european cement research academy

Status and prospects of Alternative Raw Materials in the European Cement Sector

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Objectives and contents

Objective of the study: to position the use of Alternative Raw Materials (ARM) in the clinker, cement and concrete production as a key element for the circular economy and the decarbonization of the built environment

Contents

- The current use of Alternative Raw Materials including decarbonated raw materials.
- The future potential use of Alternative Raw Materials
- The analysis of the waste management system and the country's recycling/recovery targets
- The contribution of the ARM use to the country's Circular Economy and recycling/recovery targets
- The contribution to the CO_2 emissions reduction of the cement sector
- Barriers and drivers at legal, social and technical level
- Study's coverage: 7 "key countries" (Austria, France, Germany, Italy, Poland, Spain, UK) and EU

Methodology (1)

- **Detailed statistical data with analysis on:**
  - Amount of consumed ARM in cement industry (last 3-5 years , if available) based on data from
    - Cembureau/PWC for ARM in clinker
    - National associations for ARM in cement
    - Different sources for ARM in concrete (e.g. ERMCO)
  - Current substitution rates (last 3-5 years with trend analysis)
  - Differentiation of ARM types and comparison within the 7 EU-countries
  - Interviews with respective national cement associations and members from cement companies
- **Analysis of other industries**
  - Steel industry / coal-fired power generation / waste & recycling industries for current and future availability of materials (“Fact sheets”)
  - Analysis of sector-specific roadmaps for future developments

Methodology (2)

- **Technical and environmental aspects**
  - Possible impacts on emissions (CO2, trace elements, organics)
  - Possible impacts on the products (trace elements)
  - Assessment of technical measures to allow higher ARM use (advanced emissions abatement, pre-treatment of wastes or by-products from other industry sectors)
- **Further analysis (EU level)**
  - Contribution to CO2 reduction
    - Based on lessons learnt from different “key countries”
    - What would be needed to achieve the 8%-target from Cembureau Roadmap?
  - Chances and limitations of future potential use of different ARM already used today
  - Chances and limitations of future potential use of “new” ARM

Methodology (3)

- **Definition of alternative raw materials (ARM)**
  - In this study, ARM are defined as materials that are wastes or by-products in other (mainly industrial) processes or societal sectors and which are not classified as alternative fuels
  - ARM are used in clinker, cement and/or concrete production
  - ARM can be delivered to the cement industry untreated or treated by a third party
  - Predominantly, the classification of the Cembureau data base has been adopted in this study including the terminology
  - Materials which have been reported to Cembureau, but derive from cement production itself, have been excluded (e.g. bypass dust, CKD, refractory etc.)
  - Materials which originate from natural sources, whether treated or untreated, have not been considered as ARM (e.g. natural pozzolana, calcined clays)

Seven Key Countries and EU

The ARM situation has been analysed for seven countries in Europe

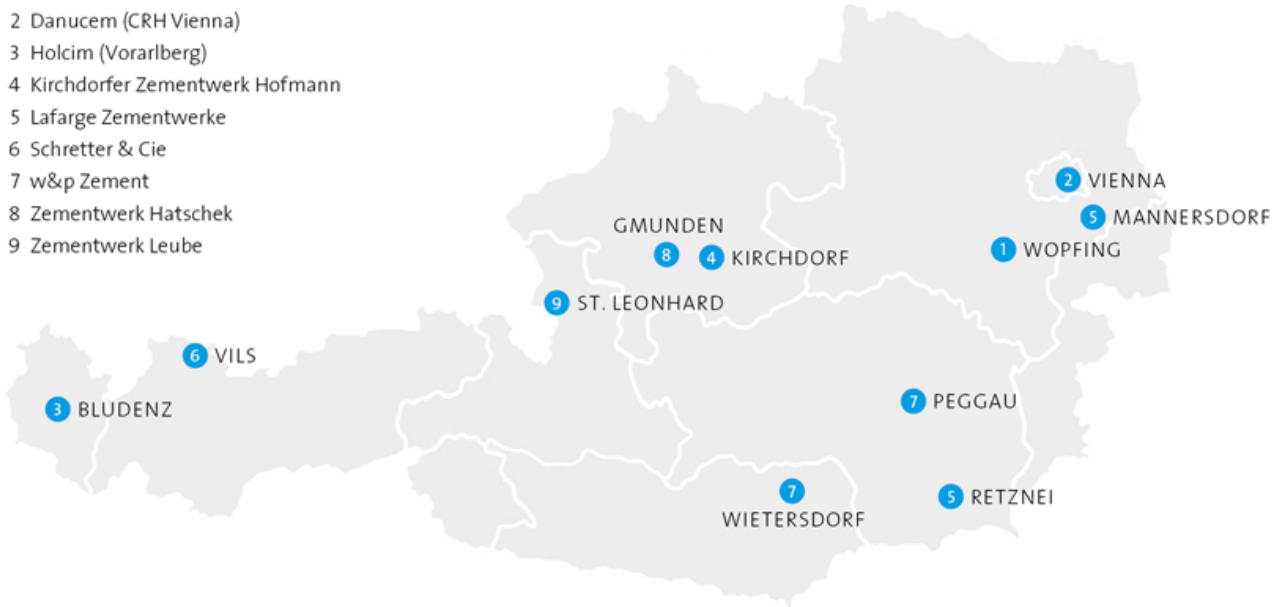
Scope:

- Substitution rates which will be achievable under certain conditions
- Description of the current use of ARM including decarbonized raw materials
- Description of the future potential use of ARM
- Analysis of the waste management system and the country's recycling / recovery targets
- Contribution of the potential ARM use to the country's circular economy recycling / recovery targets
- The contribution to the CO_2 emissions reduction of the cement sector
- The identification of barriers and drivers at legal, social and technical level

Austria

Locations of the Austrian cement industry

1 Baumit
2 Danucem (CRH Vienna)
3 Holcim (Vorarlberg)
4 Kirchdorfer Zementwerk Hofmann
5 Lafarge Zementwerke
6 Schretter & Cie
7 w&p Zement
8 Zementwerk Hatschek
9 Zementwerk Leube



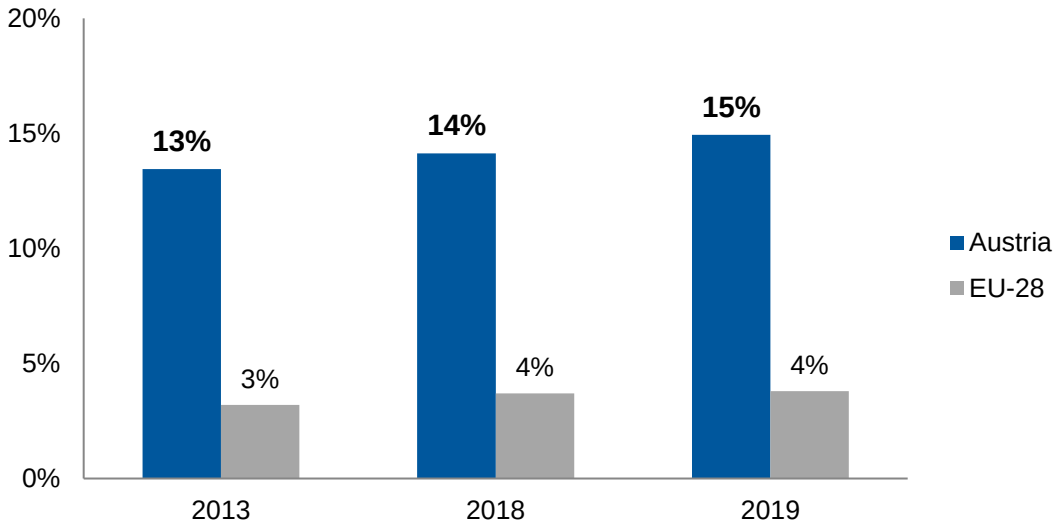
Source: VÖZ

Austria Summary

Cement industry with high degree of maturity of ARM application

Austria possesses a developed ARM market, with a level of ca.15% of ARM application in clinker production (2019), Austria has achieved the highest ARM substitution among all European nations.

ARM in clinker production: Austria vs. EU 28



Austria	Raw meal production	Clinker production	ARM application in clinker production	Ratio ARM / RM
2013	4,858,175 t	3,156,286 t	653,189 t	13.4%
2018	5,421,197 t	3,551,969 t	765,918 t	14.1%
2019	5,264,330 t	3,422,866 t	786,030 t	14.9%

The ARM market and barriers regarding ARM development in Austria		
Market organization	**Low**	ARM market in Austria is mature and well organized
Market situation	**Low**	A large variety of ARM , high flexibility for cement plants
Political environment	**Low**	No barriers identified
Societal perspective	**Medium**	Public acceptance and negative attitude of society to ARM
Cement industry	**Medium**	CAPEX and licence to operate for new ARM projects

- In 2019 1.9 mio.t of ARM have been used to produce 5.2 mio.t of cement (equivalent to 350 kg/ cement).
- This corresponds to ca. 790 kt of ARM for clinker production (15%), and ca. 1.1 mio.t as main constituents in cement (more than 21%), a stable improvement of substitution rate throughout 2013-2019 years.
- Austria has an excellent waste management system which assures the collection, sorting, and fractioning of waste.

Austria – ARM Statistics and Prospects (Clinker Production)

Current situation for clinker production

- Austrian cement sector applied 26 types of alternative raw materials
- Top 10 most used materials constitute more than 82% of all ARM used in Austrian cement industry
- Waste ceramics, bricks, waste construction products and spent bricks accumulate over 50% of total ARM. The trend over the last 7 years has been growing

Future prospects

- Waste ceramics and spent bricks utilization rate to grow further
- Fly ashes amounts will considerably shrink due to decreasing coal fired power generation
- Concrete crushed particles to partially substitute limestone
- Higher ARM flow will be sourced from abroad (import)

Most used ARM in clinker production 2019	t/a
Waste ceramics, bricks, tiles and construction products	184,070
Spent bricks	183,113
Fly ashes	77,49
Used foundry sand	44,649
Bottom ash*, slag and boiler dust	40,870
Ca sources, unless otherwise listed below	34,350
Lime waste	23,458
Wastes from the processing of slag	23,209
Mill scale	21,321
Secondary sand	15,949
Other materials	137,753

*The term “bottom ashes” refers mainly to ashes from coal fired power generation plants

Austria – CO_2 Avoidance with ARMs (Clinker Production)

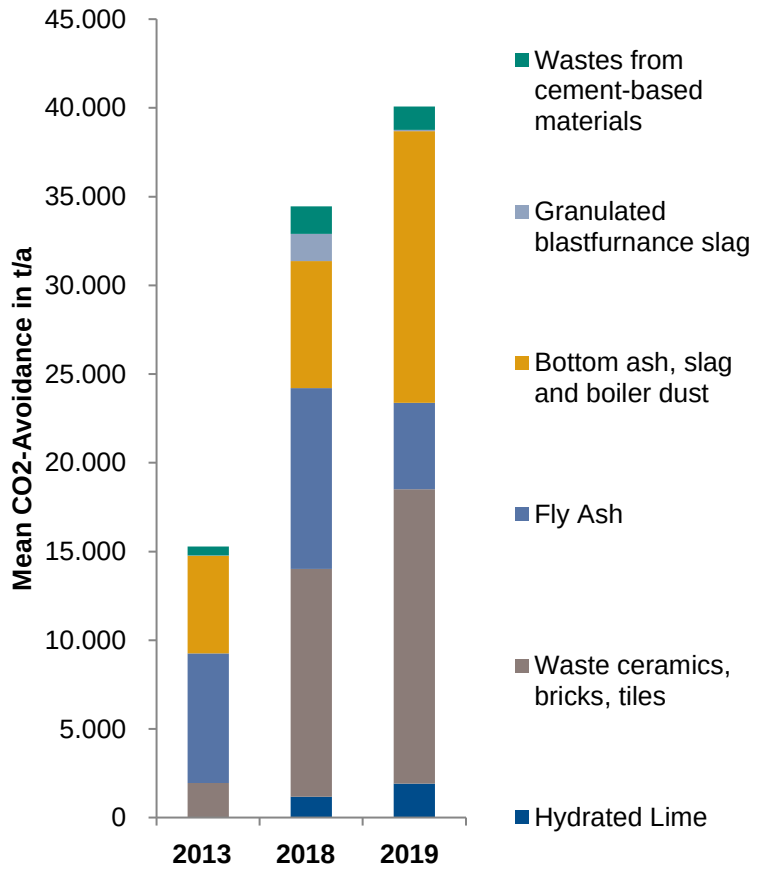


Figure: with ARM avoided CO_2 emissions in clinker production

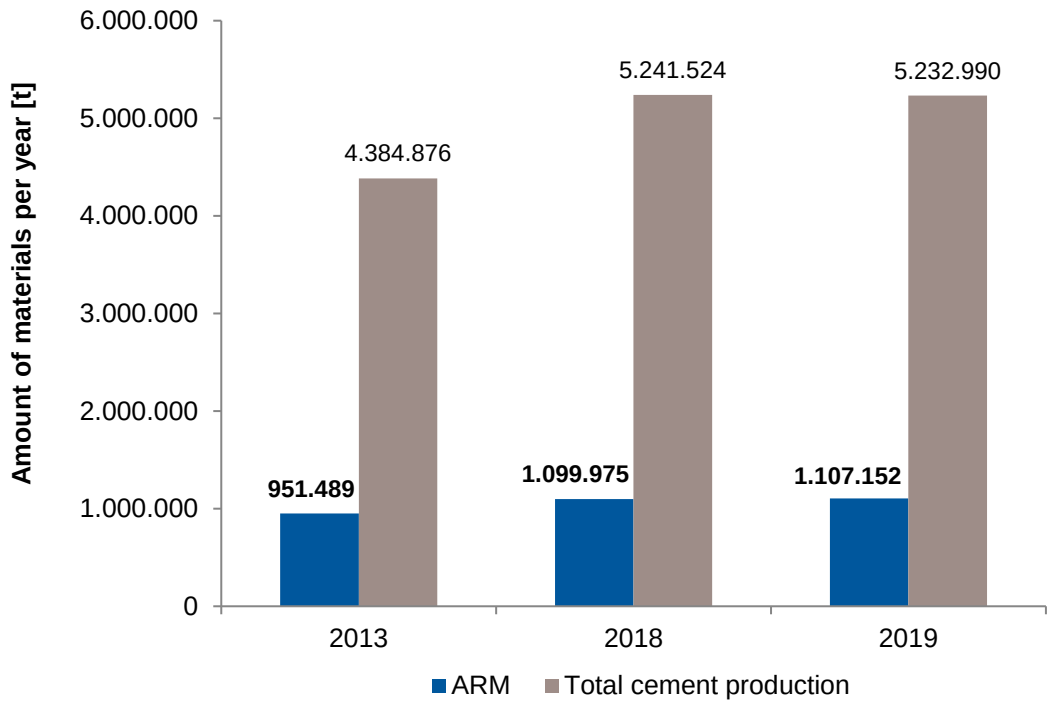
- CO_2 savings can be estimated based on the CaO content in the ARMs
- A min/max assessment yields CO_2 savings between 4.1 and 15.3 kg CO_2/t clinker

ARM	2018 t/a	min wt.-%	mean wt.-%	max wt.-%	min t CO_2/a	mean t CO_2/a	max t CO_2/a
Hydrated lime	3,185	40	47	54	999	1,174	1,349
Waste ceramics, bricks, tiles	142,350	7	12	16	7,815	12,839	17,864
Fly ash	85,181	1	8	15	1,275	10,196	19,118
Bottom ash, slag and boiler dust	43,537	5	15	25	2,389	7,166	11,943
Granulated blastfurnance slag	5,726	25	34	43	1,123	1,527	1,931
Wastes from cement-based materials	23,413	5	8.5	12	881	1,543	2,204
				Total	**14,482**	**34,445**	**54,408**

Table: ARM, its CaO content and calculated CO_2 savings in 2018 using ARM in clinker production

Austria – ARM Statistics and Prospects (Cement Production)

ARM in cement vs. total cement production



Cement	2013	2018	2019
ARM in cement	951,489 t	1,099,975 t	1,107,152 t
Total cement production	4,384,876 t	5,241,524 t	5,232,990 t
Substitution ratio	**21.7%**	**21.0%**	**21.2%**

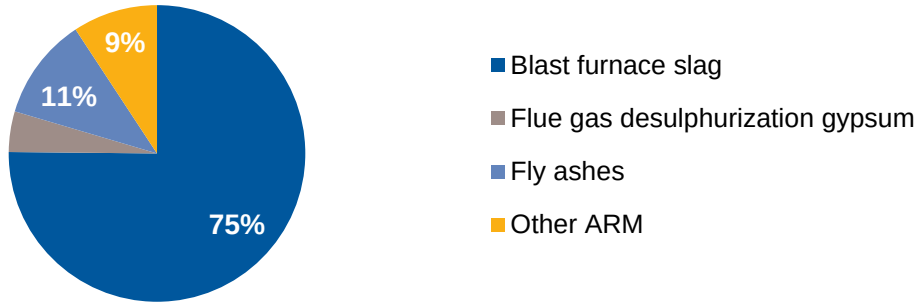
Current situation for cement production

- Four types of ARM for cement production: blast-furnace slag, fly ash, gypsum from flue-gas desulfurization, mineral ground additives (gypsum-containing residuals, recycled stone meal)
- Blast-furnace slag remains the dominating alternative constituent in the Austrian cement production with ca. 75%

Future prospects

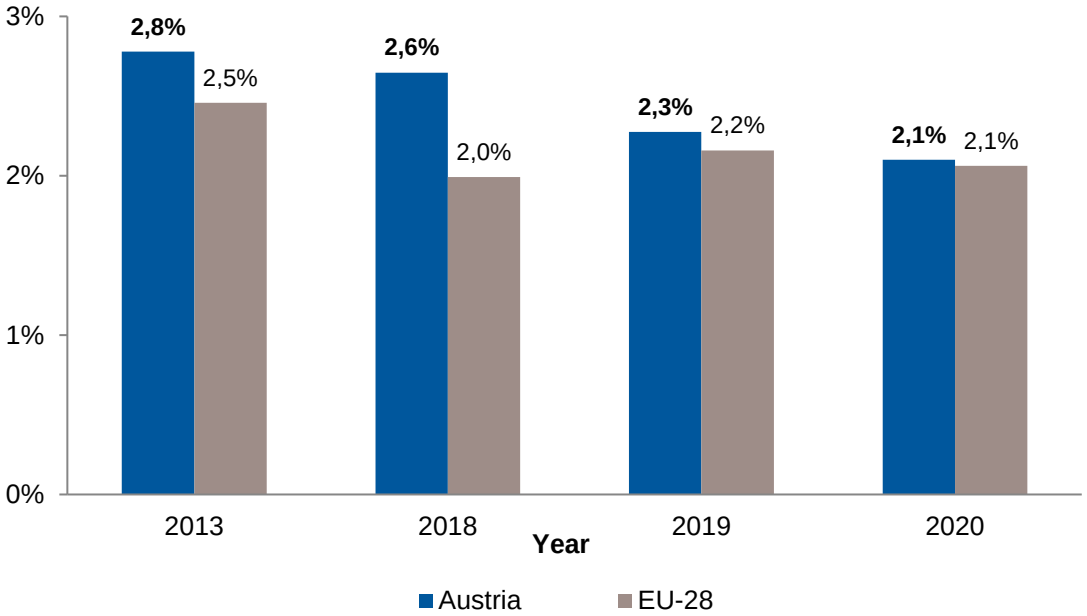
- Availability of fly ash and slag will decrease mid- to long-term
- Although displaying negative trend, mineral components have highest application potential in future, especially in regards to concrete fines

ARM in cement production 2019



Austria – ARM Statistics and Prospects (Concrete Production)

ARM in concrete production: Austria vs. EU-28



ARM in Concrete	2013	2018	2019	2020
Most used ARM	**FA/GGBS**	**Fly ash**	**Fly ash**	**Fly ash**
ARM in RMC concrete	0.7 mio.t	0.75 mio.t	0.65 mio.t	0.58 mio.t
ARM in total concrete*	1.0 mio.t	1.0 mio.t	0.9 mio.t	0.8 mio.t
Average ARM content	67 kg/m^3	64 kg/m^3	55 kg/m^3	50 kg/m^3
Recycled aggregates**	5 kg/m^3	5 kg/m^3	5 kg/m^3	5 kg/m^3
Substitution ratio* **	**2.8%**	**2.6%**	**2.3%**	**2.1%**

Cement & aggregates in concrete	2013	2018	2019	2020
Total concrete production	15.0 mio.m^3	16.0 mio.m^3	16.0 mio.m^3	15.5 mio.m^3
Ready-mix concrete	10.5 mio.m^3	11.8 mio.m^3	11.9 mio.m^3	11.5 mio.m^3
Site-mix + precast concrete	4.5 mio.m^3	4.2 mio.m^3	4.1 mio.m^3	4.0 mio.m^3
RMC/concrete ratio	70%	74%	74%	74%
Cement/concrete ratio***	11%	11%	11%	11%

Current situation for concrete production

- Austrian concrete industry has been demonstrating moderate average ARM content (50 kg/m^3) and substitution ratio (2.1%) among all the other key countries with ca. 0.8 mio.t ARM utilization in 2020
- Main ARM in the Austrian concrete production has been fly ash
- RMC/concrete ratio has remained stable since 2013 (at 70-74%)

Future prospects

- Austrian concrete industry is characterized by moderate amount of ARM utilization with a lowering trend over the recent years. It is forecasted that availability of fly ash and slag will decrease mid- to long-term. RC-aggregates will play an increasingly important role in the future

* Calculation based on figures of ARM in RMC and RMC/concrete Ratio
** Assumption, since no statistics have been made indicating the explicit value
*** Concrete density 2400 kg/m^3 used for the calculations. Only ARM considered (no RC-aggregates)

sources: ERMCO / VDZ calculations

Austria – Challenges and Opportunities

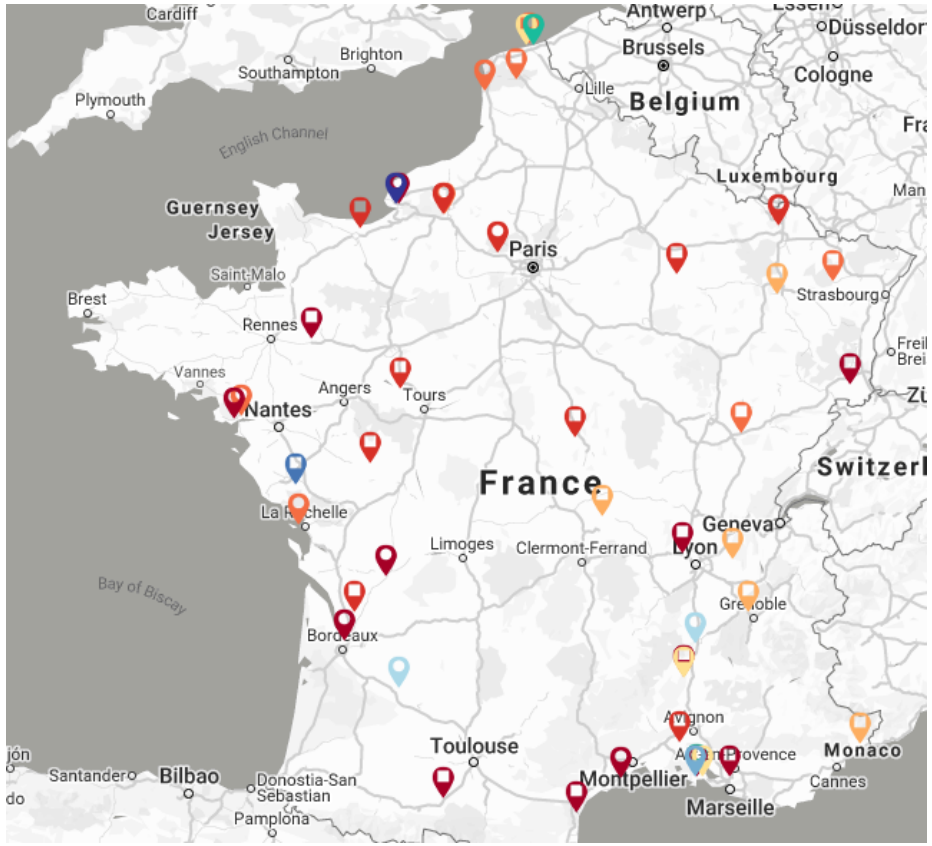
The use of ARM in Austria is well developed. Over the years, a very well working waste management system has been established which reliably guarantees the collection and sorting of waste and to provide suitable ARM for the cement industries.

In order to maintain the high level of ARM usage, the focus in the upcoming years will be on:

- Further increasing the ARM rate of currently 15% (presently considered by many cement producers as the highest possible)
- Improving societal attitude and public acceptance
- Investments for treating, sorting, and dosing ARM

Drivers and Opportunities	
Drivers	• Climate protection legislation • Transition of CO_2-intensive industries (power, steel) - decreasing availability of fly ash and slags - provides opportunities for new types of ARM • EU waste policy and circular economy • Reduction of landfill capacities • Protection of natural recourses and efficient land use
Action for stakeholders	• Research in new ARM (e.g. slag from steel production with direct reduction of iron (DRI) process) • Improve societal acceptance by specific actions to build stakeholders' trust and confidence (e.g. stakeholder involvement) • Marketing the material re-use; higher level of political acceptance and permitting • Development of new cement and clinker types
What are the opportunities?	• High use of ARM combined with high use of alternative fuels delivers valuable savings of natural resources • New cement types allow use of higher quantity of ARM • CO_2 price may compensate for higher cost for e.g. pre-treatment of materials and higher costs of calcined ARM • Austria has clear rules for the use of ARM (“Technical guidance”) • Recycling of construction, demolition and further mineral containing materials • tax on landfilling and request for demolition waste collectors are requested to contribute to cicular economy • Cement industry turns into an important player of circular economy by increasing the use of ARM

France



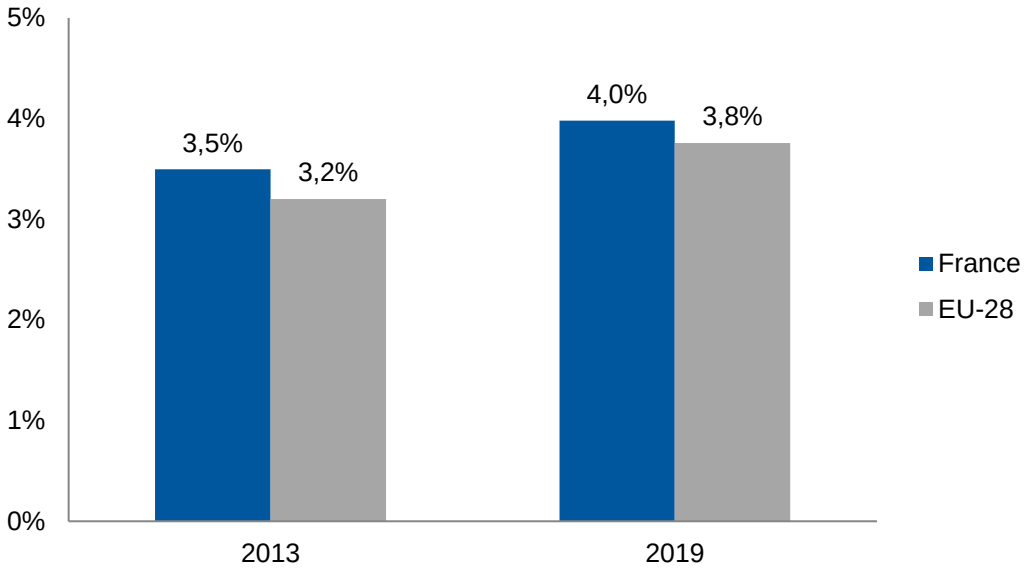
source: https://www.cemnet.com/global-cement-report/country/france

France – Summary

Cement industry with a large variety of ARM in clinker and cement production

France uses ARM in the majority of cement plants. It shows the highest variety of ARM in clinker production and cement within the EU.

ARM in clinker production: France vs. EU-28



Year	Raw meal production	Clinker production	ARM application in clinker production	Ratio ARM / RM
2013	22,044,840 t	13,778,000 t	770,459 t	3.5%
2019	20,808,000 t	13,005,000 t	827,971 t	4.0%

The ARM market and barriers regarding ARM development in France		
ARM Waste market organization	**Medium**	ARM market structures has to be further developed
ARM Waste market situation	**Medium**	Fast changing with limited material availability
Political environment	**Low**	No barriers identified
Societal perspective	**Low**	No barriers identified
Cement industry	**High**	Investments expected in most of the cement plants

- In 2019 0.87 mio.t of ARM have been used to produce 17.2 mio.t of cement (equivalent to 50 kg/ cement).
- This corresponds to ca. 830 kt of ARM for clinker production (4 %), and ca. 40 kt as main constituents in cement (0.2 %).
- ARM in France are playing an increasing role and the statistics reflect the rising trend in an alternative raw materials consumption.

France – ARM Statistics and Prospects (Clinker Production)

Current situation for clinker production

- French cement sector applied 27 types alternative raw materials
- Top 10 most used materials constitute more than 89% of all ARM used in the French cement industry
- Lime waste, soils, and used foundry sand, provide for more than half (59%) of the total ARM amount used for clinker production

Future prospects

- Lime wastes are predicted to develop in future
- Used foundry sand consumption is stable (at 10%) over the last years and is expected to maintain its share for the next years
- Utilization of secondary iron oxide was less used in the last years and is expected to decrease further
- More wastes will be introduced within the framework of circular economy. This includes waste from ceramics, bricks, construction materials, as well as wastes from cement-based composite materials

Most used ARM in clinker production 2019	t/a
Lime waste	306,151
Soils	100,344
Used foundry sand	87,002
Secondary iron oxide	63,451
Al-containing materials	56,499
Fe-containing materials	38,890
Bottom ash*, slag and boiler dust	30,147
Ca sources	20,260
Mill scale	18,116
Si-containing materials	17,018
Other materials	91,739

*The term “bottom ashes” refers mainly to ashes from coal fired power generation plants

France – CO_2 Avoidance with ARMs (Clinker Production)

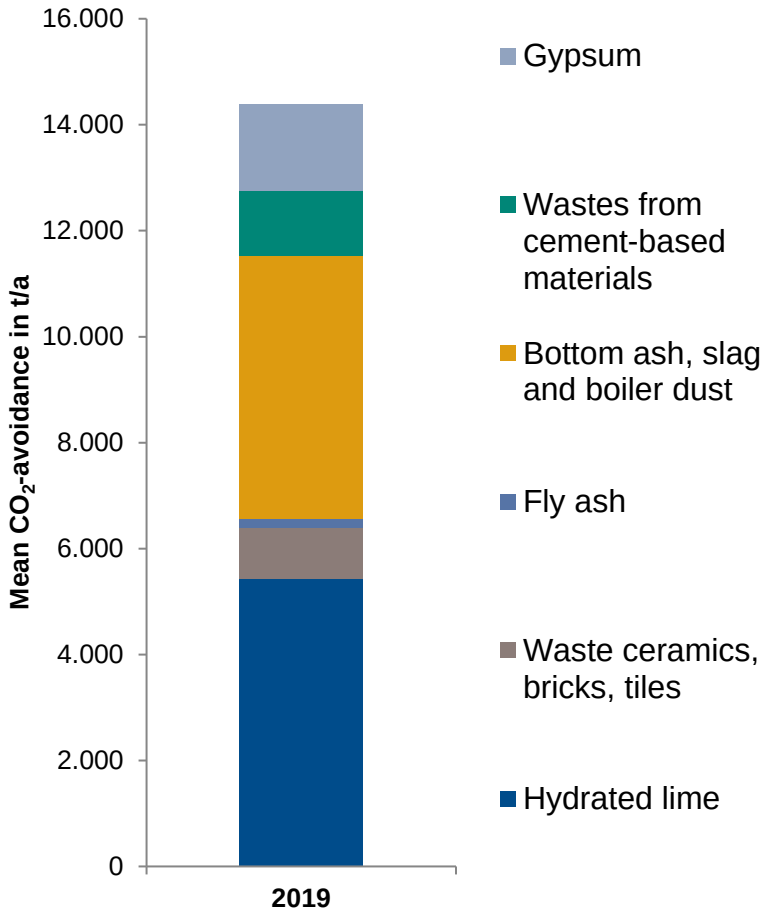


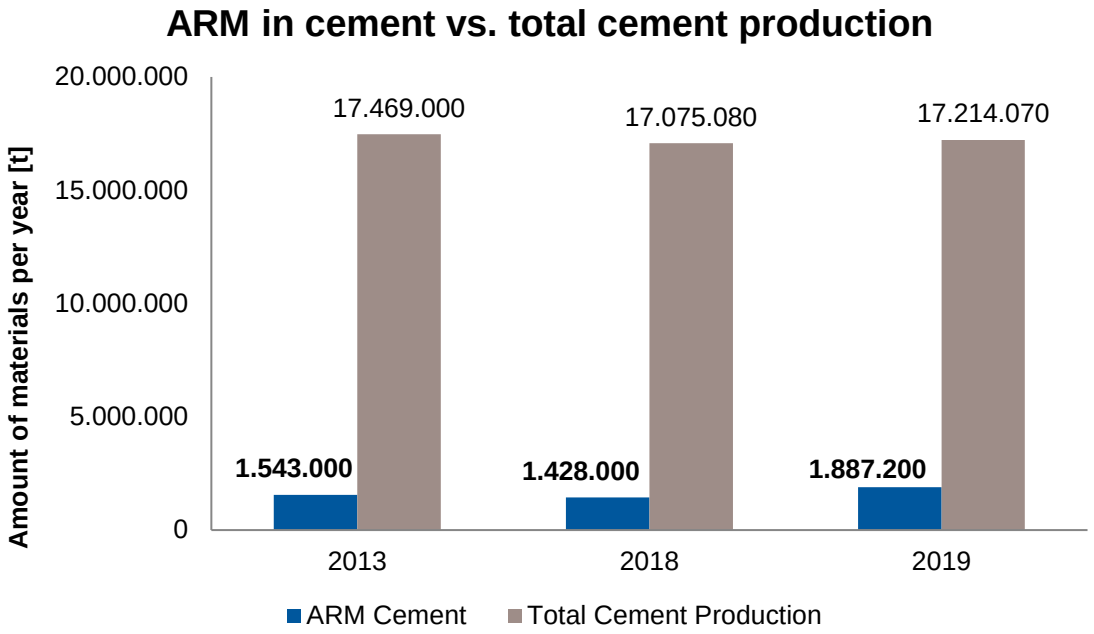
Figure: with ARM avoided CO_2 emissions in clinker production

- CO_2 savings can be estimated based on the CaO content in the ARMs
- A min/max assessment yields CO_2 savings between 0.7 and 1.5 kg CO_2/t of clinker

ARM	2019 t/a	min wt.-%	mean wt.-%	max wt.-%	min t CO_2/a	mean t CO_2/a	max t CO_2/a
Hydrated lime	10,530	40	47	54	4,622	5,430	6,239
Waste ceramics, bricks, tiles	10,630	7	11,5	16	584	959	1,334
Fly ash	2,675	1	8	15	21	168	315
Bottom ash, slag and boiler dust	30,147	5	15	25	1,654	4,962	8,270
Wastes from cement-based mat.	9,083	5	8.5	12	342	598	855
Gypsum	7,739	15	19	23	1,274	1,622	1,970
				Total	**8,507**	**13,754**	**19,001**

Table: ARM, its CaO content and calculated CO_2 savings in 2019 using ARM in clinker production

France – ARM Statistics and Prospects (Cement Production)



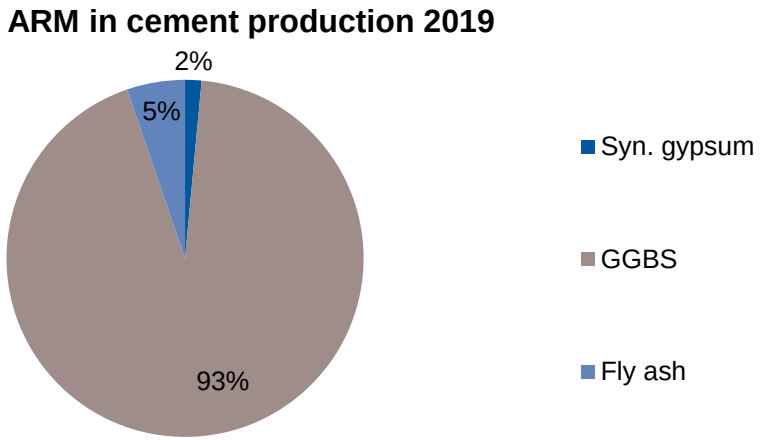
Cement	2013	2018	2019
ARM in cement*	1,543,000 t	1,428,000 t	1,887,200 t
Total cement production	17,469,000 t	17,214,070 t	17,214,070 t
Substitution ratio	**8.8 %**	**8.4 %**	**11.0 %**

Current situation for cement production

- Two alternative materials for cement production are granulated blast-furnace & converter slag, and gypsum from flue-gas desulfurization
- Granulated blastfurnace slag, according to the data provided, was the highest used ARM in cement production with the share of 93%

Future prospects

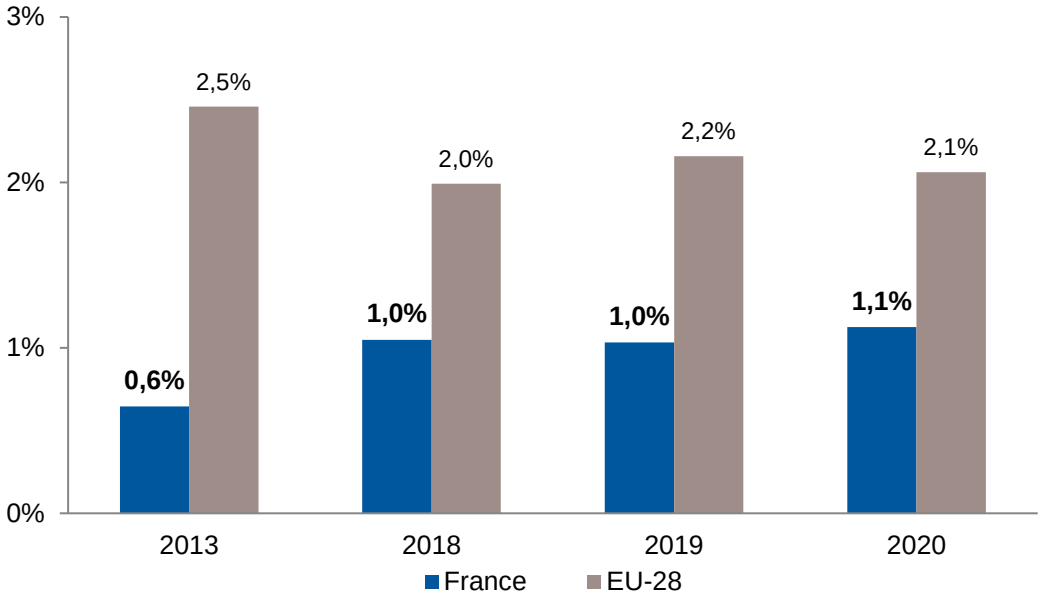
- No forecasts can be made with regard to ARM development in cement industry due to lack of data



*GNR data for GGBS and fly ash

France – ARM Statistics and Prospects (Concrete Production)

ARM in concrete production: France vs. EU-28



ARM in Concrete	2013	2018	2019	2020
Most used ARM	**Fly ash**	**Fly ash**	**Fly ash**	**Fly ash**
ARM in RMC concrete	0.6 mio.t	1.0 mio.t	1.0 mio.t	1.0 mio.t
ARM in total concrete*	0.8 mio.t	1.3 mio.t	1.3 mio.t	1.4 mio.t
Average ARM content	16 kg/m³	25 kg/m³	25 kg/m³	27 kg/m³
Recycled aggregates**	- kg/m³	- kg/m³	- kg/m³	- kg/m³
Substitution ratio* **	**0.6%**	**1.0%**	**1.0%**	**1.1%**

Cement & aggregates in concrete	2013	2018	2019	2020
Total concrete production	54.0 mio.m³	53.5 mio.m³	54.0 mio.m³	50.0 mio.m³
Ready-mix concrete	38.6 mio.m³	39.7 mio.m³	40.3 mio.m³	37.0 mio.m³
Site-mix + precast concrete	15.4 mio.m³	13.8 mio.m³	15.4 mio.m³	15.4 mio.m³
RMC/concrete ratio	71%	74%	75%	74%
Cement/concrete ratio***	12%	12%	12%	12%

Current situation for concrete production

- French concrete industry currently demonstrates low to moderate ARM content (27 kg/m³) and substitution ratio (1.1%),
- Main ARM in the concrete production has been fly ash
- RMC/concrete reflects a very stable ratio over the last 7 years without considerable fluctuations

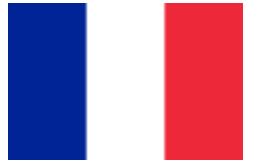
Future prospects

- French concrete industry is expected to increase its share on ARM in the concrete production, in particular by the use of recycled aggregates

* Calculation based on figures of ARM in RMC and RMC/concrete ratio
** Assumption, since no statistics have been made indicating the explicit value
*** Concrete density 2400 kg/m³ used for the calculations. No RC-aggregates considered.

sources: ERMCO / VDZ calculations

France – Barriers and Opportunities

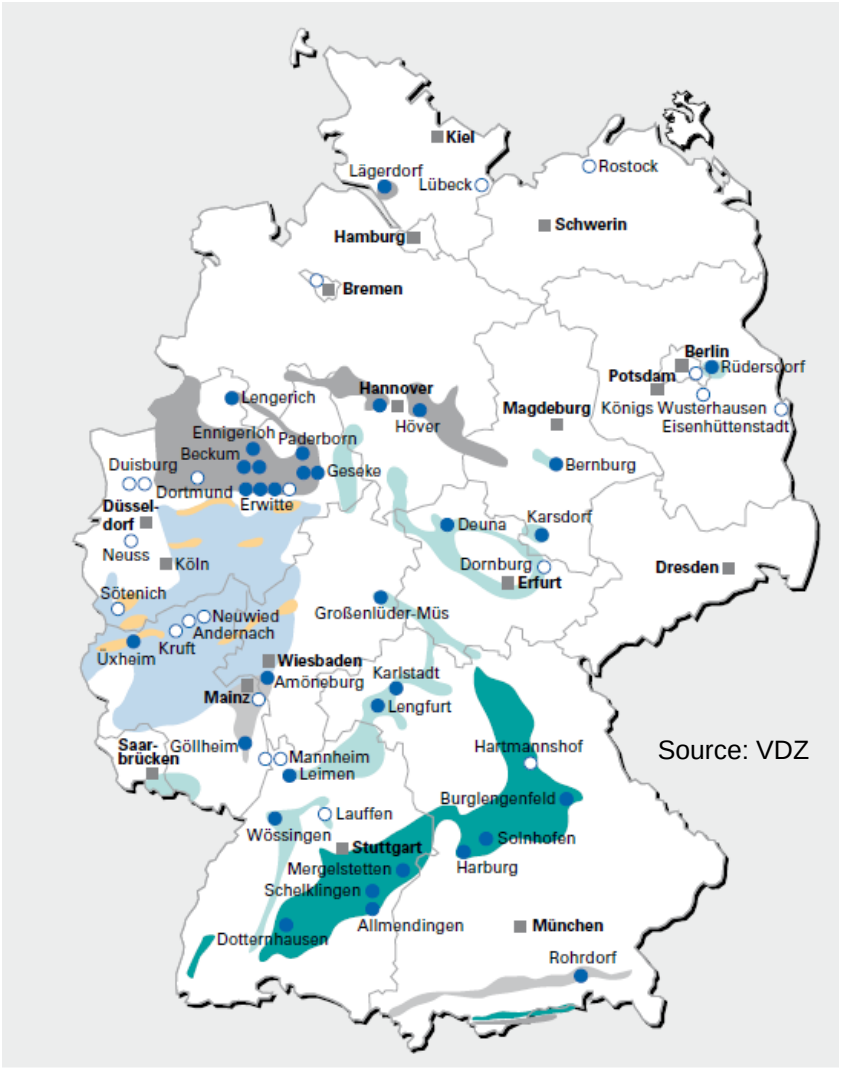


France targets to increase its ARM utilisation. There is a clear improvement trend on utilization of ARM in clinker and concrete production over the last 7 years. However, several difficulties still exist that prevent increase in ARM consumption:

- ARM availability is limited and ARM waste market needs to develop further
- High investments costs for improved ARM supply and use to increase substitution rates
- Cement producers open for long-term investment and for a cross-industry circular economy

Drivers and Opportunities	
Drivers	• Climate protection legislation • Transition of CO_2-intensive industries (power, steel) - decreasing availability of fly ash and slags - provides limited (as use is low in France) opportunities for new types of ARM • EU waste policy
Action for stakeholders	• Research in new ARM (incl. slag from DRI steel production) • Improve societal acceptance • Marketing the use of ARM in order to gain a high level of political acceptance and permitting
What are the opportunities?	• Good opportunities because of only moderate use of ARM today • New cement types allow use of higher quantity of ARM • CO_2 price may compensate for higher cost for e.g. pre-treatment of materials

Germany

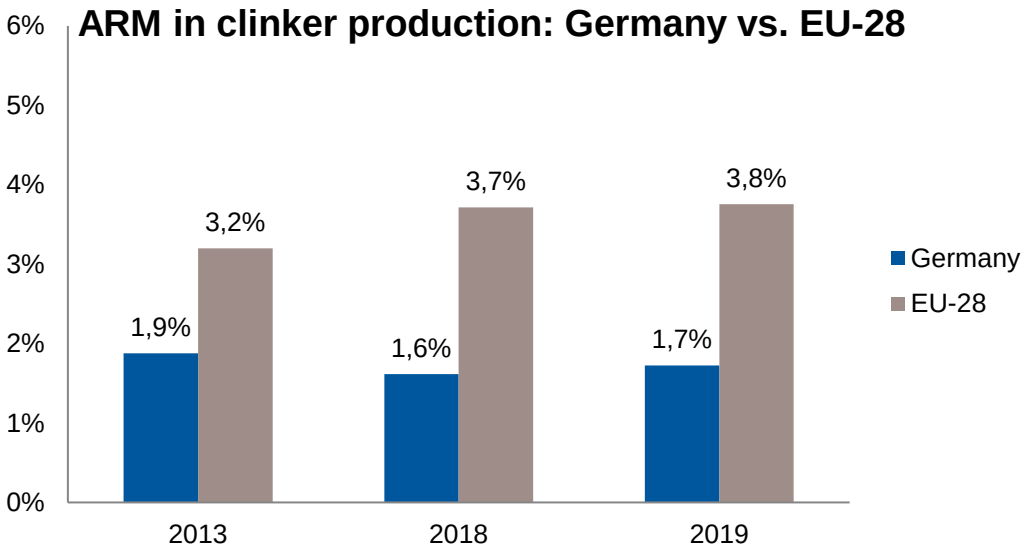


source: VDZ

Germany – Summary

ARM usage on moderate level – materials used for composite cements

The German cement shows a well established ARM utilisation. There is a continuous commitment to further improve the substitution rate of traditional raw materials. In comparison to other EU28 Countries the use of ARM in Germany is at a moderate level.



Year	Raw meal production	Clinker production	ARM application in clinker production	Ratio ARM / RM
2013	40,415,000 t	22,127,000 t	665,000 t	1.6%
2018	41,844,000 t	24,469,000 t	633,000 t	1.5%
2019	42,107,000 t	24,578,000 t	679,000 t	1.6%

The ARM market and barriers regarding ARM development in Germany		
ARM Waste market organization	**Low**	ARM market in Germany is mature and well organized
ARM Waste market situation	**Medium**	Increased recycling quotas to increase market size
Political environment	**Medium**	Strong political focus
Societal perspective	**Medium**	Regionally public focus on clinker production Environmental concerns
Cement industry	**Medium**	CAPEX and licence to operate for ARM projects

- In 2019 8.6 mio.t of ARM have been used to produce 34.2 mio.t of cement (equivalent to 250 kg/ cement).
- This corresponds to ca. 700 kt of ARM for clinker production (1.6%) and ca. 7.9 mio.t as main constituents in cement (more than 21 %).
- In the German cement industry the ARM rate in clinker production is lower than the European average; ARM-like materials are preferred to produce composite cements

Germany – ARM Statistics and Prospects (Clinker Production)

Current situation for clinker production

- The German cement sector applied 11 types alternative raw materials, with a stable substitution rate in the last 8 years
- Top 10 most used materials constitute more than 93% of all ARM used in the German cement industry
- Fly ashes, used foundry sand, and secondary iron oxide account for more than 70% of total ARM used for clinker production

Future prospects

- Fly ashes and used foundry sand volumes are expected to shrink in the next years
- Utilization of second iron oxide increased in the last years, yet expected to reduce in future
- More wastes will be introduced within the framework of circular economy, such as waste concrete, wastes from cement-based composite materials
- High ARM potential from imports, in particular ashes from the neighbouring countries (e.g. Poland)

Most used ARM in clinker production 2019	t/a
Fly ashes	197,898
Used foundry sand	167,547
Secondary iron oxide	100,300
Si-Al-Ca-Fe containing materials	57,452
Al-containing materials	49,975
Ca sources	43,841
Hydrated lime	24,001
Gypsum (residual)	10,351
Mill scale	8,724
Others materials	1,649

Germany – CO_2 Avoidance with ARMs (Clinker Production)

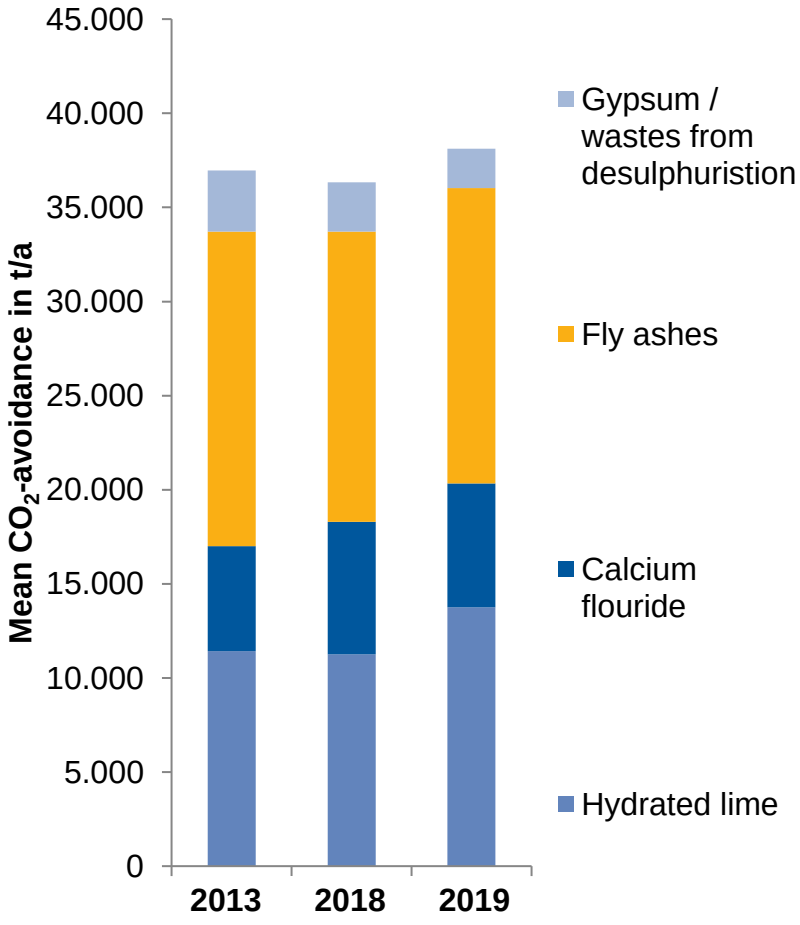


Figure: with ARM avoided CO_2 emissions in clinker production

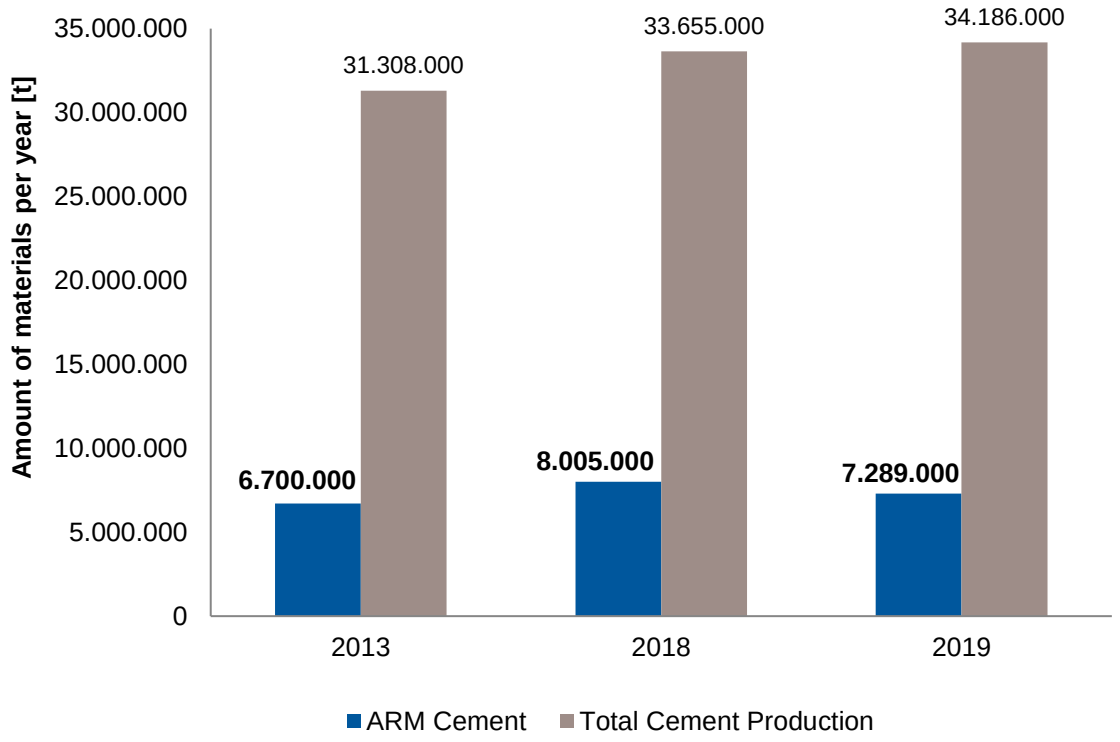
- CO_2 savings can be estimated based on the CaO content in the ARMs
- A min/max assessment yields CO_2 savings between 0.8 and 2.2 kg CO_2/t of clinker

ARM	2018 t/a	min wt.-%	mean wt.-%	max wt.-%	min t CO_2/a	mean t CO_2/a	max t CO_2/a
Fly ash	245,740	1	8	15	1,927	15,419	28,911
Hydrated lime	21,834	40	47	54	9,583	11,260	12,937
Calcium fluoride	15,773	30	40	51.3	5,192	7,034	8,875
Gypsum / FGD-gypsum	12,496	15	19	23.2	2,057	2,619	3,181
				Total	**18,759**	**36,332**	**53,904**

Table: ARM, its CaO content and calculated CO_2 savings in 2018 by using ARM in clinker production

Germany – ARM Statistics and Prospects (Cement Production)

ARM in cement vs. total cement production



Cement	2013	2018	2019
ARM in cement	6,700,000 t	8,005,000 t	7,289,000 t
Total cement production	31,308,000 t	33,655,000 t	34,186,000 t
Substitution ratio	**21.4%**	**23.8%**	**21.3%**

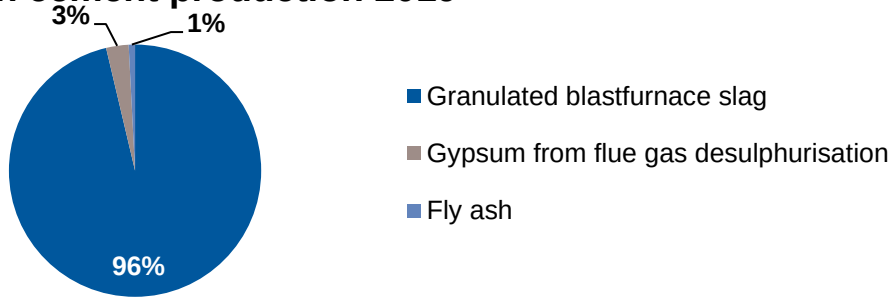
Current situation for cement production

- Only three types of ARM over the last 10 years have been applied in the cement production in Germany
- Is share has been, with some minor exceptions, stable since 2011

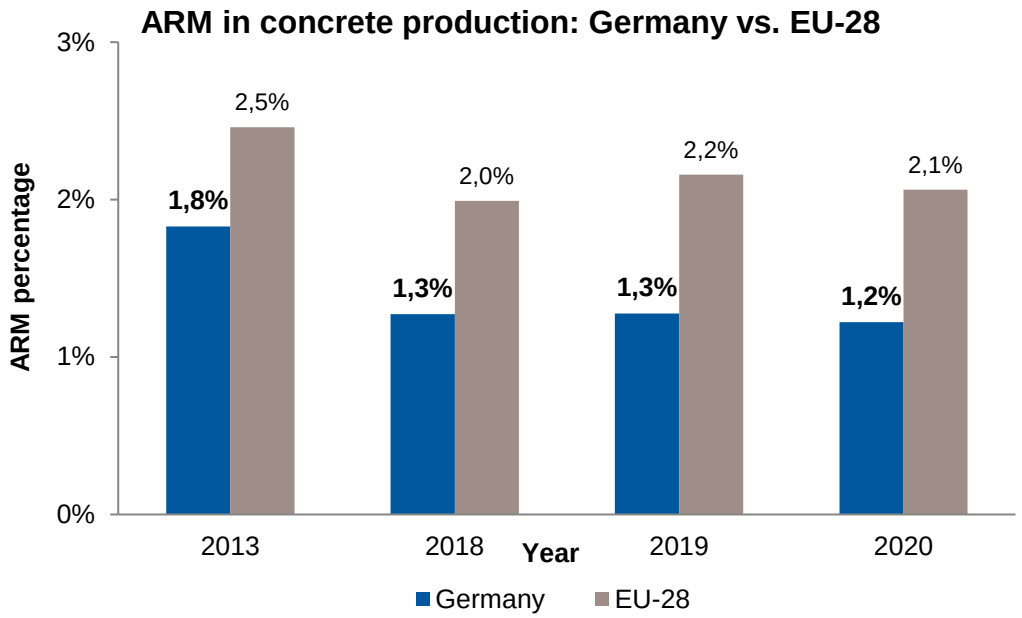
Future prospects

- Granulated blast-furnace slag expected to decrease in the next years
- Volumes from gypsum from flue gas desulphurization expected to shrink in the next years as well
- Coal phase-out planed for the next years (2030 completely expected), Fly ash to continue shrinking trend in the coming years
- Evaluation for other ARM (e.g. porcelain) ongoing

ARM in cement production 2019



Germany – ARM Statistics and Prospects (Concrete Production)



ARM in Concrete	2013	2018	2019	2020
Most used ARM	**Fly ash**	**Fly ash**	**Fly ash**	**Fly ash**
ARM in RMC concrete	2.0 mio.t	1.6 mio.t	1.6 mio.t	1.6 mio.t
ARM in total concrete*	2.9 mio.t	2.5 mio.t	2.6 mio.t	2.5 mio.t
Average ARM content	44 kg/m³	31 kg/m³	31 kg/m³	29 kg/m³
Recycled aggregates**	4.5 kg/m³	6.1 kg/m³	- kg/m³	- kg/m³
Substitution ratio* **	**1.8%**	**1.3%**	**1.3%**	**1.2%**

Cement & aggregates in concrete	2013	2018	2019	2020
Total concrete production	67.2 mio.m³	82.4 mio.m³	84.8 mio.m³	86.6 mio.m³
Ready-mix concrete	45.6 mio.m³	52.7 mio.m³	53.2 mio.m³	55.3 mio.m³
Site-mix + precast concrete	21.6 mio.m³	29.7 mio.m³	31.6 mio.m³	31.3 mio.m³
RMC/concrete ratio	68%	64%	63%	64%
Cement/concrete ratio***	12%	13%	13%	12%

Current situation for concrete production

- Main ARM in German concrete industry throughout the 2013-2020 period has been fly ash
- German ARM utilization rate was stable in recent years, while concrete volumes continued to growth

Future prospects

- Fly ash availability from coal fired power generation in Germany will decrease until 2030, latest 2038
- Fly ash reserves allow slight compensation in ARM utilization in concrete production, however for short period of time only
- Fly ash reserves can be extended in case with import from Eastern Europe

* Calculation based on figures of ARM in RMC and RMC/concrete ratio
** Assumption, since no statistics have been made indicating the explicit value
*** Concrete density 2400 kg/m³ used for the calculations. Only ARM considered (no RC-aggregates)

sources: ERMCO / VDZ calculations

Germany – Barriers and Opportunities

Main risks / challenges as well as drivers / opportunities regarding the use of ARM in German plants, taking into consideration the current situation in the waste market and socio-political perspective, have been identified as follows:

- Less availability of suitable materials due to increased recycling quotas
- Changing public acceptance
- Higher environmental constraints
- High expected investments

Drivers and Opportunities	
Drivers	• Climate protection legislation • Transition of CO_2-intensive industries (power, steel) - decreasing availability of fly ash and slags - provides opportunities for new types of ARM • EU waste policy and circular economy • Reduction of landfill capacities • Protection of natural resources and efficient land use
Action for stakeholders	• Research in new ARM (e.g. slag from DRI steel production) • Improve societal acceptance by stakeholder involvement • Marketing the use of ARM in order to gain higher level of political acceptance and permitting • Development and political promotion of new cement and clinker types • Digital recording of available and used ARM
What are the opportunities?	• New cement types allow use of higher quantity of ARM • CO_2 price may compensate for higher cost for e.g. pre-treatment of materials and higher costs of calcined ARM • Recycling of construction, demolition and further mineral containing materials • Cement industry turns into an important player of circular economy by increasing the use of ARM

Poland

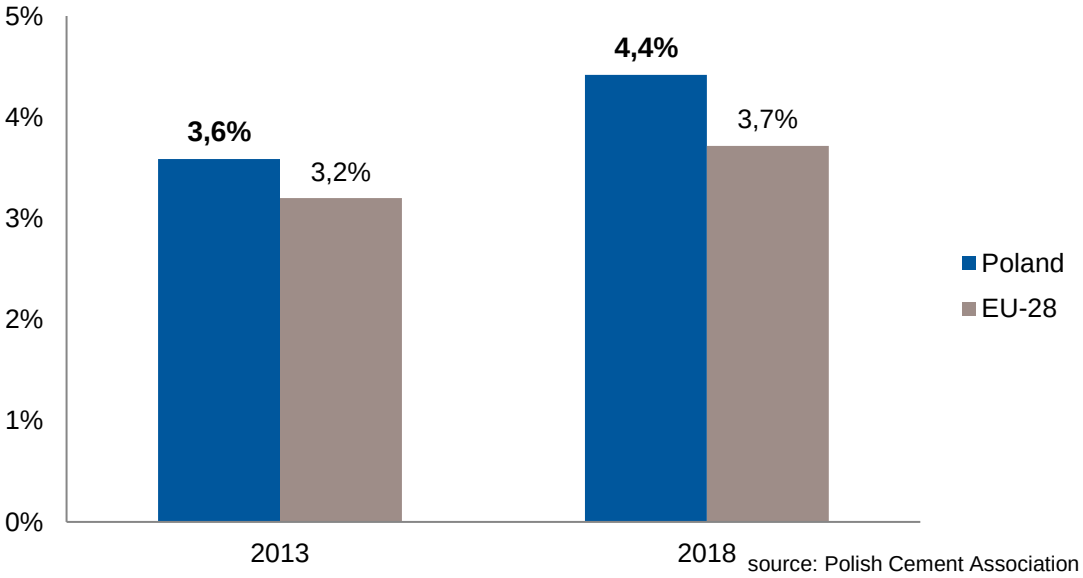
source: Polish Cement Association

Poland Summary

Cement industry with a high potential of ARM application in clinker, cement, concrete production

Poland has a strong focus on ARM utilisation with a substitution rate in cement production with above 20%. In clinker production, however, Poland shows a slightly higher utilisation rate than the average EU-28.

ARM in clinker production: Poland vs. EU-28



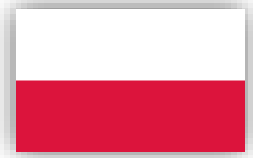
source: Polish Cement Association

Poland	Raw meal production	Clinker production	ARM application in clinker production	Ratio ARM / clinker
2013	17,279,398 t	10,799,624 t	578,410 t	3.3%
2018	22,627,859 t	14,142,412 t	967,622 t	4.3%

The ARM market and barriers regarding ARM development in Poland		
Market organization	**Medium**	ARM market structures will further develop
Market situation	**Low**	Good and stable market size
Political environment	**Medium**	No barriers
Societal perspective	**Low**	Good public acceptance
Cement industry	**Medium**	Good cooperation with suppliers of ARM Less politically, more economically oriented Substitution rate is improving year by year

- In 2018 4.7 mio.t of ARM have been used to produce 18.8 mio.t of cement (equivalent to 250 kg/ cement).
- This corresponds to ca. 970 kt of ARM for clinker production (4.3%), and ca. 3.7 mio.t as main constituents in cement (20%),
- ARM use in the Polish cement sector is very well established with promising developments in the future.

Poland – ARM Statistics and Prospects (Clinker Production)



Current situation for clinker production

- The Polish cement sector applied 13 type alternative raw materials
- Top 10 most used materials constitute more than 99% of all ARM used in Polish cement industry
- Fly ash and converter slag make up for over 67% of total ARM with a growing trend in the last 5 years

Future prospects

- Iron bearing dust and sludge consumption are expected to increase
- Availability of fly ashes from coal fired power generation is stable but it is expected to decrease in the future
- Landfilled fly ashes can play a future role as ARM
- Waste construction materials will have potential in the next years

Most used ARM in clinker production 2019	t/a
Fly ashes	197,898
Used foundry sand	167,547
Secondary iron oxide	100,300
Si-Al-Ca-Fe containing materials	57,452
Al-containing materials	49,975
Ca sources	43,841
Hydrated lime	24,001
Gypsum (residual)	10,351
Mill scale	8,724
Others (Soils)	1,649

source: Polskicement

Poland – CO_2 Avoidance with ARMs in (Clinker Production)

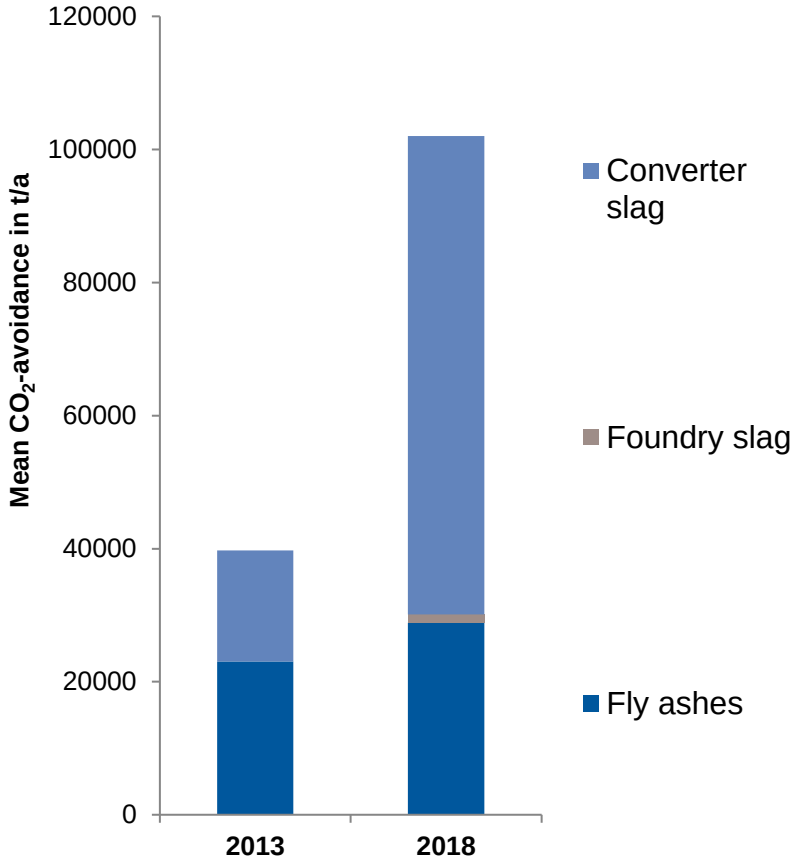


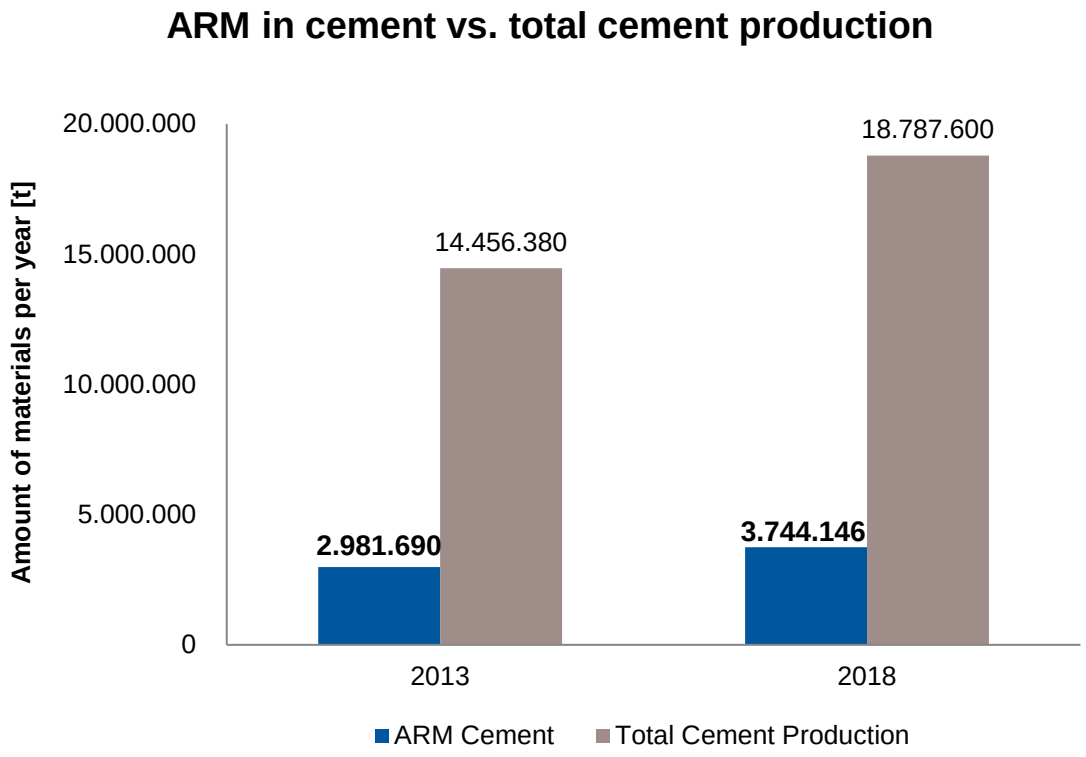
Figure: with ARM avoided CO_2 emissions in clinker production

- CO_2 savings can be estimated based on the CaO content in the ARMs
- A min/max assessment yields CO_2 savings between 4.9 and 9.5 kg CO_2/t clinker

ARM in Clinker	2018 t_ARM/a	min wt.-%	mean wt.-%	max wt.-%	min t CO_2/a	mean t CO_2/a	max t CO_2/a
Fly ashes	459,859	1	8	15	3,607	28,854	54,101
Foundry slag	4,032	30	40	50	949	1,265	1,581
Converter slag	185,157	45	49.5	54	65,350	71,884	78,419
				Total	**69,905**	**102,003**	**134,102**

Table: ARM, its CaO content and calculated CO_2 savings in 2018 by using ARM in clinker production

Poland – ARM Statistics and Prospects (Cement Production)



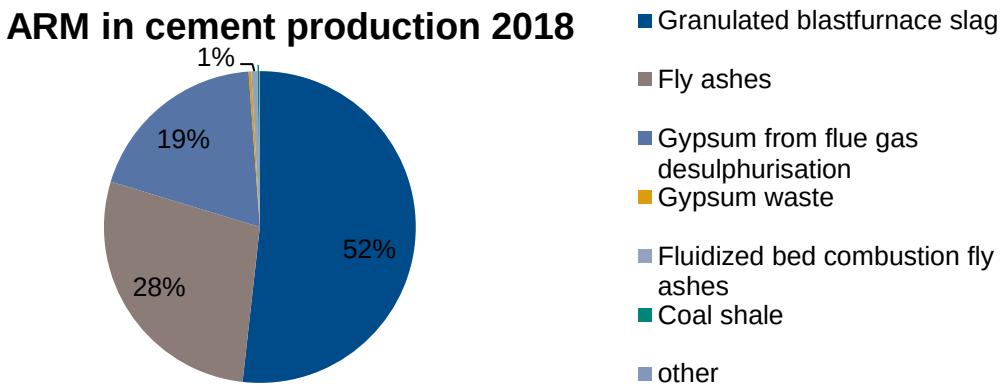
Current situation for cement production

- Poland utilizes GGBS (ca. 2 mio.t), fly ash (ca. 1 mio.t), which is among the highest in the EU-28. The rate is expected to grow in the near future.

Future prospects

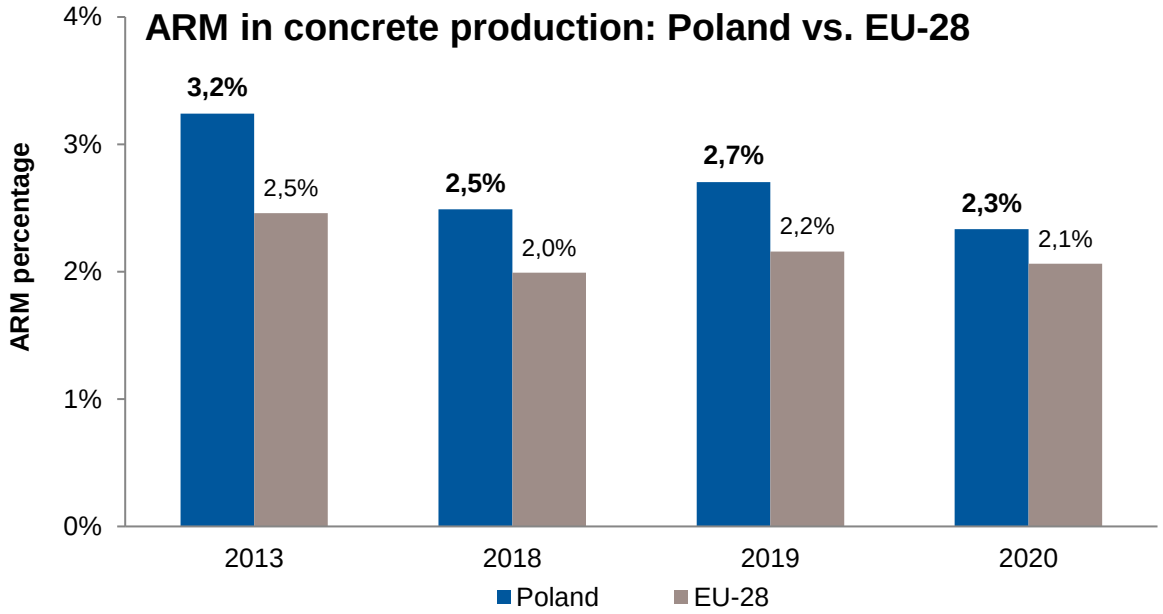
- Due to large fly ash landfills in Poland, the use of fly ash is expected to increase in the coming years - although the availability of fly ash in the EU will decrease due to coal phase out
- Export of GGBS and fly ash to other EU countries can be expected

Cement	2013	2018
ARM in cement	2,981,690 t	3,744,146 t
Total cement production	14,456,380 t	18,787,600 t
Substitution ratio	**20.6%**	**19.9%**



source: Polish Cement Association

Poland – ARM Statistics and Prospects (Concrete Production)



ARM in concrete	2013	2018	2019	2020
Most used ARM	**Fly ash**	**Fly ash**	**Fly ash**	**Fly ash**
ARM in RMC concrete	1.4 mio.t	1.5 mio.t	1.7 mio.t	1.4 mio.t
ARM in total concrete*	2.5 mio.t	3.4 mio.t	3.8 mio.t	3.3 mio.t
Average ARM content**	78 kg/m^3	60 kg/m^3	65 kg/m^3	56 kg/m^3
Recycled aggregates	- kg/m^3	- kg/m^3	- kg/m^3	- kg/m^3
Substitution ratio* **	**3.2%**	**2.5%**	**2.7%**	**2.3%**

Cement & aggregates in concrete	2013	2018	2019	2020
Total concrete production	32.1 mio.m^3	57.4 mio.m^3	58.2 mio.m^3	58.4 mio.m^3
Ready-mix concrete	18.0 mio.m^3	25.1 mio.m^3	26.2 mio.m^3	25.7 mio.m^3
Site-mix + precast concrete	14.1 mio.m^3	32.3 mio.m^3	32.0 mio.m^3	32.7 mio.m^3
RMC/concrete ratio	56%	44%	45%	44%
Cement/concrete ratio***	12%	12%	12%	12%

ARM current statistics for concrete production

- Polish concrete industry currently reflects a stable performance (56 kg/m3), yet with slight decreases in the ARM utilization over the past 3 years remaining at substitution ratio of 2.3%
- Main ARM in the concrete production is fly ash
- Poland displays a high RMC, site-mix, and precast concrete production in comparison with the other key countries, with a tendency to slightly increase.
- The 2013-2018 period is characterized by a significant rise in the total concrete production by over 80%
- RMC/concrete is less than 50%

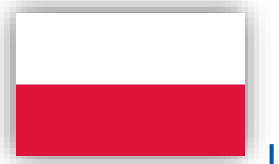
ARM future prospects

- Polish concrete industry is expected to increase its share on ARM in the concrete production, especially concerning the involvement of fly ash, as well as to considerably increase the utilization of more recycled aggregates

* Calculation based on figures of ARM in RMC and RMC/concrete ratio
** Assumption, since no statistics have been made indicating the explicit value
*** Concrete density 2400 kg/m^3 used for the calculations. Only ARM considered (no RC-aggregates)

sources: ERMCO / VDZ calculations

Poland – Barriers and Opportunities



The use of ARM in Poland is above average compared to most of European countries, but the main barriers to its use remain:

- Existing stable and consistent delivery of ARM limits innovation potential regarding other ARM
- Challenging political environment; supporting the use of ARM will even be more necessary in the future
- High cement/clinker factor because of market traditions and expectations

Drivers and Opportunities	
Drivers	• Climate protection legislation • Transition of CO_2-intensive industries (power, steel) - decreasing availability of fly ash and slags - provides opportunities for new types of ARM • EU waste policy
Action for stakeholders	• Research in new ARM (incl. slag from DRI steel production) • Improve societal acceptance • Marketing of ARM in order gain higher level political and social acceptance
What are the opportunities?	• High opportunities because of only moderate use of ARM • Good availability of ARM with good future prospects (e.g. though landfilled fly ashes) • New cement types allow use of higher quantity of ARM • CO_2 price may compensate for higher cost for e.g. pre-treatment of materials

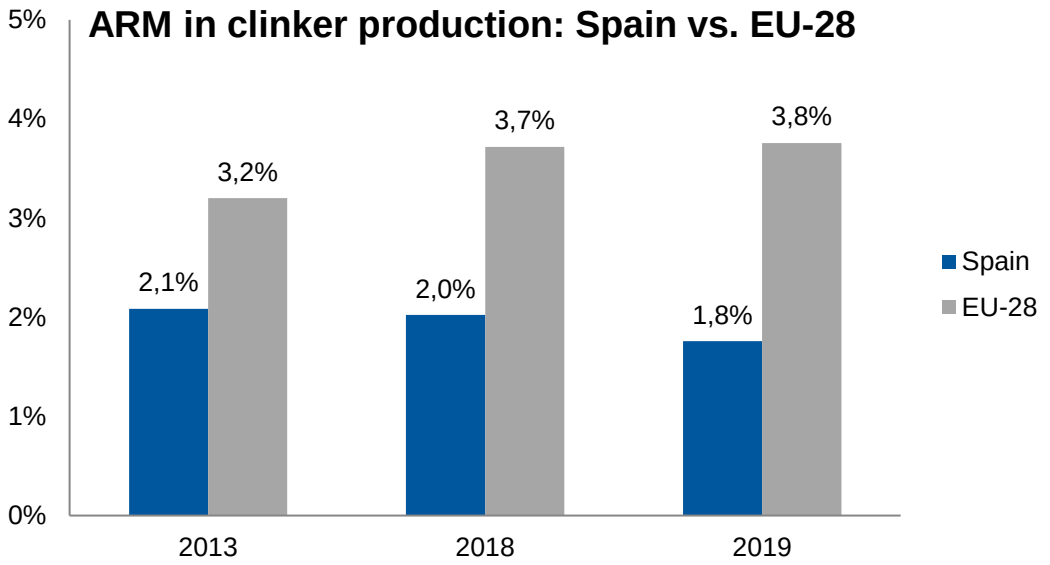
Spain

source: Oficemen, Departmento Industrial

Spain Summary

Cement industry with stable low to medium ARM application

In the Spanish cement sector the ARM utilization rate is 1.8% to 2.1% in clinker production and 3.7% to 7.3% in cement production, which is lower than the average in the European Union.



Year	Raw meal production	Clinker production	ARM application in clinker production	Ratio ARM / RM
2013	22,416,195 t	14,604,057 t	467,046 t	2.1%
2018	29,972,408 t	18,564,254 t	606,121 t	2.0%
2019	28,513,196 t	17,525,326 t	501,741 t	1.8%

The ARM market and barriers regarding ARM development in Spain		
Market organization	**Medium**	ARM market structures has to be further developed
Market situation	**Medium**	A large variety of ARM, good basis for use in cement plants
Political environment	**Medium**	AF viewed critically, which is affecting perception of ARM
Societal perspective	**High**	Low public acceptance of co-incineration, better for ARM Strong public focus on permits
Cement industry	**Medium**	Investments expected in most of the cement plants

- ARM application has been regarded as moderate, especially concerning clinker production. A small variety of ARM determines an overall low consumption in both, clinker and cement
- In 2019, the Spanish cement industry applied ca. 500 kt of ARM in clinker production and more than 650 kt of ARM in cement production
- Almost 1.15 mio.t of ARM have been used to produce 11.1 mio.t of cement. This is equivalent to the use of 100 kg of ARM per t cement.

Spain – ARM Statistics and Prospects (Clinker Production)

Current situation for clinker production

- Spanish cement sector applied 11 types of alternative raw materials. ARM volumes used in 2013 (467 kt) rose up insignificantly reaching 500 kt in 2019
- Top 10 most used materials constitute more than 99% of all ARM
- Current substitution rate of raw materials used for clinker production 2.5% (2019), with decreasing trend over the past 6 years
- Slags (steelmaking white/black slags, other slags), wastes from stone cutting and sawing, and mill scale cover over 54%

Future prospects

- Utilization of slags will further decrease, mill scale consumption continuously increasing since 2013, wastes from cutting and sawing last 4 years at 70 kt and above
- Construction and demolition waste expected to increase in the near future due to the recent regulation – taxation of this type of waste for landfilling. It will be mandatory to segregate the C&DW on construction sites in future due to the anticipated law, which is expected to be approved 2021-2022
- High ARM potential from imports, in particular ashes and used foundry sand

Most used ARM in clinker production 2019	t/a
Bottom ash*, slag and boiler dust	163,686
Fe-containing materials,	104,712
Si-Al-Ca-Fe containing materials	77,324
Wastes from stone cutting and sawing	70,101
Mill scale	45,843
Fly ashes	45,286
Used foundry sand	43,414
Pyrite ash	23,605
Waste ceramics, bricks, tiles and construction products	2,400
Other materials	38,455

*The term “bottom ashes” refers mainly to ashes from coal fired power generation plants

Spain – CO_2 Avoidance with ARMs (Clinker Production)

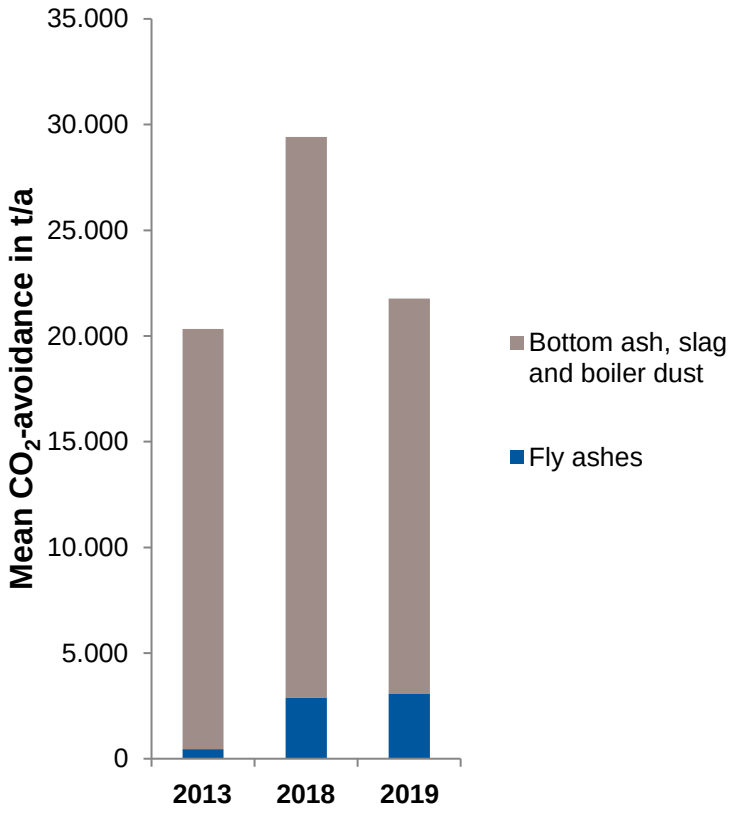


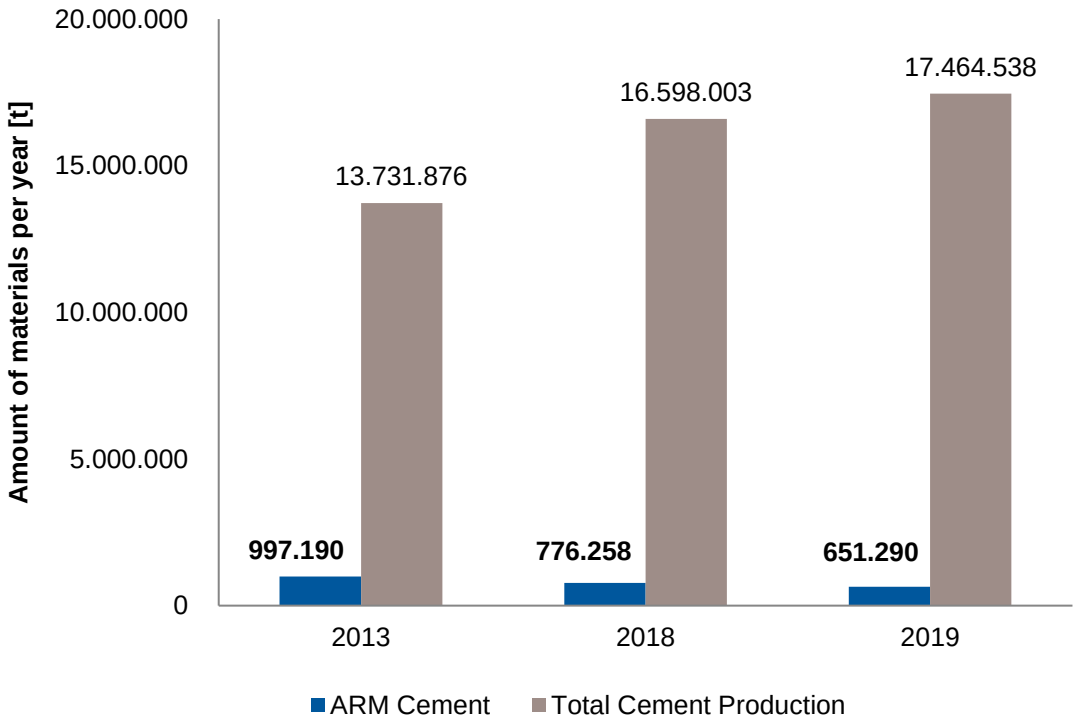
Figure: with ARM avoided CO_2 emissions in clinker production

- CO_2 savings can be estimated based on the CaO content in the ARMs
- A min/max assessment yields CO_2 savings between 0.5 and 2.7 kg CO_2/t clinker

ARM in Clinker	2018 t_ARM/a	min wt.-%	mean wt.-%	max wt.-%	min t CO_2/a	mean t CO_2/a	max t CO_2/a
Fly ashes	46,011	1	8	15	361	2,887	5,413
Bottom ash, etc	161,164	5	15	25	8,842	26,526	44,210
				Total	**9,203**	**29,413**	**49,623**

Table: ARM, its CaO content and calculated CO_2 savings in 2018 by using ARM in clinker production

Spain – ARM Statistics and Prospects (Cement Production)



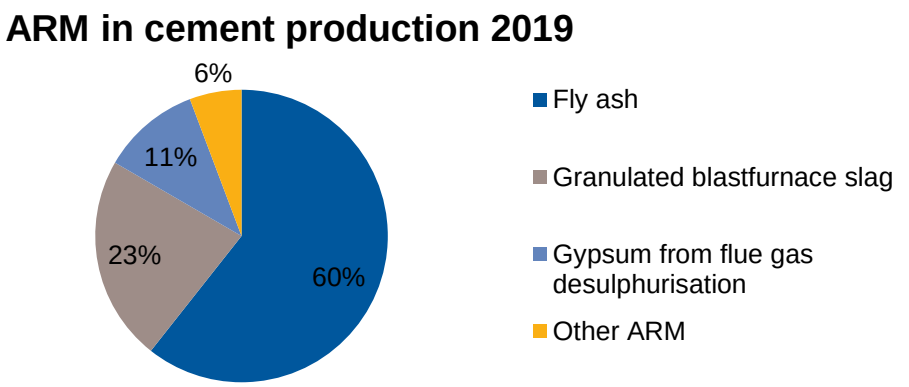
Cement	2013	2018	2019
ARM in cement	997,190 t	776,258 t	651,290 t
Total cement production	13,731,876 t	16,598,003 t	17,464,538 t
Substitution ratio	**7.3%**	**4.7%**	**3.7%**

Current situation for cement production

- Five types of alternative materials have been applied for the cement production in Spain over the last 10 years
- Share of ARM for cement production with negative trend since 2011 with an average yearly decrease at approximately 1% per year

Future prospects

- Granulated blast-furnace slag expected to further decrease
- Gypsum from flue gas desulphurization forecasted to rise



Spain – ARM Statistics and Prospects (Concrete Production)

There is no data available on alternative raw materials used in concrete in the past 8 years

Cement & aggregates in concrete	2013	2018	2019	2020
Total concrete production	32.0 mio.m³	22.2 mio.m³	27.5 mio.m³	25.3 mio.m³
Ready-mix concrete	16.2 mio.m³	22.2 mio.m³	24.8 mio.m³	22.8 mio.m³
Site-mix + precast concrete	15.8 mio.m³	0 mio.m³	2.7 mio.m³	2.8 mio.m³
RMC/concrete ratio	51%	100%	90%	90%
Cement/concrete ratio***	12%	11%	11%	11%

Current situation for concrete production

- There is no data available on alternative raw materials used in concrete in the past 8 years. In this regard no judgement can be made upon the current situation of ARM application in the concrete production
- In Spain, for safety and quality reasons, there is a limitation in the use of fly ash in concrete. As a consequence, to ensure better quality control, fly ash is mainly used in cement production

Future prospects

- Fly ash accounts for the largest share of ARM in cement production. Fly ash is also to be increasingly used as an ARM in concrete in the future.

ecra

* Calculation based on figures of ARM in RMC and RMC/concrete ratio
** Assumption, since no statistics have been made indicating the explicit value
*** Concrete density 2400 kg/m³ used for the calculations. Only ARM considered (no RC-aggregates)

sources: ERMCO / VDZ calculations

Spain – Barriers and Opportunities

Main risks / challenges as well as drivers / opportunities regarding the use of ARM in Spanish plants, taking into consideration the current situation in the waste market and socio-political perspective, have been identified as follows:

- Further development of the ARM waste market through a better cooperation across industries
- Choice variety of ARM
- Changing public acceptance

Currently, not all plants possess permits to use ARM but some plants are authorized to use ARM components as traditional raw materials. Meanwhile, there are 62 different types of wastes, which are permitted for use, nevertheless not all of them are in use. It is also worthwhile to mention that if cost of traditional materials will increase in future, the attractiveness of ARM will increase. Industry objectives: ARM increase up to 5% (2030), and 8% (2050) in clinker production.

Drivers and Opportunities	
Drivers	• Climate protection legislation • Transition of CO_2-intensive industries (power, steel) - decreasing availability of fly ash and slags - provides opportunities for new types of ARM • EU waste policy and circular economy • Circular economy plan and Industrial Symbiosis
Action for stakeholders	• Research in new ARM (incl. slag from DRI steel production) • Improve societal acceptance by specific actions to build stakeholders' trust and confidence • Promotion of circular economy, using waste as a resource • Marketing ARM in order to gain better political acceptance and permitting
What are the opportunities?	• Great opportunities for the use of ARMs, as ARMs are currently only moderately used in Spain • Reduce process CO_2 emissions • Decreasing the amount of clinker per t of cement (clinker factor) • Better management of resources • New cement types allow use of higher quantity of ARM • CO_2 price may compensate for higher cost for e.g. pre-treatment of materials

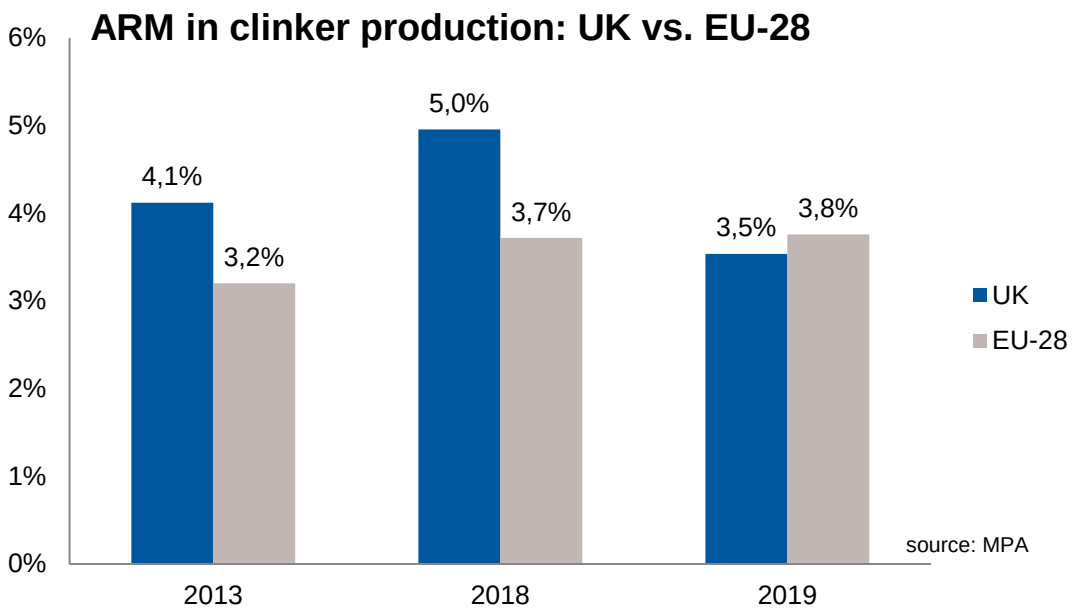
United Kingdom

source: https://www.cemnet.com/global-cement-report/country/united-kingdom

United Kingdom Summary

Cement industry with ambitious goals in ARM application in the near future

The British cement sector applied higher amount of ARM in the past with a decrease in 2019. The ARM utilization rate displays 3.5% up to 5% in clinker production and 2.5% to 5% in cement production, which is comparable to the average in the European Union.



UK	Raw meal production	Clinker production	ARM application in clinker production	Ratio ARM / RM
2013	10,694,573 t	7,130,089 t	440,671 t	4.1%
2018	12,303,462 t	7,748,010 t	609,759 t	5.0%
2019	12,028,700 t	7,869,237 t	425,300 t	3.5%

The ARM market and barriers regarding ARM development in UK		
Market organization	**Medium**	ARM market structures well developed, taxes for landfilling mineral wastes lower than for combustible wastes
Market situation	**Low**	High prices for ARM, small and medium size enterprises active in market for mineral wastes
Political environment	**Medium**	Strong political focus, active environmental groups, difficult permitting
Societal perspective	**Low**	Already high acceptance of co-processing
Cement industry	**Low**	Significant investments have already been made

- British cement sector has been regarded as moderate in terms of ARM application, especially in clinker production. A small variety of ARM selection determines an overall low consumption of alternative materials for both, clinker and cement
- In 2019, the British cement industry applied ca. 425 kt of ARM in clinker production and more than 230 kt of ARM in cement production.
- Almost 655 kt of ARM have been used to produce 9.5 mio.t of cement. This is equivalent to 70 kg ARM per t cement.

UK – ARM Statistics and Prospects (Clinker Production)

Current situation for clinker production

- Total ARM quantity in the British cement sector in 2013 (440 kt) rose to 610 kt in 2018 and fell a year later, achieving 425 kt in 2019, comprising 10 types of alternative raw materials.
- Top 10 most used materials constitute more than 96.5% of all ARM used in the British cement industry
- Current substitution rate of raw materials used for clinker production 3.5% (2019), and the trend is shrinking over the past 6 years
- Slags (steelmaking white/black slags, other slags), wastes from stone cutting and sawing, and mill scale accumulate over 54% of total ARM used for clinker production

Future prospects

- Fly ash amount will most probably continue its decreasing trend. Mill scale consumption is stable within the last 6 years. No increase expected.
- Recovered plasterboards display high potential for the substitution in clinker
- ARM share can be increased from the import potential, in particular ashes and used foundry sand

Most used ARM in clinker production 2019	t/a
Fly ash	169,176
Quarry washings	161,463
Recovered plasterboards	24,599
Mill scale	23,689
Iron oxide / fly ash blends	21,993
Shale	18,824
Alumina catalyst	2,757
Hydrated lime	1,395
Ca-containing materials	923
Sodium carbonate	481

United Kingdom – CO_2 Avoidance with ARMs (Clinker Production)

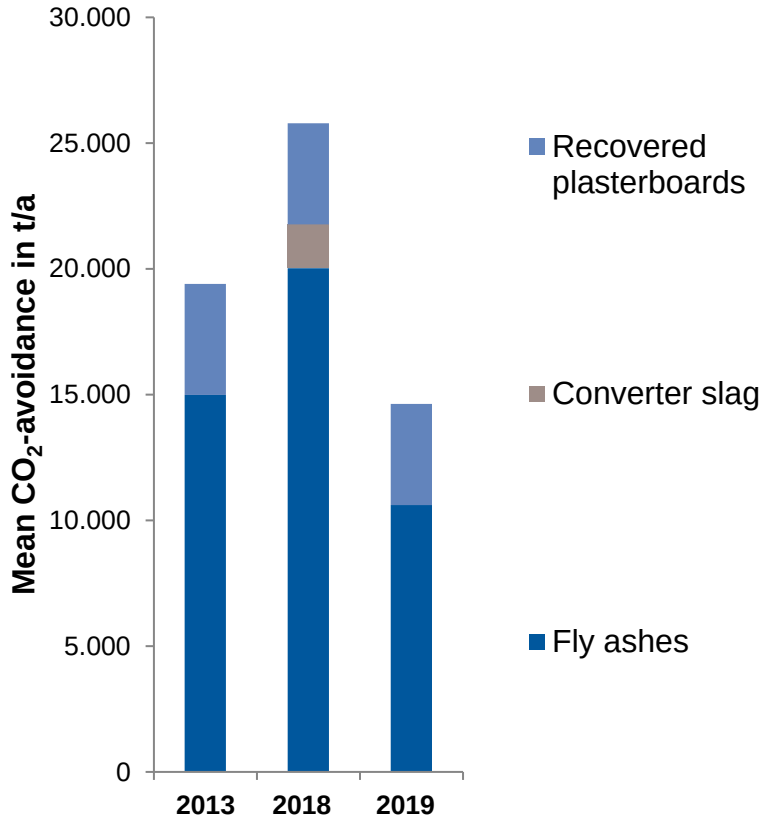


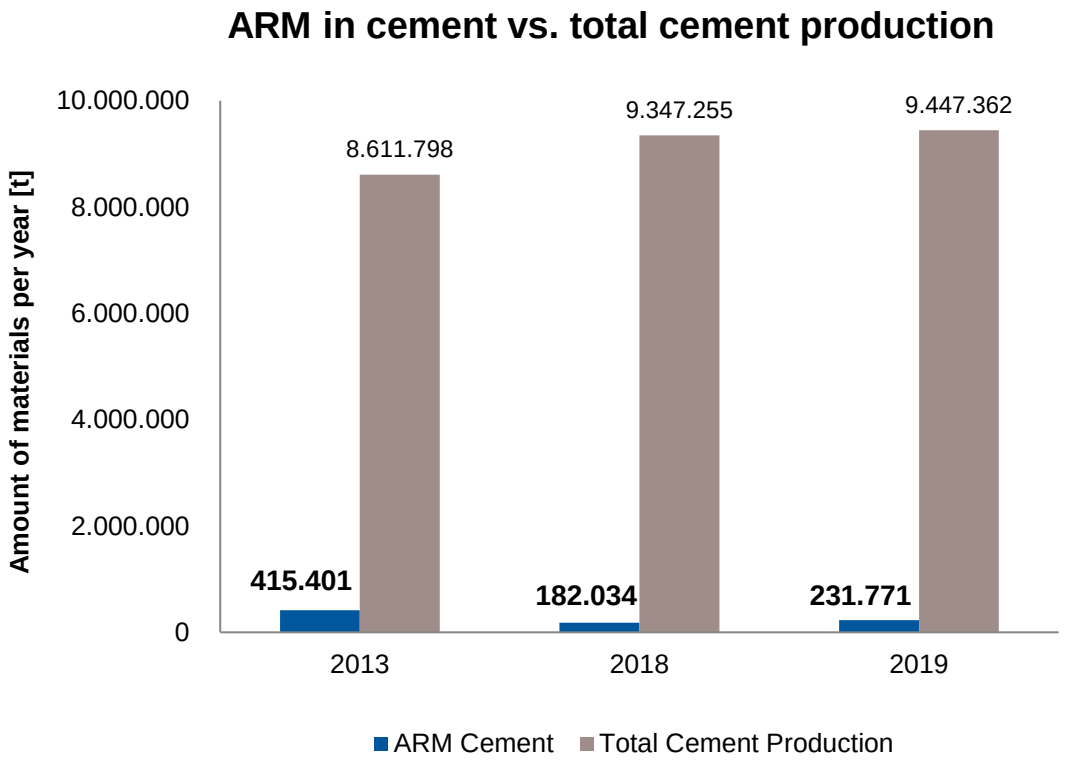
Figure: with ARM avoided CO_2 emissions in clinker production

- CO_2 savings can be estimated based on the CaO content in the ARMs
- A min/max assessment yields CO_2 savings between 0.9 and 5.7 kg CO_2/t clinker

ARM in Clinker	2018 t_ARM/a	min wt.-%	mean wt.-%	max wt.-%	min t CO_2/a	mean t CO_2/a	max t CO_2/a
Fly ashes	319,137	1	8	15	2,503	20,024	37,546
Converter slag	4,501	45	50	54	1,589	1,747	1,906
Gypsum / recovered plasterboards	19,147	15	19,1	23,2	3,151	4,013	4,874
				Total	**7,243**	**25,784**	**44,326**

Table: ARM, its CaO content and calculated CO_2 savings in 2018 by using ARM in clinker production

UK – ARM Statistics and Prospects (Cement Production)



Cement	2013	2018	2019
ARM in cement	415,401 t	182,034 t	231,771 t
Total cement production	8,611,798 t	9,347,255 t	9,447,362 t
Substitution ratio	**4.8%**	**1.9%**	**2.5%**

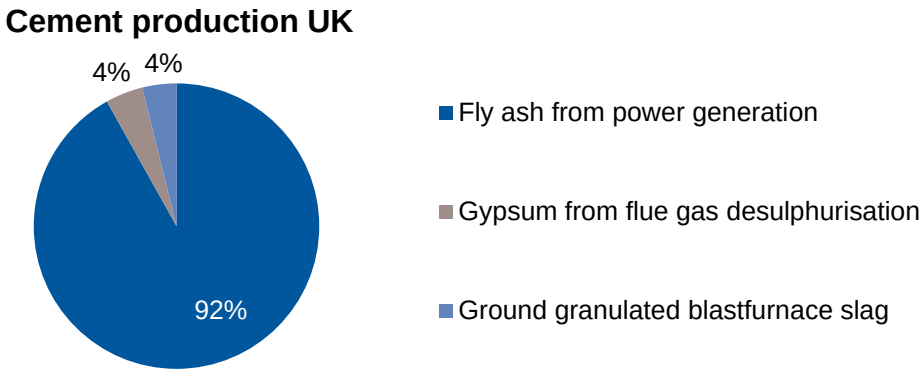
source: MPA

Current situation for cement production

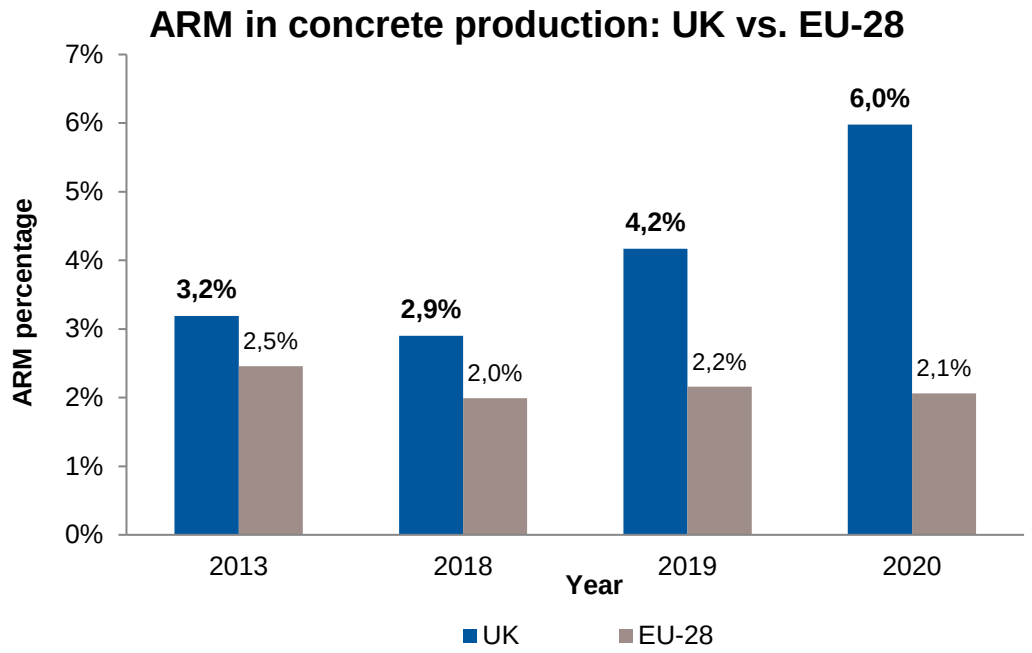
- Six main alternative materials over the last 10 years have been applied for the cement production in the British cement industry, fly ash being the by far dominant one
- ARM share sank during 2013-2018 period (by almost 3%) and rose slightly again, reaching 2.5% in 2019

Future prospects

- Being the main ARM a rise of fly ash input is forecasted short
- FGD-gypsum displays promising performance and forecasted to rise
- Both materials are expected to decrease mid-term because of decrease of coal fired power generation



UK – ARM Statistics and Prospects (Concrete Production)



ARM in concrete	2013	2018	2019	2020
Most used ARM	**GGB-slag**	**GGB-slag**	**GGB-slag**	**GGB-slag**
ARM in RMC concrete	1.5 mio.t	1.8 mio.t	2.5 mio.t	3.0 mio.t
ARM in total concrete*	2.2 mio.t	2.2 mio.t	4.3 mio.t	5.2 mio.t
Average ARM content**	77 kg/m³	70 kg/m³	100 kg/m³	143 kg/m³
Recycled aggregates	- kg/m³	- kg/m³	- kg/m³	- kg/m³
Substitution ratio* **	**3.2%**	**2.9%**	**4.2%**	**6.0%**

Cement & aggregates in concrete	2013	2018	2019	2020
Total concrete production	28.2 mio.m³	32.0 mio.m³	43.0 mio.m³	36.0 mio.m³
Ready-mix concrete	19.6 mio.m³	25.7 mio.m³	24.7 mio.m³	20.7 mio.m³
Site-mix + precast concrete	8.6 mio.m³	6.3 mio.m³	18.3 mio.m³	15.3 mio.m³
RMC/concrete ratio	70%	80%	57%	58%
Cement/concrete ratio***	10%	12%	10%	10%

Current situation for concrete production

- British concrete industry currently demonstrates the highest average ARM content (143 kg/m³) and substitution ratio (6%) among all the other key countries with ca. 4 mio.t (2019) or 4.2% and ca. 5 mio.t (2020) or 6%
- Main ARM in the concrete production has been granulated blast-furnace slag
- UK displays moderate RMC, Site-mix, and precast concrete production in comparison with the other key countries, with a tendency to increase.
- The 2013-2019 period shows a significant increase in concrete production
- increase of cement import for concrete production (cement/concrete ratio constent)

Future prospects

- Utilization of slags is expected to drop in the next years
- Nevertheless the share of ARM in concrete production, is expected to increase e.g. by utilizing more recycled aggregates

* Calculation based on figures of ARM in RMC and RMC/concrete ratio
** Assumption, since no statistics have been made indicating the explicit value
*** Concrete density 2400 kg/m³ used for the calculations. Only ARM considered (no RC-aggregates)

sources: ERMCO / VDZ calculations

UK – Barriers and Opportunities

Main risks / challenges as well as drivers / opportunities regarding the use of ARM in British plants, taking into consideration the current situation in the waste market and socio-political perspective, have been identified as follows:

- Relatively high costs for ARM
- Application for permits have become more difficult
- Applicability of different potential future ARM

Drivers and Opportunities	
Drivers	• Climate protection legislation • Transition of CO_2-intensive industries (power, steel) - decreasing availability of fly ash and slags - provides opportunities for new types of ARM • Historically UK waste policy is influenced by EU waste policy
Action for stakeholders	• Research in new ARM (e.g. slag from DRI steel production, ash from biomass) • Improve regular and specified acceptance • Supporting high level permitting processes that facilitate the circular economy
What are the opportunities?	• The current moderate use of ARMs shows opportunities for increasing ARM use in the future • New cement types allow use of higher quantity of ARM • CO_2 price may compensate for higher cost for e.g. pre-treatment of materials

Italy

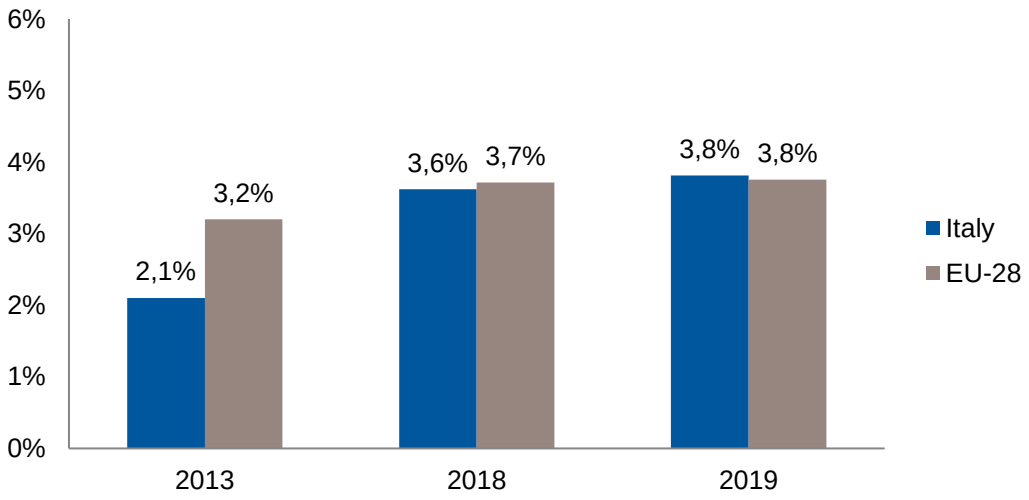
source: https://www.cemnet.com/global-cement-report/country/Italy

Italy Summary

Cement industry with a promising development rate of ARM application in the near future

Italian cement sector applies statistically lower amount of ARM in comparison to the European consumption average. Italian ARM utilization rate displays 2.1% up to 3.6% in clinker production and 3.5% to 5.8% in cement production, which is lower than the average in the European Union.

ARM in clinker production: Italy vs. EU-28



Italy	Raw meal production	Clinker production	ARM application in clinker production	Ratio ARM / RM
2013	27,042,502 t	14,798,702 t	568,839 t	2.1%
2018	23,683,056 t	14,801,910 t	857,800 t	3.6%
2019	24,168,131 t	15,105,082 t	922,438 t	3.8%

The ARM market and barriers regarding ARM development in Italy		
Market organization	**Low**	Waste market mature and well organized
Market situation	**Medium**	Potential for market growth
Political environment	**Medium**	Strong political focus, EU waste policy will force circular economy and therefore the use of ARM in the next years, permitting difficult
Societal perspective	**High**	Public acceptance of co-processing of waste is low with potential impact on ARM perception
Cement industry	**Medium**	Investments expected to boost ARM utilization No significant barriers found

- Italian cement sector is characterized as moderate in terms of both, cement production as well as ARM application in the clinker production. A small variety of ARM selection is used.
- In 2019, the Italian cement industry applied ca. 922 kt of ARM in clinker production and more than 830 kt of ARM in cement production
- Almost 1.6 mio.t of ARM have been used to produce 19.2 mio.t of cement. This is equivalent to 80 kg of ARM per t cement.

Italy – ARM Statistics and Prospects (Clinker Production)

Current situation for clinker production

- Italian cement sector applied more than 30 different types of alternative raw materials with a total amount of 922,438 tons in 2019
- Amount of total ARM quantity used in 2013 (568 kt) rose by 35%, to 857 kt in 2018 and slightly dropped back to 763 kt in 2019
- Top 10 most used materials constitute more than 84% of all ARM used in the Italian cement industry
- Current substitution rate of raw materials used for clinker production 3.8% (2019), and the trend is overall rising over the past 6 years

Future prospects

- Mill scale is expected to continue to increase in the next years
- Utilization of fly ash will continue its sinking movement further
- Secondary iron oxide will strengthen its positions, volumes expected to rise
- Wastes, such as stone cutting and sawing waste, will play increasingly important role in the ARM substitution potential in clinker production

Most used ARM in clinker production 2019	t/a
Silica based incinerator slag, containing Fe and Al oxieds	169,394
Soil and rocks from excavation	151,668
Mill scales	131,093
Iron silicate	75,560
Bottom ashes*	56,520
Waste alumina	56,417
Casting cores and moulds	56,060
Fly ash	37,181
Waste from stone cutting	36,165
Other materials	220,384

*The term “bottom ashes” refers mainly to ashes from coal fired power generation plants

Italy – CO_2 Avoidance with ARMs (Clinker Production)

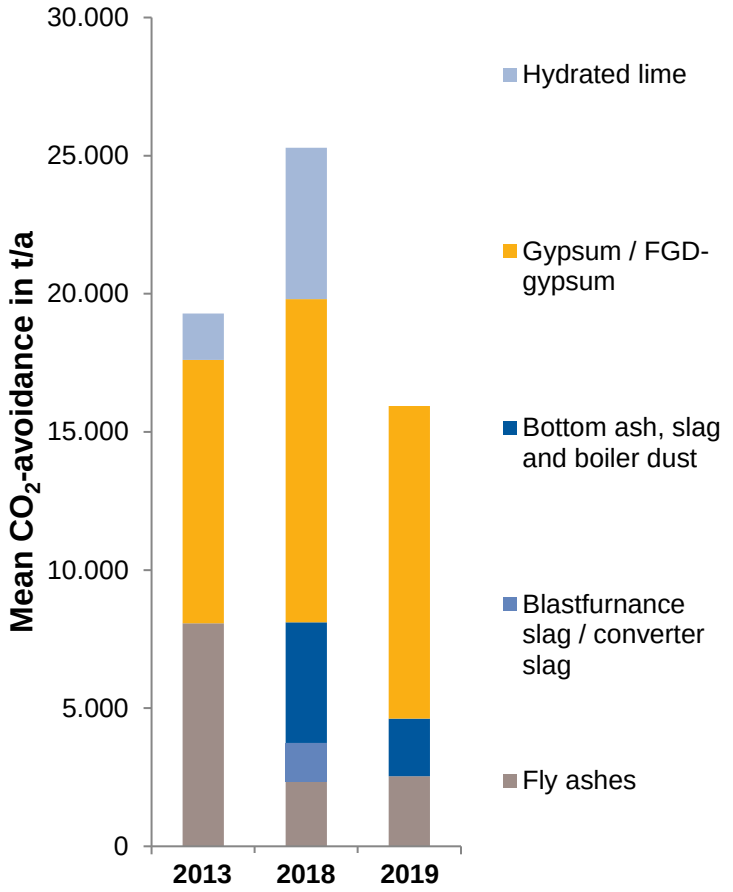


Figure: with ARM avoided CO_2 emissions in clinker production

- CO_2 savings can be estimated based on the CaO content in the ARMs
- A min/max assessment yields CO_2 savings between 1.2 and 2.8 kg CO_2/t clinker

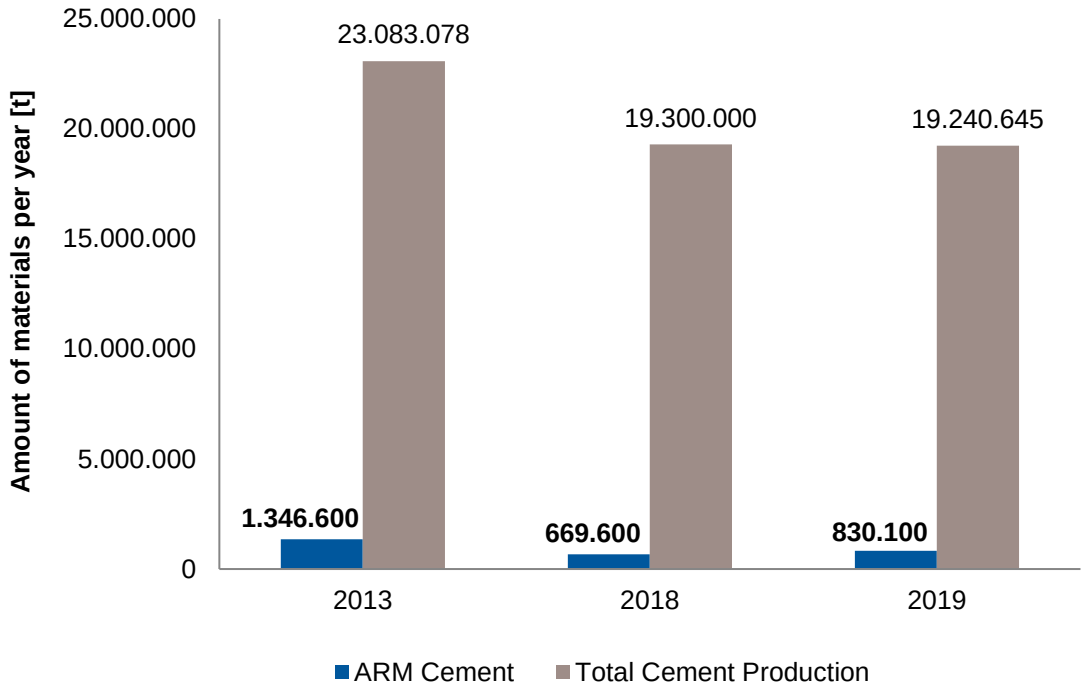
ARM in Clinker	2018 t_ARM/a	min wt.-%	mean wt.-%	max wt.-%	min t CO_2/a	mean t CO_2/a	max t CO_2/a
Fly ashes	37,181	1	8	15	292	2,333	4,374
Blast-furnace & converter slag*	4,487	25	39.5	54	880	1,197	1,513
Bottom ash	56,520	5	15	25	3,101	9,303	15,504
Gypsum / FGD-gypsum	55,797	15	19	23.2	9,184	11,694	14,204
Hydrated lime	10,632	40	47	54	4,666	5,483	6,300
				Total	**18,122**	**30,009**	**41,896**

Table: ARM, its CaO content and calculated CO_2 savings in 2018 by using ARM in clinker production

*min. CaO content of blastfurnace slag and max .CaO content of converter slag

Italy – ARM Statistics and Prospects (Cement Production)

ARM in cement vs. total cement production



Cement	2013	2018	2019
ARM in cement	1,346,600 t	669,634 t	670,702 t
Total cement production	23,083,078 t	19,300,000 t	19,240,645 t
Substitution ratio	**5.8%**	**3.5%**	**3.5%**

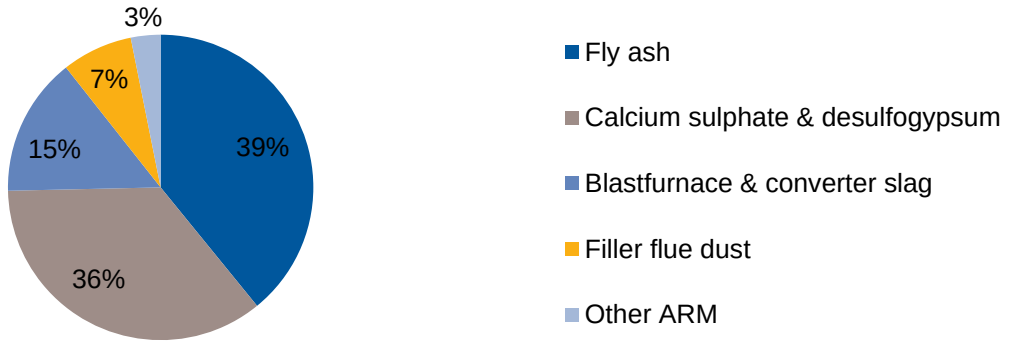
Current situation for cement production

- Italian cement production utilized 17 types of alternative materials in 2019
- Remaining ARM include Ca-based reaction wastes, iron silicate, lining/refractory wastes, as well as other minor wastes
- ARM overall situation is characterized by the unstable utilization rate

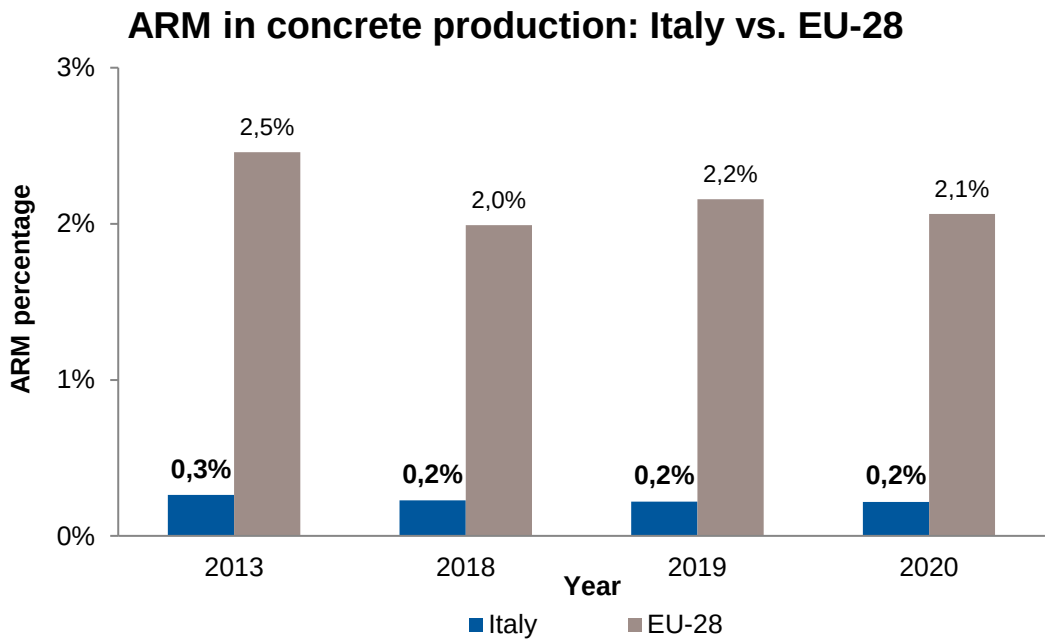
Future prospects

- Due to high ARM rate fluctuations barely any precise forecasts can be made in relation to development tendencies

ARM in cement production 2019



Italy – ARM Statistics and Prospects (Concrete Production)



ARM in concrete	2013	2018	2019	2020
Most used ARM	**Fly ash**	**Fly ash**	**Fly ash**	**Fly ash**
ARM in RMC concrete	0.2 mio.t	0.15 mio.t	0.15 mio.t	0.15 mio.t
ARM in total concrete*	0.3 mio.t	0.2 mio.t	0.2 mio.t	0.2 mio.t
Average ARM content**	6.3 kg/m^3	5.5 kg/m^3	5.3 kg/m^3	5.2 kg/m^3
Recycled aggregates	- kg/m^3	- kg/m^3	- kg/m^3	- kg/m^3
Substitution ratio* **	**0.3%**	**0.2%**	**0.2%**	**0.2%**

Cement & aggregates in concrete	2013	2018	2019	2020
Total concrete production	46.6 mio.m^3	33.0 mio.m^3	34.0 mio.m^3	35.0 mio.m^3
Ready-mix concrete	31.7 mio.m^3	27.3 mio.m^3	28.4 mio.m^3	28.7 mio.m^3
Site-mix + precast concrete	14.9 mio.m^3	15.7 mio.m^3	15.6 mio.m^3	16.3 mio.m^3
RMC/concrete ratio	68%	83%	84%	82%
Cement/concrete ratio***	13%	13%	13%	13%

Current situation for concrete production

- Italian concrete industry has a low average ARM content (5 kg/m^3) and substitution ratio (0.2%) compared to the other key countries with ca. 0.2 mio.t ARM utilization in the years 2018-2020
- Main ARM in the Italian concrete production has been fly ash
- The 2013-2018 period is characterized by a significant decrease in total concrete production
- RMC/concrete increased substantially since 2013, but stabilized at 82-84% ratio

Future prospects

- Italian concrete industry has a huge potential of increasing ARM utilization, as it currently utilizes negligible amounts of alternative materials. It is expected to substantially increase both ARM and RC-aggregates in the near future

* Calculation based on figures of ARM in RMC and RMC/concrete ratio
** Assumption, since no statistics have been made indicating the explicit value
*** Concrete density 2400 kg/m^3 used for the calculations. Only ARM considered (no RC-aggregates)

sources: ERMCO / VDZ calculations

Italy – Barriers and Opportunities

Main risks / challenges as well as drivers / opportunities regarding the use of ARM in Italian plants, taking into consideration the current situation in the waste market and socio-political perspective, have been identified as follows:

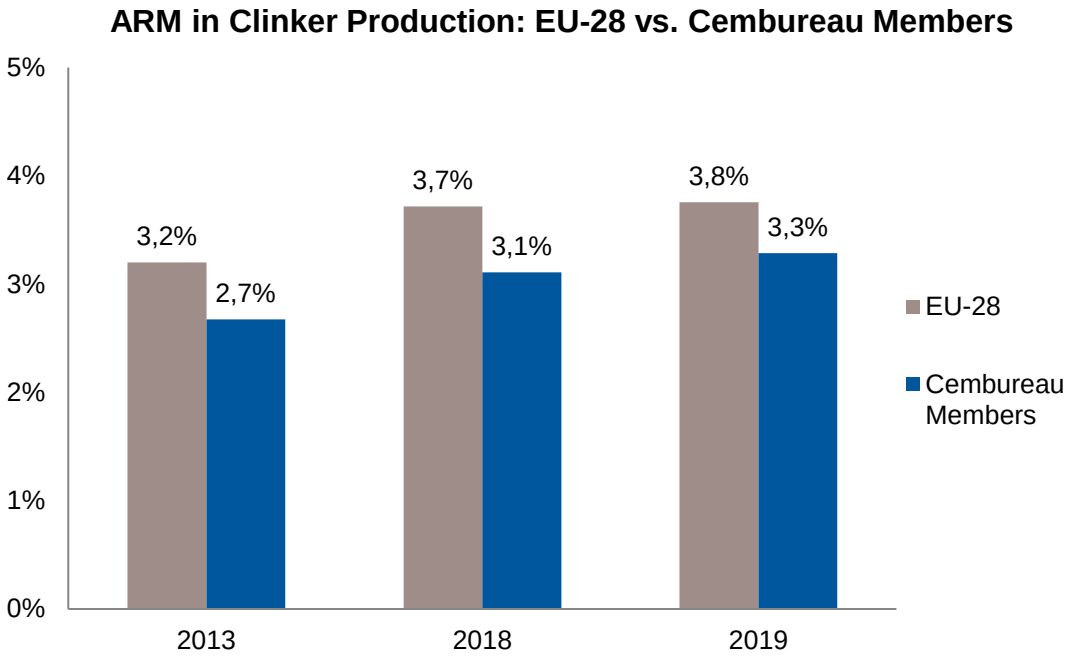
- ARM cost and their applicability
- Application permitting
- Changing public acceptance

Drivers and Opportunities	
Drivers	• Climate protection legislation • Transition of CO_2-intensive industries (power, steel) decreasing availability of fly ash and slags and provides therefore opportunities for new types of ARM • Italian waste policy is influenced by EU waste policy
Action for stakeholders	• Research in new ARM (e.g. slag from DRI steel production, ash from biomass) • Improve regular and specified acceptance • Marketing ARM in order to gain better political acceptance and permitting
What are the opportunities?	• The current moderate use of ARMs shows opportunities for increasing ARM use in the future • New cement types allow use of higher quantity of ARM • CO_2 price may compensate for higher cost for e.g. pre-treatment of materials

Europe 28

EU-28 Summary

Overarching goals of the EU cement Industry in achieving carbon-neutrality by 2050



EU-28	Raw meal production	Clinker production	ARM application in clinker production	Ratio ARM / RM
2013	193,675,469 t	121,047,168 t	6,199,478 t	3.2%
2018	209,232,489 t	130,770,305 t	7,776,908 t	3.7%
2019	207,026,744 t	129,391,715 t	7,779,623 t	3.8%

The ARM market and barriers regarding ARM development in the EU-28		
Market organization	**Medium**	EU MS with differences in ARM markets maturity Mainly small companies engaged, different from AF market
Market situation	**Medium**	Some MS with low landfill taxes for mineral wastes Large variety of ARM materials of different quality and regional availability
Political environment	**High**	Different implementation of the EU Landfilling Directive Partly long/bureaucratic permitting procedures Legal barriers regarding re-use of landfilled materials
Societal perspective	**Medium**	Sometimes little public acceptance and negative attitude towards ARM
Cement industry	**Medium**	Investment needed for ARM processing and implementation Permits often time and resource consuming

- In 2019, the EU 28 cement industry applied ca. 7,780 kt of ARM in clinker production and more than 13,300 (GNR) kt of ARM in cement production.
- All in all, almost 21 mio.t of ARM have been used to produce 180 mio.t of cement. This is equivalent to 117 kg ARM per t cement.
- In 2018 about 392 kt of CO_2 have been abated by the use of ARM in clinker production. This is equivalent to 3.0 kg CO_2 per t clinker or 0.32% process CO_2 emissions.

EU-28 ARM Statistics and Prospects (Clinker Production)

Current situation for clinker production

- EU 28 cement sector applied 36 types of alternative raw materials with a total amount of 7.78 mio. tons in 2019
- Total ARM quantity used in 2013 (5.49 mio.t) increased by 41% (2019)
- Top 10 most used materials constitute more than 69% of all ARM
- Current substitution rate of raw materials used for clinker production is 3.8% (2019), and the trend is rising
- Fly ashes (being the dominant ARM), BF and converter slag, used foundry sand, secondary iron oxide, other Fe containing wastes and secondary sand accumulate to more than 50% of total ARM. The trend over the last 7 years has been growing
- Ca-type ARM make up < 13%, most of them not being decarbonated

Most used ARM in clinker production 2019	t/a
Fly ashes	1,573,011
Blast furnace & converter slag	613,619
Secondary iron oxide	505,318
Used foundry sand	457,291
Fe-containing materials (other)	443,850
Others	415,868
Secondary sand	403,065
Lime waste	348,795
Mill scale	318,625
Wastes from stone cutting and sawing	305,017
Rest ARM	2,395,165

Future prospects

- Fly ashes amounts have been stable until 2019, but are expected to considerably shrink due to decreasing coal fired power generation
- Bottom ashes*, slag and boiler dust from power generation increased during the last years, but are as well expected to decrease in mid-term future
- BF slag and converter slag from steel production have increased since 2013, are stable since 2016 and are expected to decrease in the future due to transition in the iron&steel industry
- New materials are expected to come up or increase, like ashes from sewage sludge incineration, waste incinerator slag, concrete fines, slags from non-ferrous metal production, contaminated soils, but some of them will need to be pretreated (heavy metals), or require additional emissions abatement

*The term “bottom ashes” refers mainly to ashes from coal fired power generation plants

EU-28 – CO_2 Avoidance with ARMs (Clinker Production)

The use of ARM in EU-28 saves 0.39 Mt CO_2 equivalent to the emissions of about one integrated cement plant

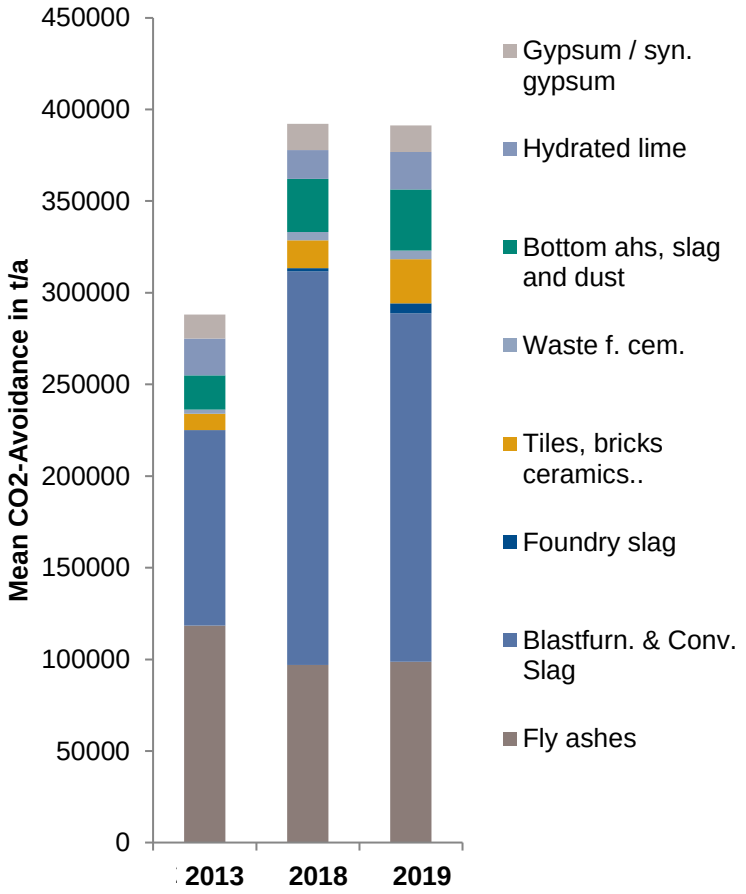


Figure: with ARM avoided CO_2 emissions in clinker production

- CO_2 savings can be estimated based on the CaO content in the ARMs
- A min/max assessment yields CO_2 savings between 1.5 and 4.5 kg CO_2/t clinker

ARM in Clinker	2018 t_ARM/a	min wt.-%	mean wt.-%	max wt.-%	min t CO_2/a	mean t CO_2/a	max t CO_2/a
Fly ashes	1,545,028	1	8	15	12,118	96,943	181,768
Blast-furnace & converter slag*	693,372	25	39.5	54	135,955	214,809	293,663
Foundry slag	5,323	30	40	50	1,252	1,670	2,087
Tiles, bricks, ceramics	167,757	7	11.5	16	9,210	15,131	21,052
Waste from cement based materials	69,393	5	8.5	12	2,612	4,572	6,531
Inc. bottom ash, slag and dust	246,276	5	15	25	9,658	28,974	48,289
Hydrated lime	42,796	40	47	54	13,426	15,776	18,125
Gypsum / synthetic gypsum	94,819	15	19.1	23.2	11,155	14,204	17,253
				Total	**195,388**	**392,079**	**588,770**

Table: ARM, its CaO content and calculated CO_2 savings in 2018 by using ARM in clinker production

*min. CaO content of blastfurnace slag and max . CaO content of converter slag

EU-28 CO_2 reduction by decarbonized ARM and future goals

The use of ARM saved a total of 392 kt of CO_2 in the European Union in 2018, which corresponds to ca. 3.0 kg CO_2/t clinker. According to Cembureau roadmap, the goal of the European cement industry is to reduce process CO_2 emissions by 3.5% (2.6 mio. tons) in 2030 and by 8% (5.9 mio. t) in 2050. Per ton of clinker, the CO_2 abatement by decarbonated ARM has to be increased by a factor of 10 in order to achieve the set target. Based on the expected future availability of decarbonated ARM, this target is extremely challenging.

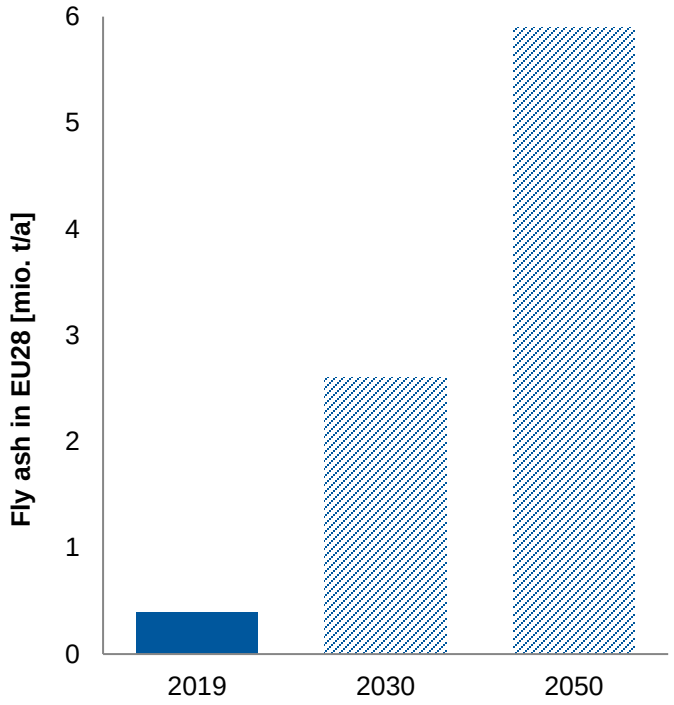


Figure: Current and future needed CO_2-avoidance EU28

With about 10 kg CO_2/ ton of clinker Austria has the lead in using decarbonated ARM in EU28.

Even if the EU cement industry were to achieve this level, an increase by a factor of more than 4 would still be required until 2050.

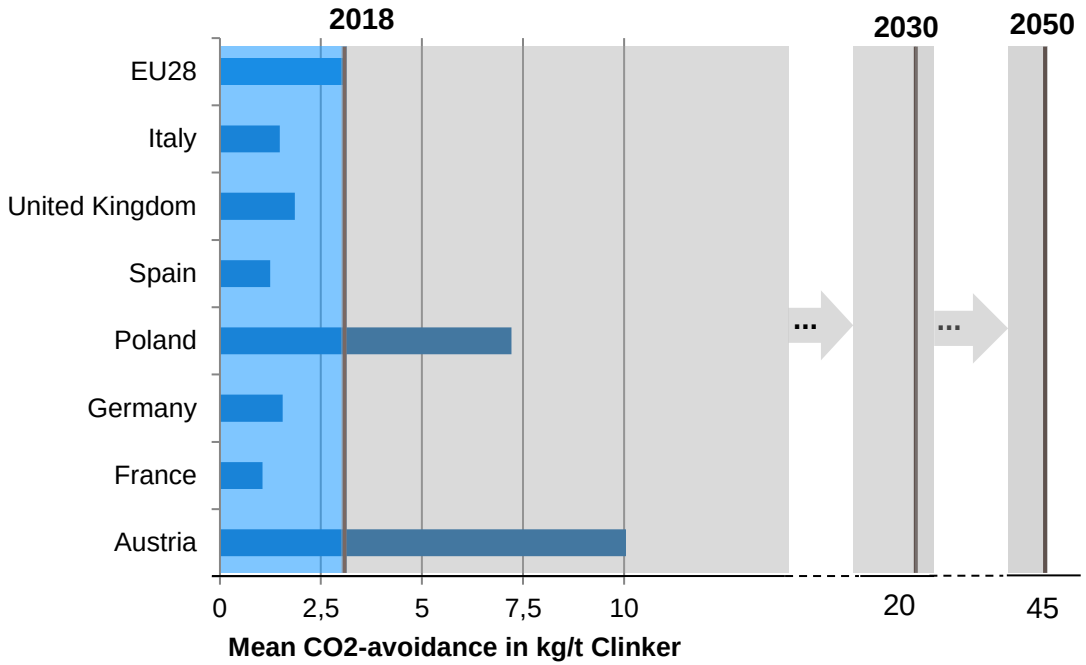
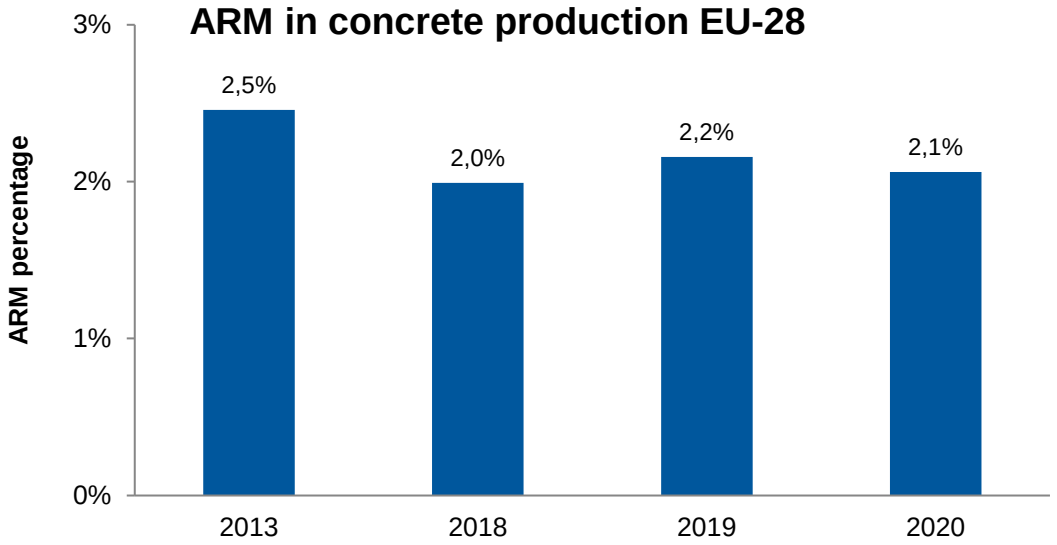


Figure: Current and future mean CO_2-avoidance

EU-28 ARM Statistics and Prospects (Concrete Production)



ARM in concrete	2013	2018	2019	2020
Most used ARM	**Fly ash / GGBS**	**Fly ash / GGBS**	**Fly ash / GGBS**	**Fly ash / GGBS**
ARM in RMC concrete	7.8 mio.t	8.8 mio.t	10.0 mio.t	10.1 mio.t
ARM in total concrete*	12.1 mio.t	12.2 mio.t	14.5 mio.t	14.2 mio.t
Average ARM content**	59 kg/m^3	48 kg/m^3	52 kg/m^3	50 kg/m^3
Recycled aggregates	1.1 kg/m^3	1.4 kg/m^3	1.4 kg/m^3	1.5 kg/m^3
Substitution ratio* **	**2.5%**	**2.0%**	**2.2%**	**2.1%**

Cement & aggregates in concrete	2013	2018	2019	2020
Total concrete production	338 mio.m^3	352 mio.m^3	379 mio.m^3	357 mio.m^3
Ready-mix concrete	218 mio.m^3	253 mio.m^3	262 mio.m^3	253 mio.m^3
Site-mix + precast concrete	120 mio.m^3	99 mio.m^3	117 mio.m^3	104 mio.m^3
RMC/concrete ratio	64%	72%	69%	71%
Cement/concrete ratio***	12%	12%	12%	12%

Current situation for concrete production

- European concrete industry has been demonstrated an ARM content of 50 kg/m^3 and substitution ratio of 2.1% with ca. 14.2 mio.t ARM utilization in recent years
- Main ARM in the European concrete production has been fly ash and ground granulated blast-furnace slag
- RMC/concrete displays steady results at an average of 70%. This is not expected to change significantly in the next future

Future prospects

- European concrete industry possesses significant potential of increasing ARM utilization. A major emphasis is expected to be made on recycled-concrete aggregates in the years to come

ecra

* Calculation based on figures of ARM in RMC and RMC/concrete ratio
** Assumption, since no statistics have been made indicating the explicit value
*** Concrete density 2400 kg/m^3 used for the calculations. Only ARM considered (no RC-aggregates)

sources: ERMCO / VDZ calculations

EU – Barriers and Opportunities

The situation of ARM usage in Europe differs significantly country by country. Some countries have already achieved high substitution rates with ARM and others still show great potential to increase ARM use. In order to further increase the share of ARM in clinker and cement production in Europe, the following main challenges still need to be overcome.

- Improve societal attitudes and public acceptance in order to increase the use of ARMs without social barriers
- Financing the high investments needed for unimpeded/uninterrupted ARM supply and substitution
- Political framework conditions for the recycling of alternative raw materials and the reduction of bureaucratic hurdles to promote the use of ARMs
- Finding alternative raw materials that can adequately replace fly ash and slag that have been widely used up to now

Drivers and Opportunities	
Drivers	• Climate protection legislation - use of decarbonized ARM • Transition of CO_2 intensive industries (power, steel) decreasing availability of fly ash and slags and provides therefore opportunities for new types of ARM • Readiness of cement industry to use more ARM • EU waste policy – improve resources efficiency • Reduction of landfill capacities • Protection of natural resources and efficient land use • Incentives to advanced treatment technologies
Action for stakeholders	• Research in new ARM (incl. slag from DRI steel production) • Improve societal acceptance by specific actions to build stakeholders' trust and confidence (e.g. stakeholder involvement) • Marketing the material re-use; high level of political acceptance and permitting • Development of new cement and clinker types
What are the opportunities?	• New cement types allow use of higher quantity of ARM • CO_2 price may compensate for higher cost for e.g. pre-treatment of materials • Production of environmentally and economically viable ARM • Recycling of construction, demolition and further mineral containing materials • Synergy of industry sectors • Cement industry turns into an important player of circular economy by increasing the use of ARM

Fact Sheets for Often Used Raw Materials

- Fly ash from hard-coal fired power generation
- Granulated blast-furnace slag (GBFS)
- Steel slags (converter and electric arc furnace slags)
- Used foundry sand
- Waste bricks and roof tiles
- Waste concrete, concrete fines and concrete sludge (construction and demolition wastes)
- Bottom ash from waste incineration

Fly ash from hard-coal fired power generation

Fly ash is an amorphous material that is a by-product in hard coal fired power generation. Fly ashes which comply with EN 450-1 are used as main constituent in cement or as concrete addition acting as a substitute for clinker in cement or cement in concrete. Fly ashes not complying with EN 450-1 are mainly used as ARM in clinker production and to a minor extent for non-structural concrete elements. Both of these reduce resource consumption and CO_2 emissions. In this respect, the use in cement and concrete is much more significant than as ARM in clinker production. Due to the European climate targets it can be assumed that the quantities of fly ash from coal-fired power plant processes in Europe and the decisions in some EU MS to completely get out of coal-fired power generation will decrease significantly in the future.

Comp.	wt.-%
SiO_2	36 - 59
Al_2O_3	20 - 35
Fe_2O_3	3 - 19
CaO	1 - 15
MgO	0.7 - 4.8
K_2O	0.5 - 6
Na_2O	0.1 - 3.5
SO_3	0.1 - 2
TiO_2	0.5 - 1.8

Table: typical composition of hard coal fly ash

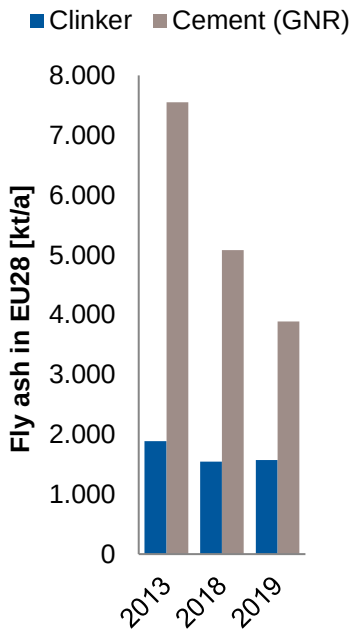


Figure: Use of fly ash in clinker and cement production

- **Characteristics**
  - The important components of fly ash for building materials industry are SiO_2 and Al_2O_3
  - Fly ash has puzzolanic properties and can therefore replace clinker in certain cement types. For concrete fly ash can have a positive influence on the workability and structural properties (EN 450; SiO_2 > 25 wt.-%, CaO < 10 wt.-%, ash content from co-combustion of other substances < 30 wt.-%, LOI < 5%)
- **Current use**
  - In 2018 about 1.5 million tons of fly ash were used as ARM in Europe for clinker production. In addition, it is estimated that about 9 million tons of fly ash are used for cement and concrete. However, the availability and use of fly ash varies significantly among countries
- **Future prospects**
  - Due to the European climate targets, the quantities of fly ash in Europe are expected to decrease significantly by 2038 and may be close to zero in 2050
  - Mio. t of fly ashes have been landfilled in the past and could be used in the future in some EU MS
- **Environmental and technical aspects**
  - The proportion of non-carbonate-bound calcium in fly ash directly reduces CO_2 emissions in clinker production
  - The use in cement and concrete can reduce CO_2 emissions and the use of primary resources
  - Fly ash has no hazardous properties

Granulated Blast-furnace Slag (GBFS)

During the production of pig iron, blast furnace slag is produced as a by-product from gangue, coke ash and aggregates. GBFS is produced by granulation. This ensures that the molten slag solidifies to a predominantly glassy consistency. GBFS is a latent hydraulic material that hardens hydraulically with an exciter (e.g. $Ca(OH)_2$, $CaSO_4$) in a technically usable time. The hydraulic properties of GBFS depend essentially on its glass content and on its chemical composition. As a result of the requirements of decarbonation the steel industry will to a large extent switch from coke based BF pig iron production to H_2 based direct reduction process. The slag from DRI route cannot be granulated into a glassy material without further treatment steps and thus has no latent hydraulic property.

Comp.	wt.-%
SiO_2	35 – 40
Al_2O_3	8 – 12
Fe_2O_3	0.1 – 10
CaO	25 – 43
MgO	7 – 16
K_2O	0.4 – 1.3
Na_2O	0.2 – 1.2
SO_3	0 – 0.2
TiO_2	

Table: typical composition of hard coal GBFS

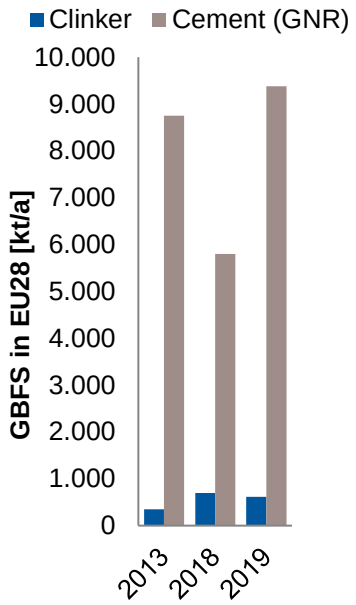


Figure: Use of GBFS (incl. converter slag) in clinker and cement production

- **Characteristics**
  - The important components of GBFS for building materials industry are CaO and SiO_2
  - GBFS has hydraulic properties and can therefore replace clinker in certain cement types
  - GBFS is mainly used in cement and concrete production, differing between EU member states
  - Small quantities of non-granulated BFS are used in clinker production
- **Current use**
  - In 2019 about 22.3 mio. tons of GBFS were used in Europe for cement and concrete production. 0.6 mio. t of BFS (incl. converter slag) have been in clinker production
  - The availability and use of BFS and GBFS varies significantly among EU MS, mainly depending on regional steel industry
- **Future prospects**
  - Due to the European climate targets, the quantities of GFBS and BFS in Europe are expected to decrease significantly by 2050
  - The aim of current research work is the utilisation of all slags expected in the future, especially for use as a Portland cement clinker substitute
  - Mio. t of BFS have been landfilled in the past in some EU MS and could be used in the future
- **Environmental and technical aspects**
  - Due to the CaO content and hydraulic properties, BFS in clinker and GBFS in cement and concrete can reduce CO_2 emissions and the use of primary resources
  - GBFS has no hazardous properties, but future DRI slags will have higher heavy metal contents

Steel Slags (Converter and Electric Arc Furnace Slags)

Converter slag or slag from basic oxygen process (BOPS / german LD slag from Linz-Donawitz-Process) is produced during the conversion of liquid pig iron to crude steel in the BOPS converter. It is formed from aggregates such as limestone or dolomite and contains Ca as well as other components as oxides. Electric arc furnace slag (EOS) is produced during the smelting of steel scrap in the electric arc furnace. It is formed from aggregates such as limestone or dolomite and also contains components that oxidize under the conditions of the process. Due to future transition of the steel industry BOPS quantities will decrease significantly. EOS quality will change significantly as iron sponge from direct reduction will be molten in the EOF. These slags are crystalline and thus have no latent hydraulic properties.

	BOPS	EOS
Comp.	wt.-%	wt.-%
SiO_2	10 – 15	10 – 18
Al_2O_3	1 – 3.5	4 – 9
Fe_2O_3	18 – 24 (as Fe)	29 – 48
CaO	45 – 54	20 – 36
MgO		3 – 7
SO_3	0.25 – 0.5	

Table: typical composition of BOPS and EOS

- **Characteristics**
  - Important components of BOPS and EOS for building materials industry are CaO and Fe_2O_3
  - BOPS/EOS are crystalline and thus cannot replace clinker in cement without further treatment
- **Current use**
  - In 2019 about 0.6 mio. tons of steel slags were used in Europe in cement and concrete production [EUROSLAG]
  - BOPS is used in clinker production in a few EU member states. EOS is not used in cement or concrete industry
- **Future prospects**
  - Due to steel industry transition, the quantities of BOPS in Europe are expected to decrease significantly by 2050
  - EOS availability is expected to increase due to continued steel production based on scrap with electric route and additional occurrence melting of iron sponge from DRI route
  - EOS properties and composition will change significantly compared to current qualities
  - The aim of current research work is the utilization of all slags expected in the future, especially for use as a Portland cement clinker substitute
- **Environmental and technical aspects**
  - Due to the CaO content EOS and BOPS can reduce CO_2 emissions and the use of primary resources in clinker production
  - BOPS and EOS have high contents of certain heavy metals (e.g. Cr), which limit their use in many countries today. Pretreatment (heavy metal removal) could significantly improve their usability.

Used Foundry Sand

Used foundry sands are waste products from the foundry industry. Foundry sands are first recycled within the casting process. After a certain number of cycles they have to be disposed. Foundry sands are mainly composed of sand and a binder. The binder can either be organic or bentonite type. While sands bound with bentonite can be fed to the raw mill of the clinker burning process, sands with organic binders have to be fed into the hot section of clinker burning in order to avoid organic emissions. The high Si content of foundry sand makes it a very good replacement of natural sand.

Comp.	wt.-%
SiO_2	93 – 99
Al_2O_3	0.1 – 1
Fe_2O_3	0.2 – 1
CaO	0.1 – 0.4
MgO	0.1 – 0.4
K_2O	0.1 – 0.2
Na_2O	0.1 - 0.2
Additives	1 – 3

Table: typical composition of waste foundry sand

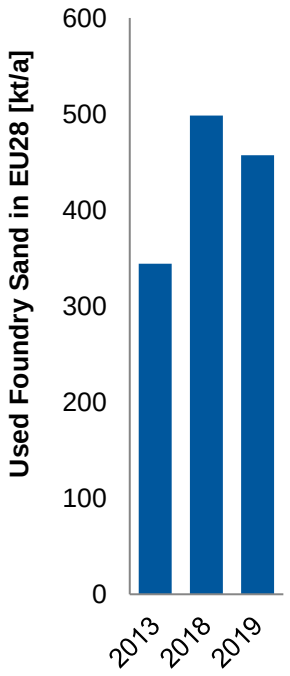


Figure: Use of waste foundry sand in clinker production

- **Characteristics**
  - The important component of used foundry sand for the cement industry is SiO_2
  - Due to the very high SiO_2 content, the use of foundry sands as a secondary raw material for cement clinker production can reduce the use of primary resources
- **Current use**
  - In 2019 about 457 kilo tonnes of used foundry sand were used as ARM in Europe for clinker production (Fig.)
  - Almost the entire quantity of foundry sand produced in the foundry industry (460 kt) goes into clinker production (99%)
- **Future prospects**
  - The potential for increasing the use of waste foundry sand is already exhausted, as almost all of the material is already used in clinker production
- **Environmental and technical aspects**
  - Saving of primary resources
  - Foundry sands with organic binders have to be fed into the hot section of the clinker burning process in order to avoid organic emissions.

Waste Bricks & Clay Roof Tiles

Bricks and roof tiles are materials containing minerals that have the potential to increasingly replace primary raw materials in cement clinker production as ARMs and as cement constituent as well in the future. Demolition material is sorted in recycling plants and processed as fine material in the cement plants. Challenging is the separating and classifying of the demolition materials into the usable pure fractions. The recycling of burnt clay material offers the opportunity to conserve primary resources and reduce CO_2 footprint of cements in the future.

Comp.	wt.-%
SiO_2	55 - 65
Al_2O_3	10 - 20
Fe_2O_3	3 - 5
CaO	7 - 16
MgO	1 - 6
K_2O	1 – 4
Na_2O	0,4 - 1
SO_3	0,1 - 1
TiO_2	0,3 – 1

Table: typical composition of waste bricks and roof tiles sand

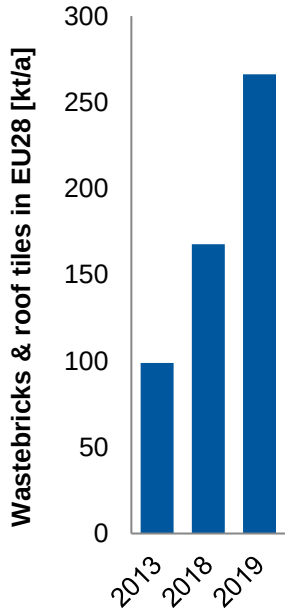


Figure: (2018) Use of waste brick and roof tiles in clinker production

- **Characteristics**
  - The important components of waste bricks and roof tile for cement industry are SiO_2 and Al_2O_3
  - Bricks and roof tiles are already calcined materials, so that they have the potential to reduce CO_2 emissions as a substitute raw material
- **Current use**
  - In 2019 about 266 kilo tonnes of waste bricks & roof tiles were used as ARM in Europe for clinker production (Fig.)
  - 184 of 266 kilo tonnes (70%) of waste bricks and tiles were used in Austria only
- **Future prospects**
  - Potential to save primary resources and CO_2 emissions to a certain extent
  - Circular economy will improve separating and classifying of such materials
  - Due to the low use of waste bricks and tiles so far, it can be expected that its use will increase in the future. The high use in Austria in comparison to the EU MS underlines this expectation
- **Environmental and technical aspects**
  - Saving of primary resources and reduction of CO_2 footprint of cements
  - Waste of old bricks and roof tiles has no hazardous properties

Waste Concrete Aggregates, Concrete Fines, (Concrete sludge)

The processing of waste concrete in a crusher produces coarse and fine fractions. The coarse fractions (> 2mm) can be reused as recycled-concrete (RC) aggregates in concrete. Depending on their composition, the fine concrete fractions can be used as an alternative raw meal component in clinker production, as a cement component (MIC) or as a sand substitute. Crushed concrete fine fractions are particularly suitable for use as a clinker raw material when they have a high Ca, low carbonate and low Si content. In most cases, the transport distances for processing and reuse are decisive for a sustainable and economic application. Refined processing to defined high quality RC-materials with low sulphate and sand (Si) components will allow for higher rates of use as partially calcined ARM in clinker and cement production in the future.

Comp.	wt.-%
SiO_2	63
Al_2O_3	4
Fe_2O_3	1.7
CaO	5 - 12
MgO	1
K_2O	1.1
Na_2O	0.6
SO_3	0.9
TiO_2	0.2

Table: typical composition of concrete fines

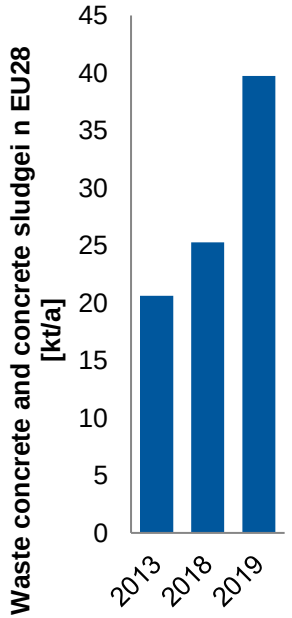


Figure: Use of Waste concrete and concrete sludge in clinker production

- **Characteristics**
  - The important components of recycled concrete for cement & concrete industry are: a) the content and use of aggregates and b) the CaO (already calcined material) and SiO_2 contained in fine fractions
  - The use as ARM in clinker saves CO_2 from calcination and the use in cement saves primary resources (e.g. limestone)
- **Current use**
  - So far, only very little amounts (< 1%) of waste concrete are recycled as RC-aggregates and crushed sand
  - In clinker: in 2019 only 40 kt of waste concrete and concrete sludge were used as ARM in EU28 for clinker production (Figure). 11 kt (28%) were used in Austria.
  - In concrete: in 2020 less than 500 kt were used as RC-aggregates in concrete in Germany (no data available from other EU MS). Most of the 60 Mt/year crushed concrete and mineral RC-materials is currently used as backfill material for underground construction.
- **Future prospects**
  - High potential for use as RC-aggregates in concrete, for use as ARM for clinker (10-18% of raw meal), and cement component (enforced carbonation/mineralization, “CCS” in fine material possible)
  - Circular economy will force the nearly complete use of wastes from demolition
  - For 2050 potential for doubling of RC-material processing (e.g. in Germany to 120 Mt/year) and predominant use for clinker, cement and concrete production is envisaged
  - Sustainable and economically viable with short transport distances (mobile processing and reuse in ready-mixed-plants)
- **Environmental and technical aspects**
  - High potential for use as ARM in clinker and cement production, thereby saving CO_2 from calcination and/or limestone
  - Capture of CO_2 from point sources by mineralisation; resulting materials are useful as RC-aggregates or cement component
  - Unwanted components in recycled concrete can be minimized to certain degrees by sorting at the demolition site and further crushing and advanced processing of concrete waste fractions

Bottom ash (slag) from waste incineration

In 2018, ca. 96 mio. tons of waste (municipal, commercial and industrial) were treated in waste-to-energy plants in Europe (source: CEWEP). The combustion process produced ca. 19 mio. tons of bottom ash (BA), which is the incombustible residual part of the incinerated waste. BA is composed of a mineral fraction (80-85%), metals (10-12%; steel and non-ferrous metals – NFM) and non-ferrous metals (2-5% of which 2/3 is aluminum). In order to extract the valuable metals, BA is processed either on site or in specialized facilities, e.g. by magnetic separation, sorting to different size fractions, separation of NFMs, stabilization by ageing (6-20 weeks). The mineral fraction (BA-MF) is today used e.g. in road construction or as artificial sand or gravel. Furthermore, BA are being used in small shares in clinker and also in concrete production.

Comp.	wt.-%	Comp.	mg/kg
SiO_2	55 - 65	Cu	1,500 – 3,500
Al_2O_3	6 - 8	Mn	700 – 3,400
Fe_2O_3	2 - 10	Pb	200 – 2,000
CaO	8 - 12	Ni	20 - 650
MgO	1 - 3	Sb	70 - 170
K_2O	0.5 - 2	V	0 - 100
Na_2O	5 - 8	Zn	2,000 – 11,000
SO_3	0 - 1	Ti	5,000 – 10,000
P_2O_5	0 - 1		

Table: Typical composition of the mineral fraction of incinerator bottom ash (source: VDZ research project)

- **Characteristics**
  - The important components of BA-MF for building materials industry are CaO and SiO_2.
  - Due to its main compounds BA-MF can principally be used as ARM in clinker production
  - The availability of BA varies significantly among EU MS, mainly depending on regional incineration capacities
- **Current use**
  - The use of BA-MF in construction materials varies significantly among EU MS, mainly depending on regional availability and permitting
  - Very small quantities of BA-MF are used as aggregates in concrete production
  - High SiO_2 content limits BA-MF use as ARM in clinker production to a few %
- **Future prospects**
  - Due to EU waste policy, CEWEP expects an increase of waste incineration until 2035 to >125. mio. tons
  - Current research aims at decreasing the heavy metal contents by pre-treating of the BA-MF
- **Environmental and technical aspects**
  - Due to the decarbonated CaO content the use of BA-MF in clinker reduces CO_2 emissions and the use of primary resources
  - BA-MF is high in heavy metal contents, which limits permitting in several EU MS

Summary (1)

- The use of ARM in EU MS differs significantly between countries because of
  - Differences in permitting (incl. environmental requirements)
  - Different historically disposal methods
  - Different technical equipment regarding emissions abatement (e.g. Regenerative thermal oxidation (RTO) to reduce organic emissions)
  - Strong variations in cement market in some EU MS
- The availability of some traditional ARM will decrease (significantly) in the future (fly ash, BF slag), ***but***
- In some MS historic landfills could be recovered and be made available for cement/concrete production
- Some new ARM have to be made available for the cement and concrete industry (e.g. ashes from sewage sludge incineration, bottom ashes from incineration, slags from steel production with direct reduction, artificial aggregates produced with captured CO_2)
- Construction & demolition wastes offer big quantities
  - Their use in clinker production is limited by their composition (e.g. concrete fines are rich in Si, which has to be compensated in clinker raw meal with high quality limestone)
  - Use of concrete waste as recycled aggregates in concrete is the biggest opportunity

Summary (2)

- Limitations:
  - Low Ca content in most ARM limits their use in clinker to a few percent
  - Some materials will have to be treated to make them suitable for cement/concrete (e.g. elimination of high heavy metal contents)
  - Content of organic matter limits the use of ARM in the raw mill – such materials can only be used in the hot kiln section or in plants equipped with RTO technology
- Impact on CO_2 emissions is limited
  - Currently about 0.4 mio t CO_2/a are abated EU-wide by the use of decarbonated ARM in clinker production
  - The availability of decarbonated ARM is very limited in quantity compared to clinker production
  - In order to achieve the 8%-target envisioned by Cembureau the use of ARM on a EU level has to be significantly increased to a degree even significantly higher than today level in Austria

List of Main Information and Data Sources

- CEMBUREAU roadmap
- ERMCO report
- CEMBUREAU statistics about ARM utilization (Annex)
- GCCA - GNR data
- Interviews with national associations of 7 key countries
- ECRA expert knowledge and research

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european cement research academy

Annex: CEMBUREAU statistics about ARM utilization (2019)

Region: CEMBUREAU All								
	Type	Tonnes	Type Si	Type Ca	Type Fe	Type Al	Type Si - Al - Ca - Fe	Type other (if significant) Please specify
1	Fly ashes	1 798 979	X	X	X	X	X	
2	Blastfurnace & converter slag	944 126		X	X	X	X	
3	Used Foundry Sand	539 793	X		X	X	X	
4	Secondary iron oxide	536 056			X		X	
5	Bottom ash, slag and boiler dust	499 723	X	X	X		X	X
6	Fe-containing materials, unless otherwise listed below	483 705	X	X	X	X	X	
7	Others	458 709	X	X			X	X
8	Si-containing materials, unless otherwise listed below	454 652	X	X	X	X		
9	Secondary sand	438 136	X					
10	Others (Soils)	428 282	No data available					
11	Waste ceramics, bricks, tiles and construction products	377 792	X	X	X	X	X	X
12	Lime waste	351 759	X	X			X	
13	Pyrite ash	320 214			X		X	X
14	Millscale	318 625			X			
15	Al-containing materials, unless otherwise listed below	309 945		X	X	X	X	
16	Wastes from stone cutting and sawing	305 017	X	X		X	X	
17	Ca sources, unless otherwise listed below	288 304		X			X	
18	Si-Al-Ca-Fe containing materials, unless otherwise listed below	262 557	X	X	X	X	X	
19	Spent bricks	183 113				X	X	
20	Waste blasting material	170 839			X			
21	Calcium-based reaction wastes from flue-gas desulphurisation in solid form	93 539	X	X				
22	Hydrated lime	57 731		X			X	
23	Skimmings	55 950				X		
24	Gypsum (residual)	53 792		X				X
25	Wastes from the processing of slag	42 760			X	X	X	
26	Waste concrete and concrete sludge	40 789	X	X			X	
27	Al-dust	35 129				X		
28	Wastes from cement-based composite materials	32 092	X	X	X		X	
29	Glass waste	31 566	X			X		
30	Refractories	21 960	X			X	X	
31	Foundry slag	17 339		X	X		X	
32	Machining sludges containing dangerous substances	16 542			X			
33	Sands from fluidised beds	6 494	X					
34	Spent katalyst	5 814				X		
35	Casting cores and moulds which have undergone pouring	5 378	X				X	
36	Wastes from mineral non-metalliferous excavation	4 960		X				
37	Spent potliners	1 400	X			X		X
38	Welding wastes	-						
39	Spent catalyst	-						
Total		9 993 559						

Annex: CEMBUREAU statistics about ARM utilization (2019)

Region: CEMBUREAU EU28								
	Type	Tonnes	Type Si	Type Ca	Type Fe	Type Al	Type Si - Al - Ca - Fe	Type other (if significant) Please specify
1	Fly ashes	1 573 011	X	X	X	X	X	
2	Blastfurnace & converter slag	613 619		X	X	X	X	
3	Used Foundry Sand	457 291	X		X	X	X	
4	Secondary iron oxide	505 318			X		X	
5	Bottom ash, slag and boiler dust	283 124	X	X	X		X	X
6	Fe-containing materials, unless otherwise listed below	443 850	X	X	X	X	X	
7	Others	415 868	X	X			X	X
8	Si-containing materials, unless otherwise listed below	149 627	X	X	X	X		
9	Secondary sand	403 065	X					
10	Others (Soils)	163 914	No data available					
11	Waste ceramics, bricks, tiles and construction products	266 355	X	X	X	X	X	X
12	Lime waste	348 795	X	X			X	
13	Pyrite ash	182 969			X		X	X
14	Millscale	318 625			X			
15	Al-containing materials, unless otherwise listed below	284 560		X	X	X	X	
16	Wastes from stone cutting and sawing	305 017	X	X		X	X	
17	Ca sources, unless otherwise listed below	206 311		X			X	
18	Si-Al-Ca-Fe containing materials, unless otherwise listed below	205 818	X	X	X	X	X	
19	Spent bricks	183 113				X	X	
20	Waste blasting material	-						
21	Calcium-based reaction wastes from flue-gas desulphurisation in solid form	55 619	X	X				
22	Hydrated lime	55 587		X			X	
23	Skimmings	55 950				X		
24	Gypsum (residual)	41 285		X				X
25	Wastes from the processing of slag	42 732			X	X		
26	Waste concrete and concrete sludge	39 755	X	X			X	
27	Al-dust	35 129				X		
28	Wastes from cement-based composite materials	32 092	X	X	X		X	
29	Glass waste	31 523	X			X		
30	Refractories	21 776	X			X	X	
31	Foundry slag	17 339		X	X		X	
32	Machining sludges containing dangerous substances	16 542			X			
33	Sands from fluidised beds	6 494	X					
34	Spent katalyst	5 814				X		
35	Casting cores and moulds which have undergone pouring	5 378	X				X	
36	Wastes from mineral non-metalliferous excavation	4 960		X				
37	Spent potliners	1 400	X			X		X
38	Welding wastes	-						
39	Spent catalyst	-						
	Total	7 779 623						