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Circular metallurgy through industrial symbiosis and hyper-connectivity in slag science

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- Summary

Top-tier industrial players in Korea

Top 10 Export Items in the First Half of 2021

Rank	Item	Export Value (USD 100 million)	Share of Exports (%)
1	**Semiconductors** System Semiconductors (5th)	571.3 175.9	18.8 5.8
2	**Petrochemicals**	260.7	8.6
3	**General Machinery**	259.7	8.6
4	**Automobiles** Eco-Friendly Vehicles	236 28.9	7.8 0.9
5	**Steel**	163.8	5.4
6	**Petroleum Products**	159.3	5.3
7	**Ships** High Value-Added Ships	118.6 49.2	3.9 1.6
8	**Auto Parts**	116.1	3.8
9	**Displays** OLED (14th)	92 58.3	3 1.9
10	**Bio-Health**	76.7	2.5

SAMSUNG
SK hynix
LG Chem
LOTTE CHEMICAL
HYUNDAI
KIA
POSCO
HYUNDAI STEEL
HD한국조선해양
Hanwha Ocean
SAMSUNG
LG Display

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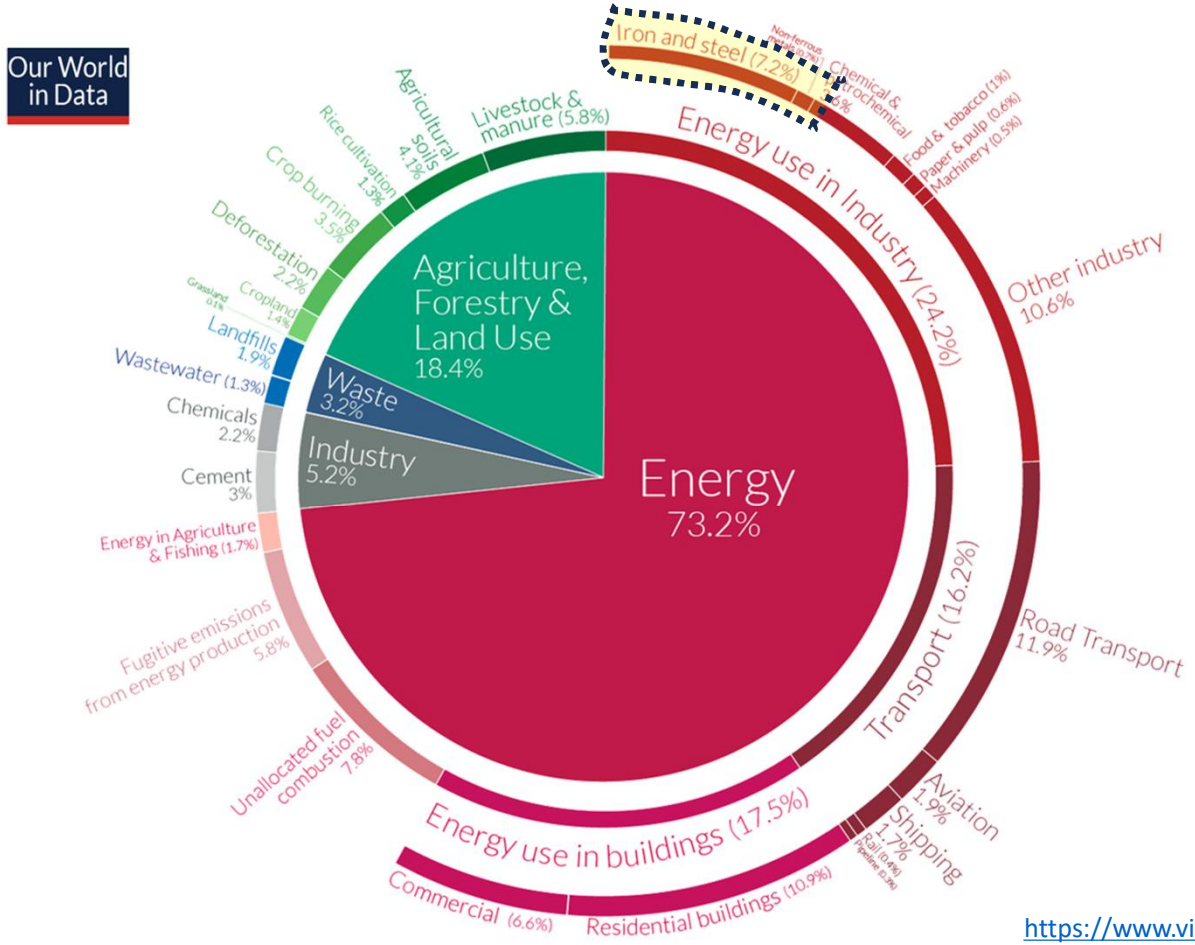
Global GHG emissions by sector (2020)



South Korea's steel industry at a glance

#6 largest steel producer globally

15% of South Korea's emissions come from steel

72% of steel production uses coal-based methods

24% – 38%
Projected cost premium of green hydrogen-based steel in 2035, compared with steel made using coal-based blast furnaces (under today's policies).

https://www.visualcapitalist.com/cp/a-global-breakdown-of-greenhouse-gas-emissions-by-sector/

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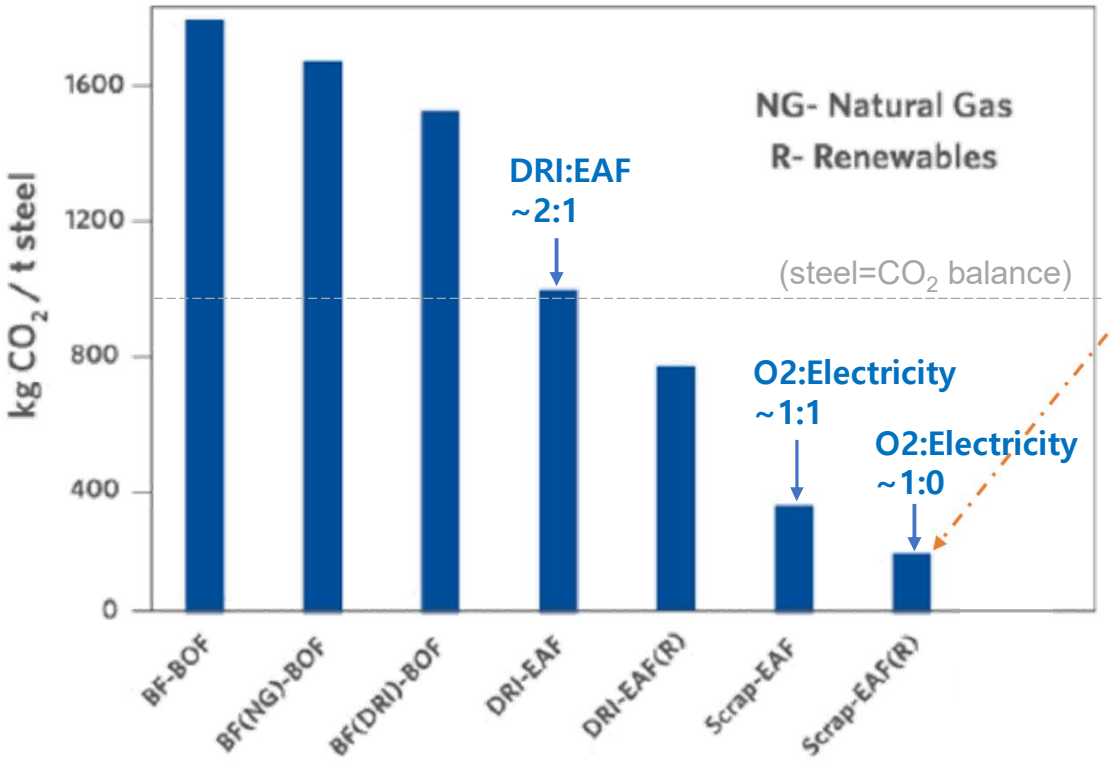
CO_2 generation by steel production routes



P.C. Pistorius (2022)

almost equivalent to 2050 CO_2 emission goal

CO_2 generation by mill type

	MTe Steel	%	MTe CO_2	%	Te CO_2/ Te_{Steel}
Total	1,869.0		3,170.2		1.6962
BF/BOF	1,346.0	72	2,961.2	92	2.2000
EAF	523.0	28	209.0	8	0.3996

- BF/BOF mill ; 72% of steel production → 92% CO_2 emission (~2.2 t-CO_2/t-steel)
- EAF(Scrap) mill ; 28% of steel production → 8% CO_2 emission (~0.4 t-CO_2/t-steel)

Case 1

Active Use of DRI/HBI in Sustainable EAF ; Perspective of EAF Slag



Image ; MIDREX, https://www.midrex.com/

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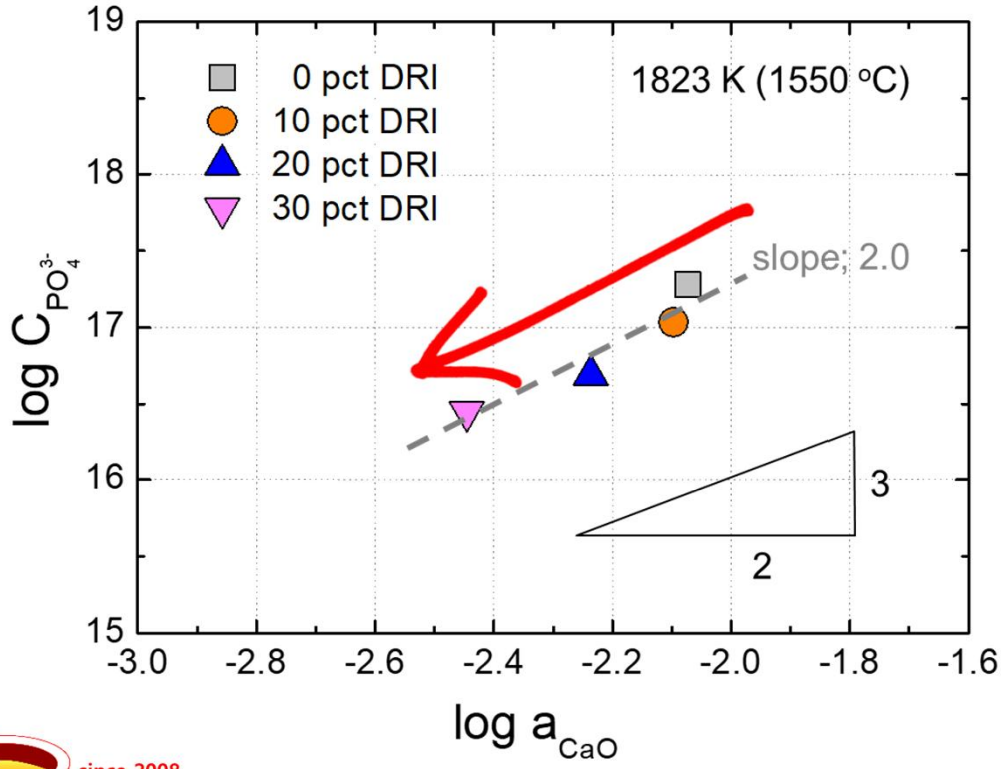
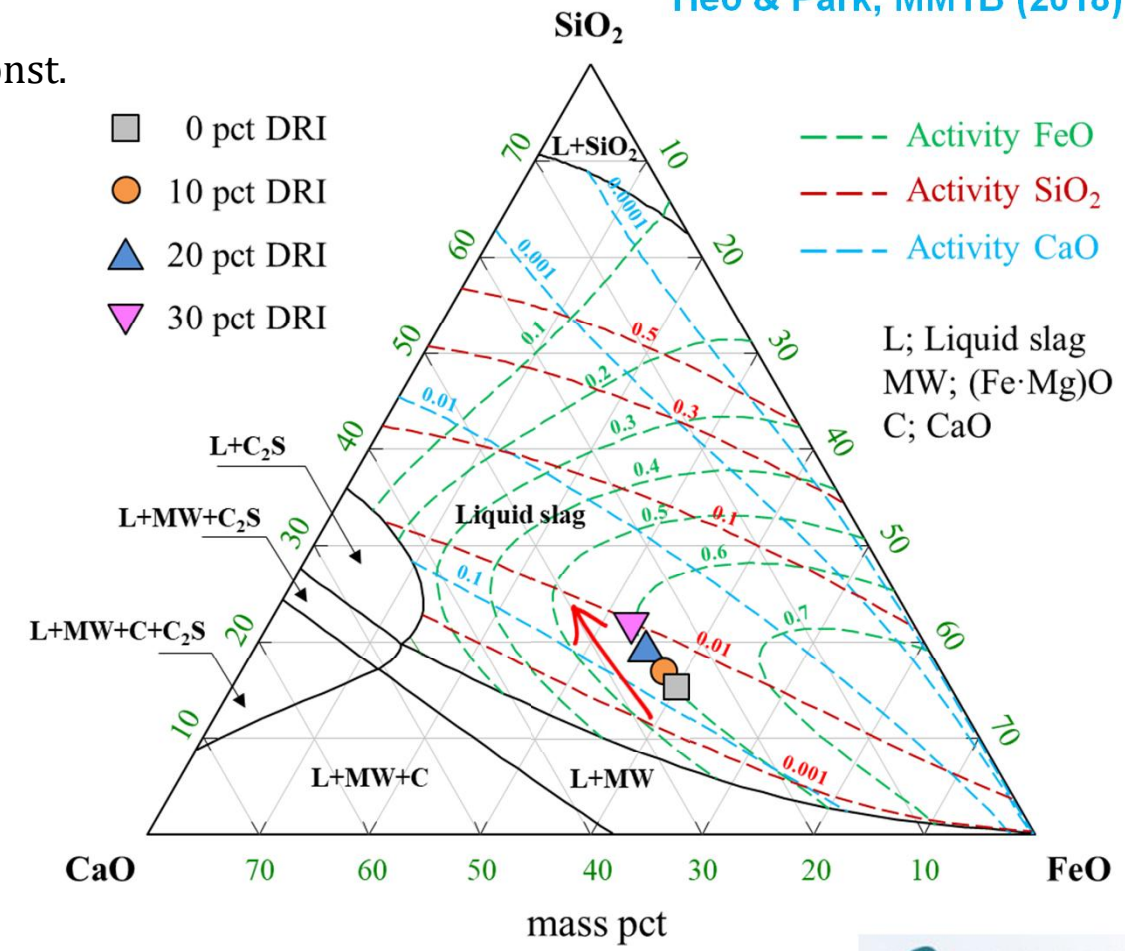
Effect of HBI on phosphate capacity of slags

$$\log C_{PO_4^{3-}} = \frac{3}{2}\log a_{CaO} - \frac{3}{2}\log a_{Ca^{2+}} - \log f_{PO_4^{3-}} + \text{Const.}$$



Heo & Park, MMTB (2018)



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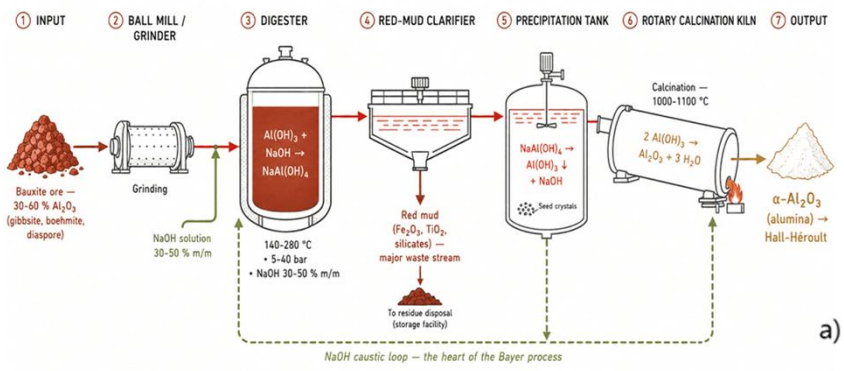
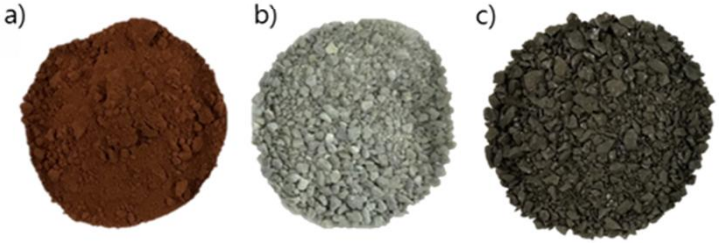
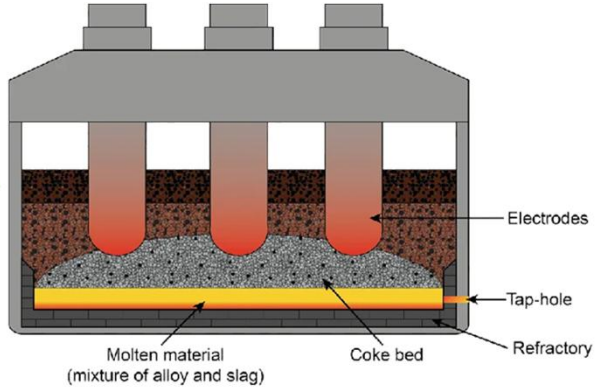
Industrial by-products as potential fluxing agents



From alumina industry



a) Red mud b) White mud c) FeMn slag

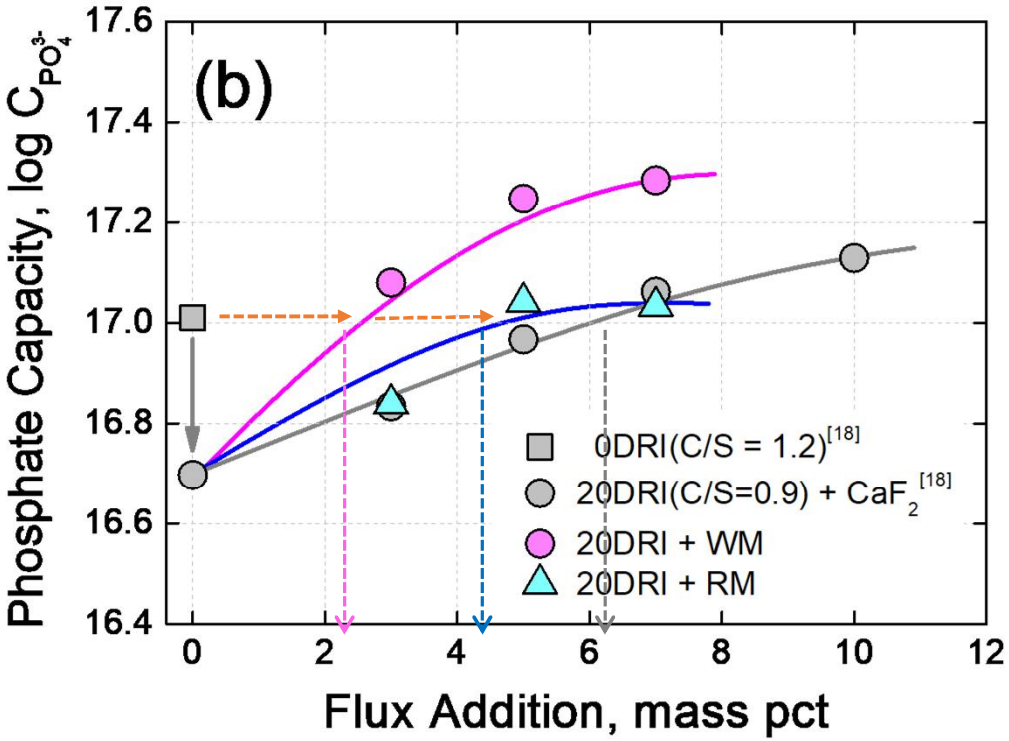


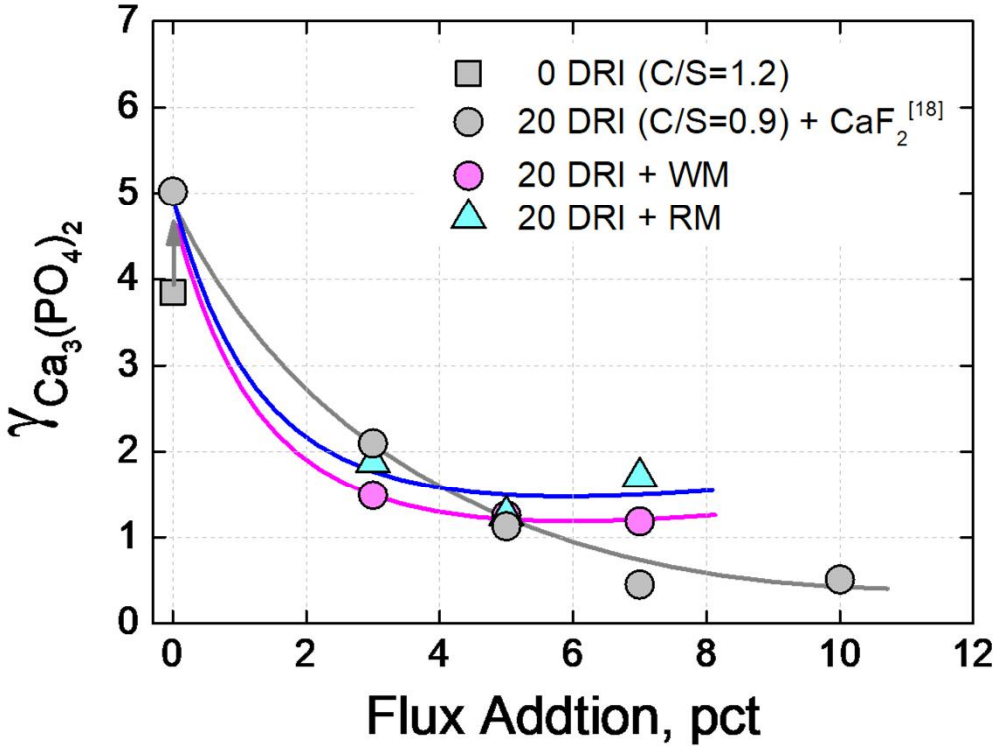
From ferroalloy industry

	CaO	SiO_2	Al_2O_3	MgO	MnO	Na_2O	Fe_2O_3	TiO_2
Red mud	7.1	12.9	26.9	-	-	4.8	40.9	7.5
White mud	46.8	2.5	40.7	0.9	-	9.1	-	-
FeMn slag	16.9	23.1	12.7	6.4	40.9	-	-	-

Park et al., MMTB (2021)

De-P efficiency of various fluxing materials





Park et al., MMTB (2021)

~2% white mud, **~4% red mud**, **~6% fluorspar**

➔ smaller than **10% lime** to restore basicity (=1.2)

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Case 2

Recovery of Fe and Mn from EAF Slag via Aluminothermic Smelting Reduction Process



Deutsche FotothekMetallurge für Erzeugung-Stahl, E-Werk

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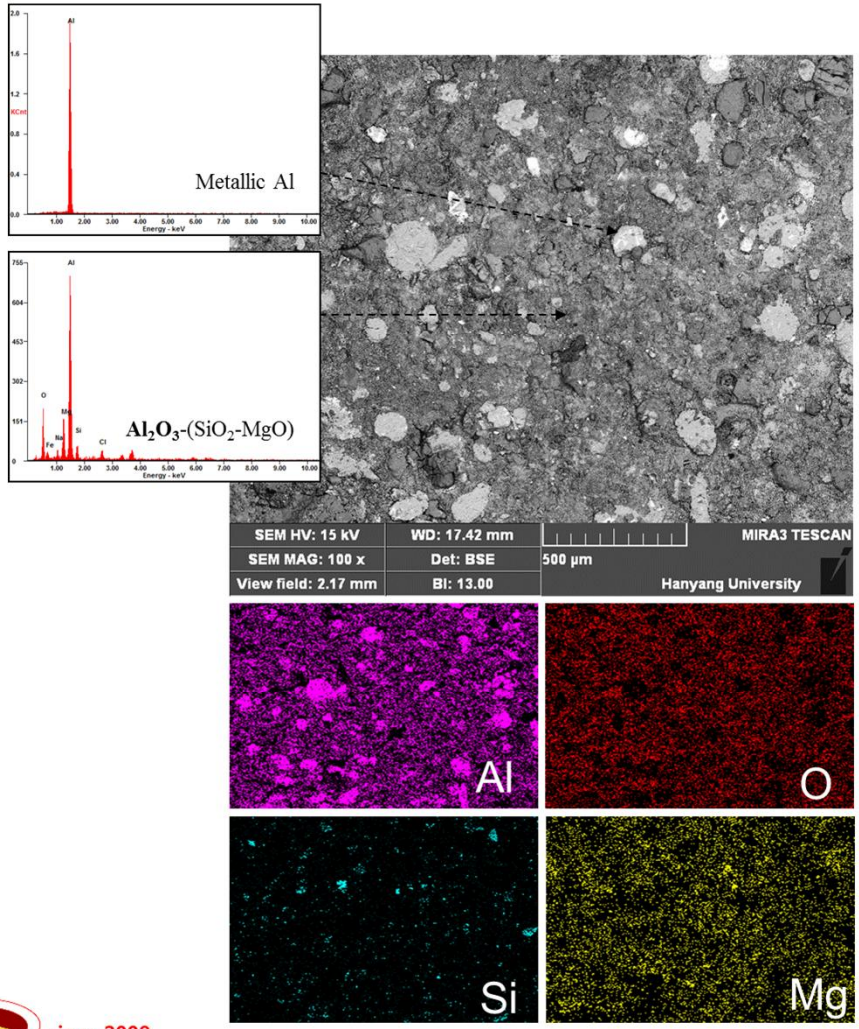
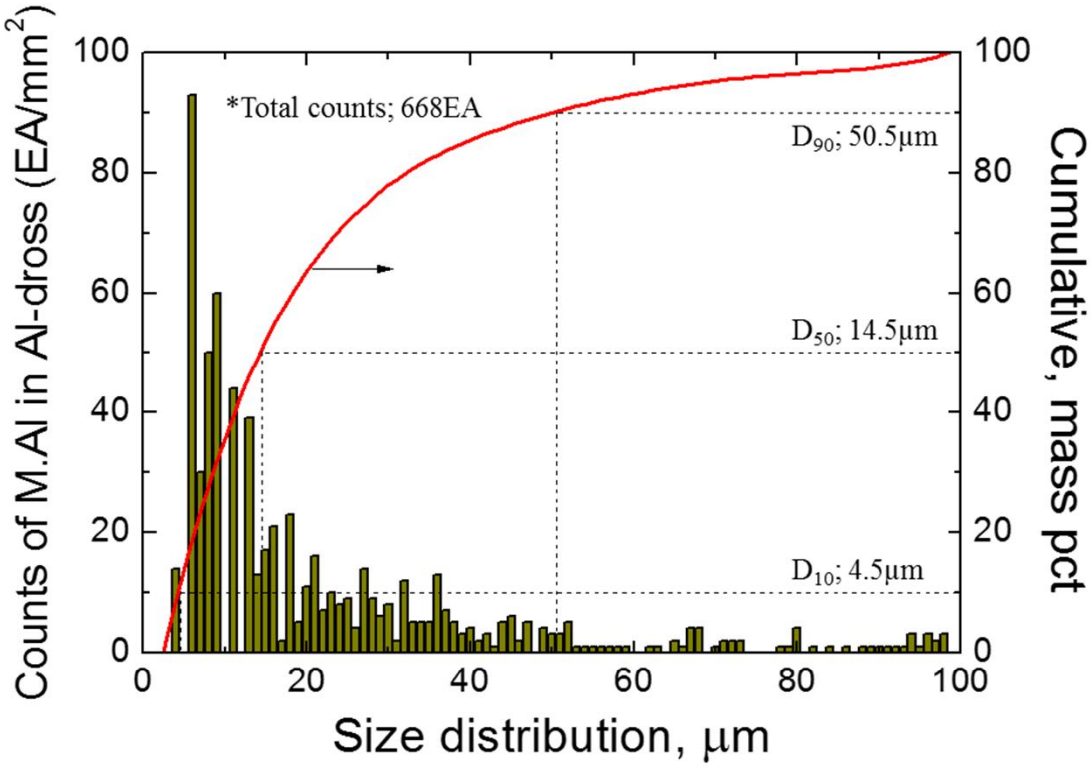
Characterization of Al-dross





→ Irregularly dispersed and fine metallic Al particles
→ Average diameter of metallic Al (D_{50}); 14.5μm

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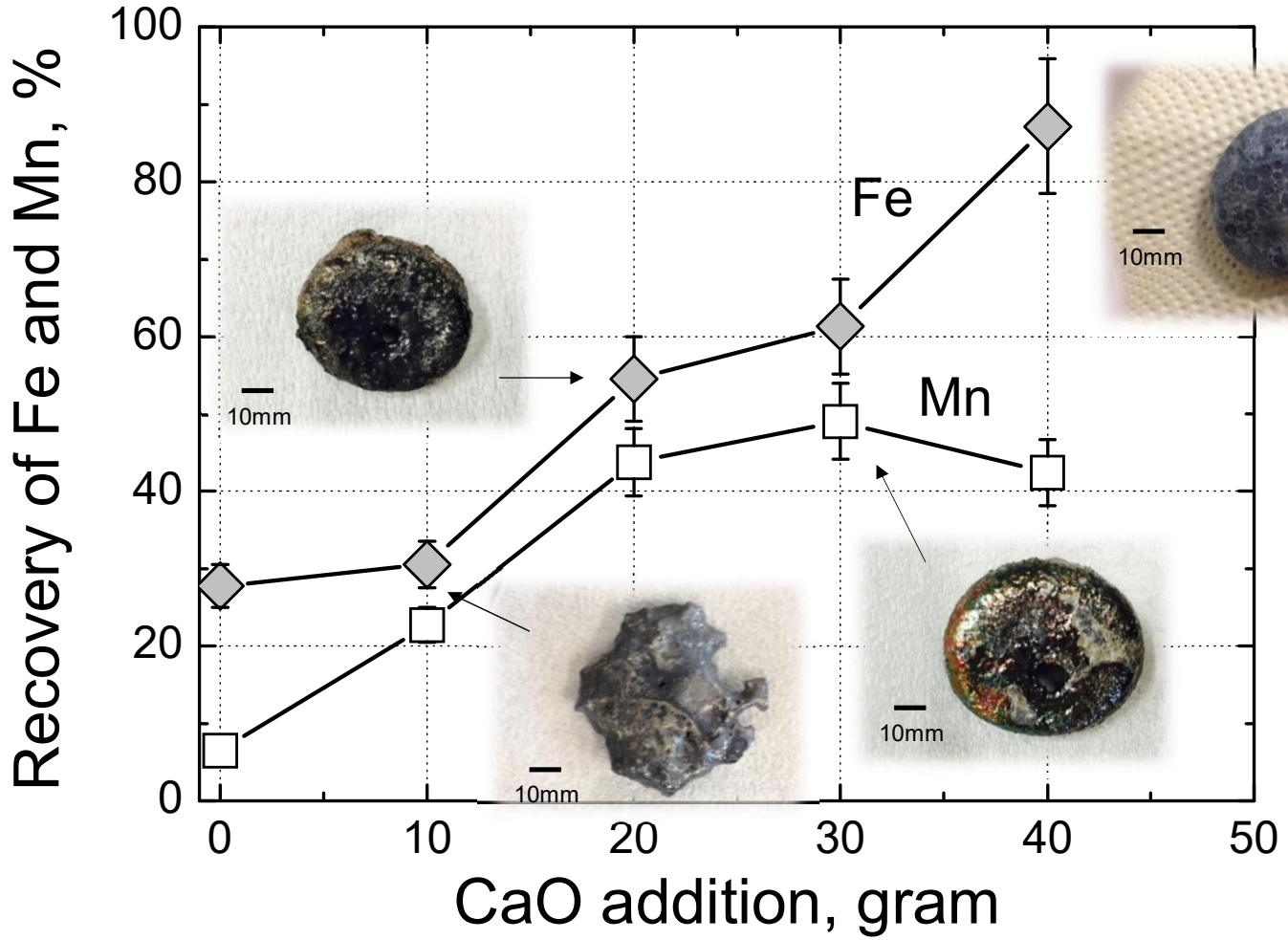
Effect of CaO addition on Fe and Mn recovery



Iron Recovery ;

$$\left(\frac{\Delta Fe(g)_{\text{in metal ingot}}}{Fe(g)_{\text{initial slag}}} \right) \times 100$$

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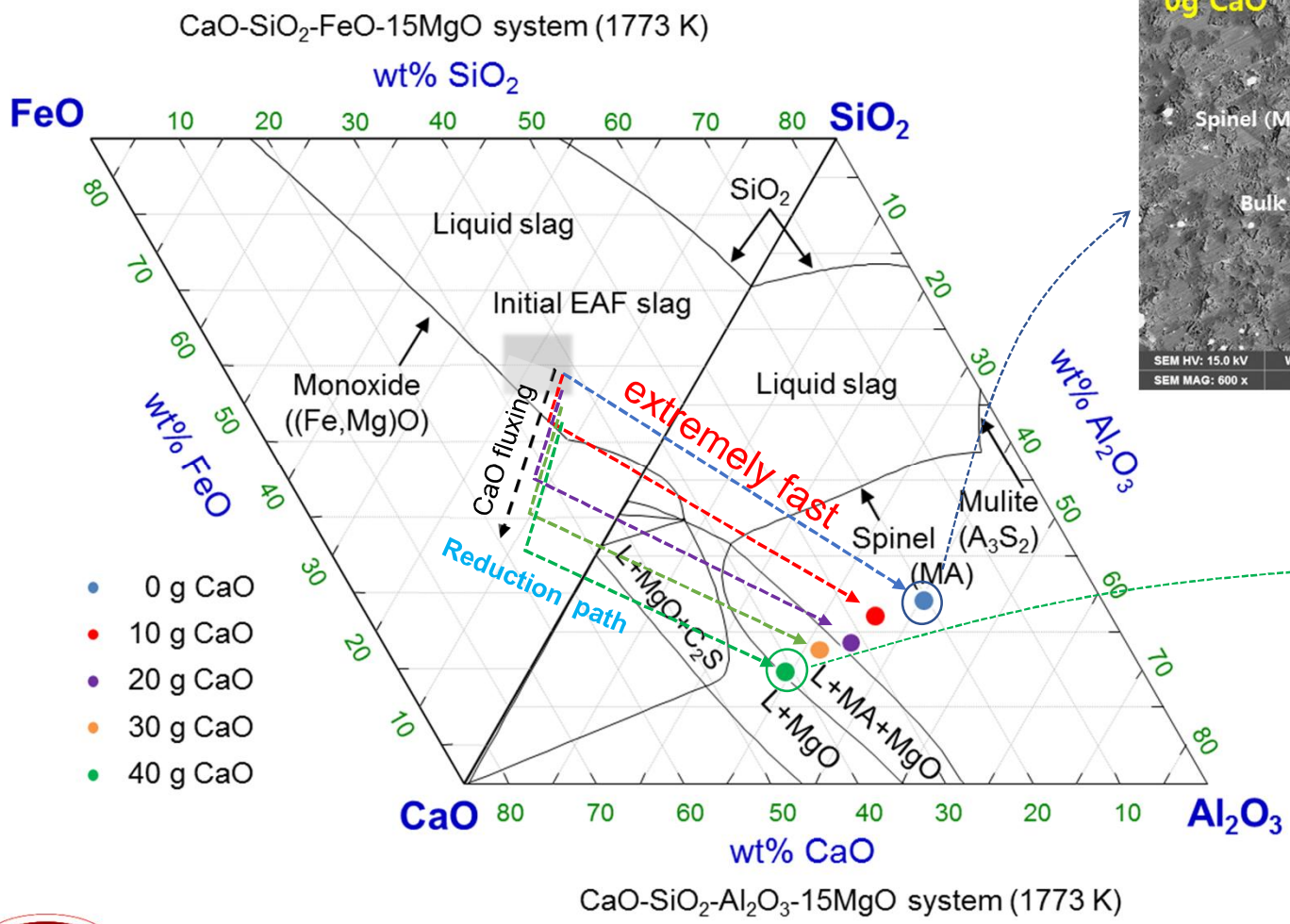
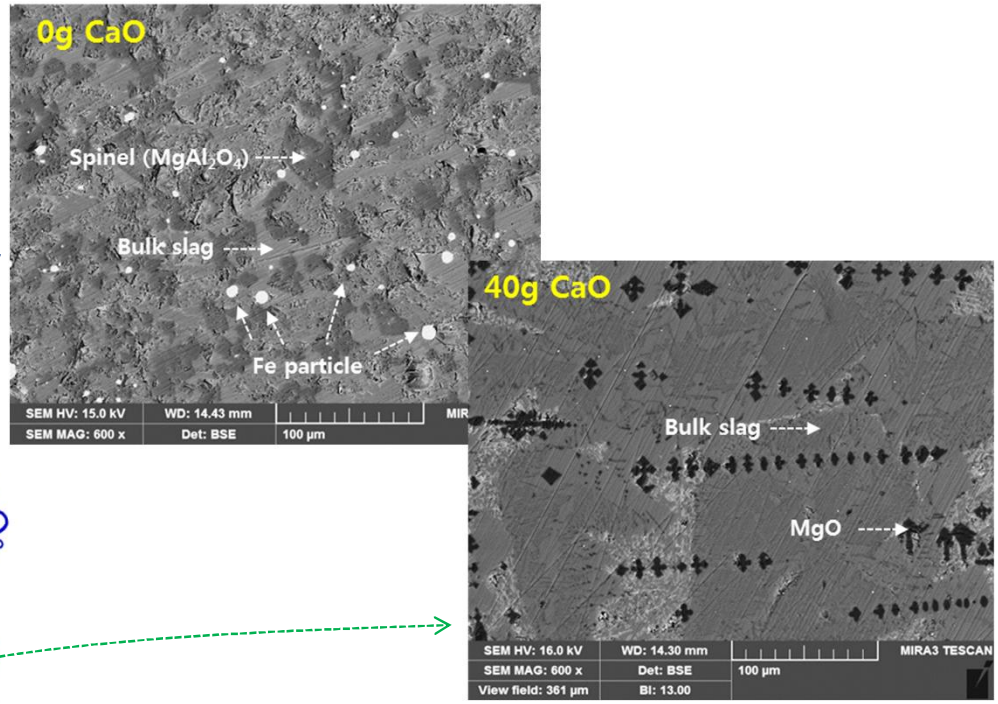
Reduction path of EAF slag by ASR process





CMAS system

➔ to be used as raw materials for refractory, cements and glass-ceramics industries

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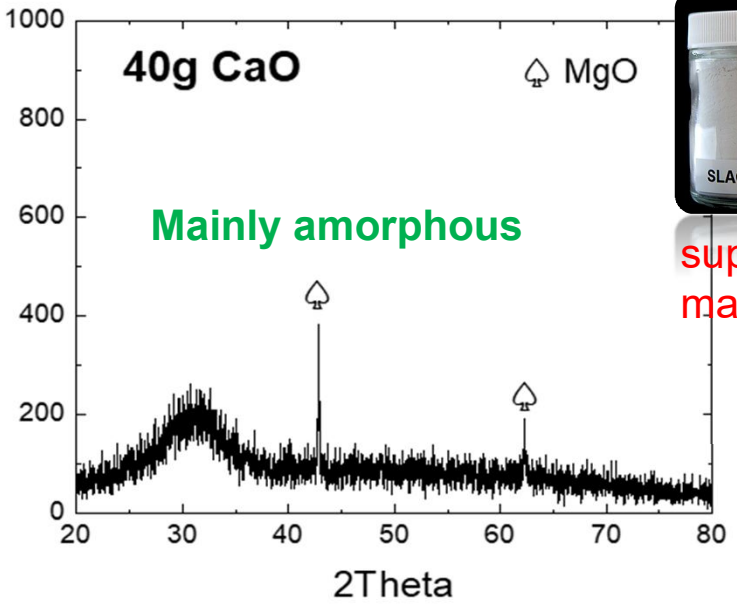
XRD analysis of final slags (60 min)

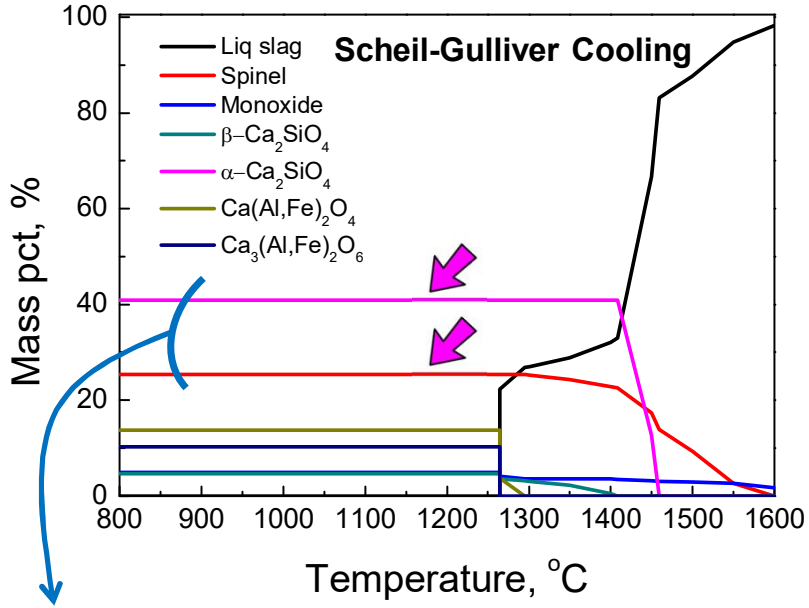
https://precast.org/blog/scms-in-concrete/

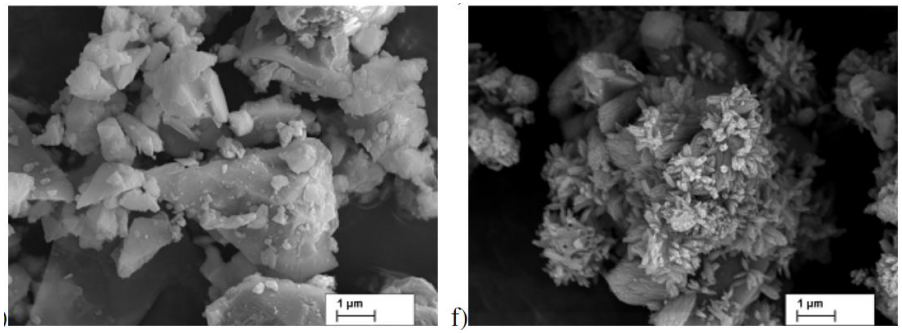




supplementary cementitious materials (SCM)

cooling





40%C2S-30%Spin.-Others

application to aqueous CO_2-binder (capture) materials
or
portland cements after separation of spinel?

Uibu et al. (Energy Procedia, '11)

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Case 3

Fluorine transfer from semiconductor industry to steel industry



Symbiotic transfer of fluorine

'F'-containing sludge cake
from Si-wafer cleaning and etching process (ca. 0.4Mton/y)

CaF_2	Al_2O_3	SiO_2	P_2O_5	S
77.2	6.4	3.8	0.2	1.1

(dried)

Conventional route



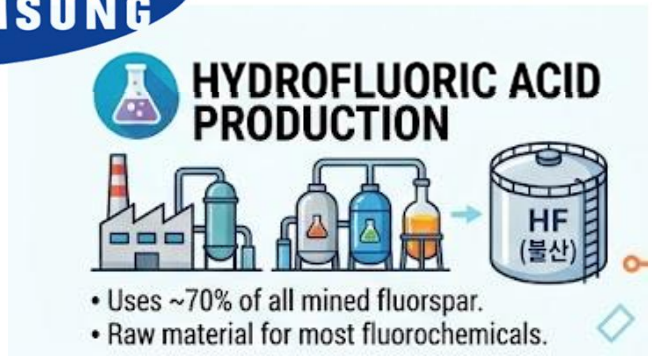
Cement industry





'F-containing flux briquet

SAMSUNG



Binder
+
Ladle slag

제철세라믹
www.poseramics.co.kr

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Symbiotic transfer of fluorine

아시아경제 실시간뉴스 > 국민의힘 문체위, 종묘·세운4구역 현장시찰

산업·IT > 기업·CEO

삼성전자-현대제철, 반도체 폐기물 재활용 신기술 개발

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제강용 불순물 거르
현대제철 매년 2t 항

[아시아경제 우수연 기
을 제철 공정의 부원료
현대제철이 매년 2만
수 슬러지)로 대체하다

유레카! 반도체 폐기물로 수입 광물 대체

2021/09/27

삼성전자와 현대제철은 반도체 제조공정에서 발생하는 폐수슬러지(침전물)를 제철 과정 부원료로 재사용할 수 있는 신기술을 공
개발했다.
※ 폐수슬러지: 반도체 공정 중 발생하는 폐수 처리 과정에서 나온 침전물로, 반도체 공정에서 발생하는 전체 폐기물의 절반 이상을

제철소의 제강 공정에서는 쇳물 속 불순물(황, 인)을 더욱 쉽게 제거하기 위해 형석을 사용하고 있는데, 반도체 폐수슬러지에 포함
(플루오린화칼슘, CaF2 50~60%)이 형석과 유사한 성분이라는 점에서 착안한 연구 결과다.
※ 쇳물에 형석(재활용제품으로 대체)을 투입하면 CaF2성분이 쇳물의 녹는점을 낮춰 불순물 제거 반응을 촉진하는 방식
※ 슬래그에 형석(재활용제품으로 대체)을 투입하면 CaF2성분이 슬래그의 녹는점을 낮춰 쇳물 속 불순물을 잘 흡수하여 제거하는
촉진하는 방식
– 쇳물 : 용융된 철(주요 성분 : Fe, C, 불순물 P, S)
– 슬래그 : 산화물(주요 성분 : FeO-CaO-SiO2-MgO)



English

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All News · 11:00 September 27, 2021

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SEOUL, Sept. 27 (Yonhap) – Samsung Electronics Co. and Hyundai Steel Co. said Monday they have developed a new technology that can reuse wastewater sludge created during the chip manufacturing process as a supplementary material in steelmaking.

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Samsung Electronics' Semiconductor Waste to Be Recycled at Hyundai Steel's Steelworks

·연합뉴스 2021.09.27 11:52 KST

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