NANYANG
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RESEARCH TOWARDS INNOVATION & ENTERPRISE

NANYANG ENVIRONMENT AND WATER RESEARCH INSTITUTE (NEWRI)

Residues and Resource Reclamation Centre
Nanyang Environment and Water Research Institute

Beyond Conventional Waste-to-Energy: The Promise of High-Temperature Slagging Gasification

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Towards zero waste for water & wastewater treatment

<u>**200,000** tonnes per year of DWS & **30,000** tonnes per year of DS</u>

Dewatered sludge

Dried sludge

28,000 tonnes
per year of ashes

Full by Year 2035

Rethink
sludge management

<u>**15,000** tonnes per year of WWS</u>

Waterworks sludge

Semakau Landfill

If we can produce

NEWater !

What stops us from generating

NEWSand ?

Waste-to-Energy Research Facility (WTERF)
Plug & play features for test-bedding and demonstration

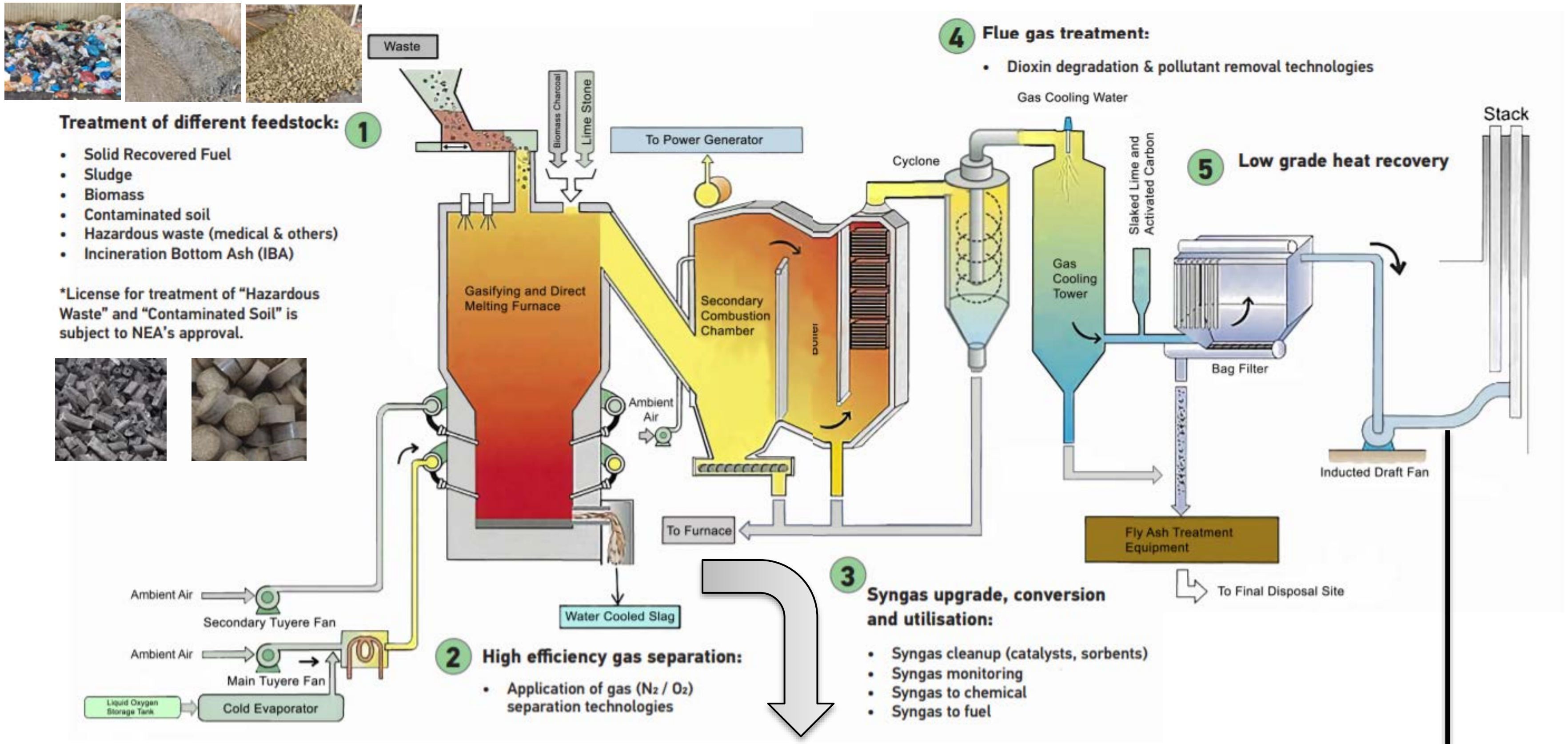
NEWSand

Environment Building

Tanah Merah Coast Road

Treatment of different feedstock → High efficiency gas separation → Syngas upgrading, conversion and utilization → Flue gas treatment → Low grade heat recovery

NTU Waste-to-Energy Research Facility – Test-bedding site



Capacity: 11.5 tonnes/day

Slag generation : 1 tonne/day

Operation time : > 6 months per year

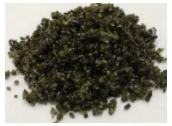
Total site area:

7000 sqm

Test-bedding area:

500 sqm

Value added by-products



Slag

Metal granules

Flue gas: 2800–3000 Nm^3/h	10-12 vol% CO_2
	65-70 vol% N_2
	6-8 vol% O_2
	15-18 vol% H_2O
	low concentrations of SO_2, NO_x, HCl, CO

Sludge and incineration ashes

Dewatered waterworks sludge from CCKWW
(Al-DWS)

Dewatered waterworks sludge from CCKWW
(Fe-DWS)

Dried sewage sludge from Changi WRP
(DS)

Dewatered sewage sludge from Ulu Pandan WRP
(UP-DWS)

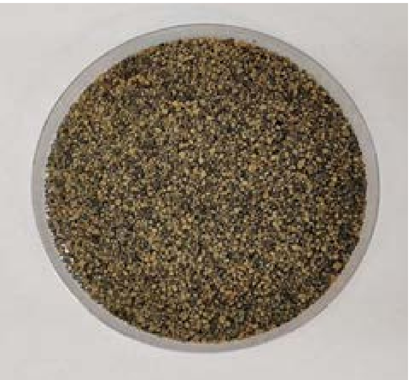
Dewatered sewage sludge from Jurong WRP
(J-DWS)

Dewatered sewage sludge from Kranji WRP
(K-DWS)

Mixed sludge incineration ash
(MA)

From incineration process 1

Sludge incineration fly ash
(FA)



Sludge incineration bottom ash
(BA)

From incineration process 2

Operation scenarios with various mixings

Operation schedule and records of various sludge/ash co-gasification at WTERF.

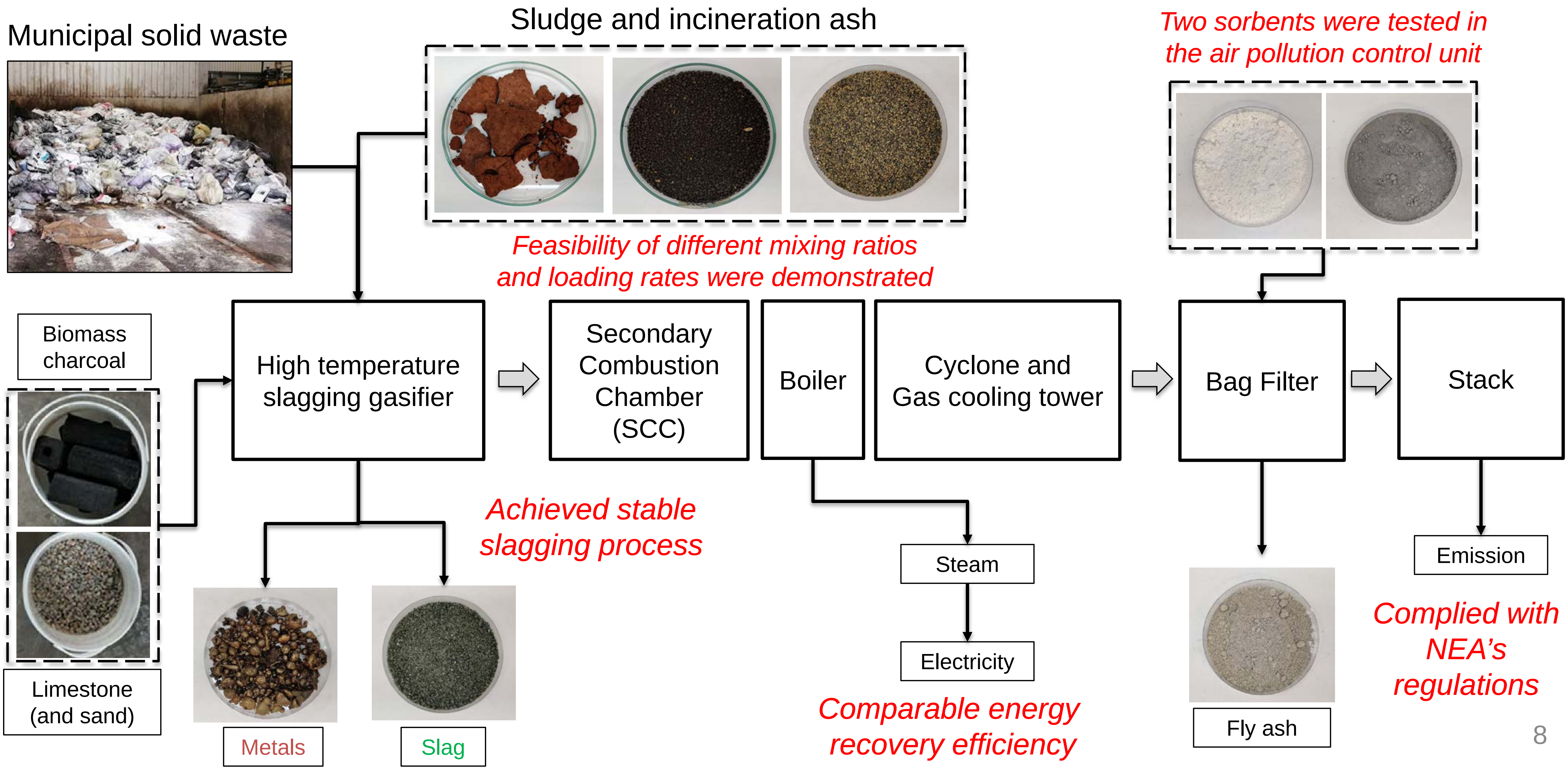
No.	Sludge/Ash	LLR loading ratio, %	HLR loading ratio, %
1	Al-DWS : MSW	10 : 90	20 : 80
2	DS : MSW	20 : 80	50 : 50
3	BA : MSW	20 : 100	30 : 100
4	DS + UP-DWS (*2:1*) : MSW	20 : 80	50 : 50
5	Fe-DWS : MSW	10 : 90	20 : 80
6	DS + J-DWS (*2:1*) : MSW	20 : 80	50 : 50
7	MA + UP-DWS (*1:1*) : MSW	20 : 90	40 : 80

Various mixing scenarios were designed to overcome the technical engineering issues including stickiness of DWS and flying fine particles of ash.

MA: Mixed ash
FA: Fly ash
BA: Bottom ash
DS: Dried sludge
DWS: Dewatered sludge
MSW: Municipal solid waste
Al-DWS: Alum waterworks sludge
Fe-DWS: Ferric waterworks sludge

- Low loading rate (LLR): Test the feasibility on co-gasification of sludge/ash with MSW.
- High loading rate (HLR): Test the limits of the operation at WTERF and establish the trends, if any.
- Loading of sludge and ash are accounted differently, where sludge is considered as the replacement for MSW (increase sludge, reduce MSW) while ash is considered as add-on to the operation of WTERF.

Co-gasification of MSW and sludge at WTERF



Leaching performance of sludge-derived slag

Batch leaching (L/S 2) EN 12457-1:2002

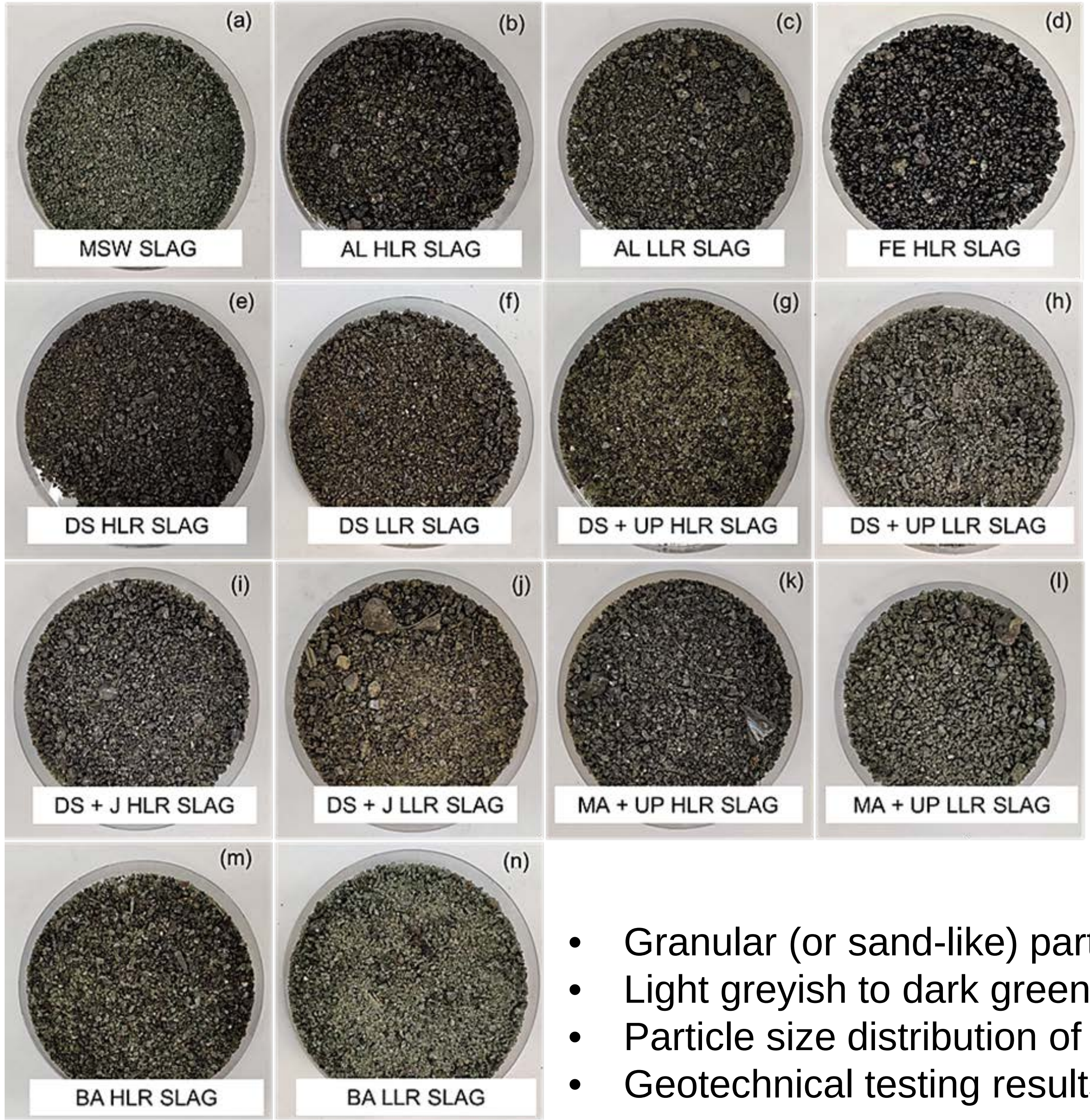
	NEA RVs	EU Criteria Inert	Slag 1		Slag 2		Slag 3		Slag 4	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
As	0.04	0.1	<0.0005		0.0011	0.0002	0.0009	0.0001	0.0017	0.0001
Sb	0.01	0.02	0.0054	0.0004	0.0035	0.0006	0.0086	0.0002	0.0035	0.0002
Ba	2	7	0.172	0.0092	0.0308	0.009	0.0332	0.0016	0.0143	0.0017
Cd	0.004	0.03	<0.0005		<0.0005		<0.0005		<0.0005	
Cr (total)	0.02	0.2	0.0046	0.0005	0.025	0.0078	0.0054	0.0001	0.012	0.0012
Cr (VI)	0.01		<0.01		<0.01		<0.01		<0.01	
Co	0.01		<0.0005		0.002	0.0007	<0.0005		<0.0005	
Cu	0.09	0.9	0.0077	0.0023	0.0627	0.0124	0.0096	0.0008	0.0101	0.0047
Mn	0.3		<0.0005		0.0708	0.0246	<0.0005		0.0077	0.0057
Hg	0.0005	0.003	<0.0005		<0.0005		0.0024	0.0001	0.0009	0.0002
Mo	0.2	0.3	0.0095	0.0015	0.0037	0.0003	0.027	0.0006	0.0056	0.0002
Ni	0.02	0.2	<0.0005		0.0042	0.0017	<0.0005		<0.0005	
Pb	0.02	0.2	0.0016	0.0005	0.0102	0.0043	<0.0005		<0.0005	
Na	400		16.4	3.7	25.3	3	12	0.3	8.3	0.4
Ag	0.01		<0.0005		<0.0005		<0.0005		<0.0005	
Se	0.02	0.06	0.0007	0.0001	0.0007	0.0005	0.0022	0.0001	<0.0005	
Sn	0.1		0.0017	0.0002	0.0053	0.002	0.0027	0	0.0017	0.0006
V	0.01		0.0008	0.0002	0.0032	0.0005	0.0044	0.0002	0.0073	0.0001
Zn	0.2	2	<0.0005		0.0372	0.0141	<0.0005		0.0024	0.0042
Br-	0.5		<0.2		<0.2		<0.2		<0.2	
Cl-	300	550	6.312	1.2524	7.1197	0.7956	4.3048	0.2292	1.6044	0.5772
F-	3	4	0.5872	0.0713	0.5623	0.0361	1.1763	0.0223	<0.2	
P	0.5		1.1967	0.152	1.1033	0.1665	0.8287	0.1266	0.71	0.1415
SO4	500	560	8.2204	1.6125	12.0493	1.0558	17.2803	0.2145	2.6158	0.2157

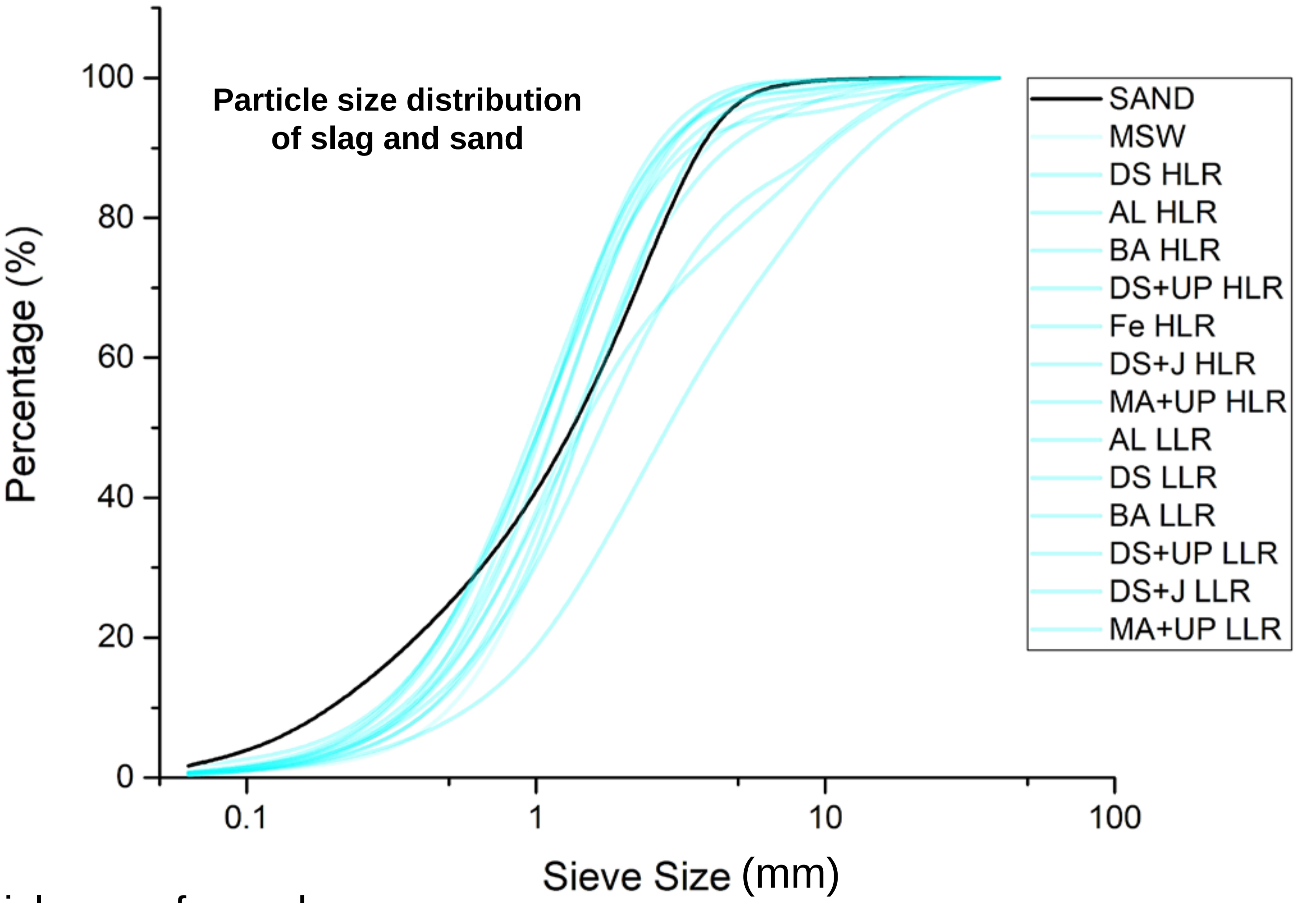
Toxicity Characteristic Leaching Procedure (TCLP)

	Regulatory levels	Slag 1		Slag 2		Slag 3		Slag 4	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
As	5	<0.02	-	<0.02	-	<0.02	-	<0.02	-
Ba	100	0.192	0.031	2.447	0.050	0.176	0.004	0.373	0.016
Cd	1	<0.02	-	<0.02	-	<0.02	-	<0.02	-
Cr	5	0.025	0.003	0.283	0.007	0.027	0.003	0.084	0.010
Cu	100	0.186	0.048	0.038	0.002	0.322	0.021	0.369	0.046
Fe	100	19.963	2.050	20.233	2.508	10.301	2.661	84.000	11.020
Pb	5	<0.02	-	<0.02	-	<0.02	-	<0.02	-
Mg	50	18.987	1.480	5.133	0.081	6.960	0.401	5.900	0.350
Hg	0.2	<0.02	-	<0.02	-	<0.02	-	<0.02	-
Ni	5	0.119	0.003	0.041	0.003	0.047	0.003	0.207	0.005
Se	1	<0.02	-	<0.02	-	<0.02	-	<0.02	-
Ag	5	<0.02	-	<0.02	-	<0.02	-	<0.02	-
Zn	100	0.258	0.045	0.195	0.052	0.605	0.118	0.397	0.303

- EU waste acceptance criteria for inert waste landfill and TCLP regulatory levels (RLs) are well met.
- Promising leaching performance was observed for the sludge-derived slags as compared to the draft Reference Values (RVs) from National Environment Agency (NEA) for wastes re-utilization.

Sludge-derived slag – a potential candidate as the NEWSand





- Granular (or sand-like) particles are formed
- Light greyish to dark green in colour
- Particle size distribution of sludge-derived slag is similar to sand
- Geotechnical testing results indicate suitability of slag to be used as concrete aggregate

Geotechnical performance of sludge-derived slag

Particle size distributions (PSD) of slag and river sand (based on BS EN 933-1: 2012).

Aggregate	Size	Percentage passing by mass			Tolerance in percentage passing by mass				Category G
		2D	1.4D	D	4	1	0.25	0.063	
Fine	D≤ 4 mm d=0	100	95-100	85-99	(±5)	(±20)	(±20)	(±3)	
Sieve size (mm)		8	6.3	4	4	1	0.25	0.063	G_F85
Slag 1	0/4	100.0	95.0	85.9	85.9	19.6	2.2	0.0	G_F85
Slag 2	0/4	100.0	98.0	85.0	85.0	15.3	2.0	0.0	G_F85
Slag 3	0/4	100.0	99.0	97.0	97.0	39.4	3.0	1.0	G_F85
Slag 4	0/4	100.0	99.0	98.0	98.0	45.0	5.0	1.0	G_F85
River sand	0/4	100.0	97.0	90.7	90.7	48.1	16.1	1.8	G_F85

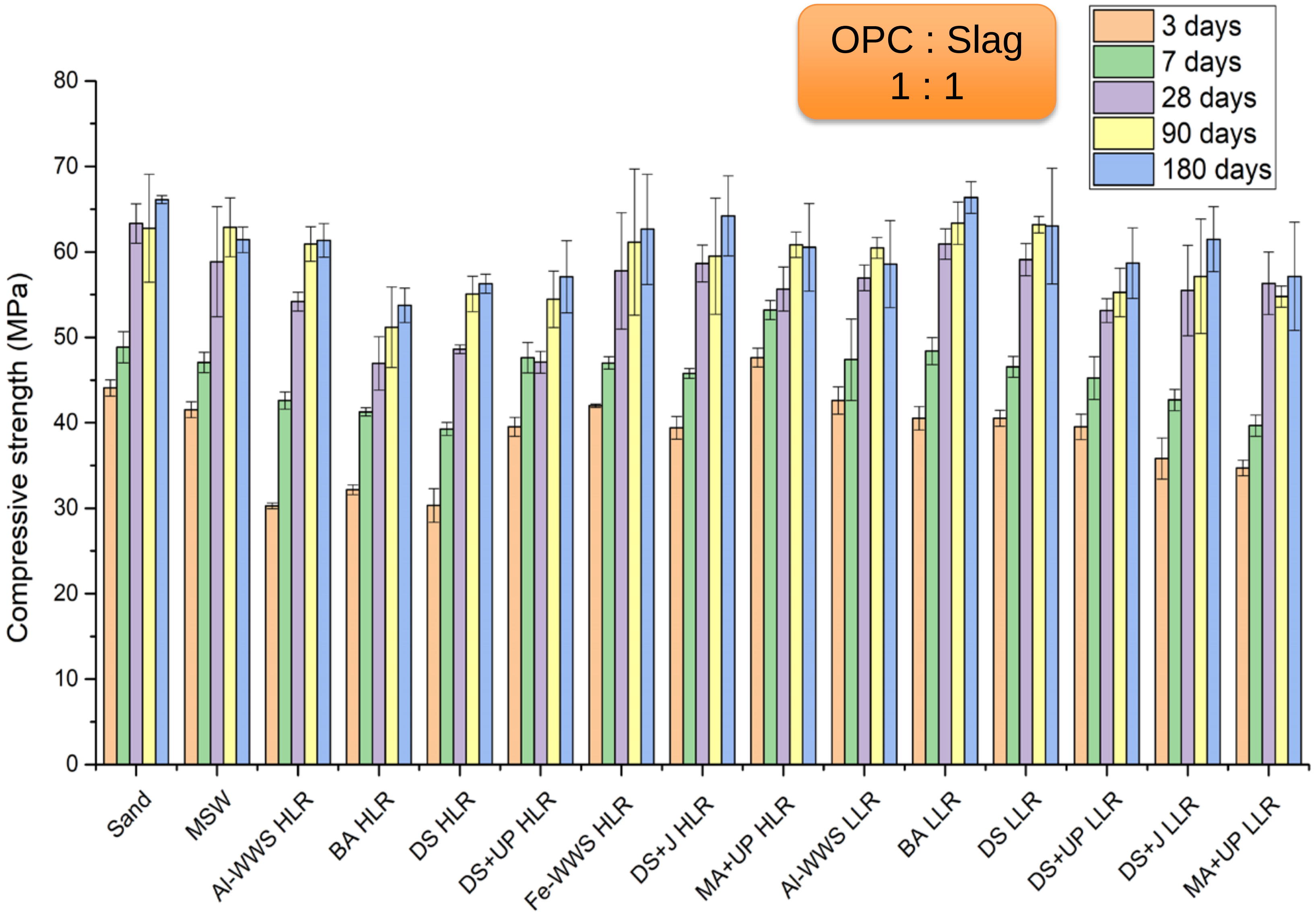
Physical property of slag

Slag

Test	Max	Min	Mean	SD	River sand
Fines content, passing 0.063mm sieve by mass (%) (BS EN 933-1: 2012)	0.90	0.30	0.58	0.24	1.83
Bulk density (g/cm^3) (BS EN 1097-3:1998)	1.51	1.31	1.39	0.07	1.34
Particle Density on an oven-dried basis (g/cm3) (BS EN 1097-6: 2013)	2.81	2.74	2.78	0.03	2.61
Particle Density on a saturated and surface-dried basis (g/cm3) (BS EN 1097-6: 2013)	2.83	2.76	2.80	0.03	2.63
Apparent particle density (g/cm3) (BS EN 1097-6: 2013)	2.86	2.79	2.83	0.03	2.66
Moisture content (%) (BS EN 1097-6)	2.74	1.07	2.09	0.62	11.45
Water absorption (%) (BS EN 1097-6)	0.66	0.60	0.64	0.02	2.30

- Slag is suitable for use as fine aggregates with a grading of G_F85 with accordance to BS EN 933-1.
- Achieved the best f_3 grading for the maximum values for fines content
- Low moisture content and water absorption

Compressive strength of slag mortar



Compressive strength of concrete mortar made of sand/slag with Ordinary Portland Cement (OPC).

Conclusions and future perspectives

- Sludge and incineration ash were successfully co-gasified at WTERF with MSW with smooth operation, stable slag generation and consistent energy recovery efficiency from these waste materials.

- Slag, a glass-like solid aggregate, is the major solid residue generated as a by-product from the co-gasification process, representing 70~90% of the overall gasification solid residues remained.

- Sludge-derived slag is showing great performance in various of leaching tests meeting different criteria.

- Sludge-derived slag is showing equivalent performance as sand when it is applied as a fine aggregate in concrete mortar which therefore can be classified as a potential candidate for producing NEWSand in Singapore.

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