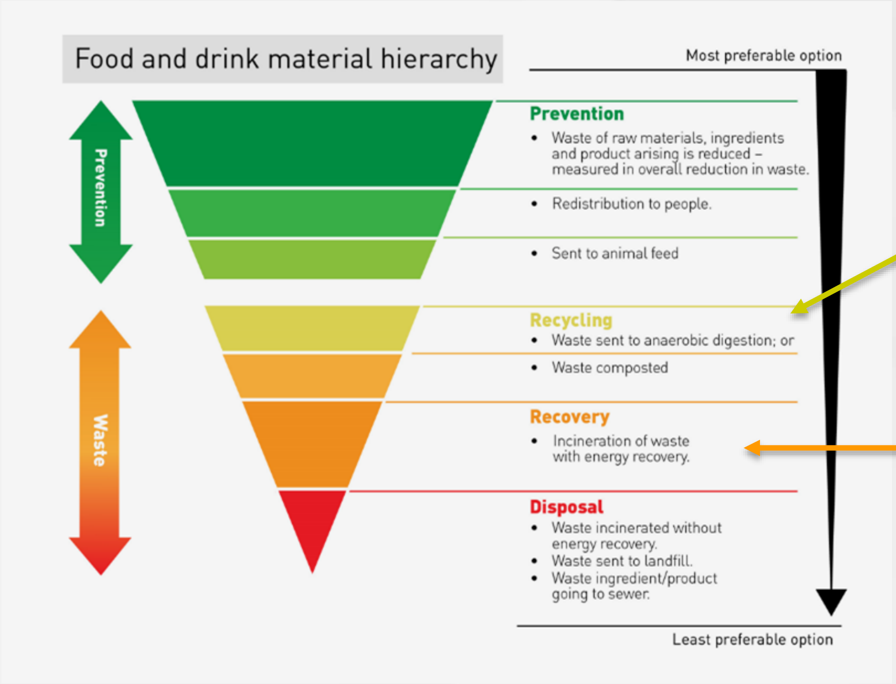
Dr Andrew N. Rollinson and Dr Tanja Radu

WASTEWATER IMPACTS OF ADVANCED ENERGY FROM WASTE TECHNOLOGIES

Wastewater Impacts of Advanced Energy from Waste Technologies

1. Introduction
    a) Waste Hierarchy
    b) Municipal Solid Waste Data for Bahrain
2. Energy from Waste (EfW) Technologies
    a) Biochemical
    b) Thermochemical
3. Wastewater Impacts of Advanced Energy from Waste
4. Conclusions

Waste Hierarchy and Energy from Waste (EfW)



WRAP. 2017. Estimates of food surplus and waste arisings in the UK (online). Accessed 19th March 2017. Available from: http://www.wrap.org.uk/sites/files/wrap/Estimates_%20in_the_UK_Jan17.pdf

There are two routes for extracting energy from waste. But, only the organic fraction of waste can be used.

Biochemical

Anaerobic digestion

- Accepts wet organic waste/slurry
- Optimum temperature ≈ ambient for Bahrain
- Produces gas rich in CH_4
  - The CH_4 is then burned:
  - $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ ΔH -890 kJ.mol^{-1}

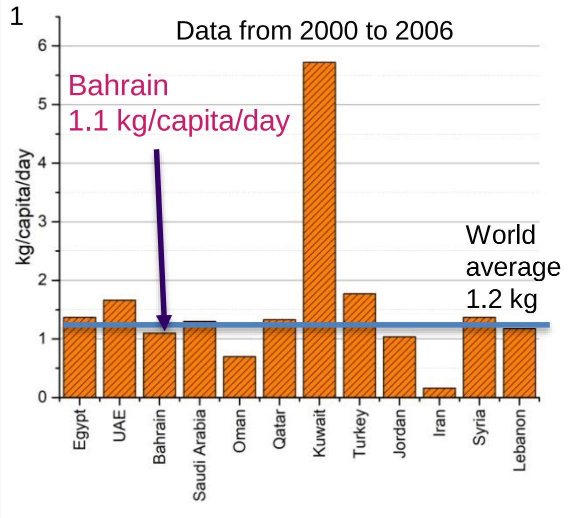
Thermochemical

Incineration, gasification, pyrolysis

- Must be solid waste (very low moisture)
- High temperature = 550 ≤ °C ≤ 1400 (system specific)
- Waste is ultimately burned:
  - $C + O_2 \rightarrow CO_2$ ΔH -394 kJ.mol^{-1}
  - $H_2 + ½O_2 \rightarrow H_2O$ ΔH -242 kJ.mol^{-1}
  - Along with other pollutants

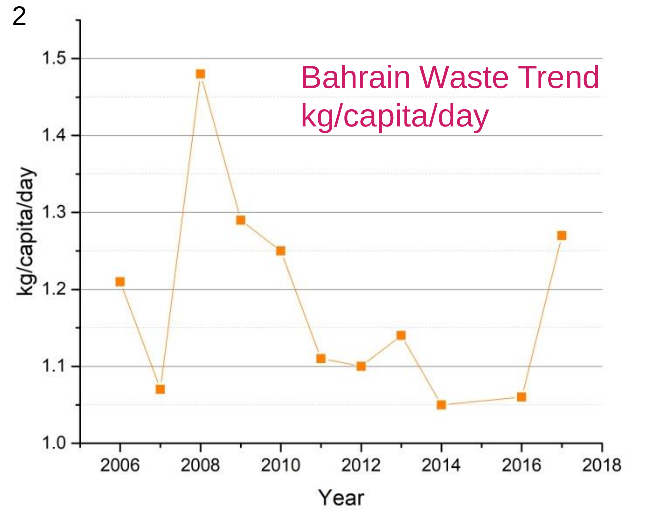
Advanced Energy from Waste

Bahrain Municipal Solid Waste (MSW) Generation



1. Hoornweg, D., Bhada-Tata, P. What a waste: a global review of solid waste management, 2012, World Bank

2. Data from Sphinx and GCCC waste management companies



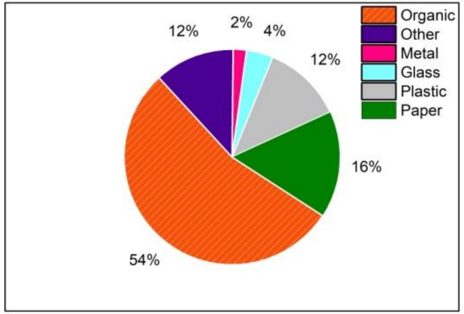
What do we mean by “generation”?

- Audited mass of waste only ?
- How much is unaccounted (litter and ocean pollution)?

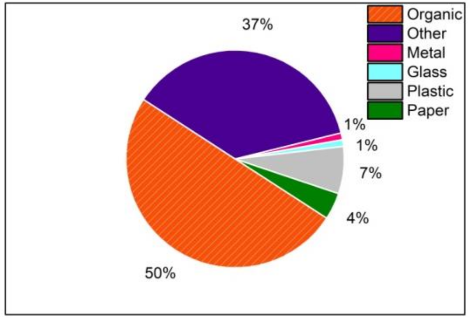
Assessing Bahrain’s Energy from Waste Resource

Composition of MSW generation in Bahrain and Other Regions of the World

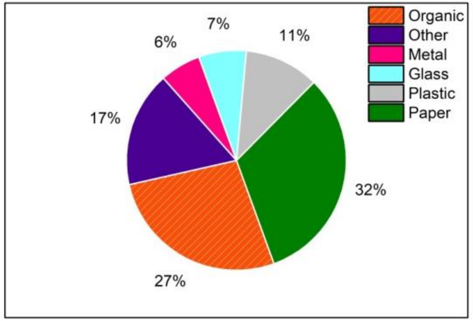
1. Latin American Countries



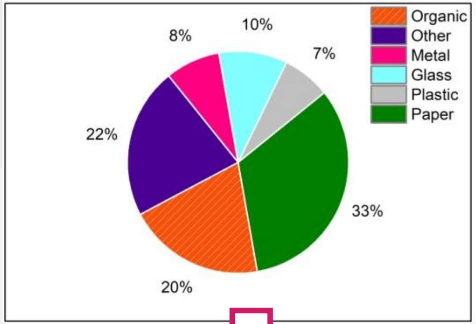
2. South Asia Countries



3. OECD Countries



4. Bahrain



- More information on composition is needed before selecting EfW routes, and…
- …to utilise this “resource”, some sorting and separation, perhaps also pre-treatment will likely be needed

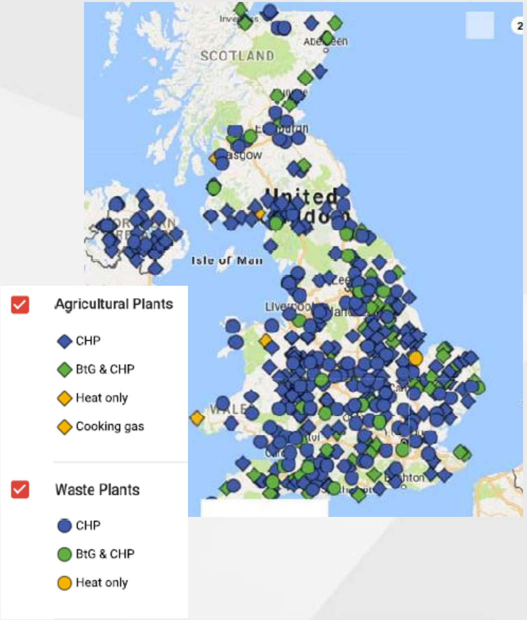
33% paper
20% organic
7% plastic
?? Other
60% at least could be used

1, 2, 3. Leckner, B. Process aspects in combustion and gasification Waste to Energy (Wte), Waste Management, 37, 2015, pp. 13-25.
4. Blanchard, R., Albuflasa, H., Musa, I., Radu, T., Thomson, M. An evaluation of Waste management for Energy Recovery for Bahrain, 7th International Conference of Solid Waste Management (IconSWM 2017), Hyderabad, India, 15th-17th December 2017.

Biochemical Energy from Waste: Anaerobic Digestion

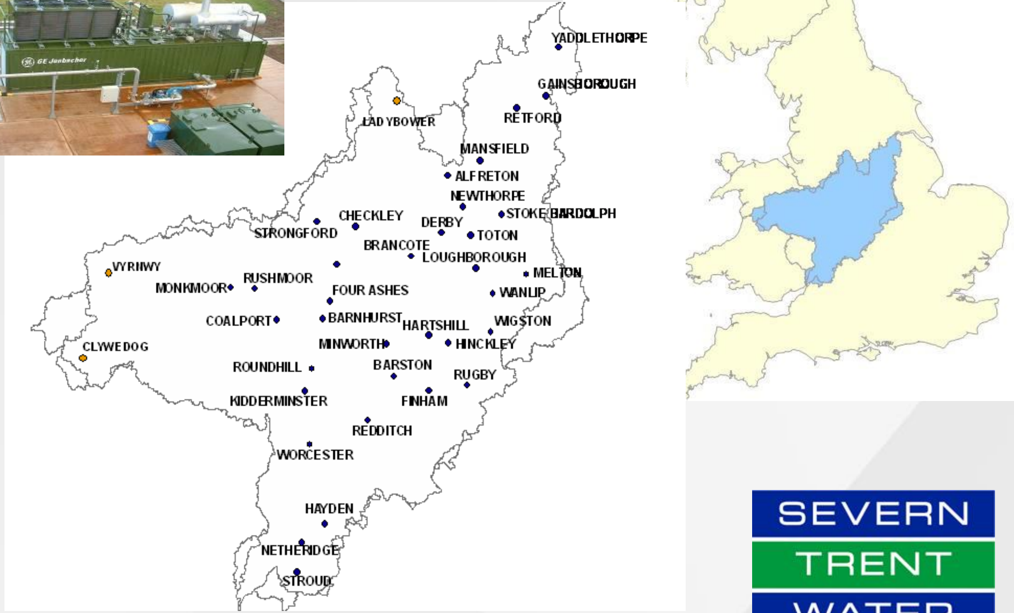
- What kind of waste can be used?
  - Food and drink
  - Processing, agricultural residues, and crops
  - Sewage sludge
- What are the benefits?
  - Biogas generation
  - Diverts waste from landfill
  - Nutrient recovery
- What are the uses of biogas?
  - Heat, electricity, combined heat and power (CHP)
- A Solution for Bahrain?
  - Existing water treatment works and production of sludge
  - Food waste easy to separate
  - Temperature

Existing biogas facilities in the UK



Severn Trent Water- a good example to follow

Sewage gas AD & CHP
55 engines on 34 sites (36.5 MW)



- Versatile renewable energy portfolio
- 100% of sewage sludge processed using AD

Data: Severn Trent Water.

Biochemical EfW – Digestate (after processing)

Liquid Digestate

- (6% dry solid)
- Can be stored until it can be recycled on the land

Solid Digestate

- (25% dry solid)
- Is sold to third-party farmers

Liquid

Solid

Liquor product - 6% DS	Kg/m³
'N' total	5.5
P_2O_5 total	1.3
K_2O total	6.5
NH_4N total	2.8

Dewatered product- 25% DS	Kg/t FM (fresh matter)	Kg/t DS
'N' total	6.0	24
P_2O_5 total	6.0	24
K_2O total	5.5	22
NH_4N total	2.2	8.8

1. Data: Stoke Bardolph Waste-water Treatment Plant, UK, Severn Trent Water.

Coleshill plant: biogas from food waste

- Plant opened in 2015, can process up to 50,000 tonnes of food waste
- The energy output 2.4MW (electricity required to power over 4,000 homes for a year)
- It produces a high quality bio-fertiliser for use on farmland.

The plant accepts food waste from:

- Food and drink manufacturers and food processing companies;
- Hospitality and food service ie pubs, cafes, restaurants and hotels;
- Local authorities (segregated household collections);
- Schools, colleges, universities and hospitals;
- Supermarkets and retail.

Data: Severn Trent Water.

Minworth plant- biogas from sewage sludge UK's biggest gas-to-grid plant

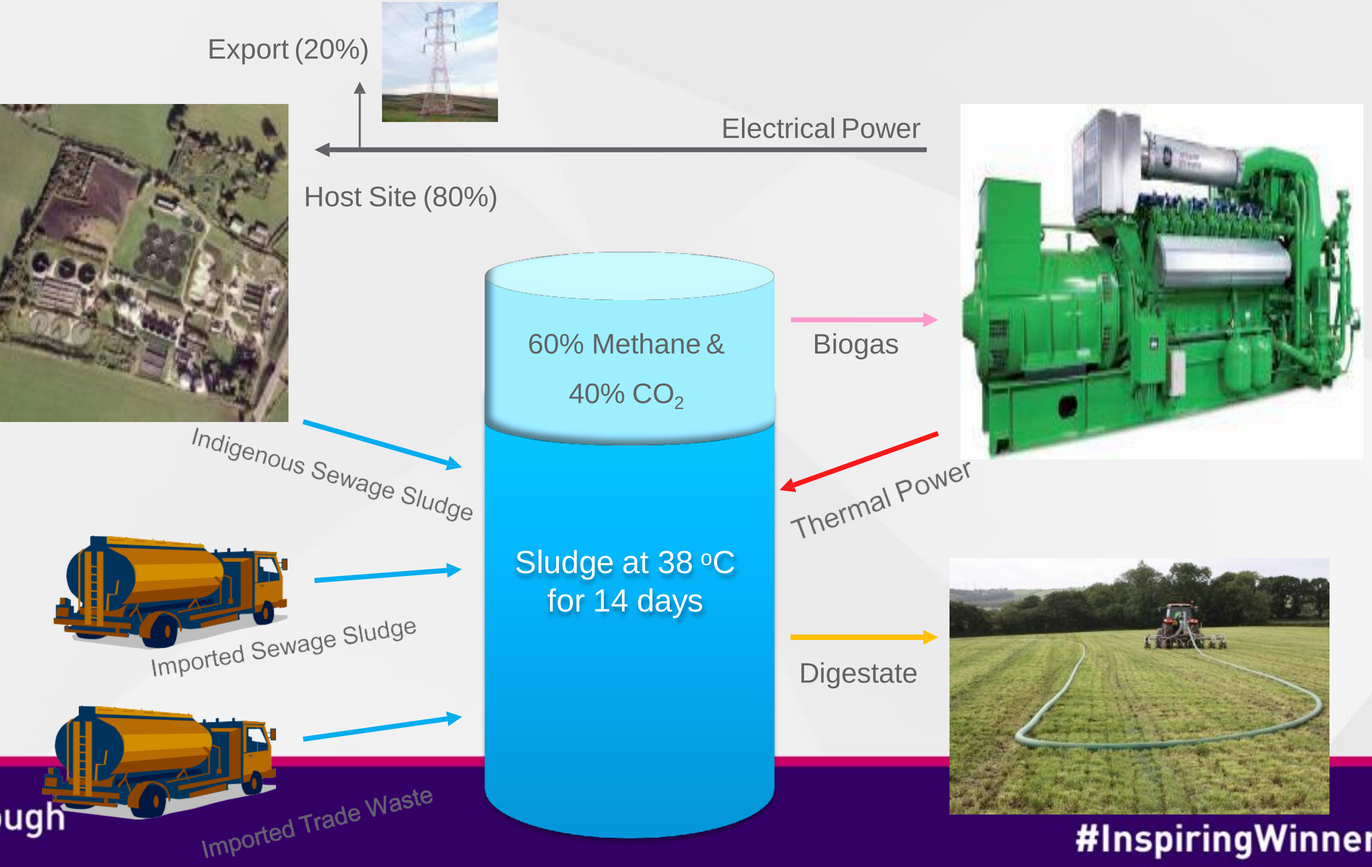
Feedstock Type	Total input (tonnes per annum)	Annual biomethane injection (kWh)	Combined Heat Power (kWe)
Sewage Sludge	1,825,000	63,000,000	8,500

- The facility purifies sewage gas, processing up to 1500m³ of renewable biogas per hour
- Suppling biogas to 4200 homes annually
- Average flow is 450 Ml/d (5.8 m^3/s)
- The plant treats sludge from an equivalent population of 2.5 million
- Thermal hydrolysis technology followed by anaerobic digestion
- Biogas upgrading: 63% to 98% methane

Data: Severn Trent Water.

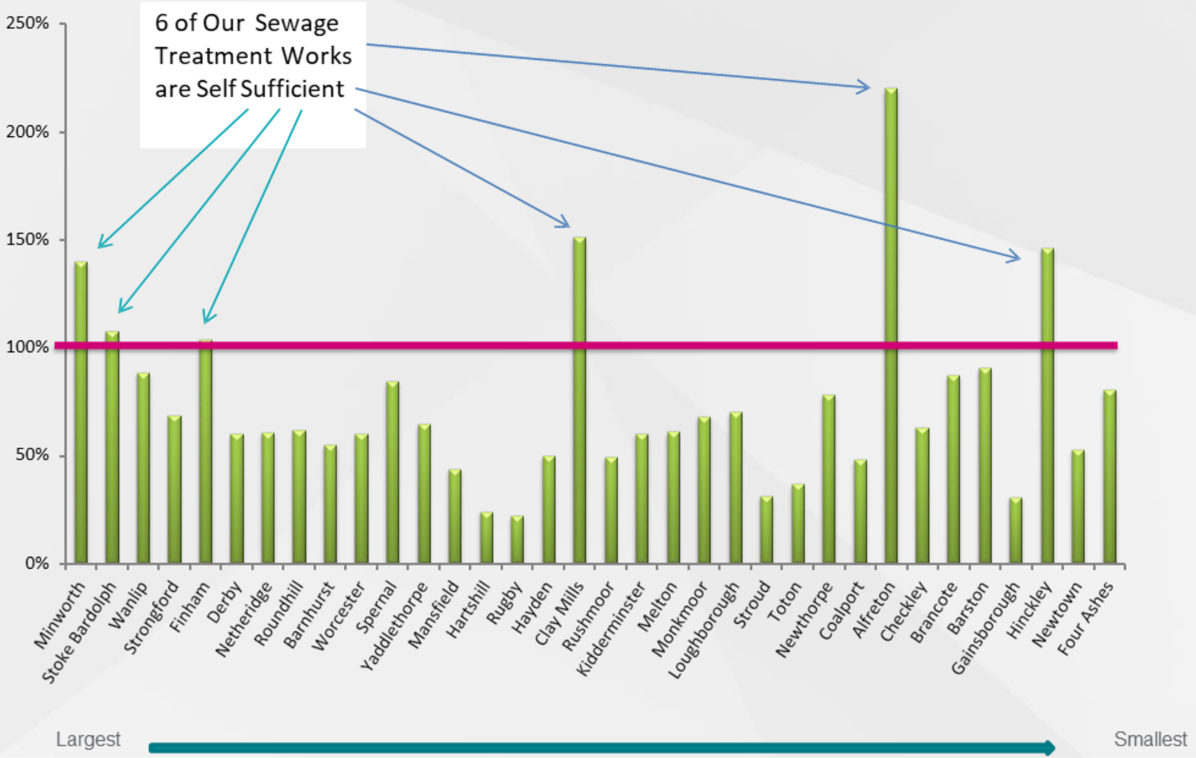
How To Extract Energy from Sewage Sludge.....

Using Anaerobic Digestion and Combined Heat & Power



Data: Severn Trent Water.

Severn Trent Water – sewage works' self sufficiency



Data: Severn Trent Water.

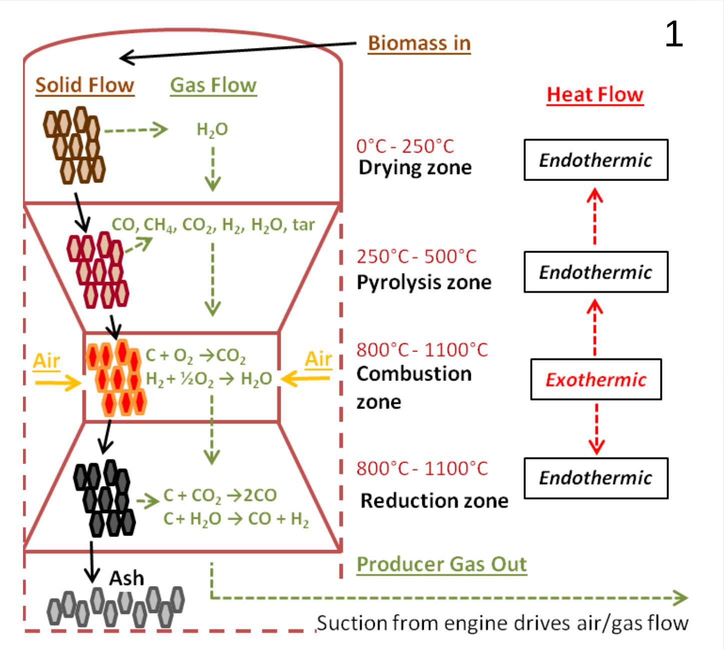
Advanced Thermochemical Energy from Waste

Pyrolysis and Gasification = Chemical Processing

- All organic material when heated without oxygen will evolve into a complex mixture of volatile organic molecules – the phenomenon of "pyrolysis"
- Pyrolysis practiced for thousands of years. Gasification technology developed in the mid 1800s.
  - So more "Antiquated" than "Advanced"
- Gasification = gas production. The gas is burned to generate heat or power
- X Gasifiers cannot tolerate variable and heterogeneous wastes

  Which is inconvenient when these are proposed for refuse EfW
- X Consequently history is replete with gasification of mixed waste failures

  This is not adequately represented by Industry!



1. Rollinson, A. 2016, Gasification: Succeeding with small-scale systems. Low-impact Living Initiative.

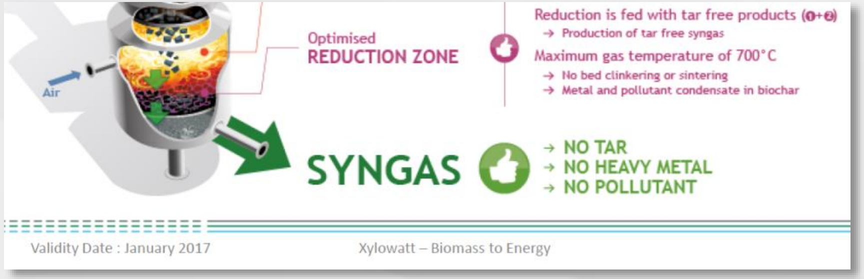
MSW Gasification Wastewater Claims – "No" Tar!

Biomass UK No.1 LLP
New Bespoke Installation Permit Application

sol environment

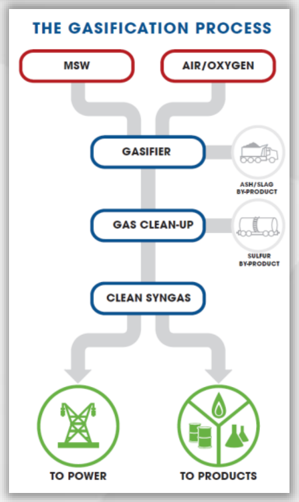
Emissions to Controlled Water

There will be no direct process emissions to controlled water arising from the Installation.



Emissions to Sewer

With the exception of domestic sewage from the offices and toilet facilities, there will be no releases to sewer arising from the Installation.



Tar-free Gasification Technology of Municipal Solid Waste-RDF

Sanjay Rao Chennamaneni[1], Saravanakumar Ayyadurai[1], Vinoth Kumar Kandasamy*[1], Yong-Chil Seo[2].

[1]*CHOGEN Powers Private Limited, Plot No.25, Phase-1, Paigah Colony, Secunderabad-500 003. Telangana, India.*
[2]*Department of Environmental Engineering, Yonsei University, Wonju, 220-710, Republic of Korea.*

hydrogen (H^+) and hydroxyl (OH^-) ions, results in simple molecules of H_2, CO and CO_2. With virtually undetectable levels of methane, no molecules with longer-chain hydrocarbons, and no cyclic hydrocarbons formed, the resulting high-energy syngas is extremely clean.

1.10 Point Source Emissions from the Facility

1.10.1 There will be no point source emissions to land, groundwater or surface water aside from clean surface water run-off and clean roof water drainage from the building.

Wastewater – All Gasifiers Produce Tar

"standard technology is insufficient for tar destruction or removal"[1]

"Converting tar completely to gas requires greater than 1,100°C without catalyst."[2]

"However, the highly water-soluble heterocyclic compounds (class 2 tars) could not be eliminated completely at the given gasification temperature of 800-825°C and approximately 4 s gas residence time"[3]

1. Zainal, Z.A., Ali, R., Lean, C.H., Seetharamu, K.N. (2001), *Energy Conversion and Management*, **42**, pp. 1499-1515.
2. Donnot, A., Magne, P., Deglise, X. Flash Pyrolysis of Tar from the Pyrolysis of Pine Bark, (1985), *Journal of Analytical and Applied Pyrolysis,* **8**, pp. 401–414.
3. Vreugdenhil,. Van Paasen, S.V.B., Kiel, J.H.A. Tar formation in a fluidised bed gasifier – impact of fuel properties and operating conditions, ECN-C—04-013, (2004), Energy Research Centre of the Netherlands.

Wastewater – Challenges of Gasifier Tar

Both polar and non-polar molecules

Molecules determined by GC-MS analysis of gasifier char extractate.

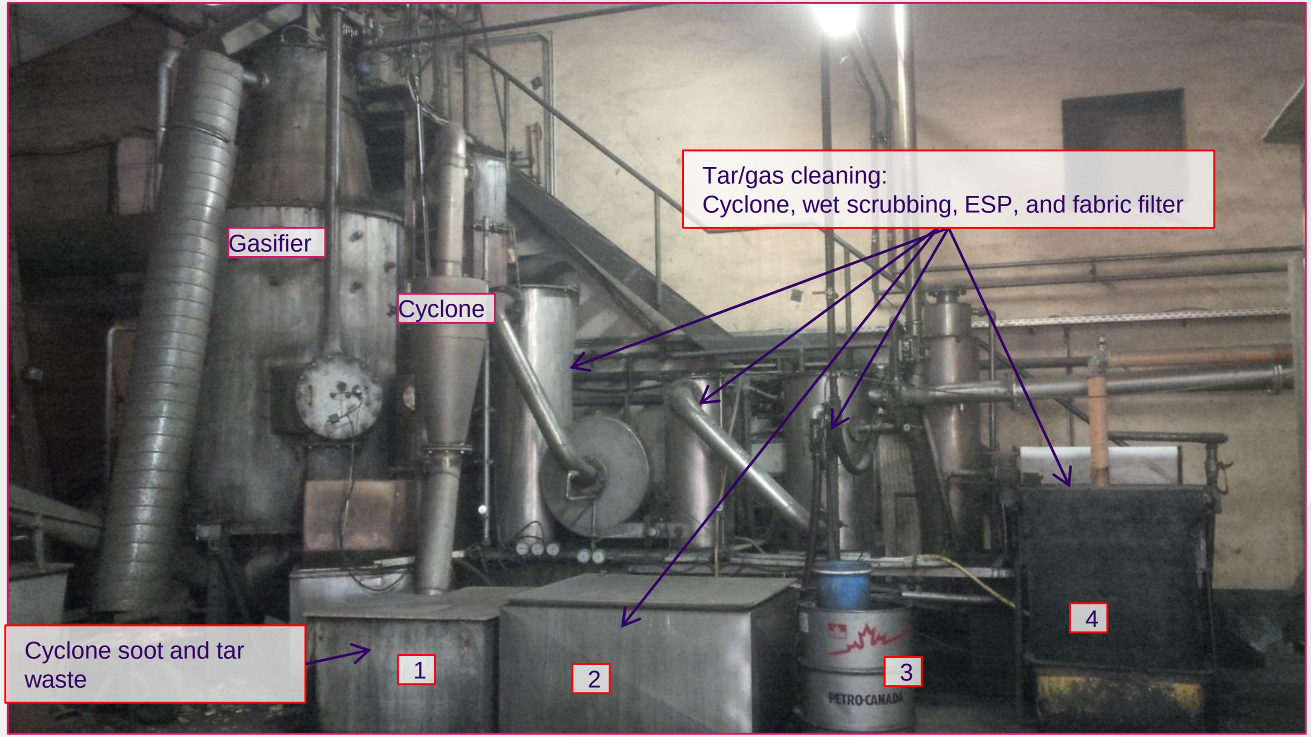
Hydrocarbon Compounds	Formula	Mw	No of Rings	Ret'n time	FM17% (1)	FM17% (2)	FM7% (1)	FM7% (2)	Average ratio 7%:17%	Functionality
				mins	µg/g	µg/g	µg/g	µg/g		
Ethylbenzene	C_8H_{10}	106		5.874	27.83	23.67	42.78	39.54	1.60	
p-Xylene	C_8H_{10}	106		6.01	31.78	26.77	48.20	45.77	1.60	
Naphthalene	$C_{10}H_8$	128	2	15.211	42.59	50.75	82.06	69.64	1.63	EPA16 PAH
2-methyl Naphthalene	$C_{11}H_{10}$	142		18.827	2.16	2.78	12.19	14.26	5.36	
1-methyl Naphthalene	$C_{11}H_{10}$	142		19.372	1.29	1.74	7.67	9.24	5.57	
Acenaphthene	$C_{12}H_{10}$	154	3	24.785	0.53	0.75	12.08	16.19	22.19	EPA16 PAH
Dibenzofuran	$C_{12}H_8O$	168		25.745	7.35	8.69	17.07	11.42	1.78	
Bibenzyl	$C_{14}H_{14}$	182		26.345	178.26	337.96	441.87	151.74	1.15	
Fluorene	$C_{13}H_{10}$	166	3	27.694	0.22	0.11	0.27	0.23	1.51	EPA16 PAH
Phenanthrene	$C_{14}H_{10}$	178	3	33.056	17.79	37.53	76.46	52.91	2.34	EPA16 PAH
Anthracene	$C_{14}H_{10}$	178	3	33.255	0.05	0.04	4.25	7.59	130.23	EPA16 PAH
Fluoranthene	$C_{16}H_{10}$	202	4	39.818	6.57	9.97	16.14	12.00	1.70	EPA16 PAH
Pyrene	$C_{16}H_{10}$	202	4	40.968	2.32	8.63	13.73	9.63	2.13	EPA16 PAH
Benzo[a]anthracene	$C_{18}H_{12}$	228	4	48.022	0.14	0.30	0.33	0.19	1.19	EPA16 PAH
Triphenylene	$C_{18}H_{12}$	228		48.22	0.29	0.53	1.48	0.32	2.19	
					70.20	108.07	205.32	168.38		Σ EPA16 PAH

Rollinson, A.N. Gasification reactor engineering approach to understanding the formation of biochar properties. *Proceedings A of the Royal Society*, 2016, 472 (2192). DOI: 10.1098/rspa.2015.0841.

Wastewater Contaminants – Gasifier Antecedents

250kW$_e$ Gasifier Example

Despite all these tar cleaning stages, an identical system was producing 200 L per month of tar-laden wastewater. To dispose of this wastewater legally in the UK it was costing the owners £10,000 every three months.



Wastewater Contaminants – Gasifier Antecedents

Large (MW_e) Gasifier Example

"Despite Interstate Waste Technologies' claim on its website that the Thermoselect technology has no water emissions, the Karlsruhe Thermoselect facility disposed of approximately ***120,000 cubic metres*** *of wastewater into the Rhine River in 2003. Further refuting this claim, Thermoselect's officers in Italy were convicted of contaminating a lake with polluted wastewater."* [1]

3

"…the maximum permissible phenol content of water released to sewers was 10g/m³ (10 mg/L), approximately 10 ppm. Typical phenol content of gasifier condensate or gas cooler system condensate is 1500 to 3000 mg/L. Dumping these condensates onto the ground or into the sewers or waterways is not acceptable." [2]

1. GAIA, 2006. Incinerators in Disguise. Available from: http://www.no-burn.org/ (Accessed 20th February 2018).
2. Reed, T., Das, A. Handbook of Biomass Downdraft Gasifier Engine Systems, (1988), Solar Energy Research Institute: Colorado
3. Creative Commons: Harald Kucharek. Available from: http://geo.hlipp.de/photo/3335

Conclusions

- Biochemical Energy from Waste:
    - Temperature in Bahrain beneficial
    - Could adapt pre-existing waste-water treatment infrastructure
    - Food waste easy to source separate
- Advanced Thermochemical Energy from Waste
    - Wastewater impacts of advanced EfW are a real and serious problem
    - Extent of gasification and pyrolysis wastewater impacts are under-reported and frequently not admitted

Thank you!

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Finally - Energy from Waste or Feeding the Beast?

When waste to energy companies propose to build incineration/gasification plants they stipulate that contracts be in place which lock-in local authorities to providing them with a fixed tonnage of waste over the lifetime of the plant (often about 25 years). Thereby, in return for their investment, the shareholders get guaranteed annual dividends. But, by making this deal, it also means that the local authority is committed to promoting consumption and the creation of high levels of waste, thus maintaining the linear (make, use, discard) economy

1. Adapted from original cartoon by Frances Howe; courtesy of www.UKWIN.org.uk