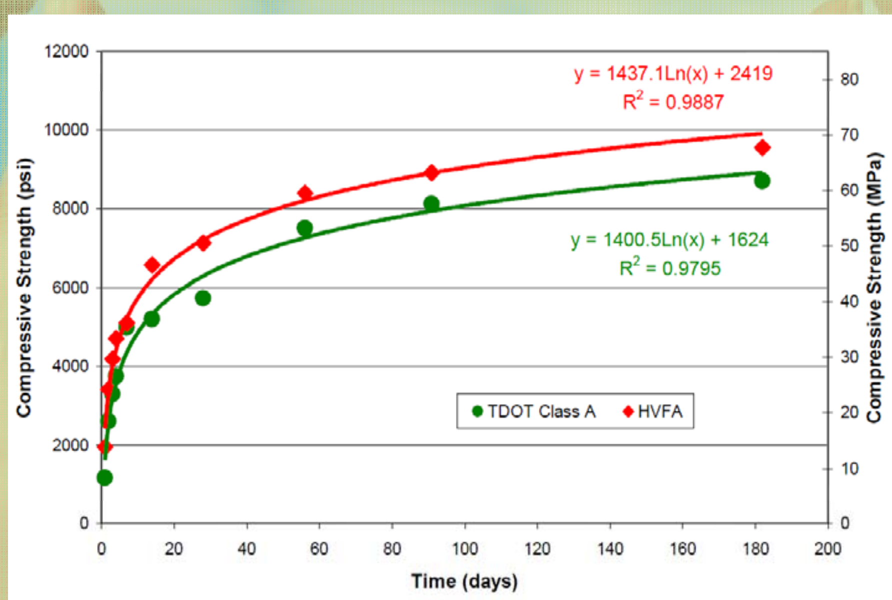



Supplementary Ingredient Materials
Cork
Wood
Crushed Glass
A1
Recycled Concrete
Electric Arc Furnace Slag
Rice Husk Ash
Scrapped Tyre Rubber
Micro Silica (Silica Fume)
Ground Granulated Blast Furnace Slag

Supplementary Cementitious Materials

Fly Ash

- Type C ⟶ Mixing with type C fly ash results in higher compressive strength
- Type F

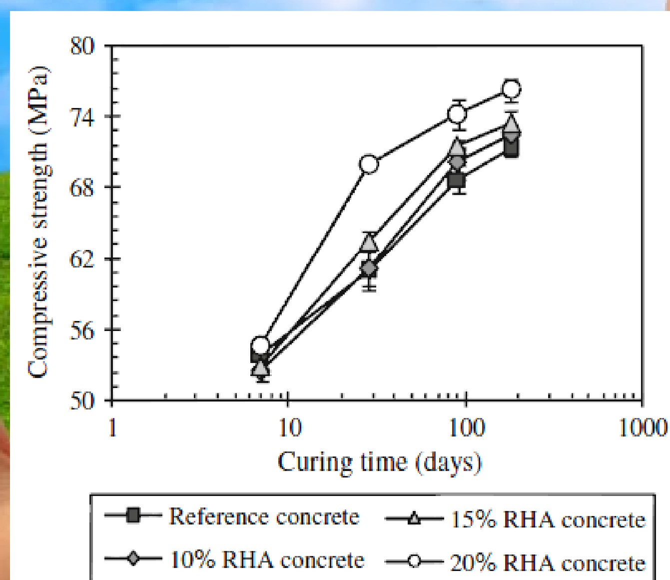


Compressive Strength vs. Time - C Ash Mixtures as by (Crouch, Hewitt, & Byard, 2007)

Supplementary Cementitious Materials

Rice Husk Ash

- 20% of rice paddy is rice husk
- 20% of those are – if burnt for a few hours between 600 and 850 °C – rice husk ash
- rice husk is burnt in biomass power plants to produce electricity → by-product RHA

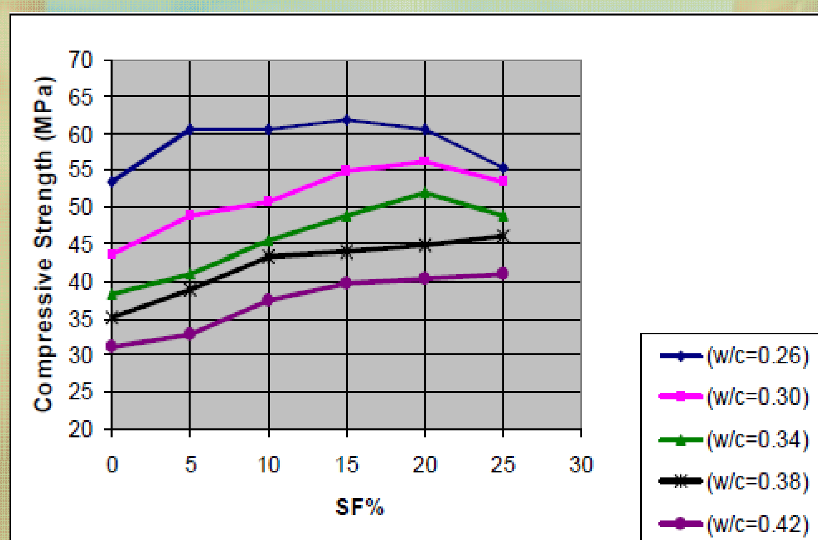


Evolution of compressive strength of concretes against curing time as by (Cordeiro, Filho, & de Moraes Rego Fairbairn, 2008)

Supplementary Cementitious Materials

Micro Silica (Silica Fume)

- byproduct from electric arc furnaces producing alloys
- highly pozzolanic, such as RHA



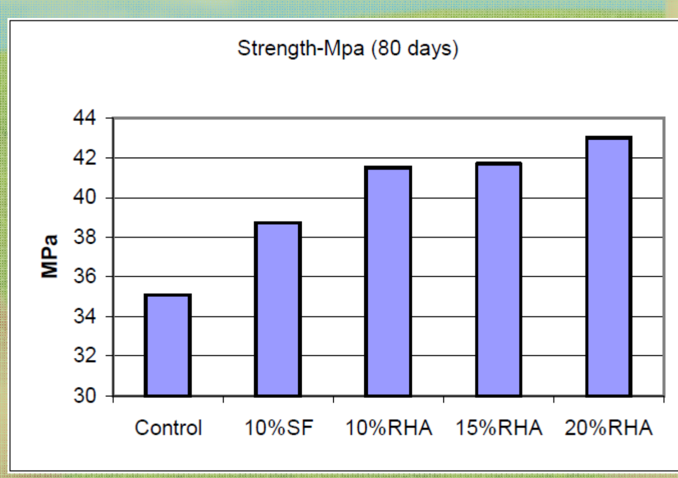
Relationship between 28 day compressive strength and percentage replacement of silica fume as by (Katkhuda, Hanayneh, & Shatarat, 2009)

Supplementary Cementitious Materials

RHA and SF - comparison

Mixture Proportions		Control	Partial cement replacement of			
		CTL	10% RHA	15% RHA	20%RHA	10% SF
cement	kg/m^3	354	321	303	283	320
silica fume	kg/m^3	-	-	-	-	35
rice husk ash	kg/m^3	-	35	53	72	-
fine sand	kg/m^3	151	152	152	153	152
coarse sand	kg/m^3	739	743	745	746	742
coarse agg. 5/15	kg/m^3	436	438	439	440	438
coarse agg.15/25	kg/m^3	568	571	572	574	571
superplasticizer	%/B	1,2%	1,2%	1.2%	1.2%	1.2%
water (w)	l/m^3	151	152	152	153	152
water/binder	w/B	0.43	0.43	0.43	0.43	0.43
slump	mm	145	15	20	20	35

Concrete mixture proportions of the mixes as by (Sampaio, J., Coutinho, J.S., Sampaio, M.N., 2000)



Average strength of the mixes as by (Sampaio, J., Coutinho, J.S., Sampaio, M.N., 2000)

Proposed Cement Replacement Levels (GGBS, Fly Ash)

Concrete Application	**Cement**
Concrete Paving	25 - 50%
Exterior Flatwork not exposed to deicer salts	25 - 50%
Exterior Flatwork exposed to deicer salts with w/cm ≤ 0.45	25 - 50%
Interior Flatwork	25 - 50%
Basement floors	25 - 50%
Footings	30 - 65%
Walls & Columns	25 - 50%
Tilt-up panels	25 - 50%
Pre-stressed Concrete	20 - 50%
Pre-cast Concrete	20 - 50%
Concrete blocks	20 - 50%
Concrete pavers	20 - 50%
High Strength	25 - 50%
ASR mitigation	25 - 70%
Sulfate resistance	
Type II equivalance	25 - 50%
Type V equivalance	50 - 65%
Lower permeability	25 - 65%
Mass concrete	50 - 80%

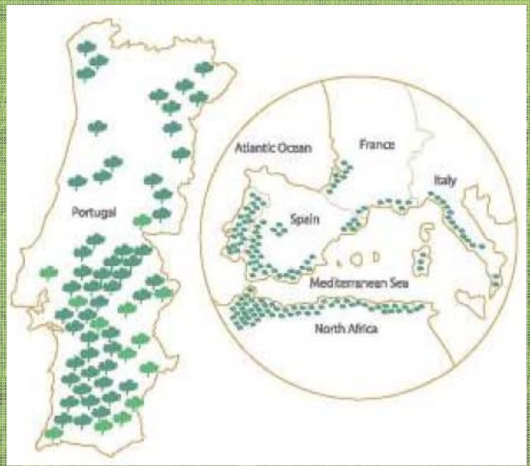
Aggregate substitutes

- **Wood**
  - Woodwaste produced by manufacturers of furniture
  - Substantial decrease in compressive strength
- **Scrap Tire Rubber**
  - Mainly used in asphalt concrete
  - Also used as lightweight aggregate in flowable fill

Aggregate substitutes

Cork

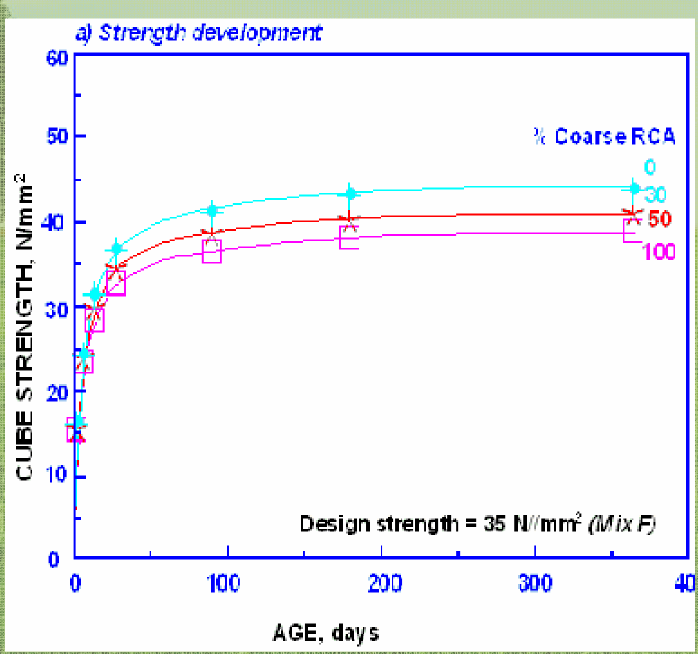
- Unique cell structure allows for additional CO_2 absorption
- Excellent insulation material (thermal and acoustic)
- Usage in cladding (consider loss in compressive strength)



Geographic distribution of cork forests as by (Cork Information Bureau, 2009, p.4)

Aggregate substitutes

Recycled and Crushed Concrete



Compressive cube strength test results as by (Limbachiya, Koulouris, Roberts, & Fried, 2004)

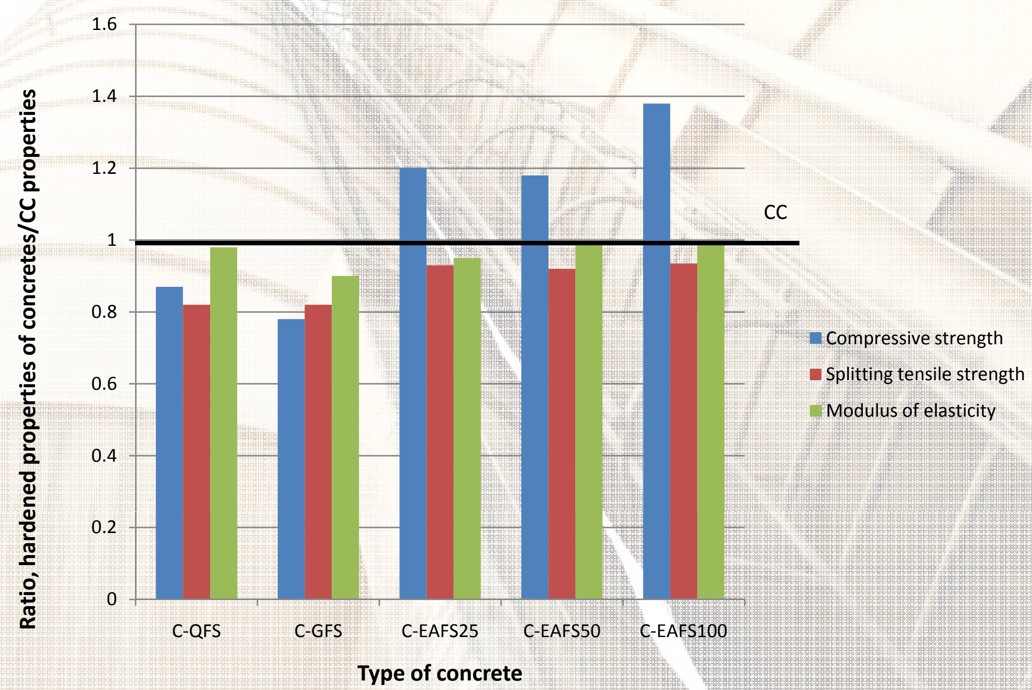
30% of coarse aggregates can usually be replaced without little or no effect on compressive strength

Waste Concrete Reuse and Recycling Methods

- crushing concrete into recycled aggregates
- washing out the waste concrete before the hardening begins- eco-friendly version, if wash-out water is recycled and reused
- recycled concrete→ use in non structural elements such as backfills, blinding slabs, core filling, embankments and road construction

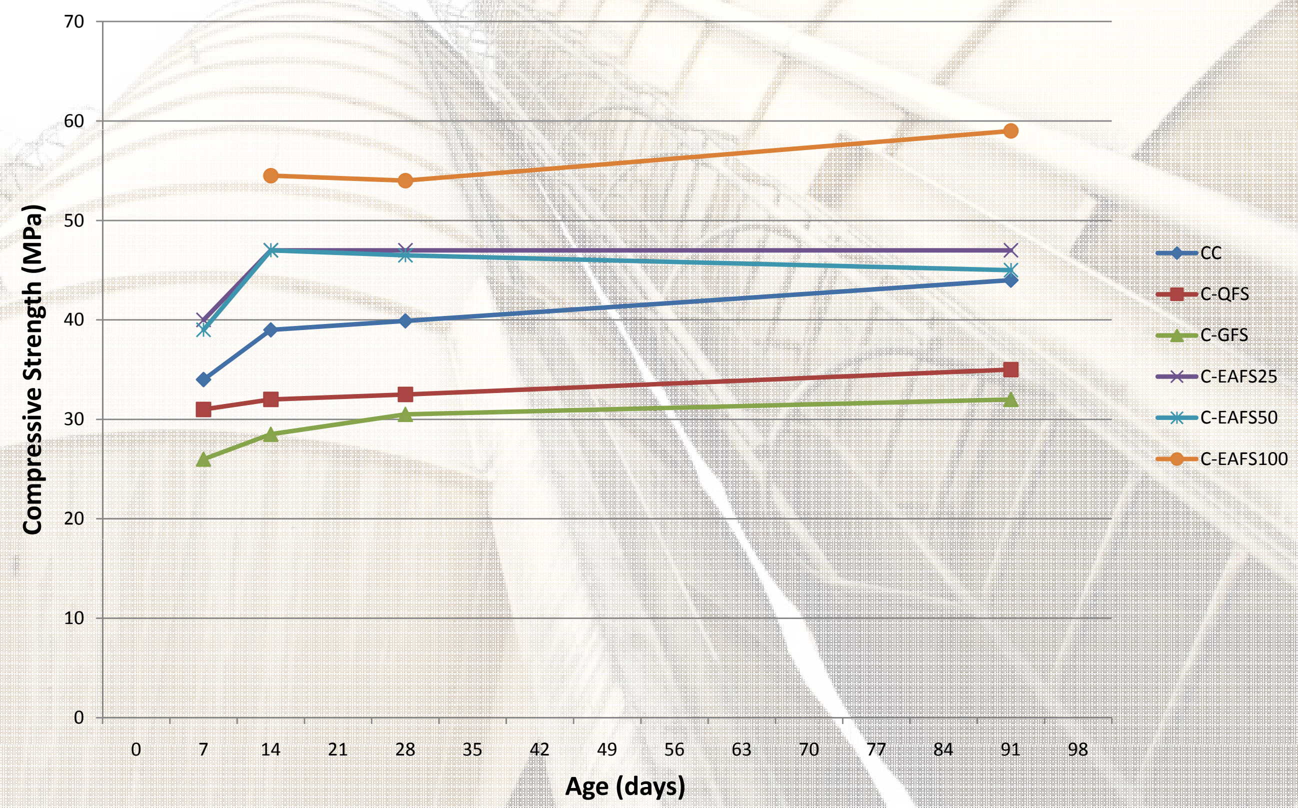
Coarse Aggregate Replacement

Electric Arc Furnace Slag

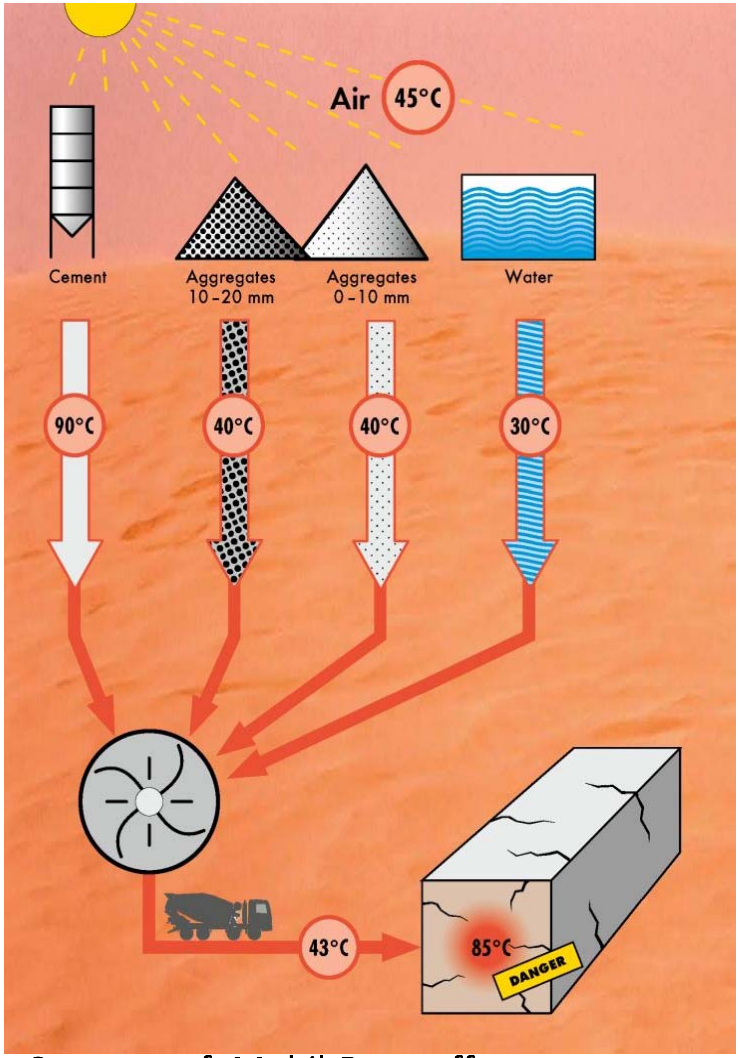


Ratio Hardened Properties / Conventional Concrete as by (Etxeberria, et al., 2010)

Electric Arc Furnace Slag



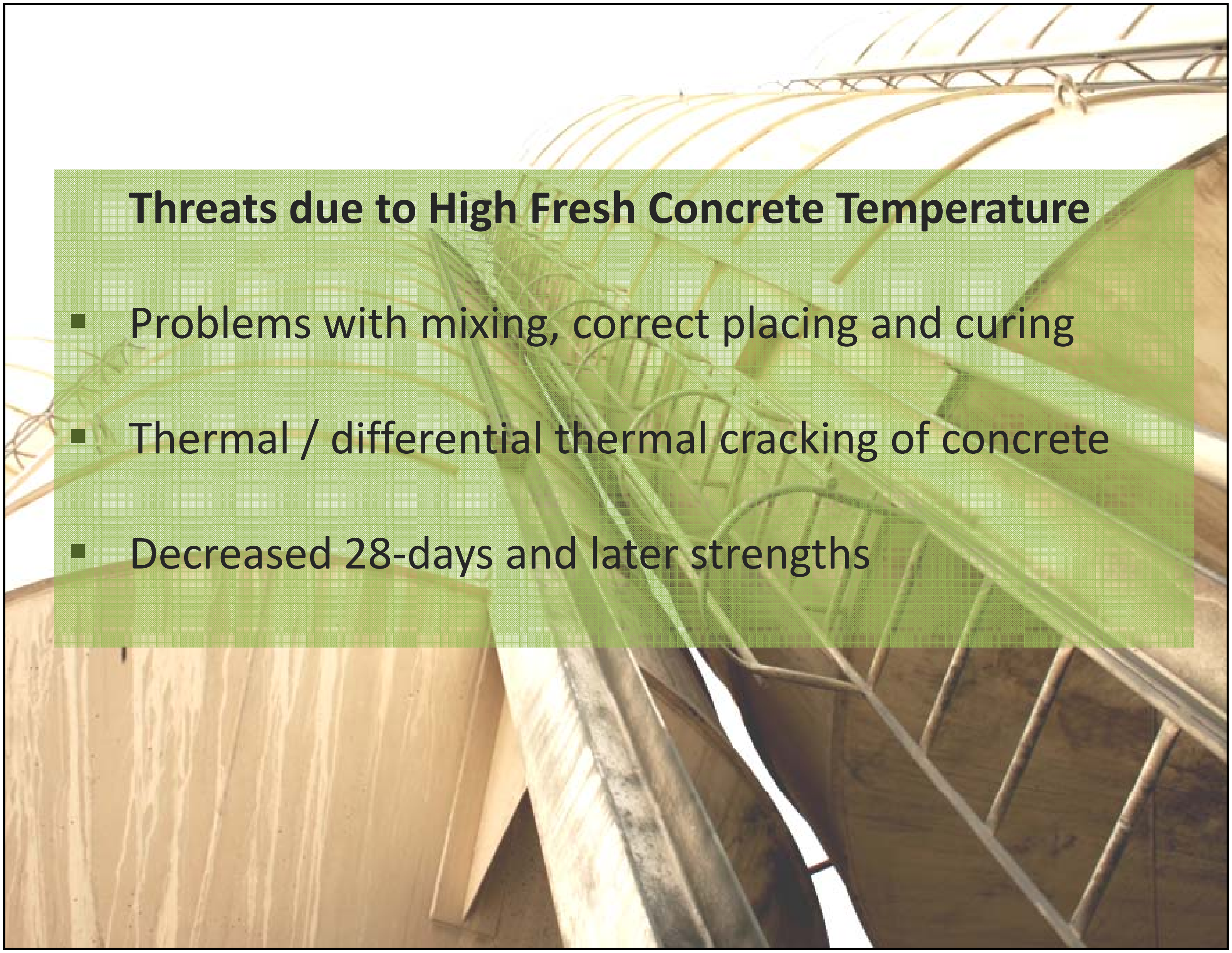
Compressive Strength as by (Etxeberria, et al., 2010)



Courtesy of: Mobil-Baustoffe

Concrete without Cooling

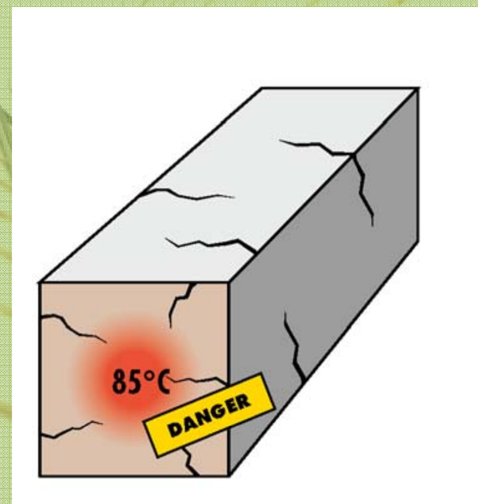
- short time workability due to a faster setting process
- extreme high concrete temperatures caused by heat of hydration at the setting process
- uncontrollable cracking
- high costs for intensive curing
- extension of construction periods due to a production stop caused by high temperatures



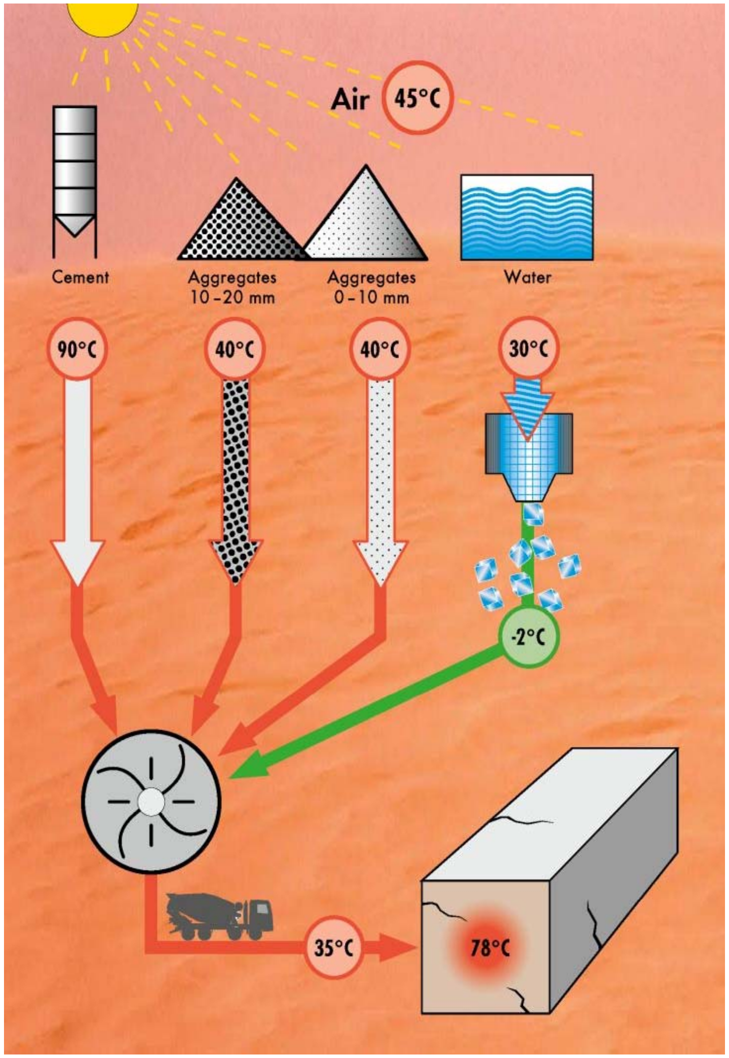
Threats due to High Fresh Concrete Temperature

- Problems with mixing, correct placing and curing
- Thermal / differential thermal cracking of concrete
- Decreased 28-days and later strengths

Threats due to High Fresh Concrete Temperature



- Delayed Ettringite Formation (DEF) in concrete when exceeding a temperature of about 65°C during hydration, which can cause cracking even years after installation



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Flake-Ice Cooling

- At high temperatures further activities are needed; such as shading the aggregates or the production of concrete during the cooler night time period
- Lower production capacity due to a limited ice production and a long mixing process.

SAMPLE MIX (8% moisture content in fine aggregates)

- Cement 400kg
- w/c ratio ≤ 0.40
- humidity in sand 8% =58l
- maximum water content= 160l
- concrete temperature without cooling= 47°C
- cooling 1°C = 7.5kg of ice

SAMPLE MIX (2% moisture content in fine aggregates)

- Cement 400kg
- w/c ratio ≤ 0.40
- humidity in sand 2% =14.5l
- maximum water content= 160l
- concrete temperature without cooling= 47°C
- cooling 1°C = 7.5kg of ice

SAMPLE MIX (8% moisture content in fine aggregates)

- Maximum possible addition of water:

102 litres

- Fresh concrete temperature after adding flake ice:

= 34°C

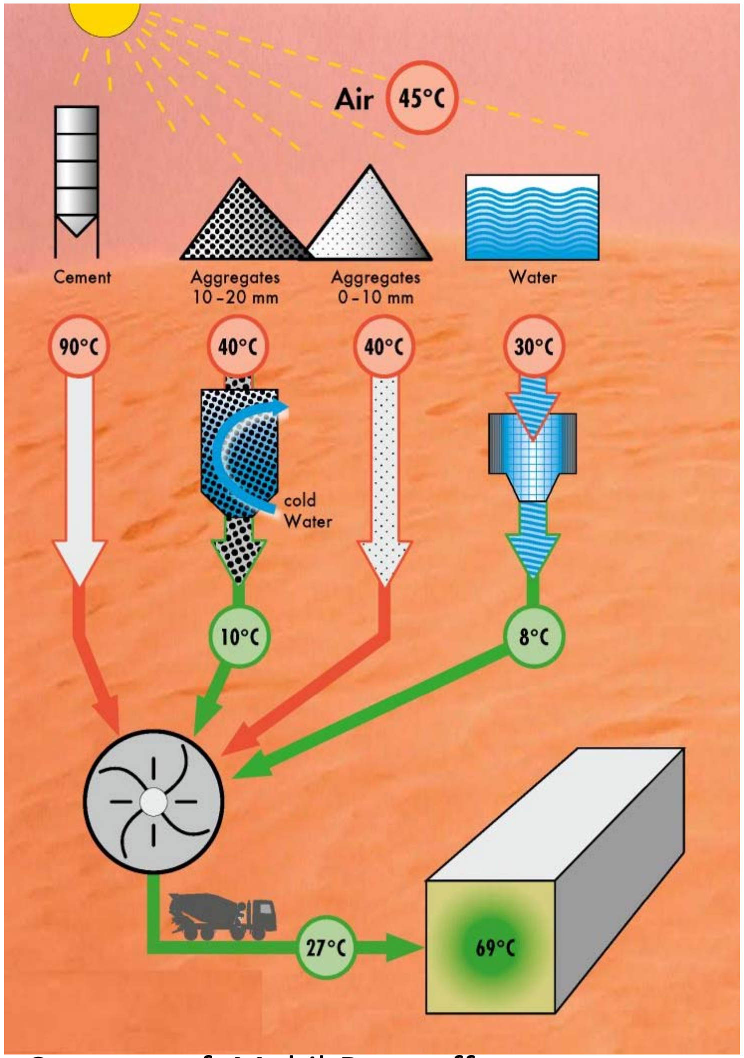
SAMPLE MIX (2% moisture content in fine aggregates)

- Maximum possible addition of water:

145.5 litres

- Fresh concrete temperature after adding flake ice:

= 28°C



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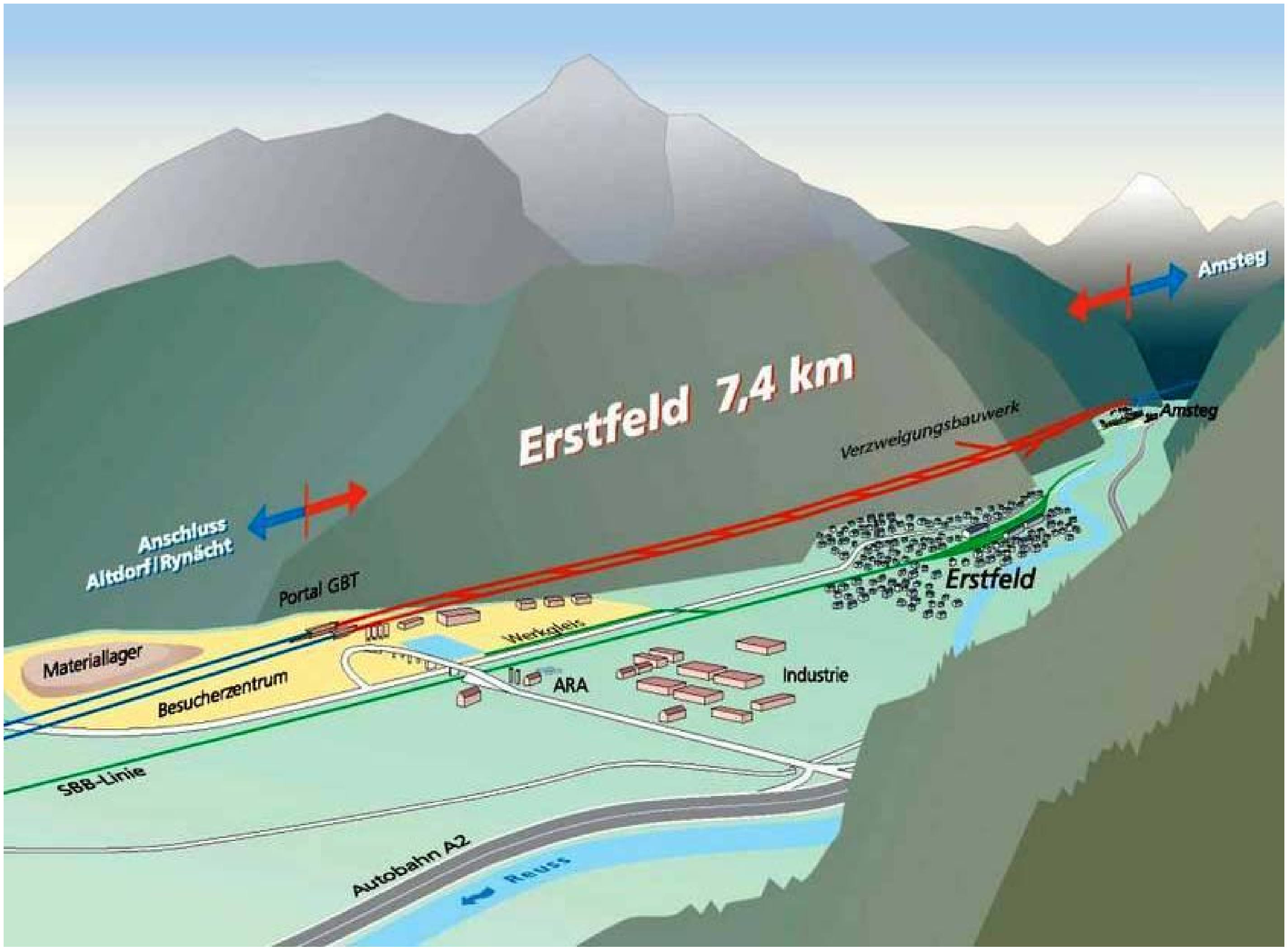
Coarse Aggregate Cooling

- More time to place and finish concrete works on site
- Significant energy savings
- Reduced dust emissions
- Reduced admixture usage
- Cement savings (low w/c ratio)
- Achieving concrete temperatures as low as 25 Degree Celsius.
- Reduces the risk of rejected concrete due to temperatures out of specification
- Transportation over longer distances possible

CASE STORY
Gotthard Tunnel North- Lot Amsteg and Erstfeld

- **Client:** Arbeitsgemeinschaft Amsteg, Switzerland
- **Quantity:** 1,000,000m3
- **Duration:** 70 months
- **Maximum Capacity:** 2x240m3/h

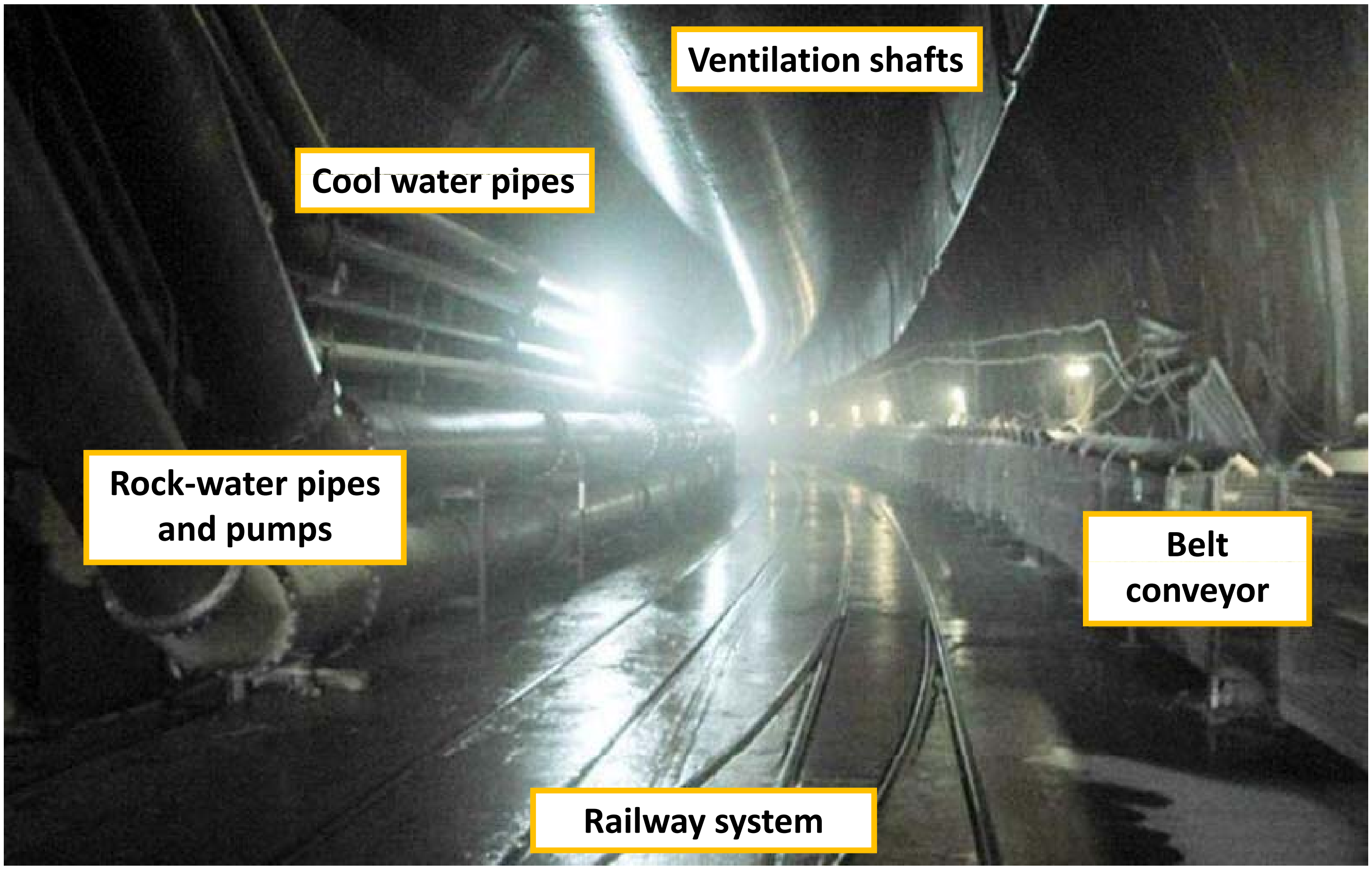

Sedrun
Sedrun
Amsteg 11.4 km
Erstfeld 7.4 km
(inkl. Nordportal)
Kraftwerk
Amsteg
Kabelstollen SBB
Amsteg
Silenen
Kantonsstrasse
Autobahn A2
Kraftwerk
Arniberg
Quartier Dörfli
Zugangsstollen
Quartier Grund
Installations-
platz
Unterkünfte
Zeughaus

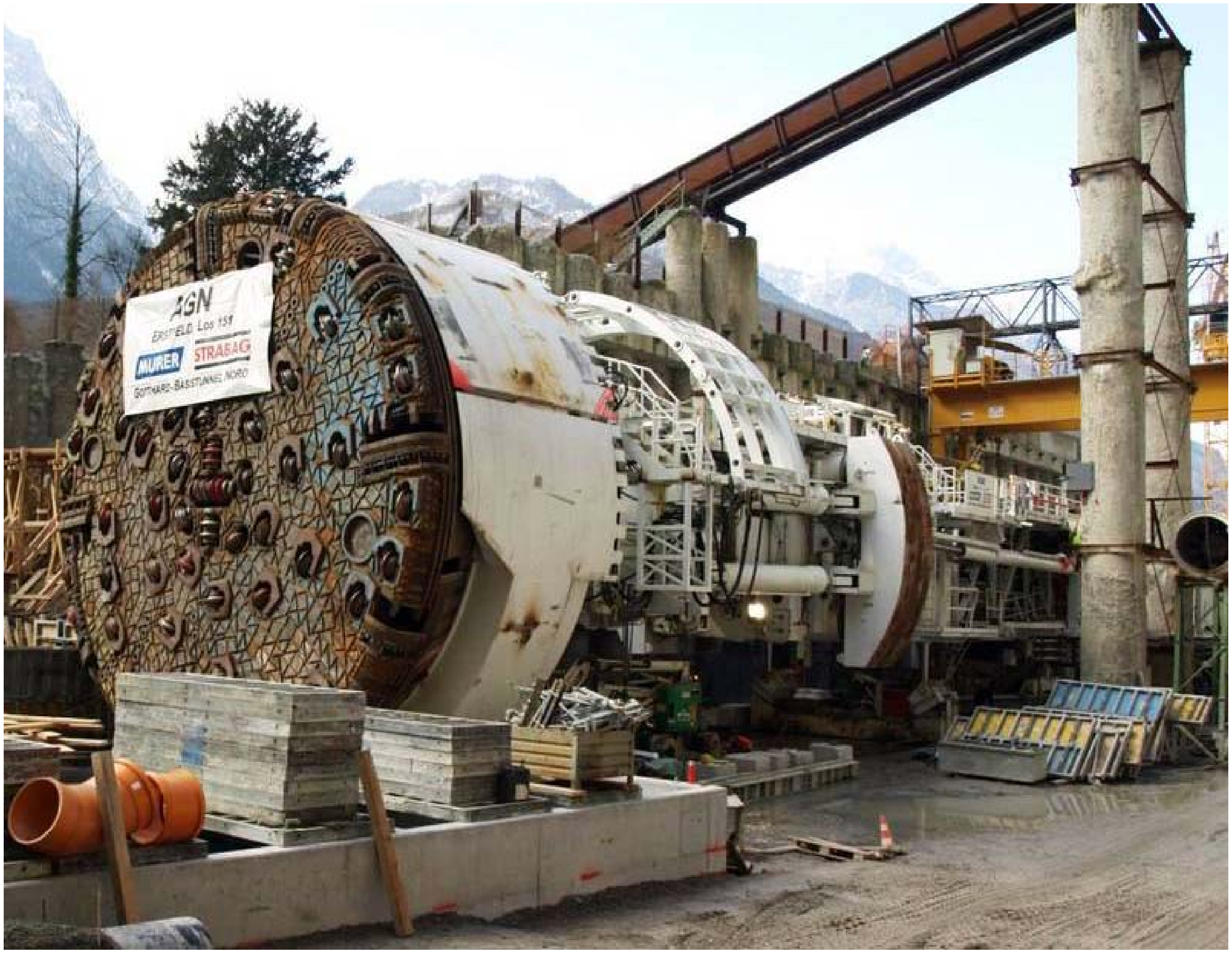

Erstfeld 7,4 km
Amsteg
Amsteg
Verzweigungsbauwerk
Anschluss
Altdorf/Rynächt
Portal GBT
Erstfeld
Materiallager
Werkgleis
Besucherzentrum
ARA
Industrie
SBB-Linie
Autobahn A2
Reuss


STRABAG

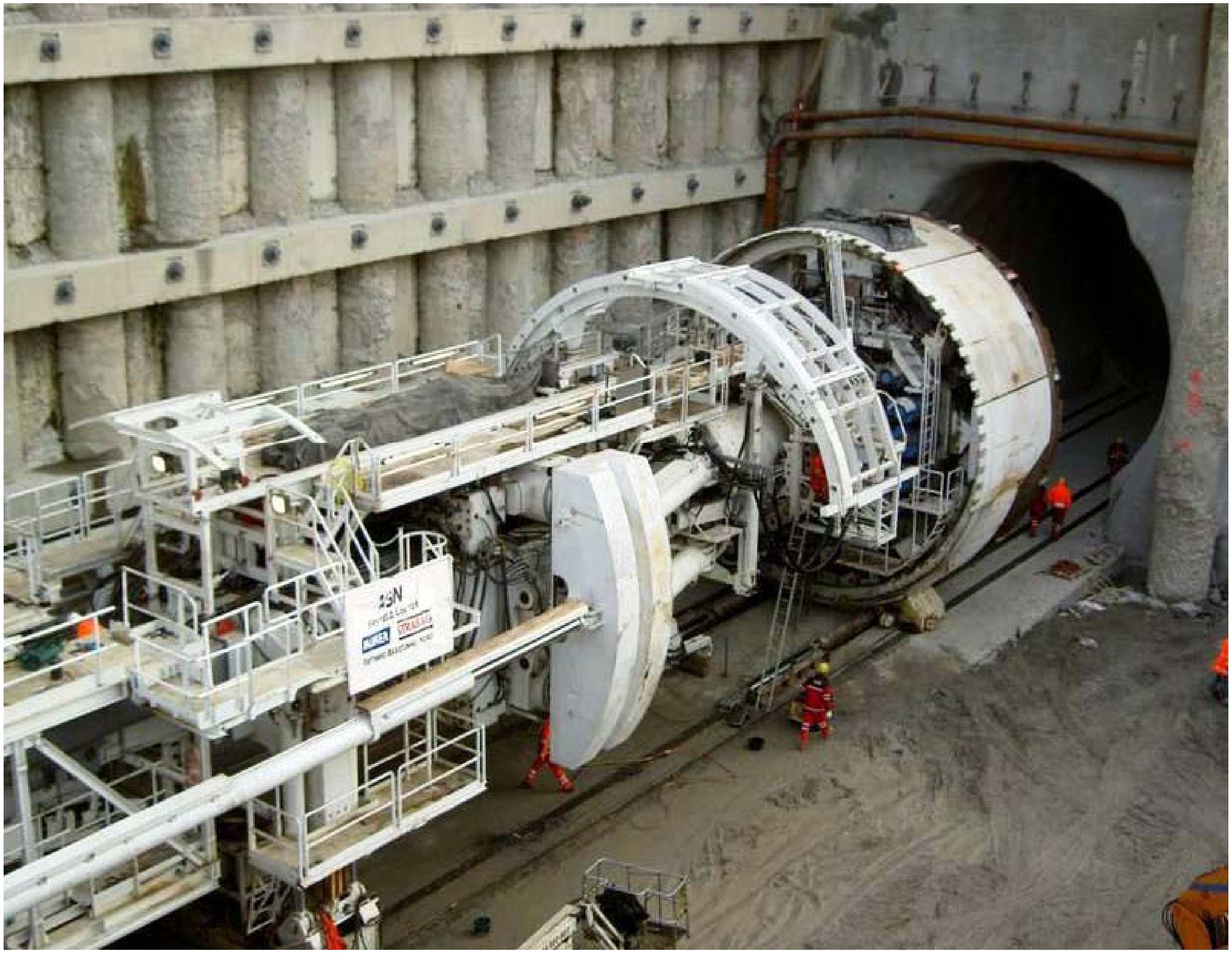

Betonanlage


L12

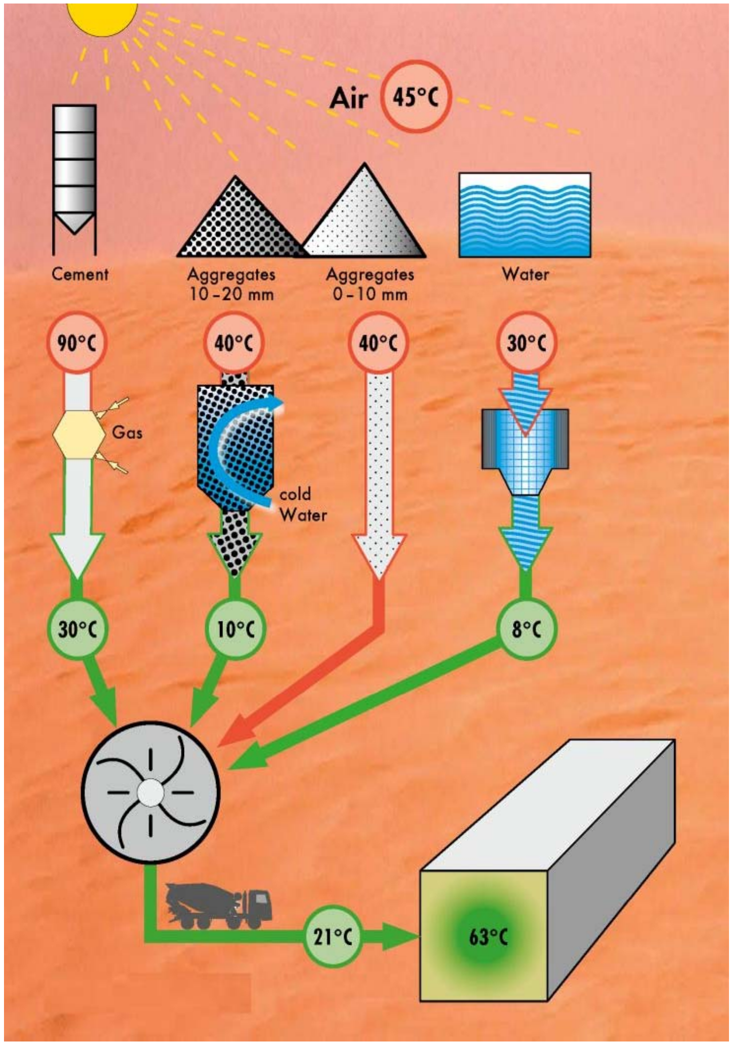

Ventilation shafts
Cool water pipes
Rock-water pipes and pumps
Belt conveyor
Railway system


AGN
MURER
STRABAG


AlpTransit
AGN
AMSTEG, LOS 252
MURER
STRABAG
GOTTHARD-BASISTUNNEL NORD



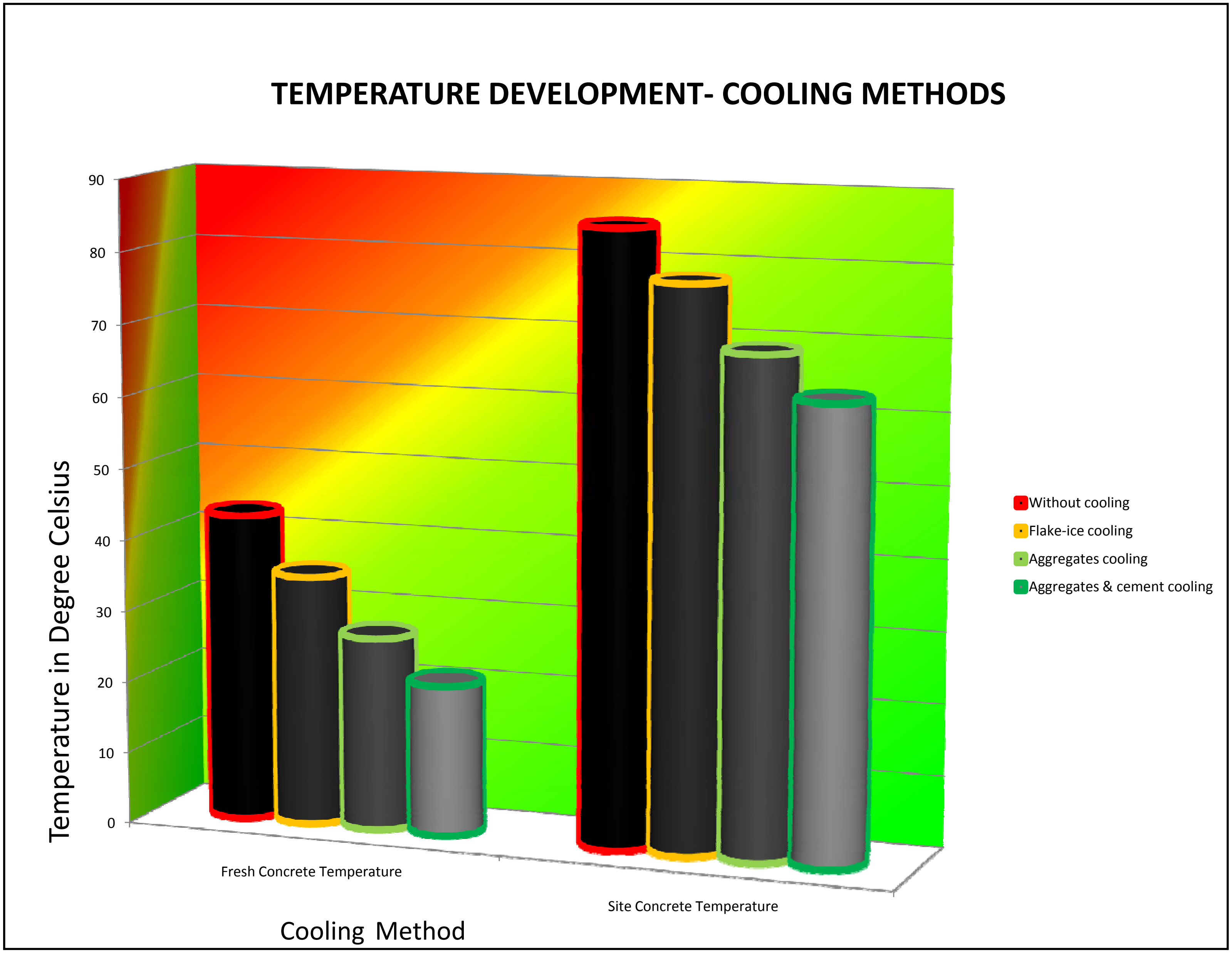

AGN
MURER
STRABAG
L 18



Courtesy of: Mobil-Baustoffe

Aggregate & Cement Cooling

- Cement cooled down by 10 °C results in a reduction of the overall concrete temperature of 1 °C
- Methods:
    - Air
    - Nitrogen or carbon dioxide



TEMPERATURE DEVELOPMENT- COOLING METHODS
Temperature in Degree Celsius
90
80
70
60
50
40
30
20
10
0
Fresh Concrete Temperature
Site Concrete Temperature
Cooling Method
Without cooling
Flake-ice cooling
Aggregates cooling
Aggregates & cement cooling

Cooling Method Comparison: 1500 m3 of Concrete in 24h

(as per mix and air temperatures from previous sample with **<u>8% moisture content in fine aggregates</u>**)

Conventional flake-ice cooling	Energy saving flake-ice cooling	Coarse aggregate cooling system
up to 316 kW per unit	135 kW per unit	350kW per unit
407 kW/h*	**270 kW/h***	**350 kW/h**

1kW = 0,32 l Diesel
1°C= 7.5kg of ice/m3

3125 l/day	2074 l/day	2688 l/day
2,1 l per m^3	**1,4 l per m^3**	**1,8 l per m^3**

* Usage of the best case scenario ice plant mix

Cooling Method Comparison: 1500 m3 of Concrete in 24h

(as per mix and air temperatures from previous sample **2% moisture content in fine aggregates**)

Conventional flake-ice cooling	Energy saving flake-ice cooling	Coarse aggregate cooling system
up to 316 kW per unit	135 kW per unit	350kW per unit
632 kW/h*	405 kW/h*	350 kW/h

1kW = 0,32 l Diesel

1°C= 7.5kg of ice/m3

4854 l/day	3110 l/day	2688 l/day
3,2 l per m^3	2,1 l per m^3	1,8 l per m^3

* Usage of the best case scenario ice plant mix

Sample project

- assess embodied CO_2 within the concrete for each of the listed mixes
- following sources of CO_2 emitters were taken into account for the LCA:

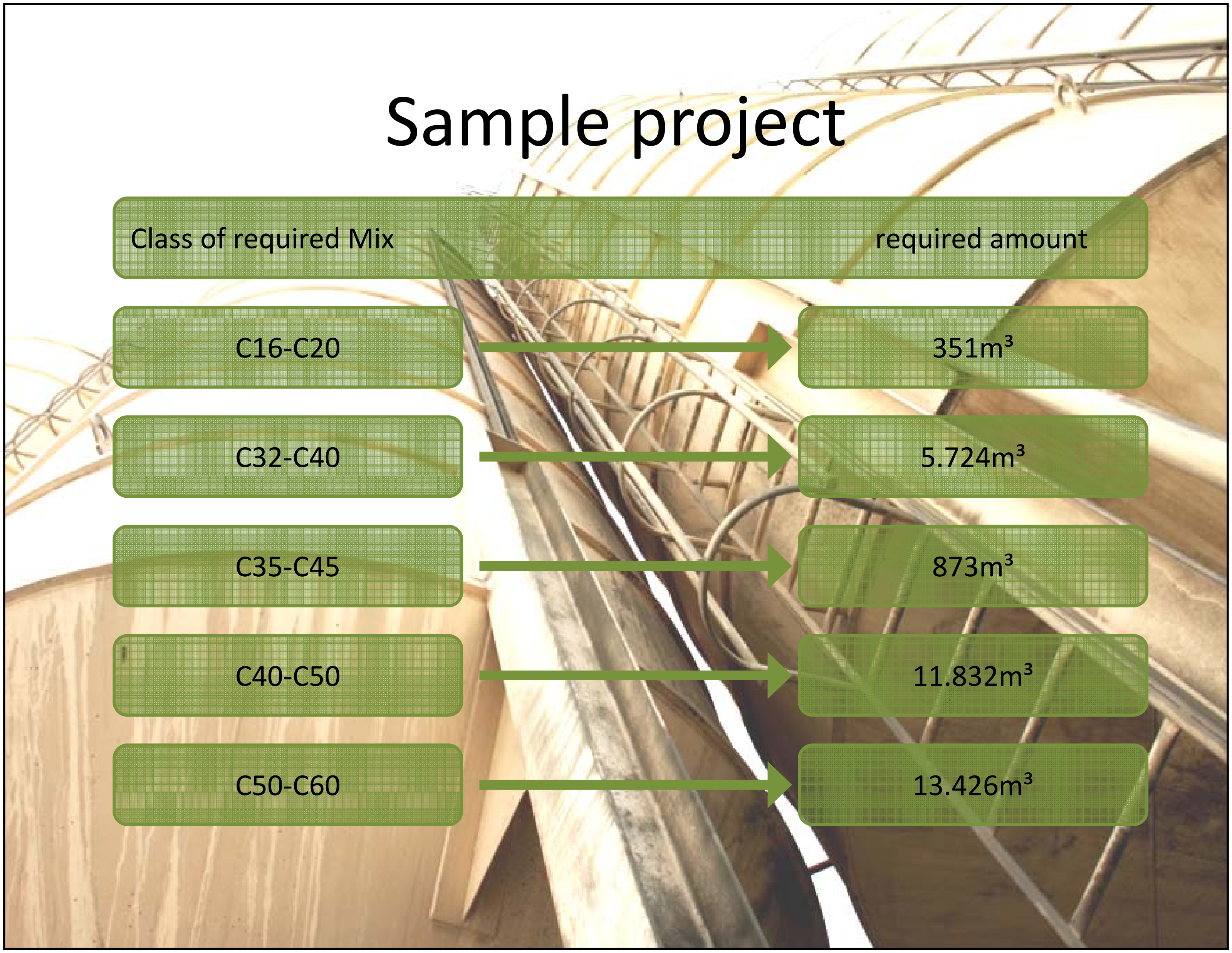
• winning of raw materials for concrete (e.g. fossil fuel consumption)

→ raw materials extracted and processed for cement

• all of the transportation necessary (transport to construction site not included!)

→ transportation of raw materials to the batching plant

• water consumption (incuding energy required for chilling and processing)



Sample project

Class of required Mix	required amount
C16-C20	351m³
C32-C40	5.724m³
C35-C45	873m³
C40-C50	11.832m³
C50-C60	13.426m³

Green Mixes

Fly Ash — by-product in the process of coal combustion (replacement level: up to 40%)

GGBS — produced from blast furnaces used to make iron (replacement level: up to 80%)

EAFS — by-product in the process of smelting iron in an electric arc furnace (replacement level: up to 100%)

Green Mixes

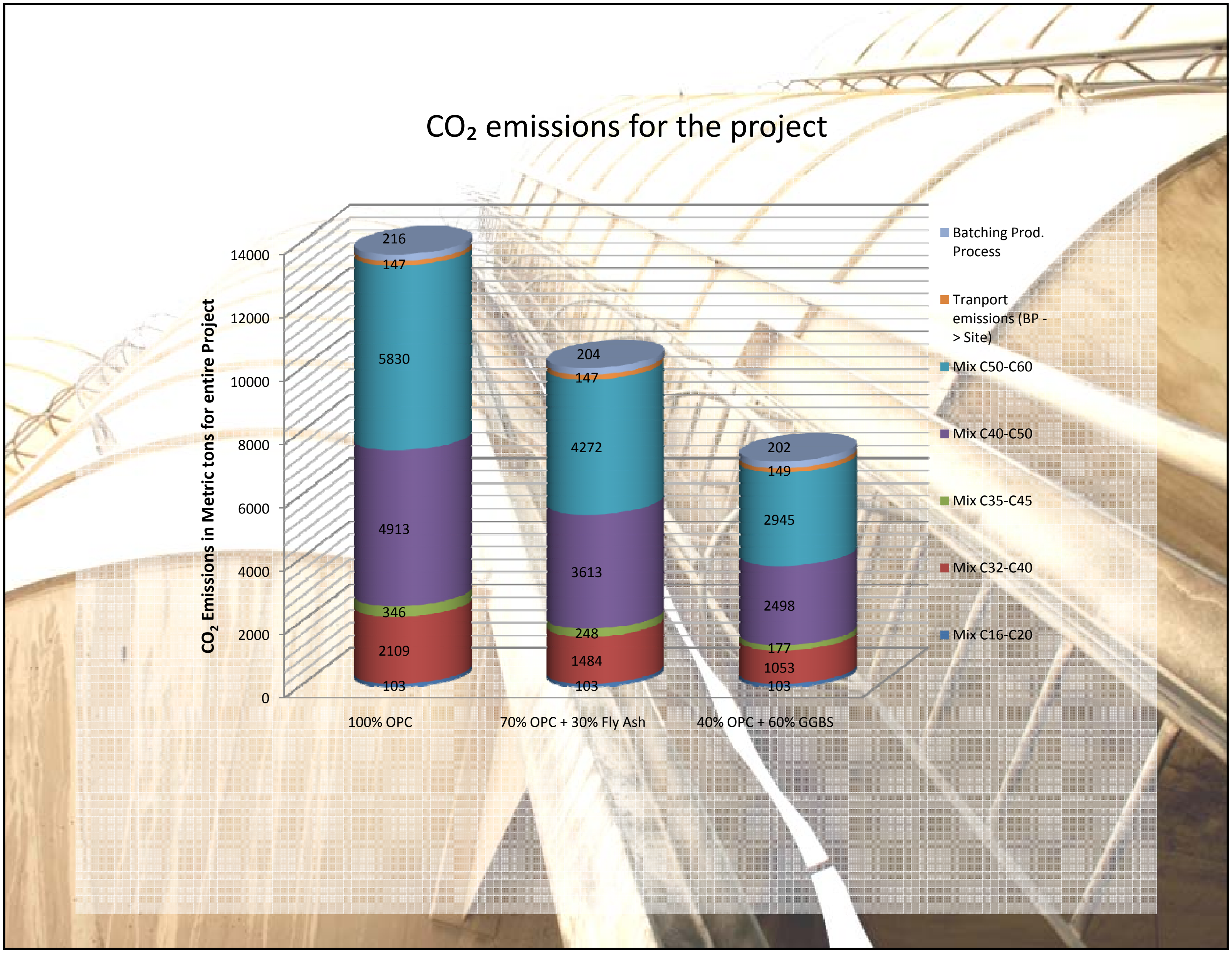
Average Reduction of PM_{10} Emissions for Standard Mixes:

OPC + GGBS	7%	$PM_{10} \rightarrow$ 6,5g/m^3
OPC + GGBS + EAFS	49%	$PM_{10} \rightarrow$ 42,1g/m^3

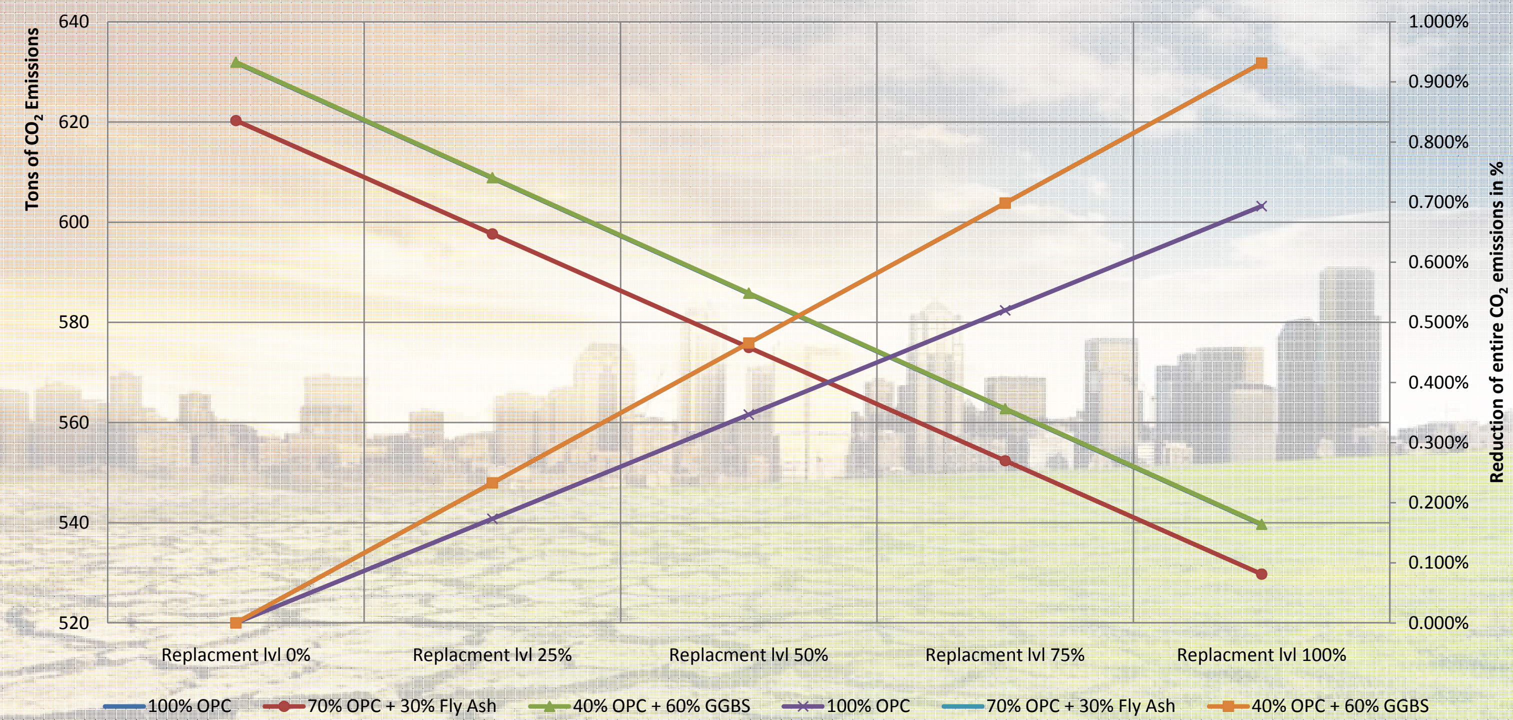
Green Mixes

Average Reduction of CO2 Emissions for Standard Mixes:

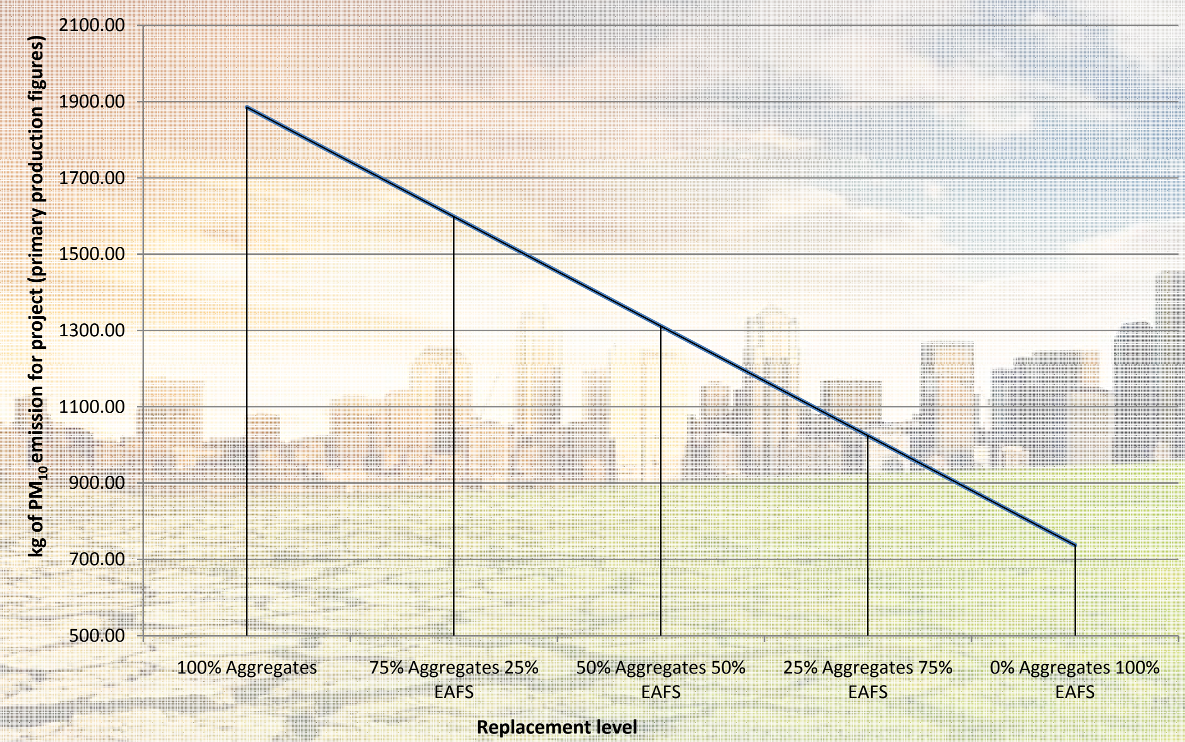
OPC + GGBS	48%	CO2→ 219kg/m³
OPC + GGBS + EAFS	49%	CO2→ 222,1kg/m³


CO₂ emissions for the project
CO₂ Emissions in Metric tons for entire Project
0
2000
4000
6000
8000
10000
12000
14000
100% OPC
70% OPC + 30% Fly Ash
40% OPC + 60% GGBS
216
147
5830
4913
346
2109
103
204
147
4272
3613
248
1484
103
202
149
2945
2498
177
1053
103
Batching Prod. Process
Tranport emissions (BP -> Site)
Mix C50-C60
Mix C40-C50
Mix C35-C45
Mix C32-C40
Mix C16-C20

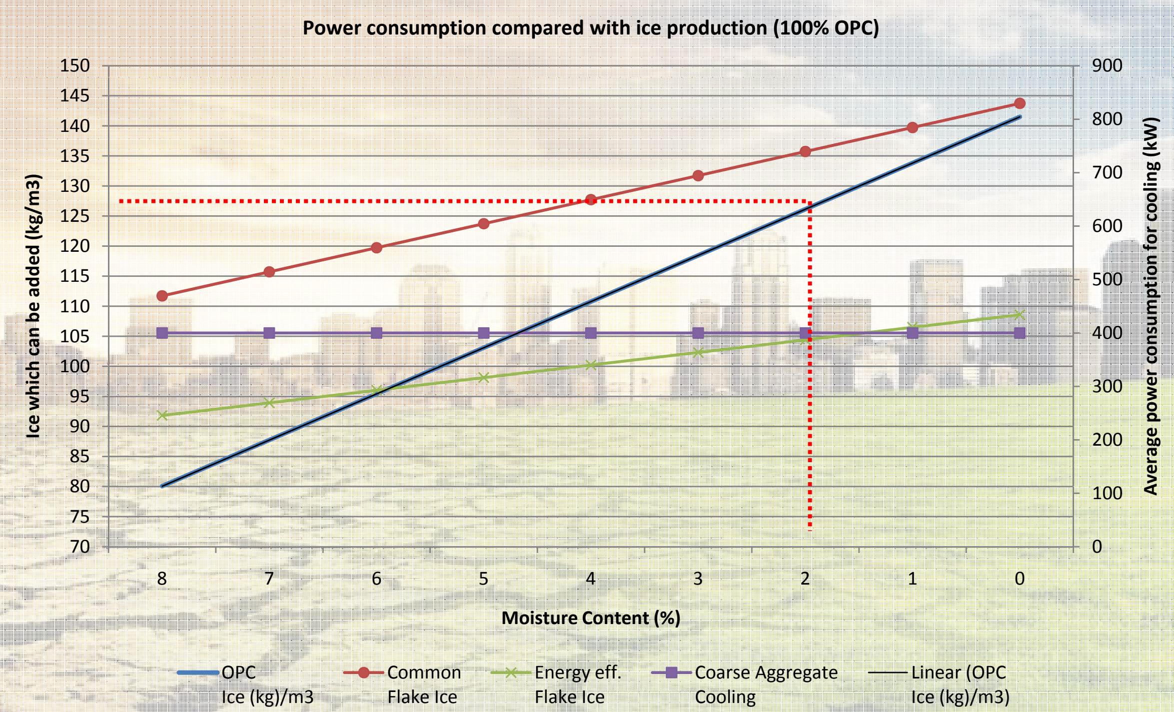
Reducing CO_2 emissions by substituting coarse aggregates with EAFS



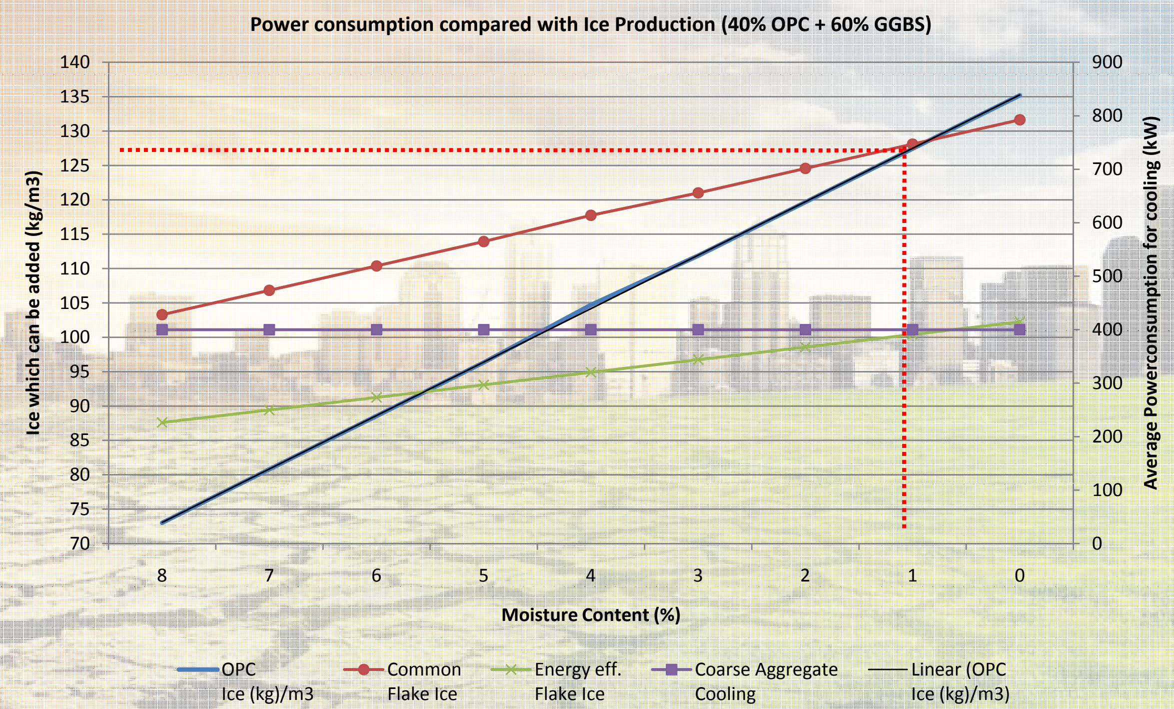
Reducing PM_{10} emissions by replacing natural coarse aggregates with EAFS



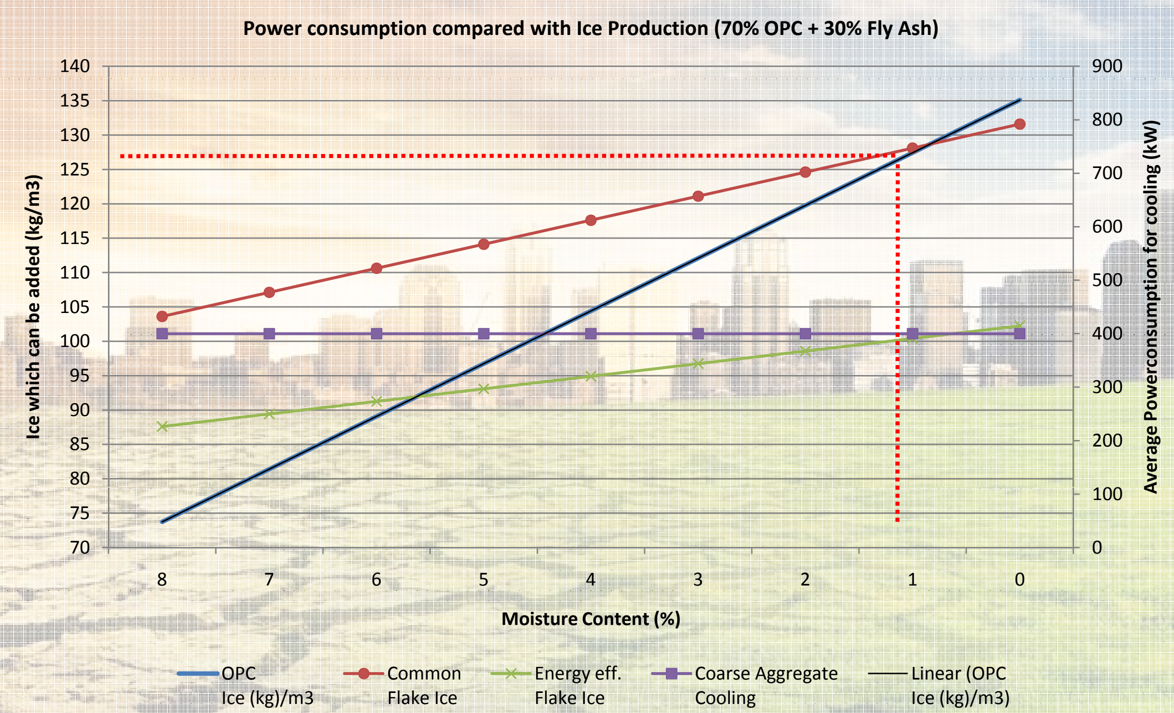
Power consumption compared with Ice production

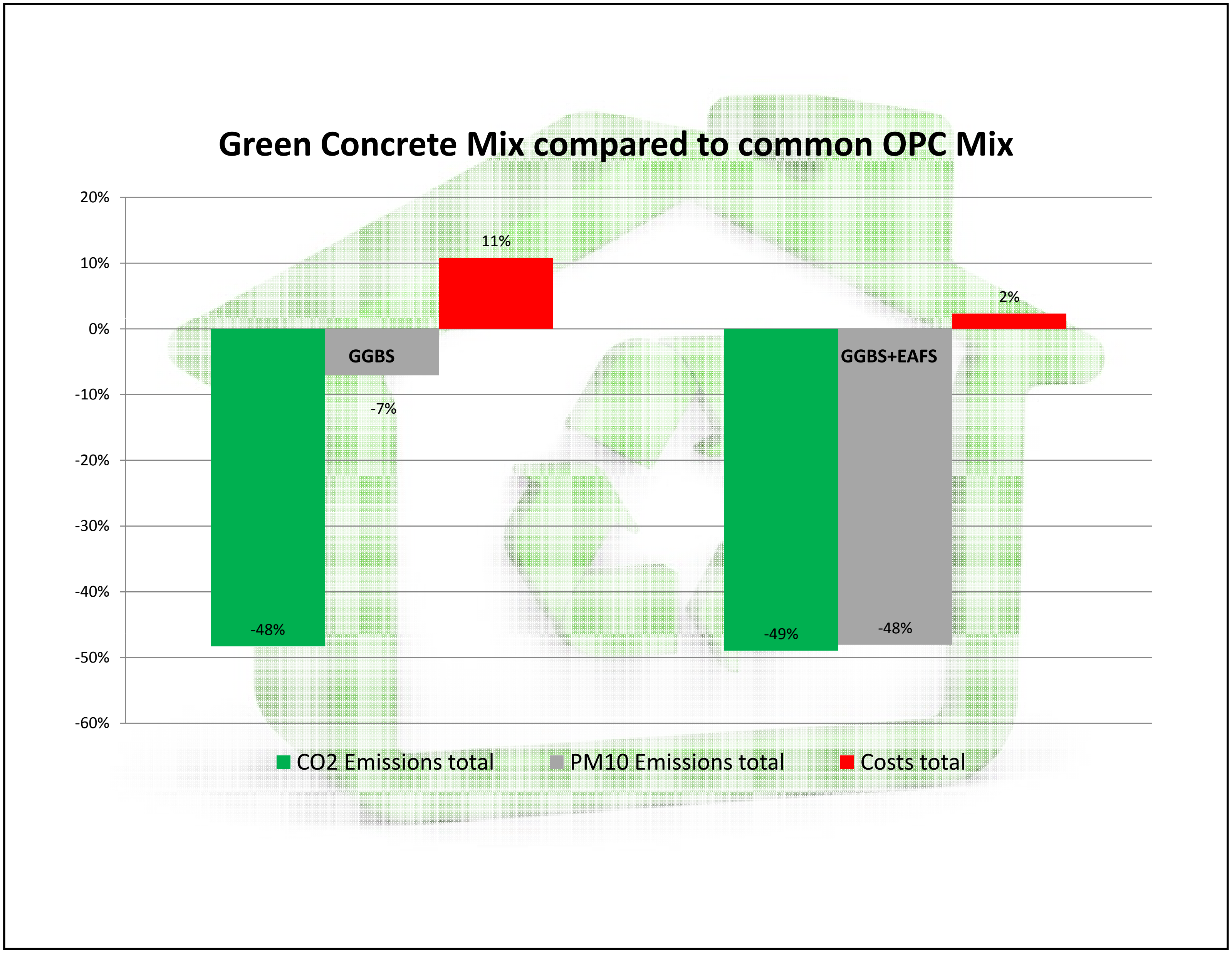


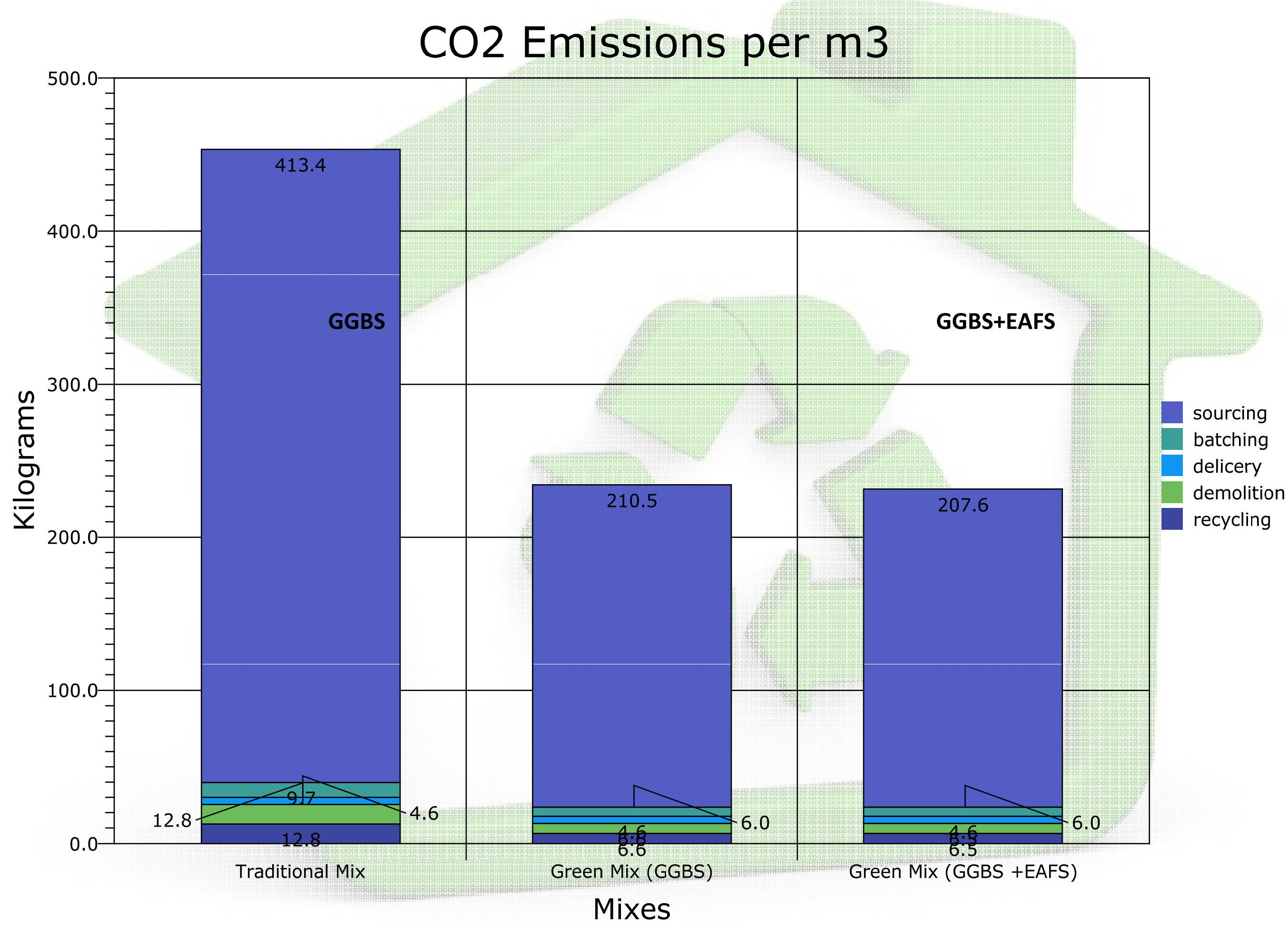
Power consumption compared with Ice production

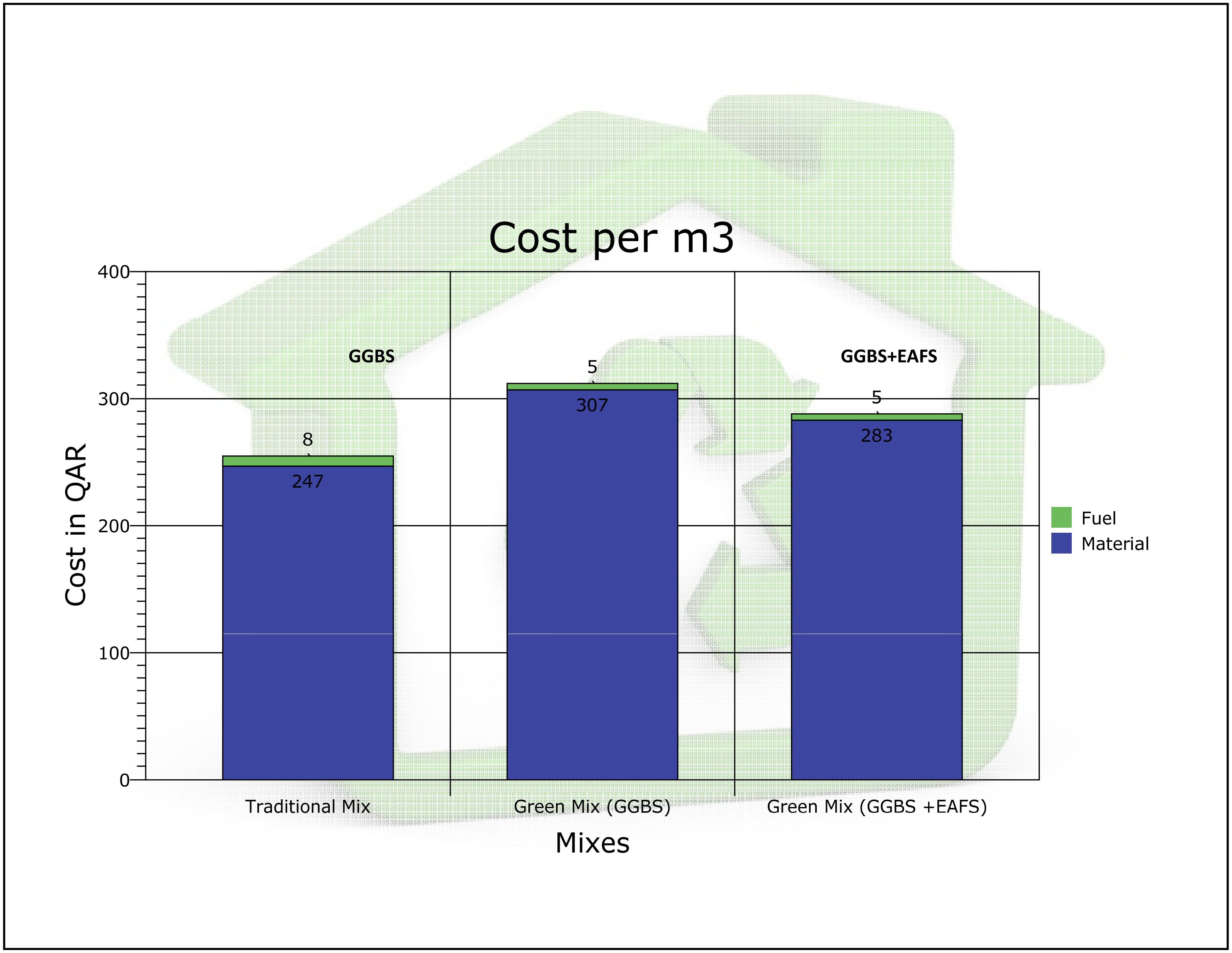


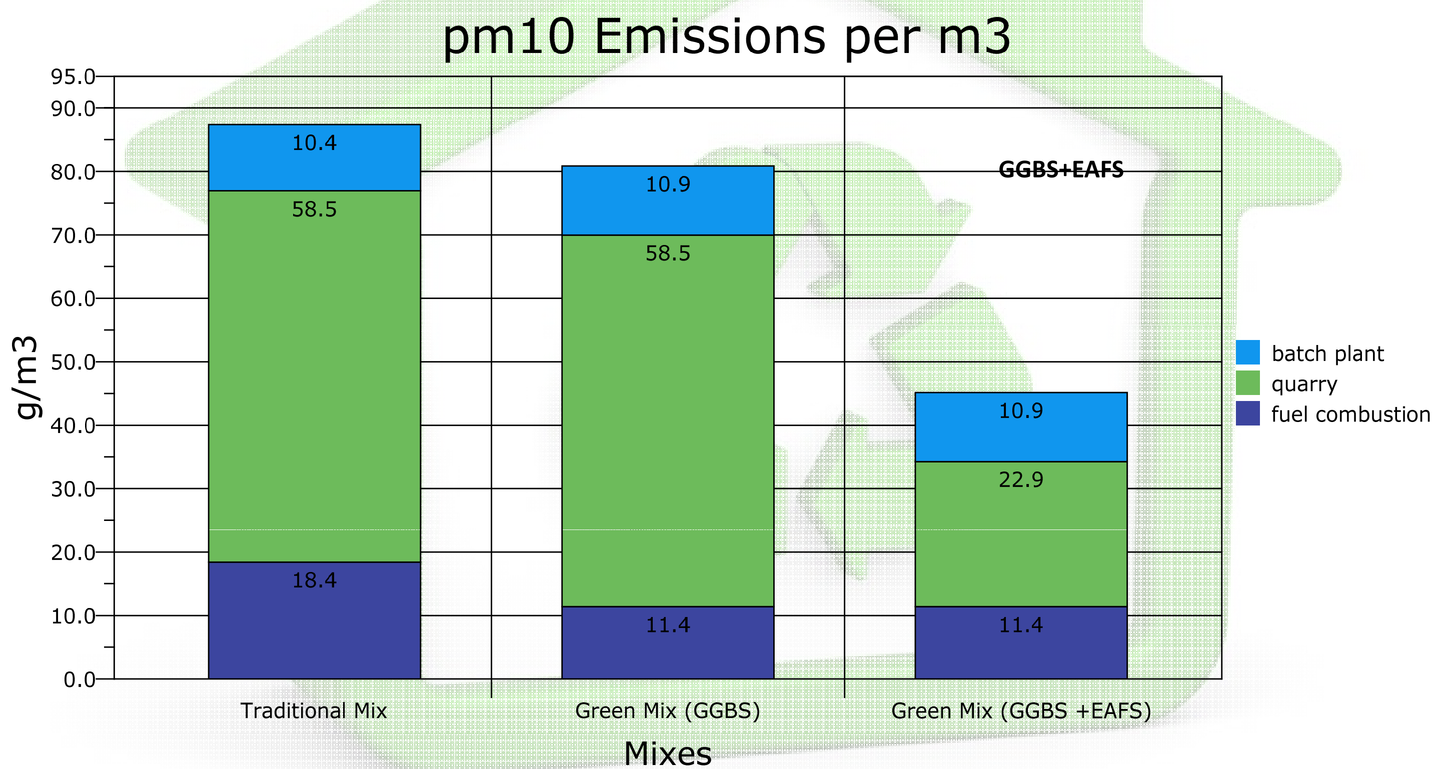
Power consumption compared with Ice production




Green Concrete Mix compared to common OPC Mix
20%
10%
0%
-10%
-20%
-30%
-40%
-50%
-60%
11%
GGBS
-7%
-48%
2%
GGBS+EAFS
-49%
-48%
CO2 Emissions total
PM10 Emissions total
Costs total


CO2 Emissions per m3
Kilograms
500.0
400.0
300.0
200.0
100.0
0.0
413.4
GGBS
GGBS+EAFS
210.5
207.6
12.8
9.7
4.6
12.8
4.6
6.0
6.6
6.5
Traditional Mix
Green Mix (GGBS)
Green Mix (GGBS +EAFS)
Mixes
sourcing
batching
delicery
demolition
recycling


Cost per m3
Cost in QAR
400
300
200
100
0
GGBS
GGBS+EAFS
8
247
5
307
5
283
Fuel
Material
Traditional Mix
Green Mix (GGBS)
Green Mix (GGBS +EAFS)
Mixes


pm10 Emissions per m3
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
g/m3
10.4
58.5
18.4
10.9
58.5
11.4
GGBS+EAFS
10.9
22.9
11.4
Traditional Mix
Green Mix (GGBS)
Green Mix (GGBS +EAFS)
Mixes
batch plant
quarry
fuel combustion

CASE STORY
Ras Laffan Port Expansion Project, Doha Qatar

- **Client:** Jan De Nul Dredging Ltd.
  Boskalis Westminster Middle East Ltd
- **Quantity:** 330.000m3
- **Duration:** 24 months
- **Maximum Capacity:** 150m3/h


GTO 1888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