By-Products from EAF Dust Recycling and Their Valorisation

Vlad POPOVICI

Bredero Shaw, Canada

5th Global Slag Conference, Brussels, 23-24 November 2009

Agenda

- Electric Arc Furnace Dust Global Production
- EAF Dust Recycling Processes
- By-Products of the EAF Dust Recycling
- Applications and Benefits

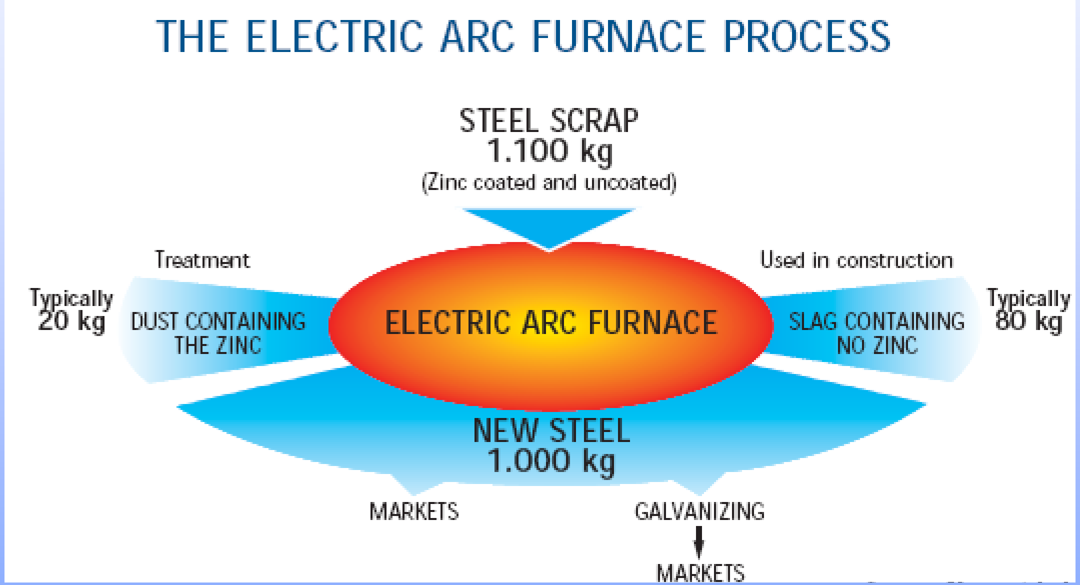
Electric Arc Furnace Dust Global Production

•Electric Arc Furnace (EAF) and Basic Oxygen Furnaces (BOF) represent ~98% of the global steel production

•Electric arc furnaces (EAF) use zinc-coated steel scrap as raw material

•For every tonne of EAF steel produced, 15-25 kg of EAF dust is generated

•EAF dust is generated as metals (zinc, lead) are being vaporized in the furnace and then oxidized and cooled in the outgoing air flow



Source EUROFER/IZA

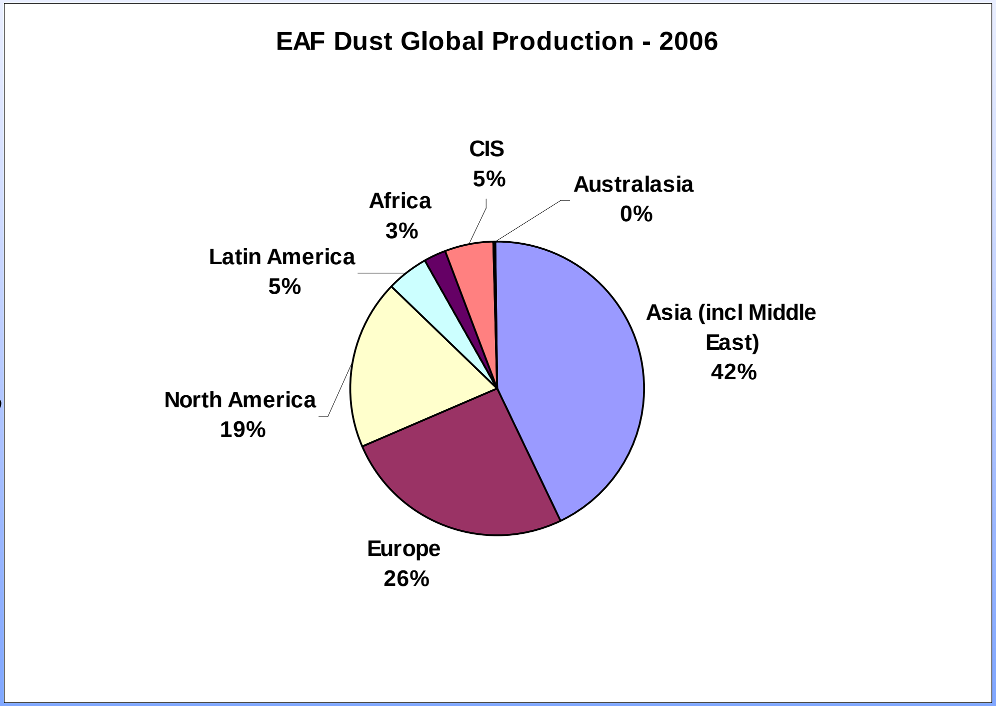
Electric Arc Furnace Dust Global Production

- EAF steel represented 32% of the global steel production in 2006

- The estimated global EAF dust production for 2006 is almost 7 million tonnes

- Significant producing regions are Asia, Europe and North America

- EAF dust production is expected to continue the growing trend of the last decades, as steel recycling grows around the world



Source: author calculations

Electric Arc Furnace Dust Global Production

Compound Name	% by Weight
Iron oxide	20-35%
Zinc oxide	5-40%
Calcium oxide	5-25%
Magnesium oxide	5-10%
Manganese	1-5%
Alumina	1-5%
Amorphous silica	2-7%
Lead	0.1-1%
Chromium	0.1-1%

Typical composition of an EAF dust material
Source DOFASCO

- EAF dust major components:
  - Fe and Fe oxides (30-40% by weight)
  - Zn (18-35% as Zn oxide, sulphide or chloride)
  - Calcium and silicon compounds
- Minor and hazardous components – lead, cadmium, chromium, etc.
- EAF dust is generally listed as a hazardous material in most countries (K061 in the US)
- EAF dust producers currently have two major options:
  - Chemically stabilize the dust and landfill it
  - Processing the dust in a metal recovery facility
- EAF dust – from both carbon steel and stainless steel production - is increasingly recycled, as the stabilization and disposal costs of hazardous materials are very high

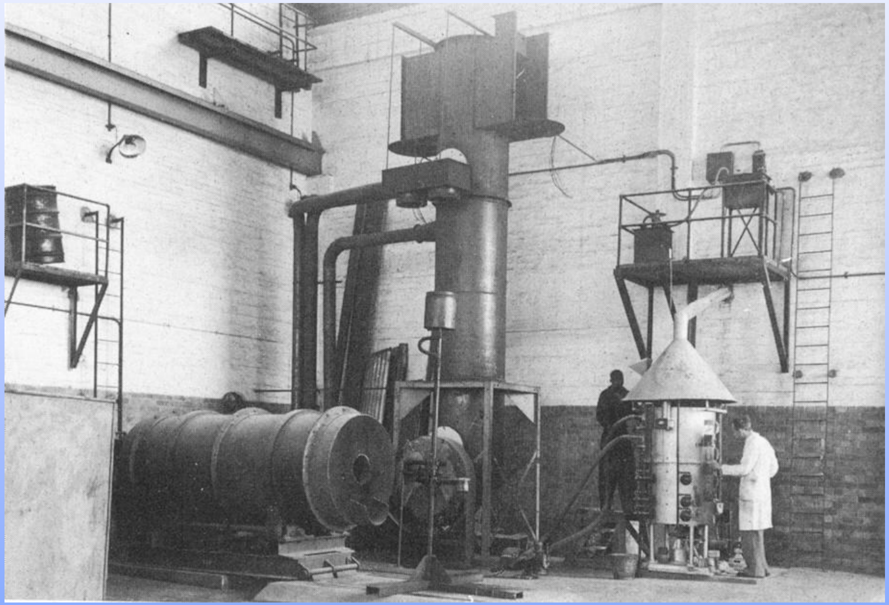
EAF Dust Recycling Processes

- More than 15 EAF dust recycling processes have been studied and developed
  - –Pyrometallurgical processes
  - –Hydrometallurgical processes
  - –Chemical separation processes

- However, >95% of the current EAF dust recycling capacity worldwide is provided by pyrometallurgical processes

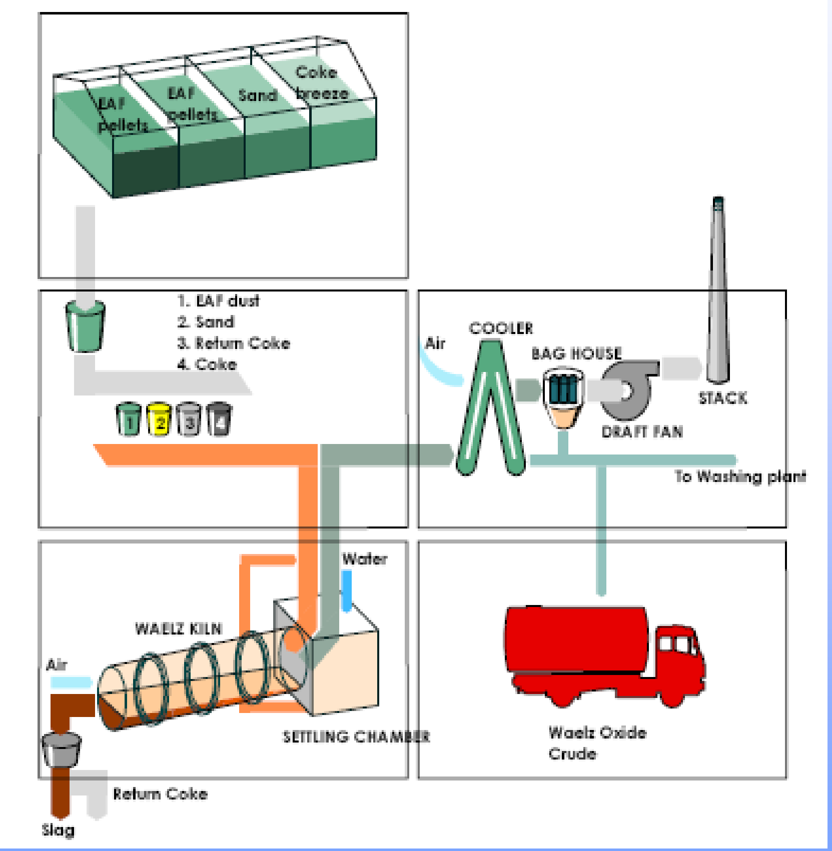
- The most common pyrometallurgical processes are the Waelz rotary kiln, rotary hearth furnace, plasma furnaces and shaft (OxyCup) furnaces

- 80% of the pyrometallurgical recycling capacity installed worldwide are Waelz rotary kilns



Pyrometallurgical laboratory in the 1950s
Source Mintek

EAF Dust Recycling Processes



The Waelz process for zinc recovery
Source ValoRes GmbH

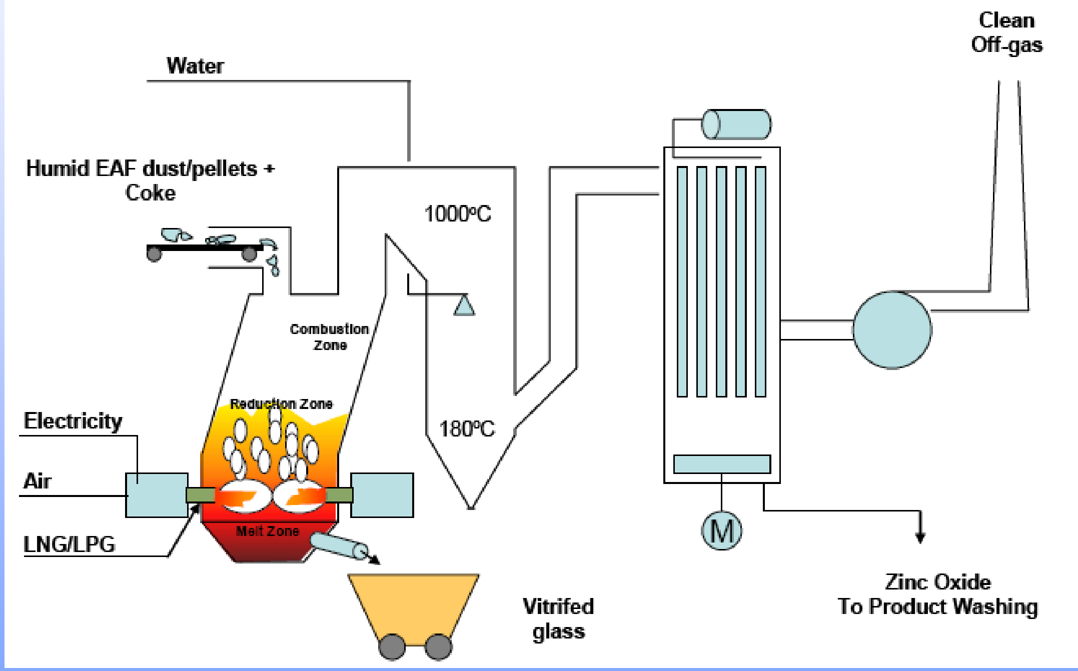
Waelz Rotary Kiln

- Reduction and volatilization of the EAF dust non-ferrous metals in a rotary kiln
- The kiln has a 2-3% inclination and rotates at about 1 rpm
- Inputs – pelletized EAF dust, coke breeze, binder (sand or lime), electricity and gas
- Outputs:
  - Zinc oxide – 55-65% Zn
  - Waelz slag – heavy iron-rich slag
- The process dominates the industry due to its long history (more than 100 years) and established technology status (listed as Best Available Technology in the US)

EAF Dust Recycling Processes

Submerged Plasma Process

- Reduction and volatilization of the non-ferrous metals in a 6 x 3.5 m furnace with plasma generators
- ZnO particles are carried by the outgoing gas and collected in a bag filter
- Inputs – pelletized EAF dust, coke, binder (sand or lime), electricity and gas
- Outputs:
  - Zinc oxide – 55-65% Zn
  - Heavy slag – iron, calcium and silica rich slag



The submerged plasma process for zinc recovery
Source ScanArc ASA

EAF Dust Recycling Processes

Output per tonne of EAF dust processed	Waelz Rotary Kiln	Rotary Hearth Furnace (RHF)	OxyCup Furnace	Submerged Plasma	Plasma Generators
Zinc Oxide	300-350 kg	50-100 kg	50-100 kg	400-450 kg	150-200 kg
Direct Reduced Iron (DRI)	-	600-750 kg	-	-	-
Pig Iron	-	-	300-900 kg	-	450-500 kg
Slag	**600-650 kg**	**-**	**350-400 kg**	**500-550 kg**	**400-450 kg**

Material Valorisation

- Valorisation of the main products of the EAF dust recycling processes is straightforward
  - **Zinc oxide** – sold to zinc concentrators – FOB price as of mid-2009: 1,400 USD/tonne
  - **Direct reduced iron (DRI)** – sold to steel producers – FOB prices as of mid-2009: 330-370 USD/tonne
  - **Pig iron** – sold to steel producers – FOB prices as of mid-2009 – 300-350 USD/tonne

- Valorisation of the by-product slags is more complex

By-Products of the EAF Dust Recycling

- EAF dust recycling slags are rich in calcium and silica oxides and have minor components such as magnesium, aluminium, zinc, etc

- Iron is a major component for slags generated in processes that do not recover the iron as DRI or pig iron

- Slags can contain hazardous materials such as heavy metals – lead, cadmium, chromium, etc

- Iron-rich slag material have a higher density range (up to 4,000 kg/cubic m)

Compound Name	**Weight Range (%)**
Fe	35-45%
CaO	17-25%
SiO_2	7-10%
Zn	2-3%
Mn	2-4%
Al_2O_3	2.5-3.5%
MgO	2.0-3.5%
$Na_2 + K_2O$	1-3%

Composition of a typical basic slag from the recycling of carbon steel EAF dust through the Waelz process

By-Products of the EAF Dust Recycling

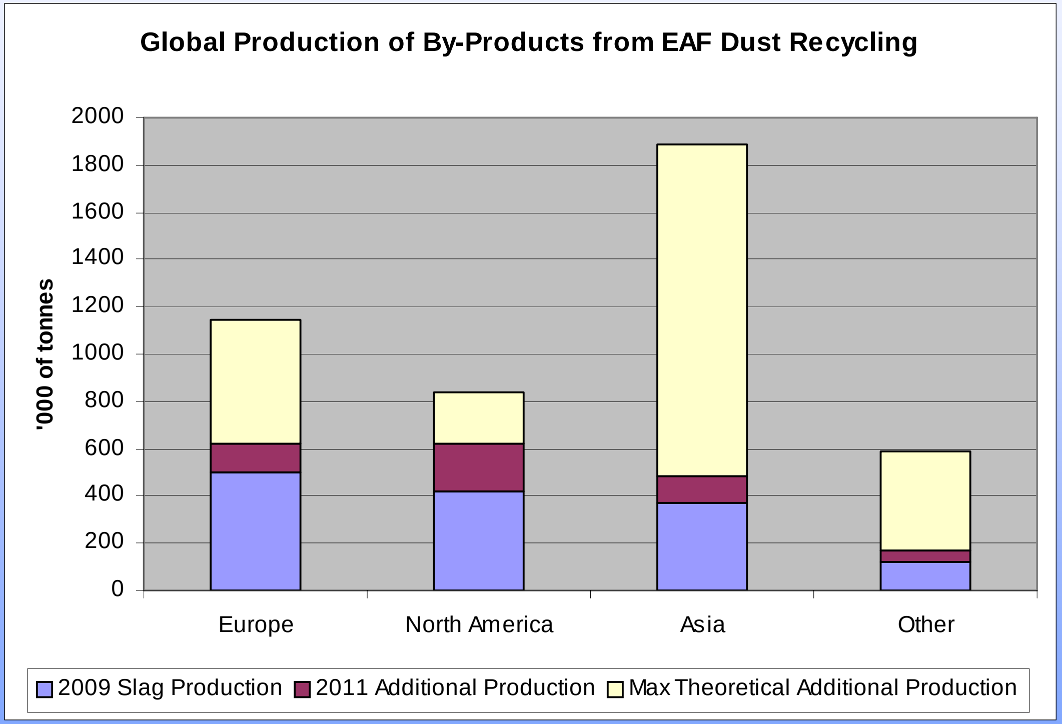
Compound Name	Weight Range (%)
FeO	0.5-5.5%
CaO	23.5-46.5%
SiO_2	25.0-46.0%
MnO	1.5-7.5%
Al_2O_3	1.5-19.5%
MgO	0.5-6.0%
TiO_2	0.5-6.0%
F	0.5-2.0%

Composition of a typical acidic slag from the recycling of stainless steel EAF dust through the plasma generators process

- When sand is used as a binder in the feed, the resulting slag will be acidic (more silica compounds than calcium and magnesium compounds)
- When lime is used in the feed, the resulting slag will be basic
- Granularity of the slag materials is variable depending on the cooling method at the end of the process
- Most slags are stable and are not considered hazardous materials

By-Products of the EAF Dust Recycling

- The annual global production of EAF dust recycling slags is currently around 1.5 million tonnes
- The main producing countries are the US, Germany, Spain, France, Italy, Taiwan, Mexico, Japan and Turkey
- New EAF dust recycling projects will bring online an estimated 500,000 tonnes of slag during 2010-11
- Beyond 2011, Asia (mainly China and India), Europe (including CIS) and Latin America have the highest non-tapped EAF dust recycling slag production potential



Source: author calculations

By-Products of the EAF Dust Recycling

Although it is difficult to estimate the future impact of the production growth drivers, we can assume that **the maximum theoretical global production of slag attainable during the next 5-10 years could reach up to 4.5 million tonnes per year !!!**

The main drivers of the global production of EAF dust recycling slags are:

- Increasing global steel production
- Increasing relative weight of the EAF steel production in the global steel production
- Increasing rates of EAF dust recycling around the world
- The increasing competition among the different EAF dust recycling processes

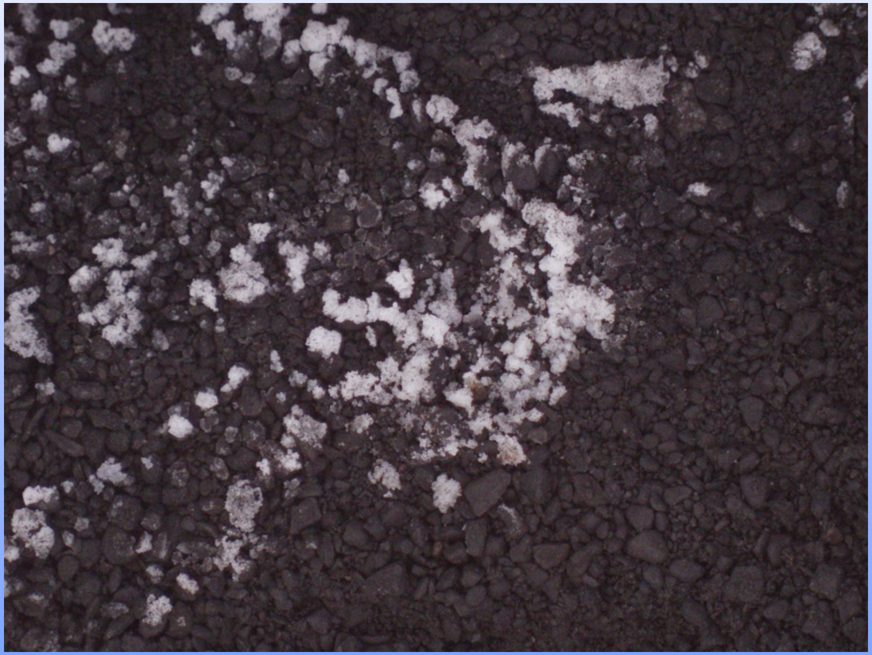
Applications and Benefits

	Application	Examples	Comments
High value applications	Cement production	- Iron-rich slags are used in kiln feed	- Slag replaces expensive iron ore
Medium value applications	Concrete manufacturing	- Slags can be used in structural concrete - Iron-rich slags are qualified for special concrete applications – concrete coatings for oil and gas pipelines	-Slag replaces natural aggregates -Slag enhances technical performance of concrete in some applications
Low value applications	Geotechnical applications	-Slag as road base aggregates -Used for landfill covers -Used in ground stabilization applications	- Slag replaces low-quality natural aggregates or other industrial by-products
	Asphalt	- Slag used as an aggregate in asphalt	- Slag replaces natural aggregates

Applications and Benefits

- **Material limitations**:
  - – Chemical composition – high concentration of heavy metals or leachates, undesirable components for certain applications (magnetite in certain cement manufacturing applications), outdoor aging impact
  - –Material composition is not consistent
  - –Each source and material has to be separately qualified for use
  - –Granularity – material has to be crushed or ground before use
- **Regulations**:
  - –Usage and applications restrictions in some countries
  - –Import/export restrictions
- **Logistics**:
  - –High logistic costs – the value-to-volume ratio of the slag materials is relatively low and does not justify their long-distance transportation

Slag Use Limitations



Outdoor storage whitening effect on an EAF dust recycling slag
Source: ShawCor

Applications and Benefits

	Cement production	Concrete manufacturing	Geotechnical and asphalt applications
Source and Slag Material Qualification Criteria	-Chemical composition -Composition consistency -Available slag volume -Slag FOB price -Slag freight costs	-Chemical composition – no leachate and hazardous materials -Composition consistency -Slag outdoor aging behavior -Slag density (for some applications) -Slag FOB price -Slag freight costs	-Chemical composition – no leachate and hazardous materials -Slag outdoor aging behavior -Slag FOB price -Slag freight costs

Applications and Benefits

Benefits

- **Users**
  - – Very good quality kiln feed material or natural aggregate
  - –Significant cost savings – lower material purchase price (especially when the slag replaces the iron ore in kiln feed) and logistic cost savings (if the slag source is closer than the iron ore or natural aggregate source)
  - –Avoided carbon dioxide emissions – as an example, 100 kg of carbon dioxide are emitted for the extraction of every tonne of iron ore

- **Suppliers**
  - –Avoided disposal costs
  - –Potential incremental revenue streams from high-value applications

Conclusion

- The EAF dust is increasingly recycled around the world

- The by-product slags from EAF dust recycling processes are interesting materials with growing worldwide production

- These slags have multiple high, medium and low value applications in the building materials and construction industries

- The use of these industrial by-products has clear benefits for both their users and their suppliers

- More work has to be done to increase the use of EAF dust recycling slags in high-value applications and to fairly share the value between suppliers and users

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