Introduction to Waste to Energy / Fuels

Stephen S. Peters
Senior Energy Specialist (Waste-to-Energy)
Sustainable Development and Climate Change Department

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What is Waste to Energy?

Any process, transformation of a wasted resource into usable forms or energy.

We will cover in each part of this presentation:

A. Biogas, with Biogas CHP plant at a Cassava Starch Factory in Cambodia

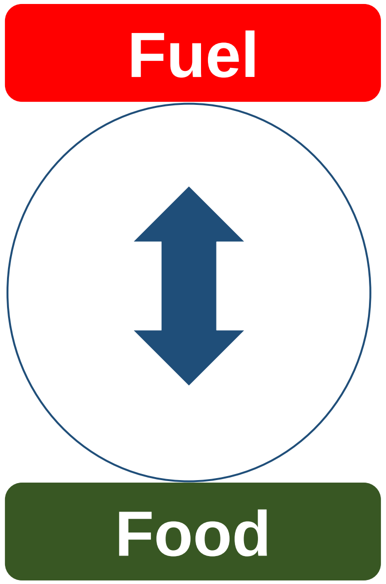
B. Thermal Technologies, with Biomass Power plant using Palm Biomass in Indonesia

C. Municipal Waste Treatment, with Biogas and Refuse Derived Fuel Approach

D. Some Innovative Ideas

Key Theme – Energy Transition – Distributed and Renewable

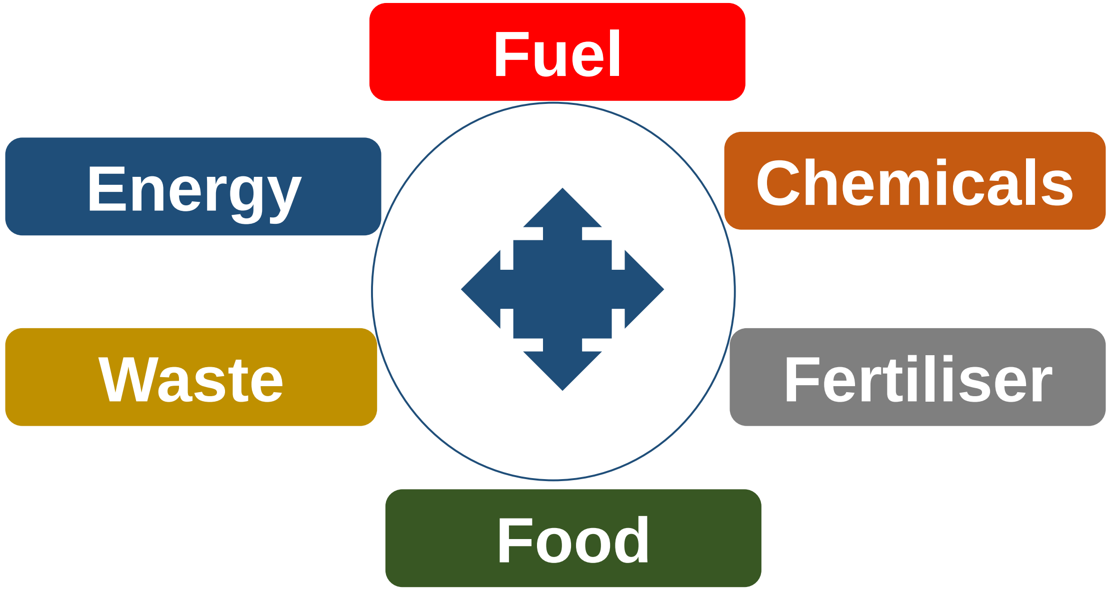
Energy Transition



The Waste Supply Chain and Competing Use

Solid – Briquettes, Pellets, Biochar
Liquid – Bioethanol, Biodiesel, DME, FAME, LPG, LNG
Gas – NG, CNG, BioCNG, Hydrogen, Syngas

Thermal, Electrical, Stored, Transportable, Distributed/Microgrid
Centralised Grid
Emerging DC / Nano



C5, C6, C7… upwards
Bags, plates cutlery
Biochemical Industry

Solid – Rice Husk, Food Scraps, EFB, Fiber, MSW, Offal, Spent Grain, Ash,
Liquid – POME, Process Waste, Sewerage, Sludge,
Gas – Waste gases, Waste heat, Emissions, Fly Ash, Radiant heat

NPK, UREA,
Silica Phosphate
Soil conditioners
Biochar, Ash

Crops -Corn, Cassava, Palm, Sweet Sorghum, Sugar, Wheat, Rice, Edible Oils, Fruits, Algae, Grasses, Trees etc.
Livestock – Chicken, Beef Cattle, Diary, Duck, Sheep, Deer, Fish, Seafood et al

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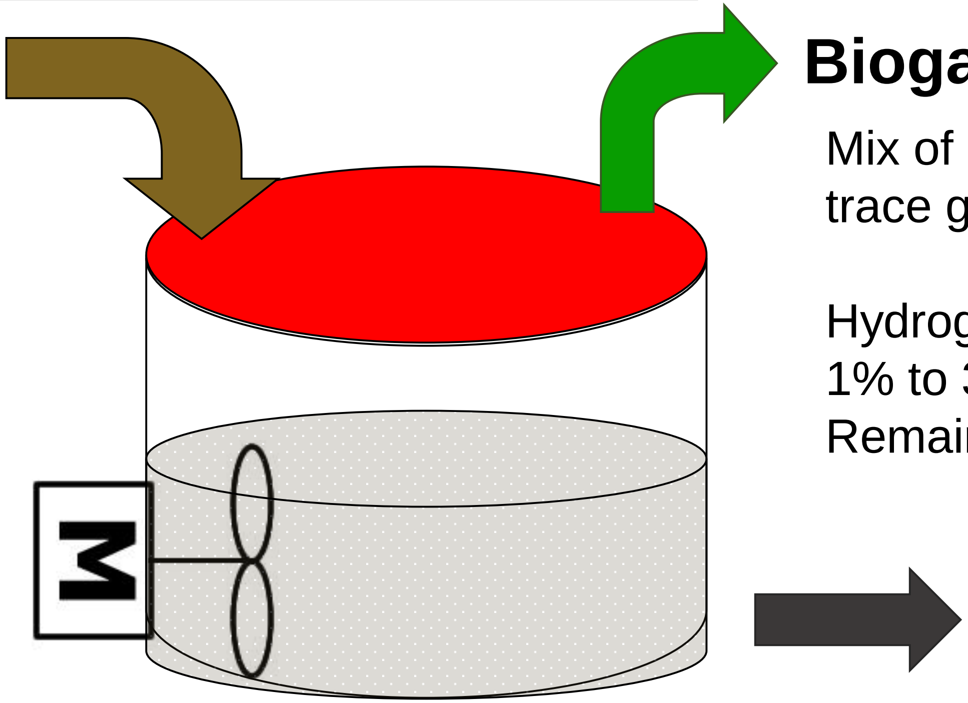
Part A - Biogas - Methane (CH4)

Input Waste Water

A watery slurry of about 8-10% solids from various sources:

- Food waste
- Cassava Starch Effluent,
- Brewery Effluent
- Palm Oil Mill Effluent,
- Ethanol Factory Effluent,
- Sewerage Plant Sludges



Biogas

Mix of methane, CO_2, H_2S and trace gases.

Hydrogen Sulphide varies from 1% to 3% (must be removed). Remainder is CO_2.

Sludge/Biosolid

Carbohydrates → Sugar

Fats → Fatty acids

Proteins → Amino Acids

→ Carbonic acids and alcohols; Hydrogen, Carbon dioxide, Ammonia

→ Hydrogen, Acetic acid, Carbon dioxide

→ Methane, Carbon dioxide

Hydrolysis **Acidogenesis** **Acetogenesis** **Methanogenesis**

Methane Sources

Animal feces

Food waste

Landfills

Biogas 30-65% Methane (CH4)

Sewerage

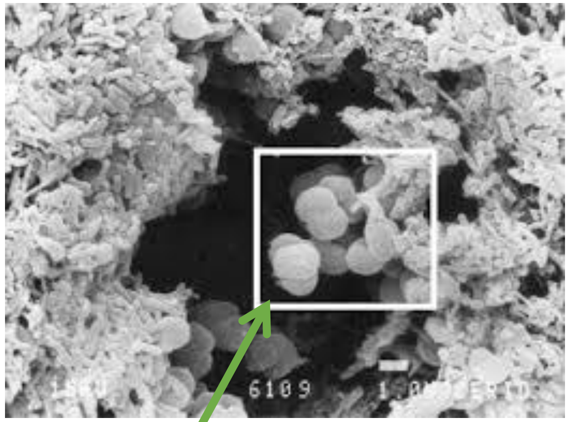
*Anything Putrescible With High Carbon measured in **<u>COD</u>** – Chemical Oxygen Demand – mg/l or Kg/day*

Factory waste water
(palm, cassava, ethanol, brewery, food processing)

Images courtesy of W2E Pte Ltd

Types of Bacteria and Reactions

- **Hydrophilic** – performance related to volume, works well in tropical climates with constant ambient temperatures. Cheap & Easy.
- **Mesophilic** – takes place between 35°C and 50°C. Depending on location heating will be required. Not so Cheap.
- **Thermophilic** – takes place above 50°C. Requires heating for tanks and insulation to ensure constant temperature. Expensive.
- **Exotics** – saline tolerant and temperature tolerant methanogens. These have not been widely used. Very Expensive.



Methanogens in action

***They are very lazy. The food must come to them*.**

Image courtesy of SciELO Aregntina

Project – Cassava Starch Factory, Cambodia

Image courtesy of W2E Pte Ltd

Kampong Cham

CIGAR™ Biogas Technology

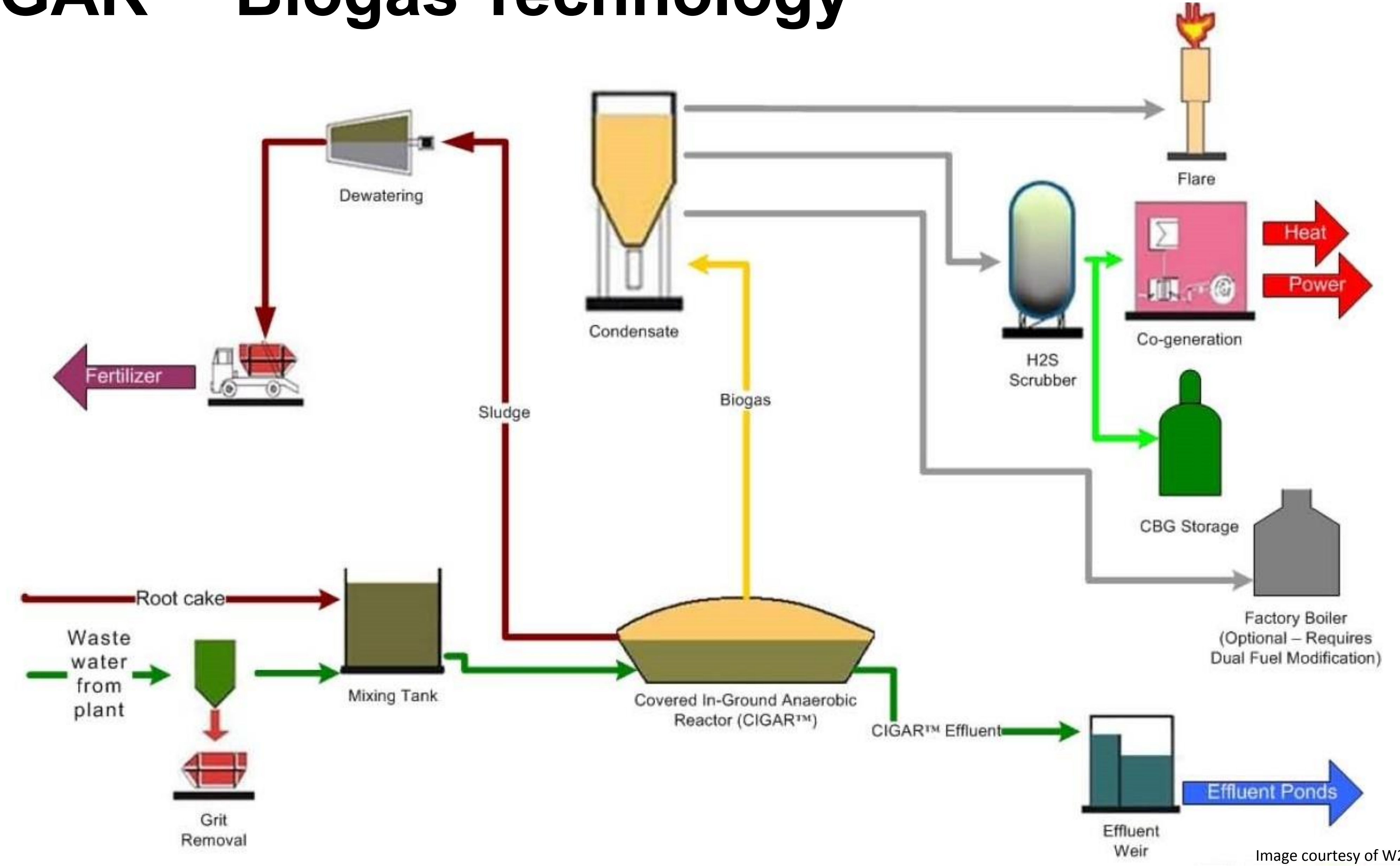


Image courtesy of W2E Pte Ltd

Simplified Impacts on Cassava Factory

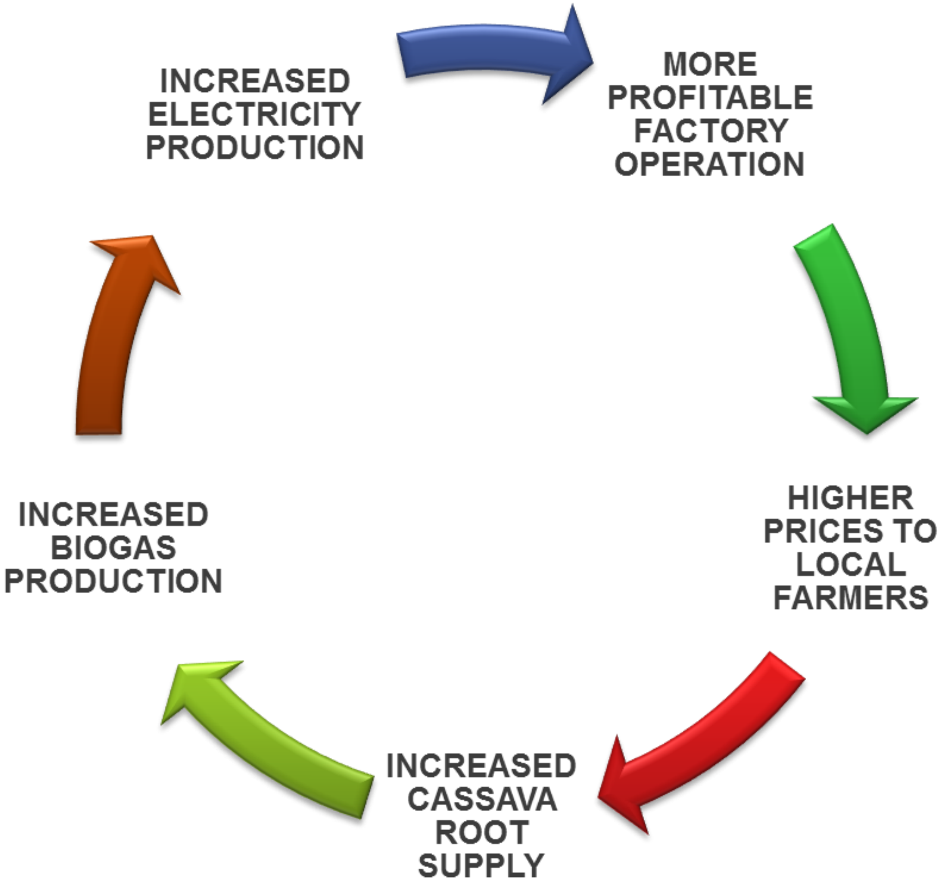
YEARLY	Cassava Factory (operating at 90T/hr -55% capacity)			Cassava Factory with Biogas Plant			Cassava Factory with Biogas Plant with increase production and root price		
	Unit	Cost $	Σ $	Unit	Cost $	Σ $	Unit	Cost $	Σ $
Inputs			$ 4,312,364			$ 4,098,621			$ 6,188,793
Operating (Days)	260	$ 900	$ 234,000	260	$ 1,100	$ 286,000	260	$ 1,100	$ 286,000
Roots (T)	77,220	$ 32	$ 2,471,040	77,220	$ 32	$ 2,471,040	115,830	**$ 35**	$ 4,054,050
Raw Water (M3)	2,162,160	$ 0.15	$ 324,324	2,162,160	$ 0.15	$ 324,324	3,243,240	$ 0.15	$ 486,486
Grid Power (Kwhrs)	5,000,000	$ 0.163	$ 815,000	0	$ -	$ -	0	$ -	$ -
Heavy Fuel Oil (L)	936,000	$ 0.50	$ 468,000	0	$ -	$ -	0	$ -	$ -
Biogas Power (Kwhrs)	0	$ -	$ -	5,000,000	$ 0.138	$ 690,000	7,500,000	$ 0.138	$ 1,035,000
Biogas Heat (Nm3)	0	$ -	$ -	1363571	$ 0.24	$ 327,257	1363572.5	$ 0.24	$ 327,257
Output			$ 4,601,212			$ 5,203,872			$ 7,805,808
Waste Water (M3)	1,945,944	$ 0.05	$ 97,297	1,945,944	$ 0	$ 97,297	2,918,916	$ 0	$ 145,946
Emissions (TCO2e)	0	$ -	$ -	26,500	$ 14[1]	$ 371,000	39,750	$ 14[1]	$ 556,500
Cassava Starch (T)	23,400	$ 190	$ 4,446,000	23,400	$ 190	$ 4,446,000	35,100	$ 190	$ 6,669,000
Biosolids (T)	11,583	$ 5.00	$ 57,915	11,583	$ 25.00	$ 289,575	17,375	$ 25.00	$ 434,363
Factory Operating Profit			**$ 288,848**			**$ 1,105,251**			**$ 1,617,015**
Capital Cost			**Nil**			**$ 3,100,000**			**$ 3,100,000**

1 Pricing from 2008 Project. No longer subject to confidentiality.

Agricultural Biogas Project Virtuous Cycle

Project driven by power quality issues.
Existing supply was degraded.
This caused equipment damage to motors and pumps.

Subsequent benefits became clear.
With secure and good quality power,
Capacity could be reached and
Farmers encouraged to grow more
Cassava roots.



Innovation step – use starch to make compostable bags and cutlery in totally renewable environment.

Image courtesy of W2E Pte Ltd

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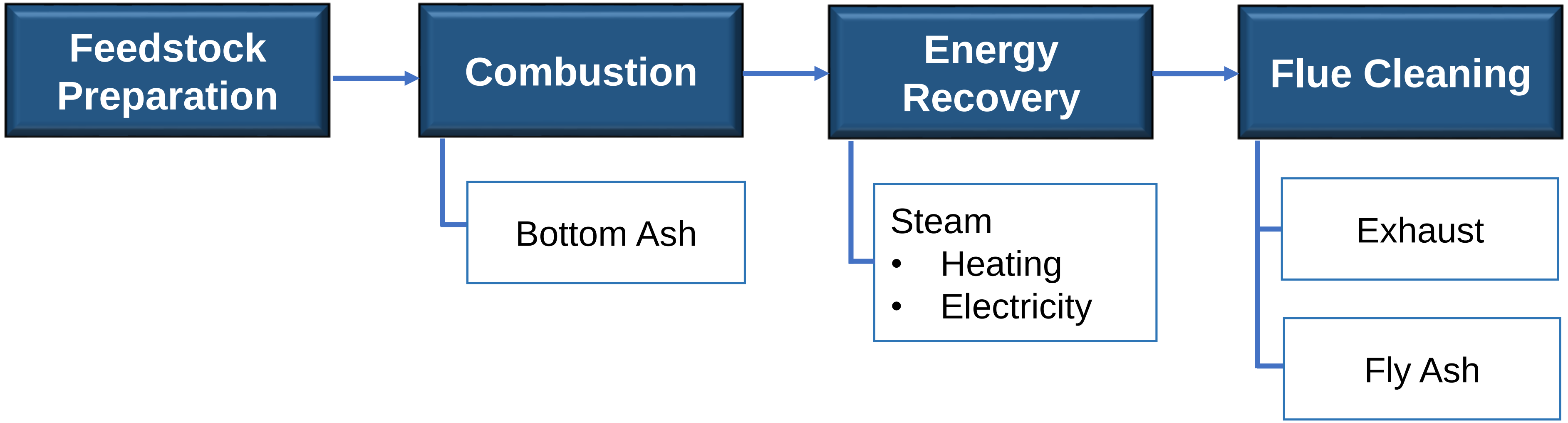
Part B - Thermal Technologies

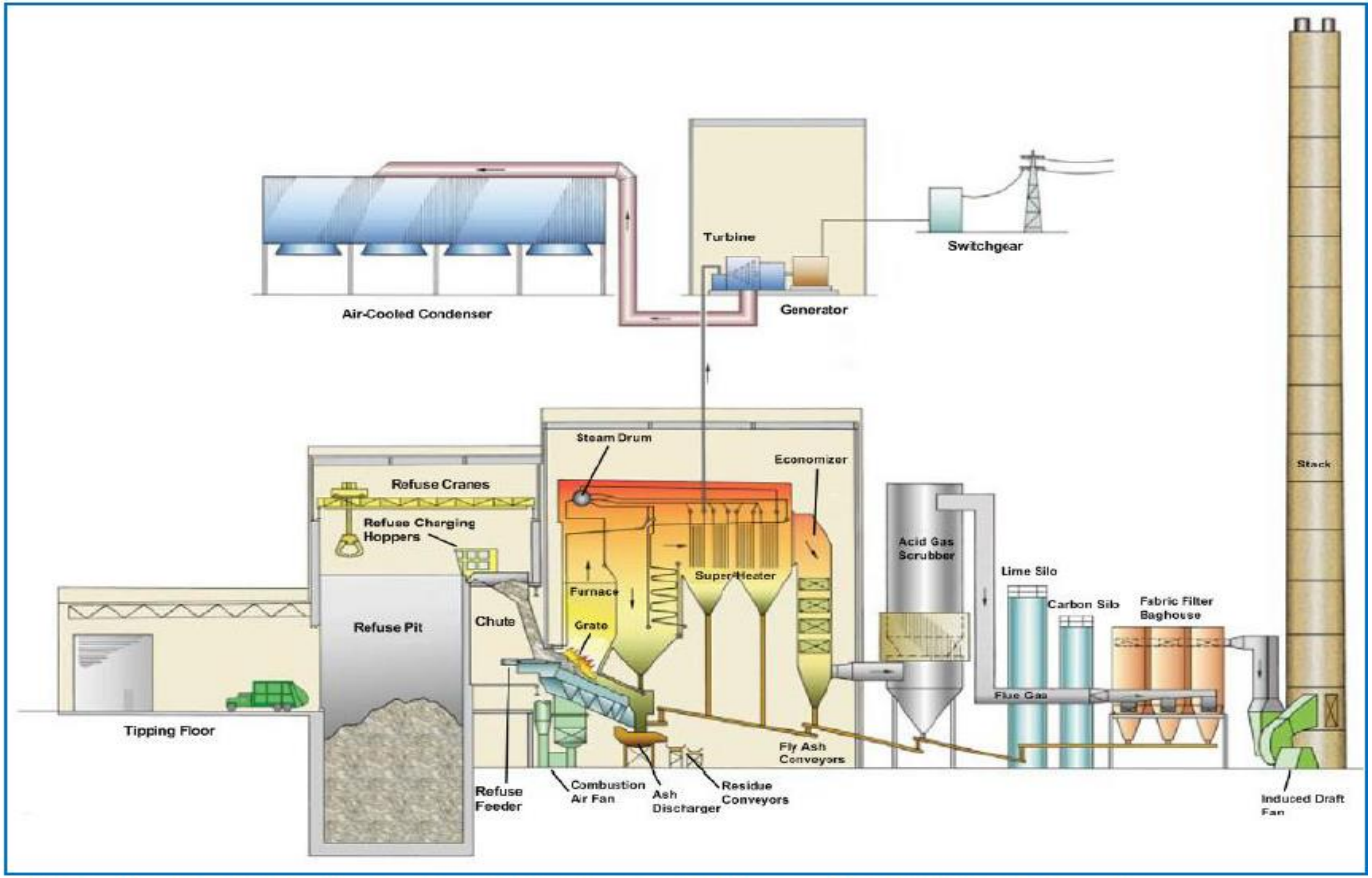
- Mass Burn (Incineration -Thermal Oxidation)
- Pyrolysis
- Torrefaction
- Gasification
- Plasma Arc Gasification

Mass Burn – Incineration



- Proven technology for volume reduction
- Cogeneration potential
- Disposal of created ashes (10% to 25% of input)
- Bottom Ash – MSW contains metal slags with limited reuse options other than landfill
- Fly Ash - toxic ash – can be used in cement production
- Dioxins and Furans – family of toxic substances with similar chemical structure, crystalline “Agent Orange”. Produce between 450°C to 850°C – Form in cooling

Overview of Single-Stage Mass Burn Incinerator Plant



Source: Stantec Consulting Limited. 2009. Durham/York Residual Waste Study Environmental Assessment

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Video on Mass Burn - Incineration

https://www.bing.com/videos/search?q=Municipal+Waste+to+Energy+Plants&&view=detail&mid=48C98D32A44B5D4CACD448C98D32A44B5D4CACD4&rvsmid=03BD81A5EE2D9DF14C5603BD81A5EE2D9DF14C56&FORM=VDQVAP

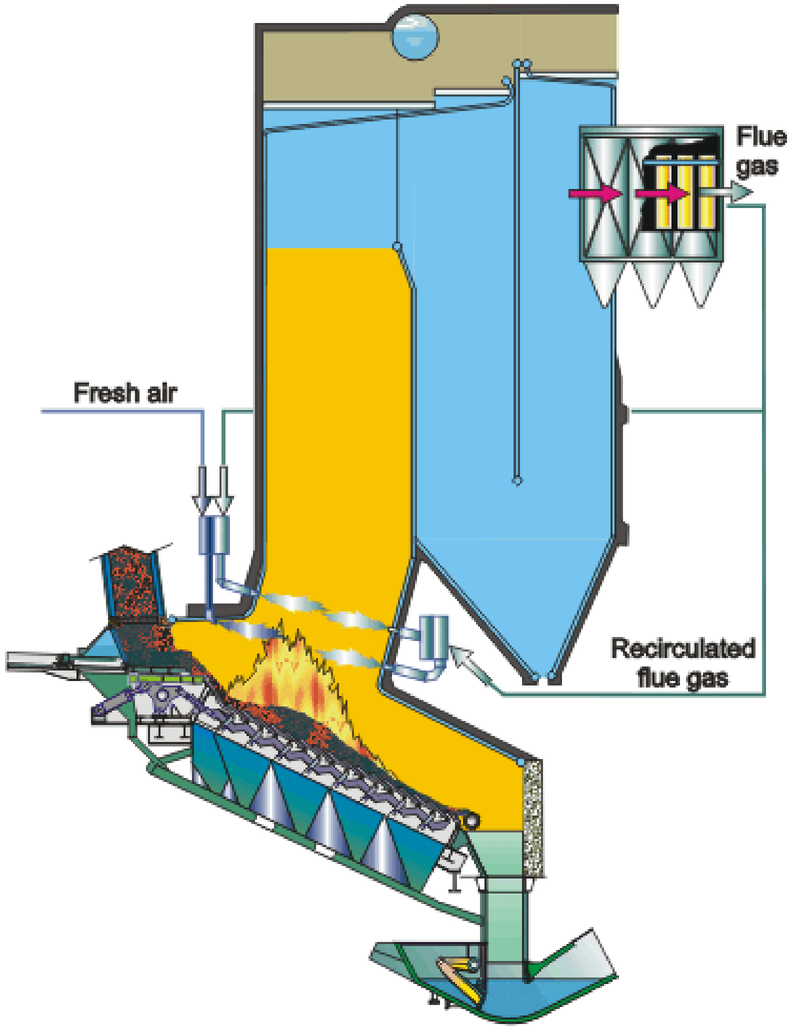
Types of Boilers Used in WTE Plant

Here is a list of some of the commonly used technologies

- GF - Grate-firing/fired – 140 year old technology
- MG – Moving grate – Used to limit caking of burnt materials
- VGF – Vibrating grate – Common in Palm Oil Boilers
- FB - Fluidized bed
- FBC - Fluidized bed combustor
- FBI - Fluidized bed incineration
- BFB - Bubbling Fluidized Bed
- CFB - Circulating Fluidized Bed
- RFB - Rotating Fluidized Bed

Differing waste residency times, operating temperature and combustion dynamics.

Moving Grate

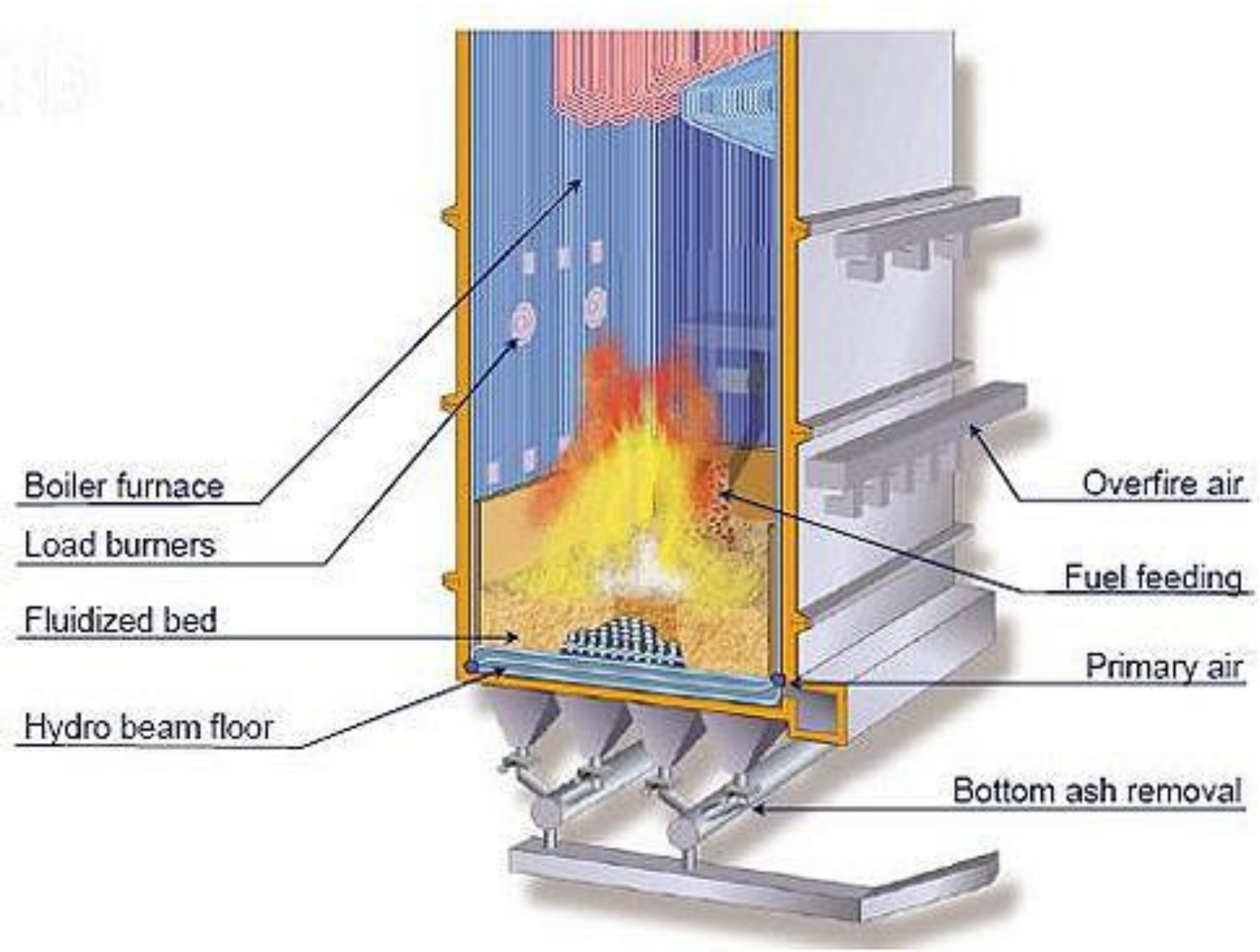


Material placed on a grate which moves and has air injected to keep burning pile at residence temperature.

Grate fired boilers have a slopping grate so that the brunt solids (Ash) can slide to collector.

Ash materials cool, slag forms and can be recovered.

Bubbling Fluidised Bed



Materials are delivered onto a bed with air blowing from underneath to create a bubbling effect. Allows for more efficient air access to combustible materials.

Heat is transferred to boiler tubes filled with water to run steam turbine. These are shown in the top of the illustration.

Circulating Fluidised Bed

A more efficient combustion design allows for higher efficiencies, more complete combustion and emissions benefits

Circulation of materials reduces operating temperature and generally provides for Lower Nox emissions

IMPORTANT TO NOTE:
Emission and Energy are directly related to the feedstock used, its handling into the boiler, the process controls and emissions reduction equipment used.

Flue gas cleaning using Bag filters, ESPs (Electrostatic Precipitators) and a range of filtering solutions need to be integrated to meet best practice for emissions.

Key Terms Used in WTE Plant

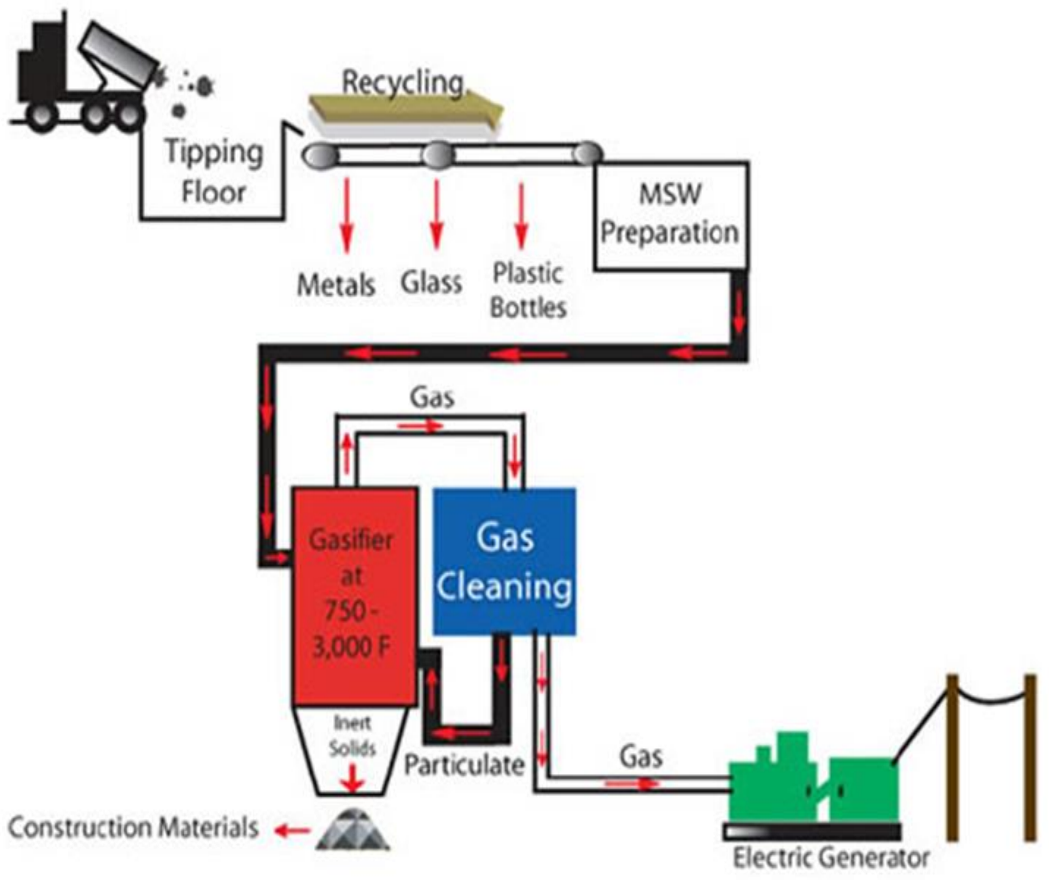
Here is a list of some of the commonly used terms with simplified explanation:

- MJ Mega joule is a measure of energy
- Higher heating value $HHV\ MJ/kg$ or Cal/lb
- Lower heating value $LHV\ MJ/kg$ or Cal/lb
- Nitrogen oxide(s) $NOx\ kg$
- Sulphur Oxides SOx kg
- CHONS – Relative proportions of Carbon, Hydrogen, Oxygen, Nitrogen and Sulphur
- Heavy Metals - cadmium, mercury, lead, arsenic, manganese, chromium, cobalt, nickel, copper, zinc, selenium, silver, antimony and thallium
- Dioxin – family of Chlorinated Compounds formed in oxygen combustion between 250°C and 900°C. Dioxin and Furans are tetrotoxic carcinogens
- Sensible Heat – the energy needed to change material phase for instance Solid to Liquid
- Fouling – damage to the interior of the boiler from caked combustion products. Reduces efficiency/energy output and increase maintenance cost
- Acid gas – gases formed which can damage internal components.

Pyrolysis

- **Pyrolysis**: the thermal decomposition of carbon-based materials in absence of oxygen/air to produce a synthetic gas (syngas)
- Depending on type of starting materials, yield of bio oil may be up to 70% by mass of the feedstock and is usually used a heating fuel rather than a transport fuel.
- The syngas may be used to generate energy more efficiently, if a gas engine is used, whilst incineration can only generate energy less efficiently using steam turbo generators.
- The calorific value of this syngas will depend upon the composition of the input waste to the gasifier.

Torrefaction > Pyrolysis > Gasification Processes



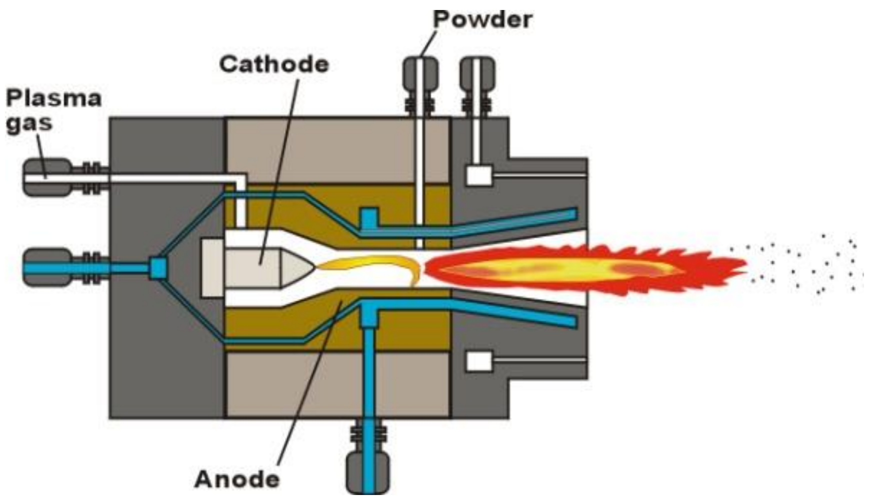
- Temperatures, Torrefaction (350–400°C), Pyrolysis (350–500°C) and Gasifier (500–900°C)
- Main Product Torrefier (Biochar), Pyrolyser (BioOil / BioChar) and Gasifier (Syngas – CO/H2)
- All process dependent on moisture content of feedstock
- Preferred moisture content - approx. 10% to 20% dependent on technologies
- Operating and maintenance issues with tars and particulate matter in gaseous emissions
- Limited production of Dioxins makes gas clean up easier. (Note Dioxins form in cooling phase also)
- Disposal of char / tars residue issues if not salable

Plasma Arc Gasification

Plasma, the fourth state of matter - an ionized gas with temperatures 2,000°C to 5,000°C. Hot ionized gases created by an electrical discharge. The gas is typically air, oxygen, nitrogen, hydrogen, argon or a combination of these gases.

A plasma torch is powered by an electric arc ionizes gas and catalyse organic matter into synthetic gas and slag solid waste.

A key product is the conversion of solid waste into syngas, mainly carbon monoxide and hydrogen which can be converted to energy (steam and/or electricity), other gases, fuels and/or chemicals.



Images courtesy of Westinghouse INc

Biomass Power – Indonesia

Empty Fruit Bunch (EFB)

Palm Kernel Shell (PKS)

Images courtesy of W2E Pte Ltd

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Typical Biomass Plant Configuration

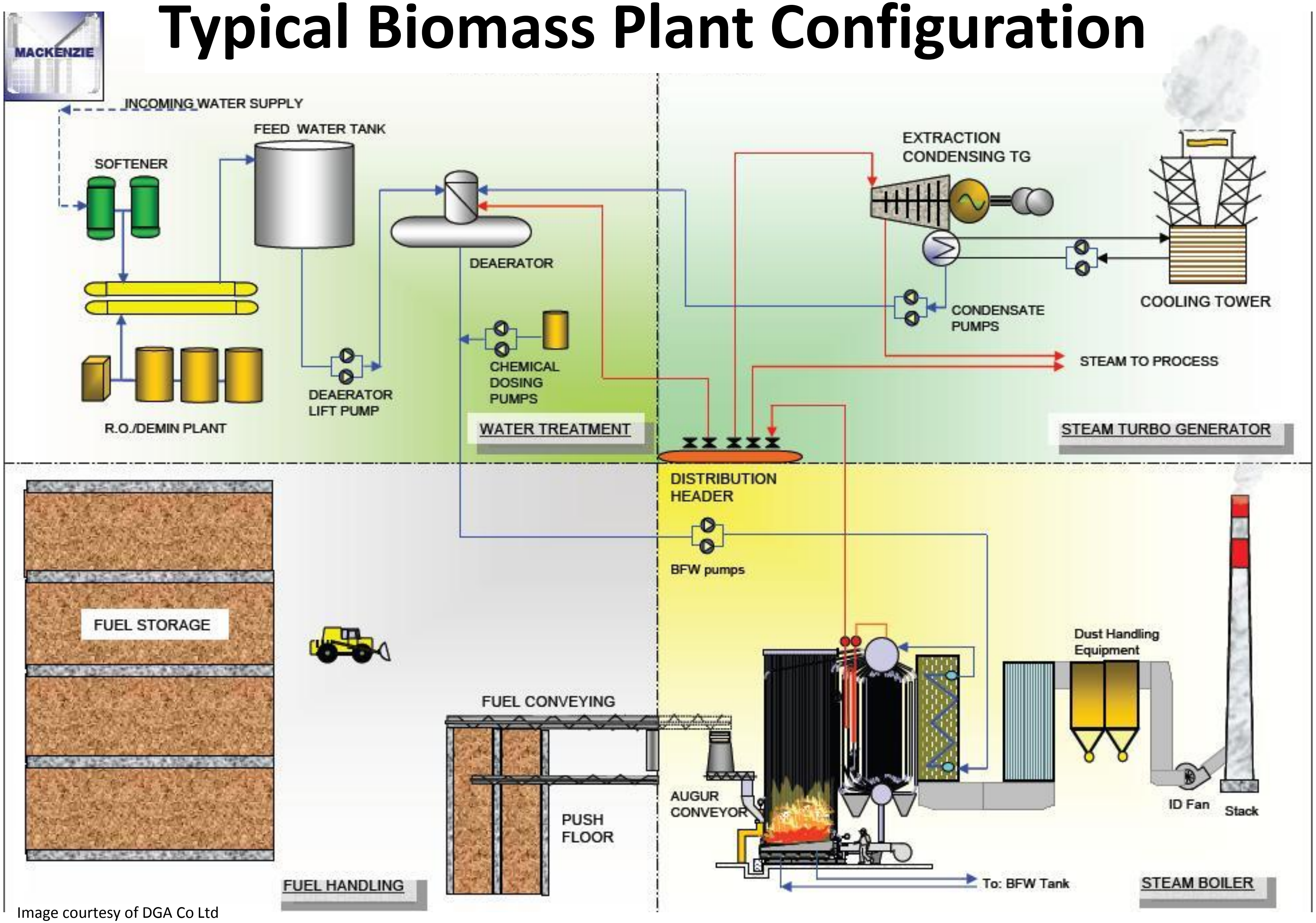

Image courtesy of DGA Co Ltd

Commercial Scale Financing

YEARLY	**3 Mills - EFB Sold**			**10 Mwe EFB Powered Plant**		
	Unit	Cost $	Σ $	Unit	Cost $	Σ $
Inputs			**$ (967,104)**			**$ 878,453**
Operating (hrs/yr)		$ -	$ -	8059.2	$ 100	$ 805,920
Empty Fruit Bunch (T)	80,592	$ (12)	$ (967,104)	80,592	$ -	$ -
Raw Water (M3)				24,178	$ 3.00	$ 72,533
Output						**$ 10,090,355**
Electrical Power (Kwhrs)				82,000,000	$ 0.11	$ 9,020,000
Emissions (TCO2e)				73,000	$ 14.00[1]	$ 1,022,000
Ash (T)				3,224	$ 15.00	$ 48,355
Operating Profit			**$ 967,104**			**$ 9,211,902**
Capital Cost			**Nil**			$ 21,000,000

1 Pricing from 2008 Project. No longer subject to confidentiality.

Risks/Safeguards

Source of Biomass is of particular concern in multi-fuel and multi-supplier business model. Significant reputational risk.

Social safeguards in supply chain should be well researched to avoid or transform areas utilizing exploitative practice on vulnerable or exploited persons. Seek collaboration with POWI programs.

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Important – Fuel Preparation

- Mass Burn WTE plants can take a wide range of materials – wet garbage, oils, tars, sludges. Moisture contents of 50% can be incinerated however energy is lost in boiling of the waste. The drier the better.
- Pyrolysis and Gasification Plants require a much more controlled moisture content 15% with +/- 5% margin
- Fuel preparation, storage and handling is highly important.
- Refuse Derived Fuels (RDF) is the plastics, textiles, timber, rubber and other combustible materials shredded and compressed into a fuel pellet. This pellet can be combusted (with oxygen) or gasified (without oxygen)

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Part C - Municipal Solid Waste

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MSW Simplified Biogas Approach

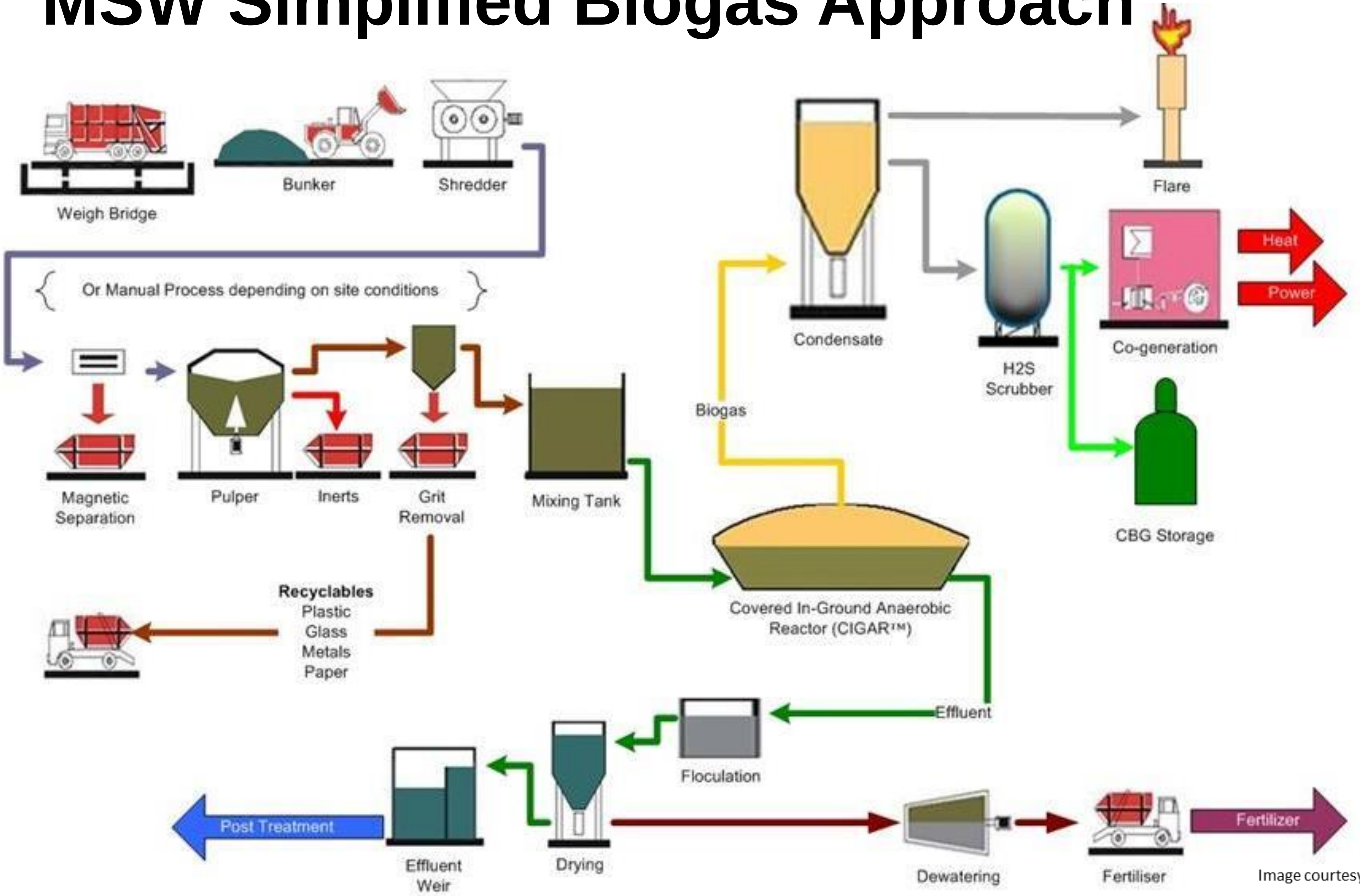

Image courtesy of W2E Pte Ltd

MSW – Agreement Structures – Biogas and RDF

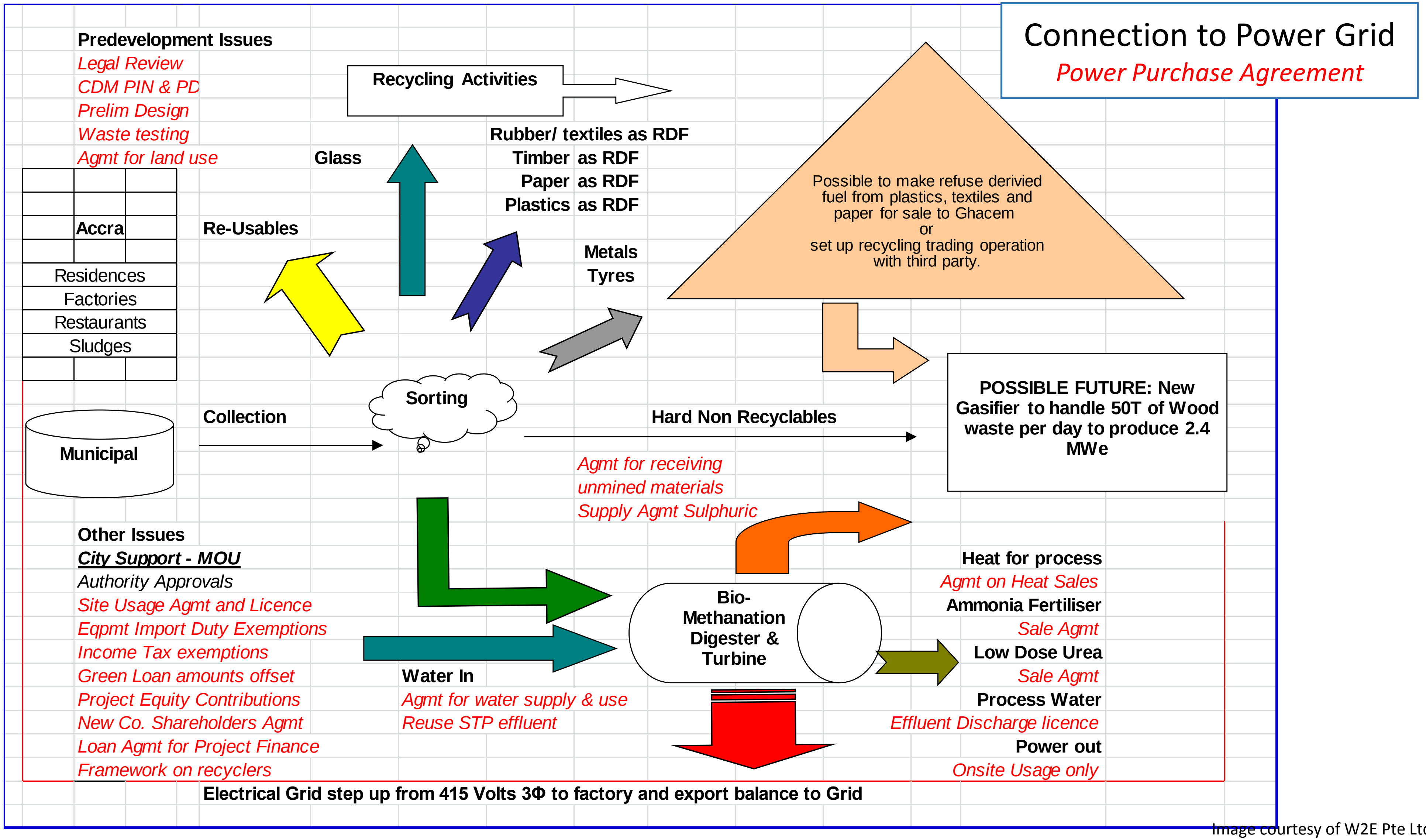

Image courtesy of W2E Pte Ltd

Cheaper & Cleaner than Incineration Only

<u>YEARLY</u>	**18 Mwe MSW Biogas Powered Plant (selling Refuse Derived Solid Fuel)**		
	Unit	Cost $	ΣCost
Inputs Costs			**$ 3,609,496**
Operating (hrs/yr)	8,059	$ 380	$ 3,062,496
Raw Water (M3)	5,470,000	$ 0.10	$ 547,000
Output			**$ 18,472,900**
Tipping Fee	547,000	$ 3.50	$ 1,914,500
Electrical Power (Kwhrs)	118,200,000	$ 0.09	$ 11,110,800
Heat Energy (Kwt)	135,930,000	$ 0.02	$ 2,718,600
Emissions (TCO2e)	*107,000*	*$ 14*[1]	*$ 1,498,000*
Biosolid (T)	24,700	$ 75.00	$ 1,852,500
Recyclables	10,000	$ 32.00	$ 320,000
RDF	27,800	$ 35.00	$ 973,000
Operating Profit			**$ 14,863,404**
Capital Cost			**$ 56,000,000**

1 Pricing from 2008 Project. No longer subject to confidentiality.

- *Refuse Derived Fuels or Solid Recovered Fuels are high calorific fuels made to substitute coal.*
- *RDF/SRF used in cement production where high lime content limits dioxin formation. Buyer secured.*
- *Exportable power is about 14MWe due to parasitic plant load.*
- *Note equipment was priced directly from suppliers – name main contractor not included (add 18% if required)*
- *Land cost of US$ 100,000 included in Capital cost.*

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Landfill Mining –Trommel and Shred

https://www.youtube.com/watch?v=m8P2LOcNOWc

Landfill Mining – Pelleting of RDF

https://www.bing.com/videos/search?q=rdf+pellet+machine&&view=detail&mid=BB59629D3FF11422D651BB59629D3FF11422D651&rvsmid=C105891F319982F64E06C105891F319982F64E06&FORM=VDQVAP

Phnom Penh Waste Story

Population

2015 – 2.6M pp → 2,300 Mt/day MSW

2025 – 4.4M pp → 5,000 Mt/day MSW

Infrastructure for Waste

A – Steung Meanchey Landfill (Closed)

B - Dang Kau Landfill (EOL 2020)

New Infrastructure

C – Riverside MRF & Biogas Plant (600T/d)

D – **Snaor Biogas & Incinerator (2,000T/d)**

A+ - Mine RDF/MRF/Biogas at Steung Meanchey

B+ - Biogas/RDF at Dang Kau (1,200T/d)

E - Riverside North MRF & Biogas Plant (600T/d)

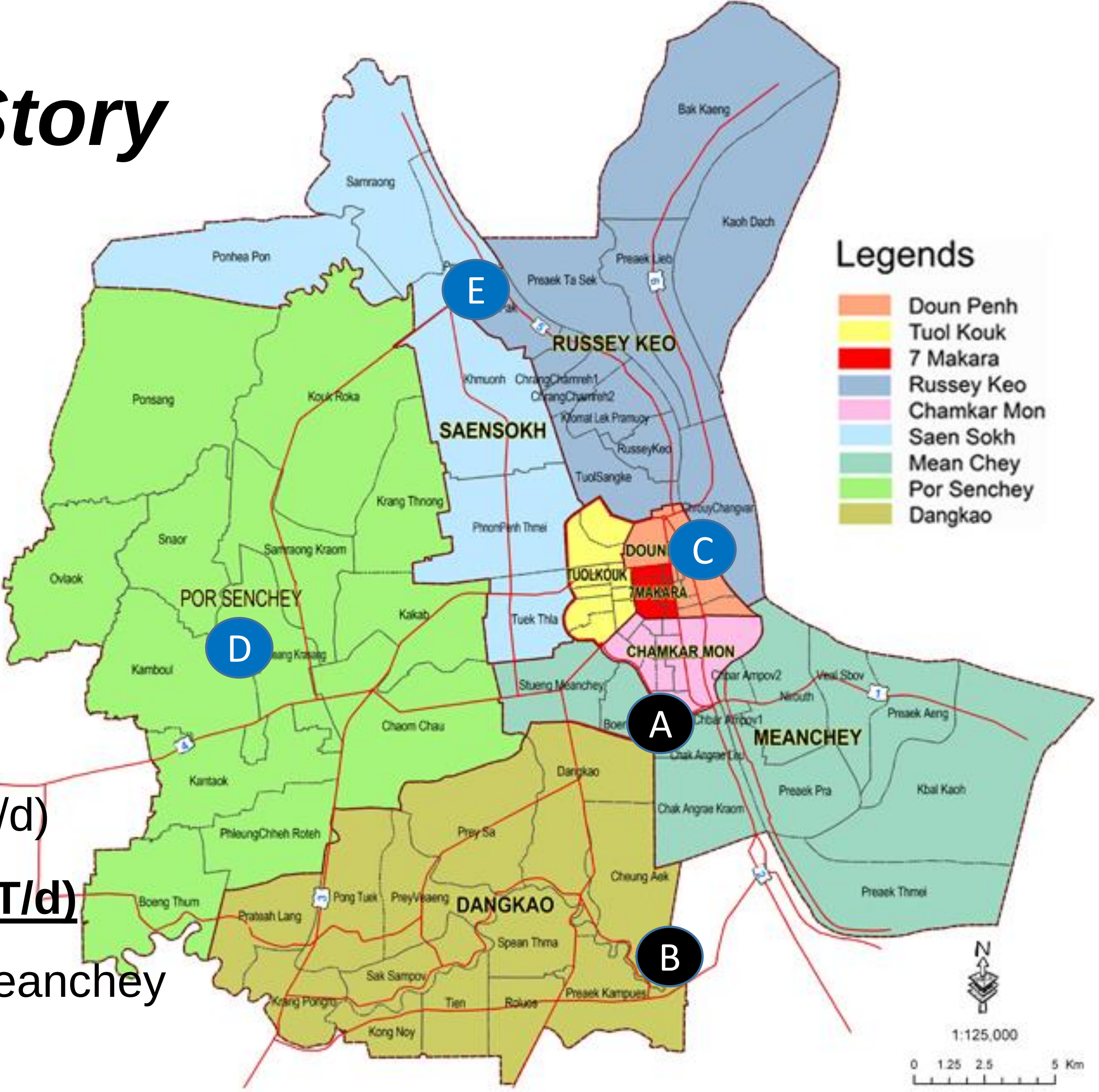

Image courtesy of Koonkhmer.com

Technology Portfolio & Terms

	Code	Technology		Code	Technology		Code	Technology
Municipal Solid Waste (MSW)	INCINERATOR	Municipal Incinerator	Biogas	SEWERGAS	Biogas Sewerage + Power	Biomass	FORESTRY	Biomass Forestry Waste
	GASIFIER	Municipal Gasifier		BIOGAS	Biogas Cassava Waste Water + Power		BAGASSE	Biomass Sugar Bagasse
	PLASMA	Municipal Plasma Gasifier		HICOD	Biogas Ethanol Waste Water + Power		EFB	Biomass EFB Waste
	PYROLYSIS	Municipal Pyrolysis Plant		POME	Biogas Palm Oil Mill Effluent + Power		MIXED FUEL	Biomass Mix Fuel Agriculture
	OFMSW	Organic Fraction of Municipal Solid Waste to Biogas + Power		FARMGAS	Biogas Cattle/Piggeries + Power		MICROGASIFIER	Biomass Small Scale Waste
	DRY OFMSW	Municipal Dry Fermenter + Power		DRYFARMGAS	Cattle/Piggeries Dry Fermenter + Power	Bio Fertiliser	TORREFIER	Torrefied biosolids
	OFMSW + RDF/SRF	OFMSW + Refuse Derived Fuel/Solid Recovered Fuel)		CHICKEN	Biogas Chicken Farm + Power		ZeoChar	Modified Gasification of sludge & Silica
	RDF/SRF	Municipal RDF/SRF + Gasifier		LFG	Landfill Gas		SLUDGE	Soil Conditioner from Biogas Process
	Torrefaction	Torrefaction - BioCoal		FARM	Household/Farm Biogas		BIOCHAR	Biochar
	TDP	Thermal Depolymerization	Soil Fuels	BRIQUETTE	Briquettes - Char		COMPOST	Windrow, anaerobic, biodry or other
				PELLETS	Fuel Pelletisation from biomass			

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Technology Portfolio & Terms

	Code	Technology		Code	Technology
Waste Heat Recovery	CCGTup	GT to CCGT (Gas Turbine - Combined Cycle Gas Turbine)	Biofuels	DME	Dimethyl Esther
	ORC	Organic Rankine Cycle (ORC) System (Reverse Absorption Chiller)		BioDME	DME made from Biological feedstock
				FAME / Biobutanol	Fatty Acid Methyl Esther / Gasohol
	PREHEAT	Preheating with waste heat		BIOFAME	FAME using Enzymes
	DRYING	Waste heat used for drying		CATALYTIC FAME	FAME using Catalysts
	PROCESS	waste heat used to heat fuel oil		BioCNG	Compressed Natural Gas made from waste
	HEAT PUMP	Heat pumps are used for district heating and energy transfer (hot water)		BioLNG	Liquified Natural Gas made from waste
	Nano Antennae	Nano Antennae harvesting radiant heat/radiation around the 300 nanometer spectrum.		BioEthanol	Ethanol using Enzymes
				SYNMETH	SYNGAS to Methanol (Gasifer)
Bio Plastics	BIOPLASTIC	Bioplastics - Bags/Cutlery		CATALYTICS	Syngas to methanol using catalysts
	MSW>C5,6,7	MSW to Chemicals - Ethylene		BIOMETHANOL	Methane to methanol using catalysts

Part D – Innovation - Changing Logistics Models

Bio Energy kiosk in rural areas selling biofuels, BioCNG and other fuel substitutes directly to consumers at roadside kiosk close to source.

Innovation in Action – Enerkem Rotterdam

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Innovation in Action – Copenhagen Example

Distributed bioenergy facilities in neighborhood MRFs (Material Recovery Facilities). Empowers local communities to derived financial social and environmental benefits from their waste resources (local renewable energy, local jobs, less truck impact on roads, local center for circular economy and general increase in local cohesion.

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Thank you!