Harvest green energy through energy recovery from waste: The story of Singapore

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- **Seeking renewable energy from MSW**



- Anaerobic Digestion
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1 Anaerobic Digestion

Anaerobic Digestion

- A microbial process to convert organic matter under oxygen free conditions into biogas, which mainly consists of methane (CH_4) and carbon dioxide (CO_2) with traces of other impurities, such as hydrogen sulphide (H_2S), ammonia (NH_3), and water vapor.

- The transformation of complex high-molecular-weight organic compounds can be generally expressed by the equation below.

$$\textbf{Organic matter} \rightarrow CH_4 + CO_2 + H_2 + NH_3 + H_2S$$

Digestion of FW in Singapore

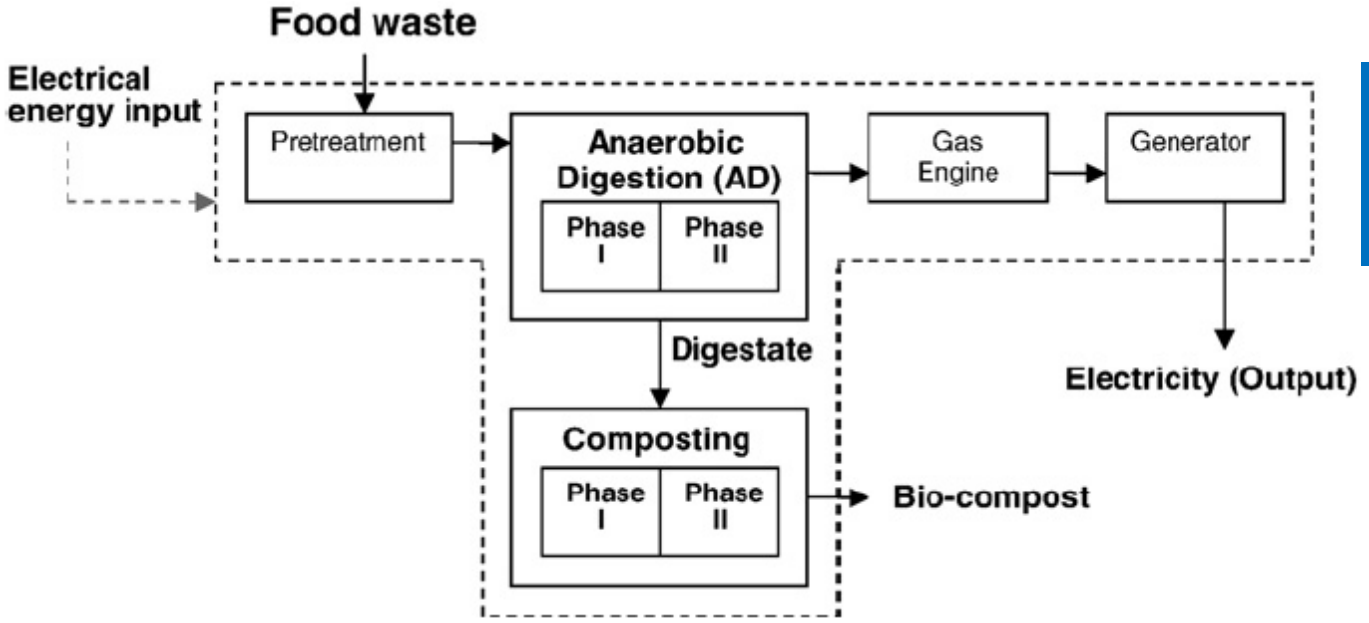
Year	Food waste disposed of (tonne)	Food waste recycled (tonne)	Total food waste generated (tonne)	Recycling rate
2016	680,260	110,740	791,000	14%
2015	681,400	104,100	785,500	13%
2014	687,200	101,400	788,600	13%
2013	696,000	100,000	796,000	13%
2012	618,100	85,100	703,200	12%
2011	605,800	69,700	675,500	10%
2010	538,100	102,400	640,550	16%
2009	529,400	76,700	606,100	13%
2008	500,000	68,000	568,000	12%
2007	507,700	51,200	558,900	9%



Digestion of FW in Singapore

- **IUT Global Pte. Ltd.** (1st food waste recycling company)

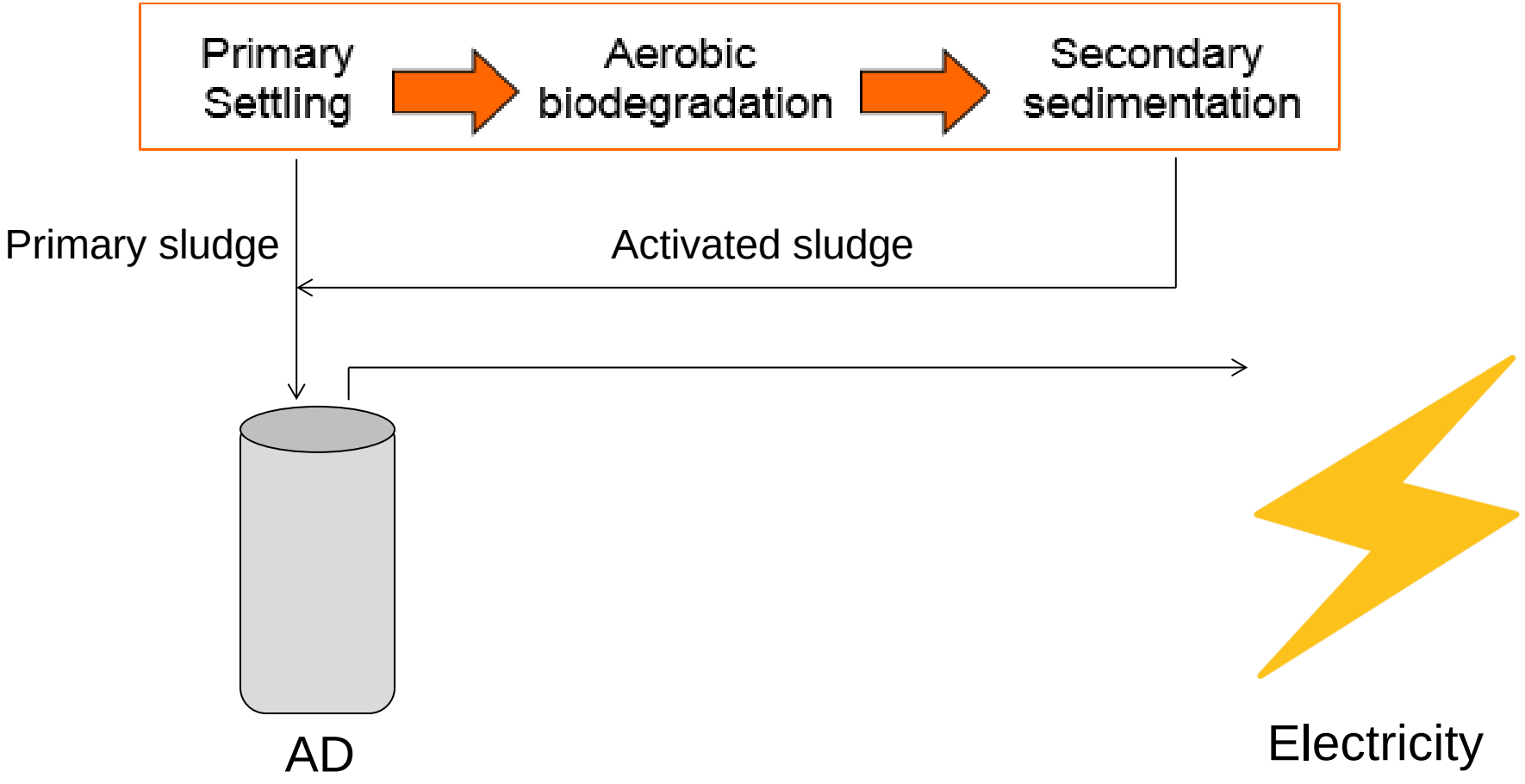
Establishment date	2005 - 2011	
Treatment Capacity	Phase I (*since 2007*): • 3.5 MW power • 300 tonnes of FW daily	Phase II (*since 2009*): • 6 MW power • 500 tonnes of FW daily
Food Waste source	Hawker centres, food courts, hotel, restaurants, and other commercial, industrial food establishments	



Reason for shutting down:
- Insufficient FW (130 t/day)
- Higher impurity (40%)

Digestion of Sewage Sludge in Singapore

- Currently **4** Wastewater Treatment Plants (WWTPs) in Singapore.

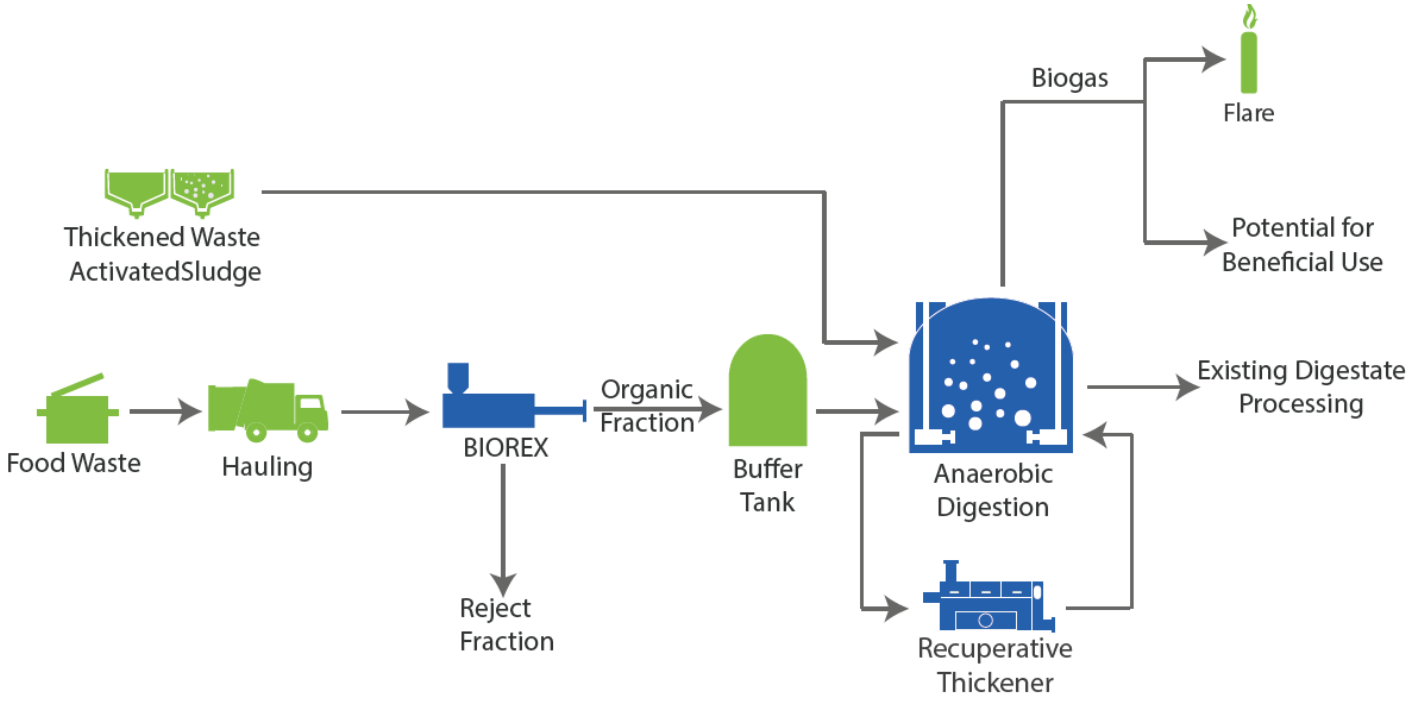


45% of VS decomposed
0.80 m^3 of biogas/kg degraded VS

supply 20-30% of energy in plant

Co-digestion of Sewage Sludge and FW

1st Co-digestion Plant	
Establishment year	2015
Company (s)	PUB and Anaergia Pte Ltd
Location	Ulu Pandan Water Reclamation Plant
Treatment Capacity	Testing phase; 40 tonnes feedstock/day
Benefits	• Utilize nutrients and microbes in both substrates • Take advantage of synergistic effect of microorganisms



Future plan:
- Co-digestion plant at IWMF
- 400 tonnes/day of FW

Integrated Waste Management Facility (IWMF) will co-locate with PUB's Water Reclamation Plant (TWRP) at Tuas.



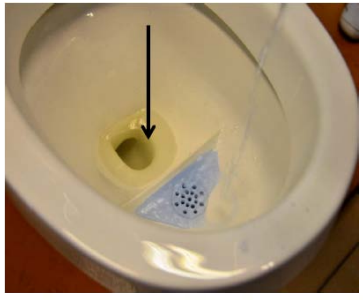
Animal Manure



Brown Water

Research trends of AD in Singapore

Horticulture Waste



Pre-treatment of Sewage Sludge



Nanyang Environment & Water Research Institute

NEWRI

R3C Residues and Resource Reclamation Centre

NUS National University of Singapore

E2S2 CREATE Energy and Environmental Sustainability Solutions for Megacities

NEWRI Your Global Research & Technology Partner

AEBC Advanced Environmental Biotechnology Centre

2 Combined Heat and Power generation from biomass firing

CHP generation from biomass

- Combustion based CHP, also known as co-generation, refers to the thermodynamic process which simultaneously produces electricity and heat from biomass firing in the furnace.

- Tri-generation is an extension to co-generation which involves the simultaneous production of electricity, heating and cooling in one conversion process.

Existing biomass CHP practice in Singapore

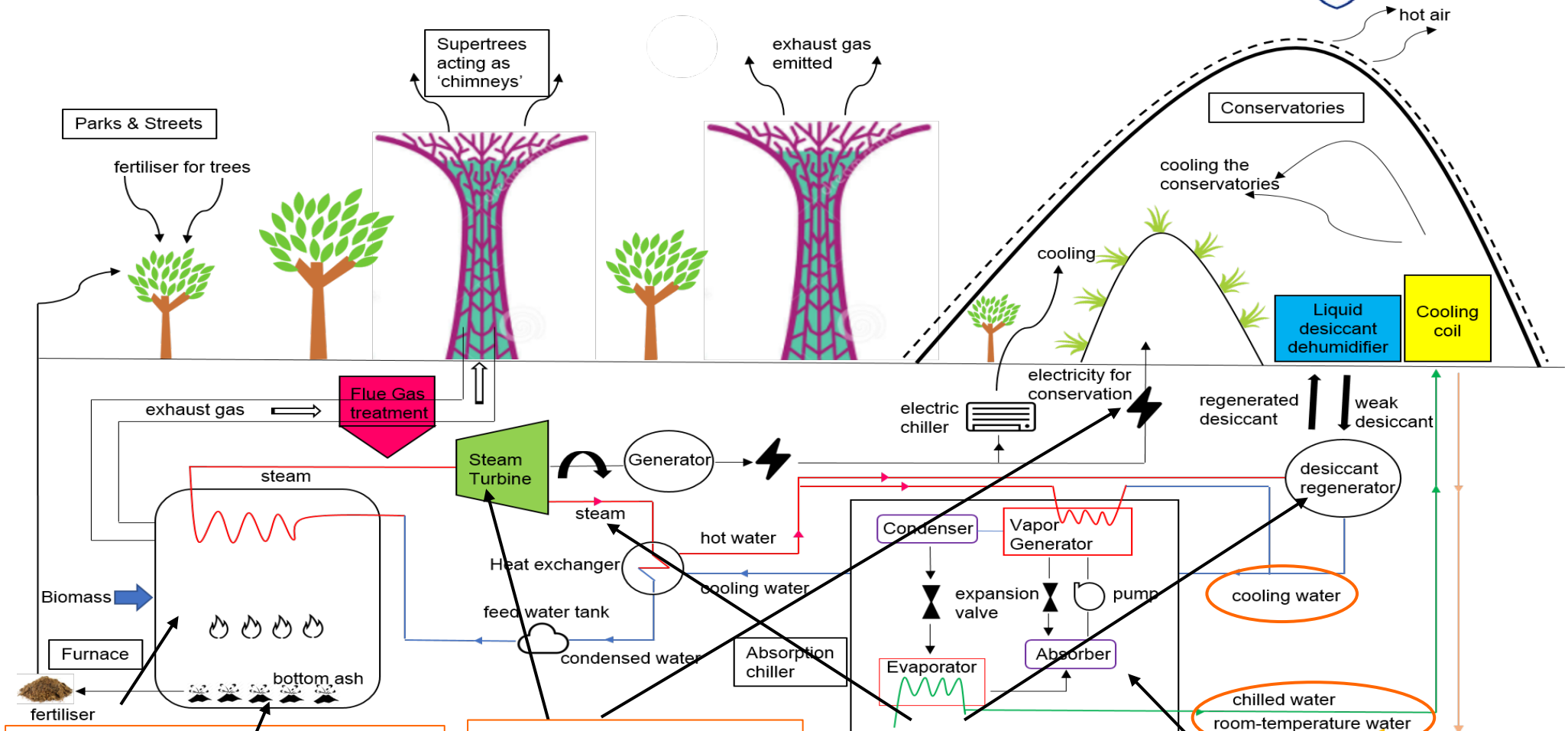
Waste Type	Waste Generated (tonnes)	Waste Recycled* (tonnes)	Recycling Rate (%)
Horticulture waste	**362,000**	**237,200**	**66**
Waste wood	**370,600**	**293,700**	**79**

*278,000 tonnes were used in biomass power plants
*252,900 tonnes were converted into compost and new wood products

2 Co-/Tri-Generation biomass plants, all managed and operated by *Ecowise* group.

- **Tri-Generation Energy Resource Centre @ Gardens By the Bay**
- **Co-Generation biomass power plant @ Sungei Kadut**

- **Tri-Generation Energy Resource Centre @ Gardens By the Bay**



Biomass from tree cutting and wood waste processed off-site and feed into in-situ furnace.

Ash leftovers from furnace are utilized as soil amendments as well as fertilizers on site.

Steam drives turbine to output 0.93 MW electricity to power grid.

Waste heat recovered from turbine used to regenerate the liquid desiccant.

Heat is used in absorption chillers to produce a cooling load of 675 kW.

- **Co-Generation biomass power plant @ Sungei Kadut**

Plant	**Year 2005**	Horticultural waste and wood
Electricity	**1 MW**	Operating electrical facilities on site
Steam	**15 tonnes/hour**	• Drying wet spent barley grains/ soya beans to produce animal feeds • Heating ISO-tankers





- **3rd biomass boiler in the Sakra area of Jurong Island**

Plant	**Year 2011**	Woodchip from construction and demolition waste
Steam	**17 tonnes/hour**	Meet petrochemical manufacturers' demanding

Strictly speaking, this plant cannot be classified as CHP system, since the product is steam only.



Future planning in biomass CHP application in Singapore

- A **fluidised bed (FB) combustor** as part of the Integrated Waste Management Facility (IWMF) in 2027 (800 t/d of dewatered sludge)
  - ✓ Produced power is supplied to national grid,
  - ✓ Steam is consumed during sludge thermal hydrolysis in digester and greasy waste treatment in TWRP.

- A local and stable **heat or cooling consumer** is critical to achieving the maximized efficiency and financial outcome of CHP system.
  - ✓ Biomedical park in Tuas
  - ✓ Silicon wafer parks in Woodlands and Tampines

3 Gasification

Gasification

Gasification is a process with a **controlled amount of oxygen** that converts organic or fossil fuel based carbonaceous materials into CO, H_2 and CO_2.

$$C_xH_yO_z + O_2 \longrightarrow xCO_2 + y/2\,H_2O \qquad \text{Combustion}$$

$$C_xH_yO_z + O_2 \longrightarrow \underbrace{CO + H_2 + CH_4 + CO_2 + H_2O + \text{tar}}_{\text{Syngas}} + \text{char} \qquad \text{Gasification}$$

Advantages of gasification

- Syngas can be used to produce methanol and hydrogen.
- Little or no formation of dioxins and furans in gasifiers.

Gasifier Types

- **Fixed-bed Gasifier**

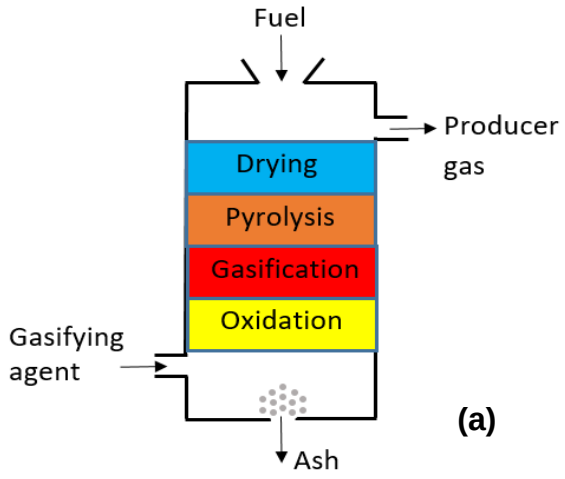
(a) Updraft (counter-current)
(b) Downdraft (co-current)

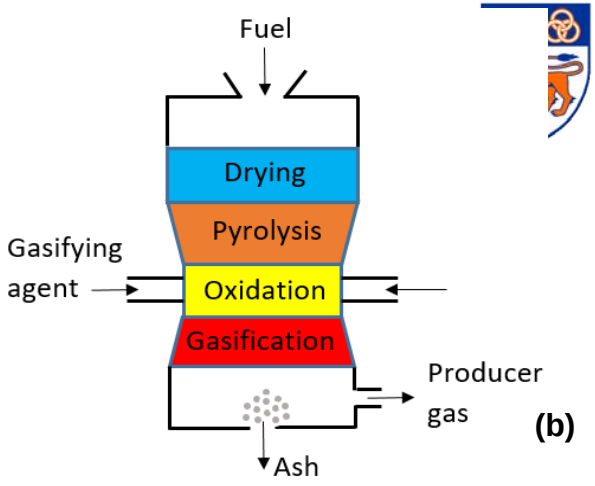
- **Fluidized Bed Gasifier**

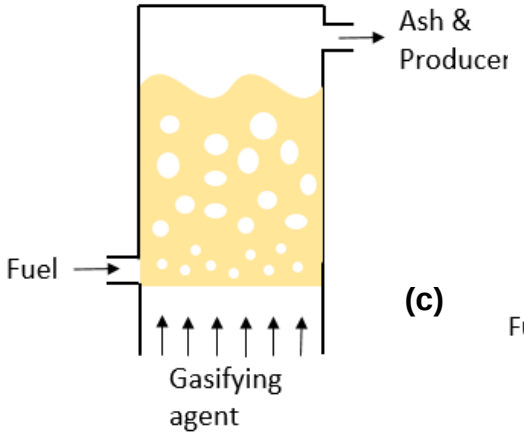
(c) Bubbling fluidized bed
(d) Circulating fluidized bed

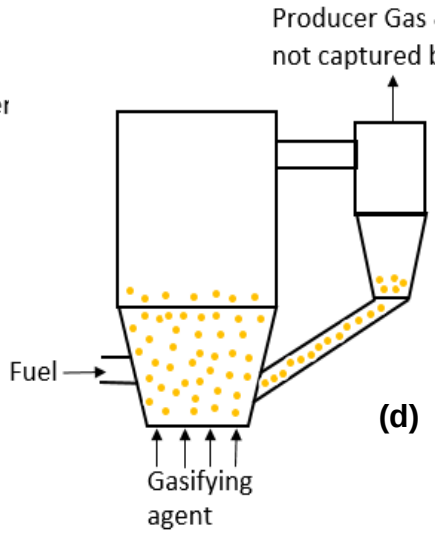
- **Entrained Flow Gasifier**

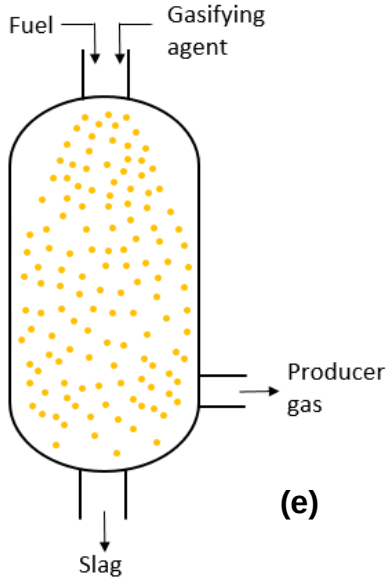
(e) Entrained Flow Gasifier





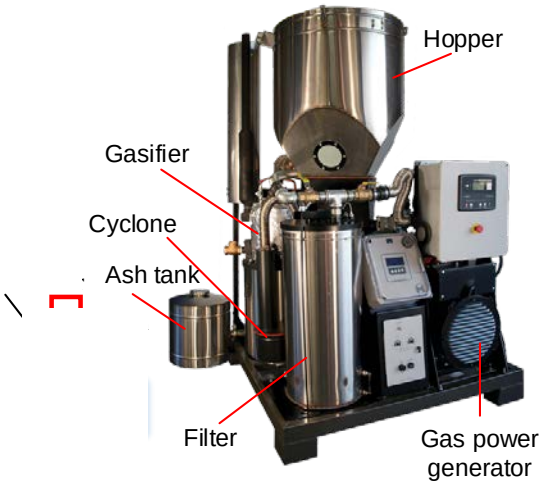






Current gasification status in Singapore

- In **Singapore,** research investigations on pilot-scale and lab-scale gasification technology are ongoing.



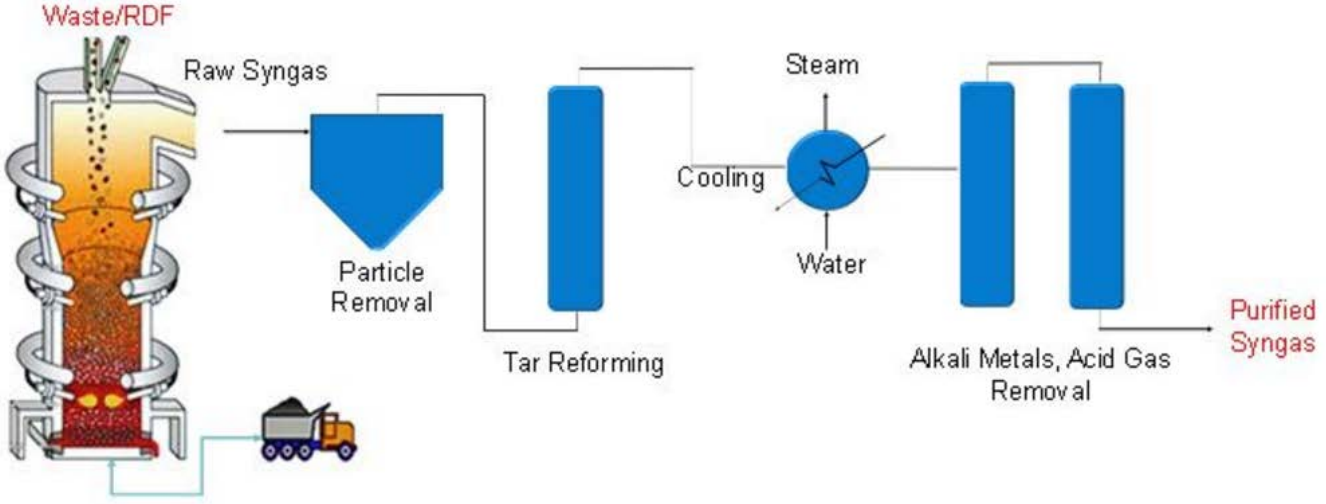
Pilot scale 10 kg/h



1MW industrial scale from BioPlas Energy

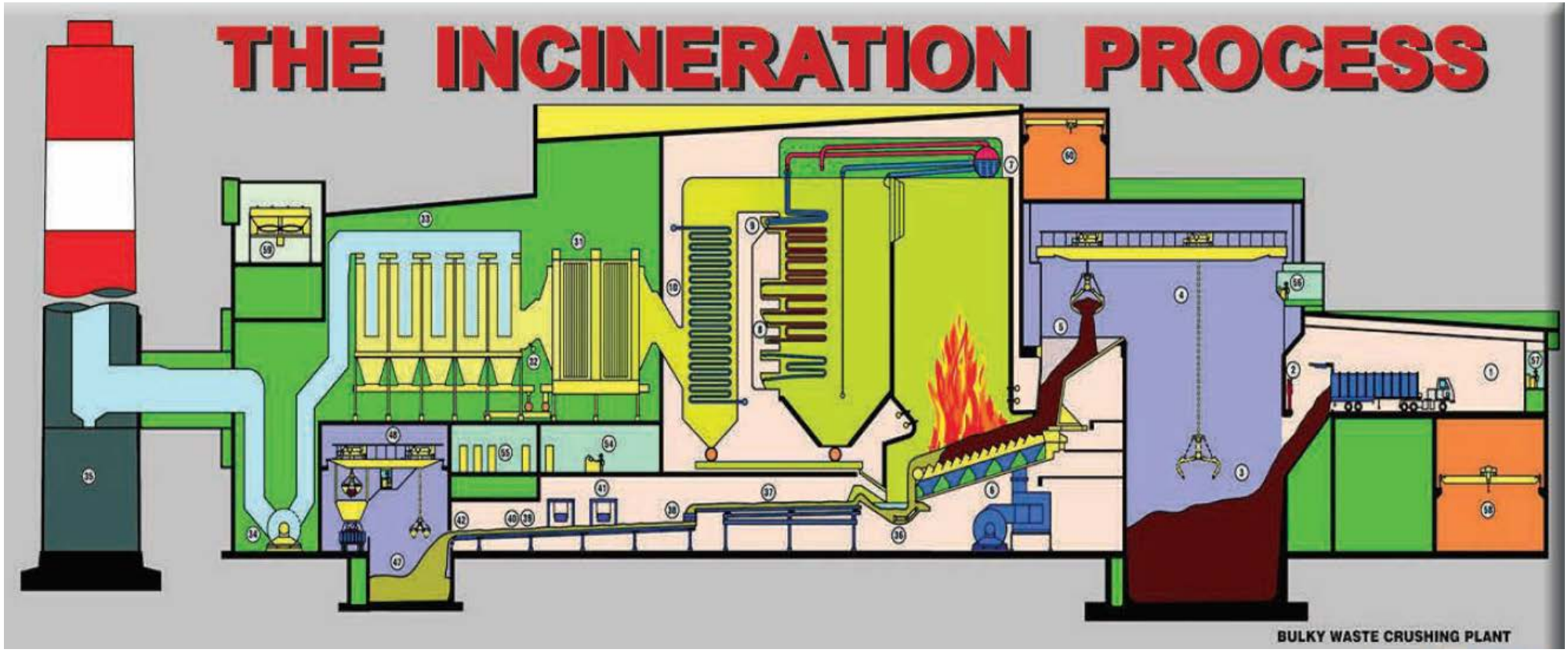
Nanyang Environment & Water Research Institute
NEWRI
R3C Residues and Resource Reclamation Centre

- Tuas Industrial area
- 11 tons of MSW daily
- Completion in 2018



4 Waste Incineration

Waste Incineration



Current incineration status in Singapore

- Operation details of Singapore's Waste Incineration plants (IP).

Plant	Startup year	Capacity	Turbine rated capacity	Gross electricity output	Land occupation	Land capacity	Construction cost
		t/day	MW	kWh/t	ha	t/day/ha	million
Ulu Pandan	1979	1600	1×16	180	-	-	130
Tuas	1987	2000	2×30	350	6.3	270	200
Senoko	1992	2400	2×36	450	7.5	320	560
Tuas South	2000	3500	2×66	550	10.5	411	900
Keppel Seghers Tuas	2009	800	1×22	450	1.6	500	450
Sembcorp	2016	1000	-	Steam	-	-	250
TuasOne	2019	3600	120	800	4.8	750	653
IWMF	2027	5800	230	952	68	-	3000

There are currently **5** operating WTE plants in Singapore with two more in the pipeline.

The first IP in Singapore, was phased out in 2009 after 30 years of servicing period.

TuasOne IP will replace Tuas IP in 2019 as Tuas IP reaches its 30 years lifetime.

IWMF will replace Tuas IP and Senoko IP, and can process 5,800 tonnes of waste, 400 tonnes of FW, 250 tonnes of household recyclables and 800 tonnes of sludge from the TWRP.

Sembcorp IP generates steam as the sole product. It can produce up to 140 tonnes of 400 °C steam per hour.

Current incineration status in Singapore

- The land processing capacity almost doubled in the past 20 years, when comparing Keppel Seghers Tuas IP (500 tonnes/day/hectare) with Tuas IP (270 tonnes/day/hectare)

- Current 4 existing plants (*Tuas, Senoko, Tuas South, Keppel Seghers Tuas*) can produce an average of 450 kWh electricity per tonne of waste incinerated, obtaining a 150% increment compared with first Ulu Pandan IP (180 kWh/tonne waste).

- Considering that Singapore MSW net calorific value is in the range between 7,000 and 10,000 kJ/kg, the gross electricity efficiency of current IPs is around 19%.

- The IPs coming online is expected to push the power output to a new level, approaching 1000 kWh/tonne of waste and 27% or even higher net electrical efficiency for the overall plant.

5 Conclusion

- More electricity could be harvested if wet waste are diverted away from incineration and fed into anaerobic digester.
- Failure of Singapore's first FW recycling company suggests that efforts should be made to increase garbage source separation among civilians.
- WTE systems should incorporate waste-to-material measure to up-recycle the WTE residue for extending the life span of Semakau landfill.



Digestate compost



gasification biochar



Incineration ash concrete

NUS National University of Singapore

THANK YOU