Renewable Energy workshop
Mauritius Research Council
24-25 July 2006

Solid Wastes as a Potential Energy Source

Dr R.Mohee and H. Rughoonundhun
Department of Chemical and Sugar Engineering
University of Mauritius.

25 July 2006.

Renewable Energy workshop
Mauritius Research Council
24-25 July 2006

Overview

- Municipal Solid Wastes
  - Direct combustion of wastes
    - International practices
    - Mauritius case study
  - Anaerobic digestion and Landfill gas
    - Energy production from biogas
- Sludge
  - Direct Combustion
  - Anaerobic digestion

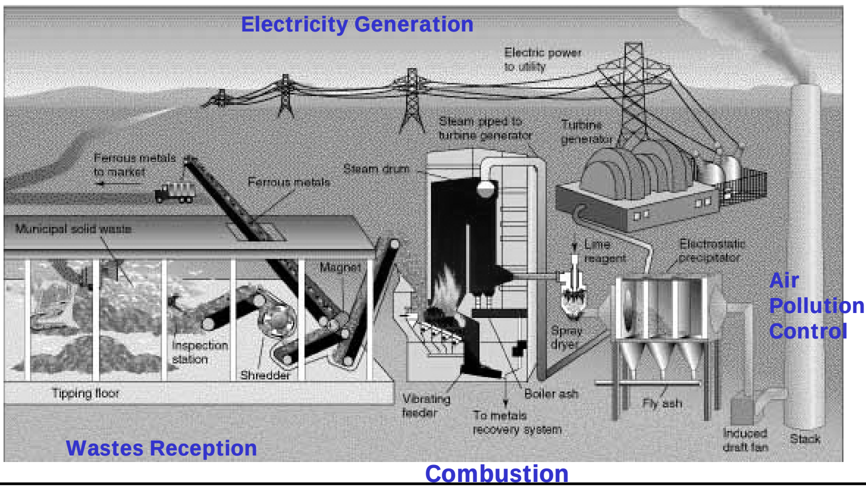
Incineration from municipal solid wastes

Technology	Product
▪ MSW	
▪ Mass Burn systems	Steam & Electricity
Modular incinerators	Steam
▪ Preprocessed MSW	
▪ Fluidised bed	Steam & Electricity
▪ RDF incinerator	Steam & Electricity
▪ Biogasifcation	Medium quality Fuel gas
▪ Thermal Pyrolysis	Low to medium quality fuel gas

The dominant WTE technology is mass burning, because of its simplicity and relatively low capital cost.

Renewable Energy workshop
Mauritius Research Council
24-25 July 2006

Typical waste to energy facility



Advantages and Constraints

- **Advantages**
  - Production of energy
    - **Waste-to-energy is a "clean, reliable, renewable source of energy," according to the U.S. EPA.**
  - Decrease in solid wastes disposal
  - Avoid methane emissions, hence avoided CO2 emissions

- Constraints
  - Quantity of Energy variable- Wastes characteristics
  - High Capital and Operating costs
  - Air emissions (PM, VOC, SOx, NOx)
  - Public Acceptability
  - Cost of energy produced (Rs / KWh)

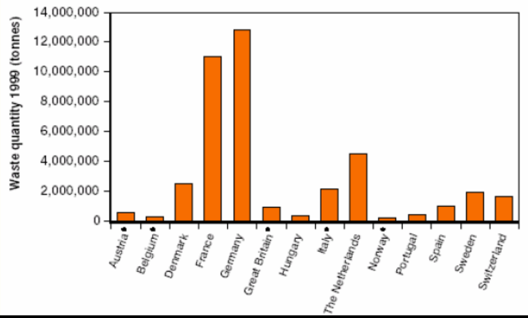
Status of energy recovery

Material	Calorific value (kJ/kg)
Oil	42000
Plastics	25000 - 30000
Wood	18810
Charcoal	29260
Sub-bituminous coal	14860
Rice husks	14886
Bagasse	20500
Municipal solid wastes	5000-17000

- A typical large-scale power plant uses approximately 11000 kJ to produce 1 kWh; therefore, combusting one ton of the "dry" and "wet" mix should generate about 1000 kWh.
- However, the best WTE plants produce about 650 kWh per ton of mixed MSW .
- The same WTE plants fueled only by the "dry" combustible fraction would produce about 1000 kWh/ton

Status of waste incineration in Europe

- Worldwide, about 130 million tonnes of municipal solid waste (MSW) are combusted annually in over 600 waste-to-energy (WTE) facilities that produce electricity and steam for heating.
- The total amount of waste incinerated in the 14 European countries in 1999 amounted to approximately 41 million tonnes, with Germany the country incinerating the most waste, at about 13 million tonnes



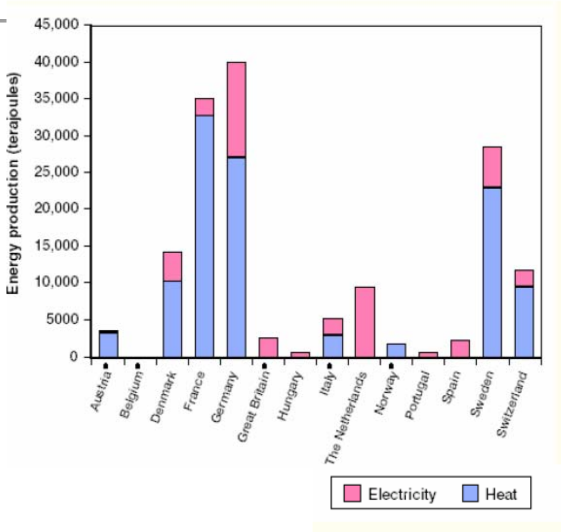
Waste to Energy plants

TABLE 1. Waste-to-energy plants in Europe operating in 2003.
SOURCE: CEWEP

	Number of WTE plants	Treated waste (million tonnes)
France	123	11.25
Spain	11	1.86
Portugal	3	1
UK	15	3.17
Belgium	17	1.64
Netherlands	12	5.18
Luxembourg	1	0.12
Switzerland	29	2.97
Italy	49	3.47
Austria	5	0.88
Germany	58	13.18
Czech Republic	3	0.4
Poland	1	0.04
Hungary	1	0.19
Denmark	31	3.28
Norway	21	0.79
Sweden	28	3.13
Finland	1	0.15

Status of Energy recovery

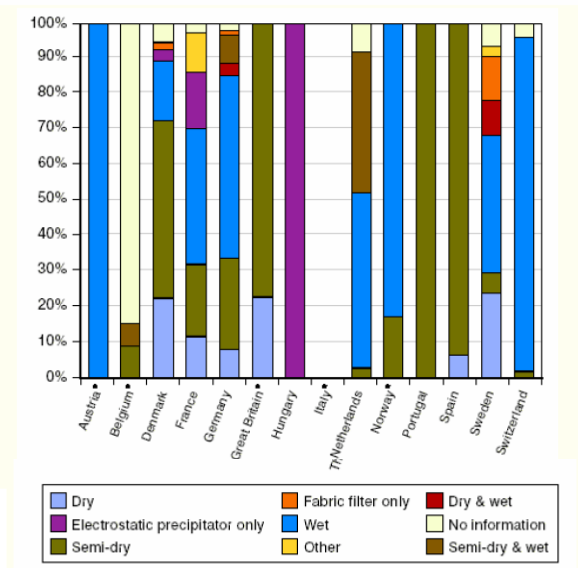
- In general, there are two important uses for the energy recovered.
  - Scandinavian countries use a high percentage of the recovered energy to produce **hot water** for district heating;
  - The other countries mainly produce **steam for electricity production**, mostly without using the remaining energy, which simply goes to waste.
  - There are now moves towards **combined heat and electricity** production.



Renewable Energy workshop
Mauritius Research Council
24-25 July 2006

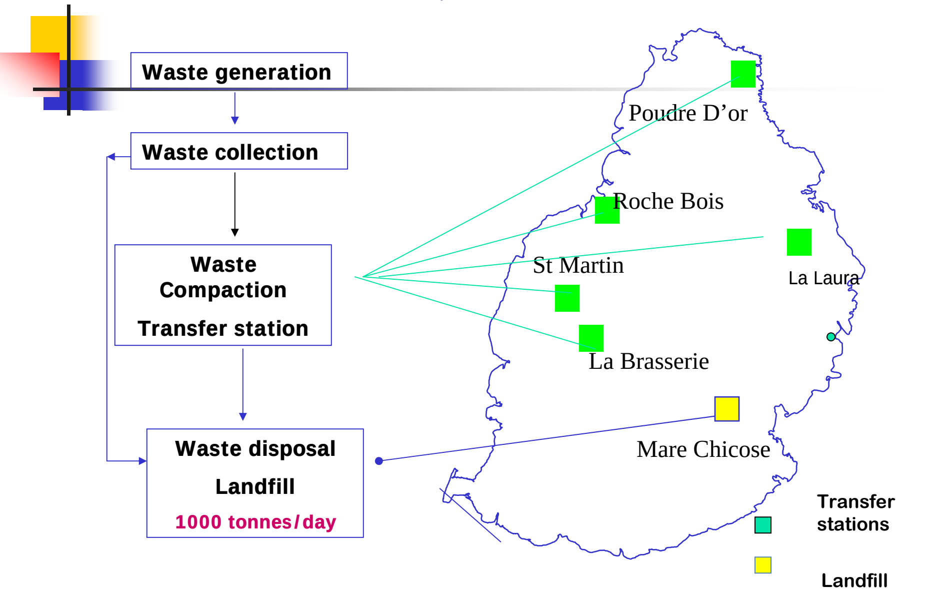
Requirements for air pollution control

- Most WTE have to be equipped, to be consistent with EU standards with
  - electrostatic precipitators
  - multi-stage wet scrubbers with wastewater evaporation
  - fabric filters or wet electro-venturies
  - DeNOx equipment.



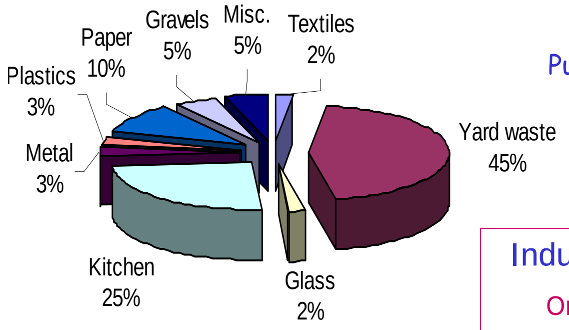
Renewable Energy workshop
Mauritius Research Council
24-25 July 2006

Solid Waste Data for Mauritius



Renewable Energy workshop
Mauritius Research Council
24-25 July 2006

Typical Solid wastes Composition in Mauritius



Putrescible wastes:
80% (w/w)

Industrialized countries

Organics : 25 to 40%

Plastics: 15-20%

Paper: 20 to 30%

Combustion parameters

- The variation in calorific value of the MSW is from 9000 to 12000 kJ/kg and moisture content varied from 40 to 68% during the year.
- A report form SIDEC Arupp 1998 concluded that the overall net calorific value in Mauritius is likely to be between 6.7 and 7.5 MJ/kg.
- Fichner 2002 also reported net calorific values between 9.3 and 13.5 MJ/kg for mixed municipal solid wastes with a moisture level of 47%.

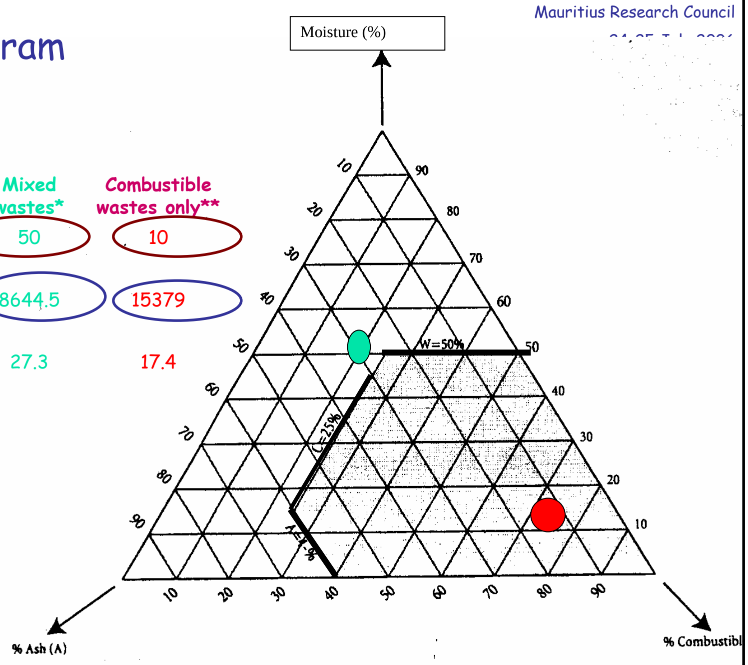
Combustible fractions of municipal solid wastes

Component	Moisture (% wet weight)	Ash (% dry weight)	Calorific value (kJ/kg)
Plastics	7.3	1.9	**43600 ± 565**
Paper/cardboard	15.87	6	17800 ± 700
Textile	26.2	3.5	16000 ± 200
Packaging materials	18.05	11	**24200 ± 500**
Organics	44.5	13	10500 ± 700

Renewable Energy workshop
Mauritius Research Council

Tanner diagram

	Mixed wastes*	Combustible wastes only**
Moisture content(%)	50	10
Calorific value (kJ/kg)	8644.5	15379
Ash content (% dw)	27.3	17.4

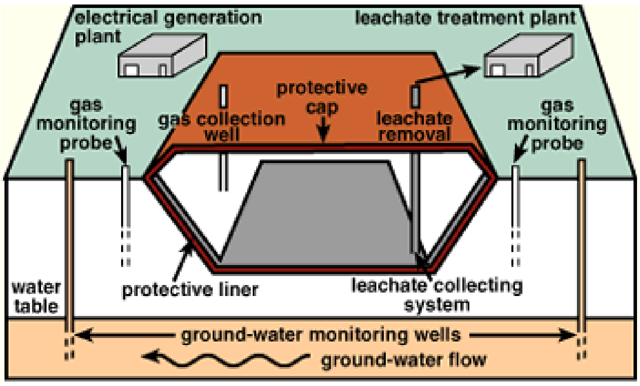


Renewable Energy workshop
Mauritius Research Council
24-25 July 2006

Conclusions

- Incineration of mixed MSW would lead to low amounts of energy
- Removal of putrescible wastes would increase calorific value.
- Energy can be used for operation of incinerator, office and x/s energy can also be sold to the central grid.
- Siting of incinerator, air emission standards, cost of electricity produced are important issues

Energy from landfill gas



Biogas flaring plant at Mare Chicose

Landfill data

Table 4: Yearly placement of wastes

Year	Wastes input (tons)
1997	6,854
1998	64,987
1999	180,788
2000	265,817
2001	306,691
2002	363,913
2003	372,442
2004	381,204
2005	385,016

Table 5: Estimated amounts

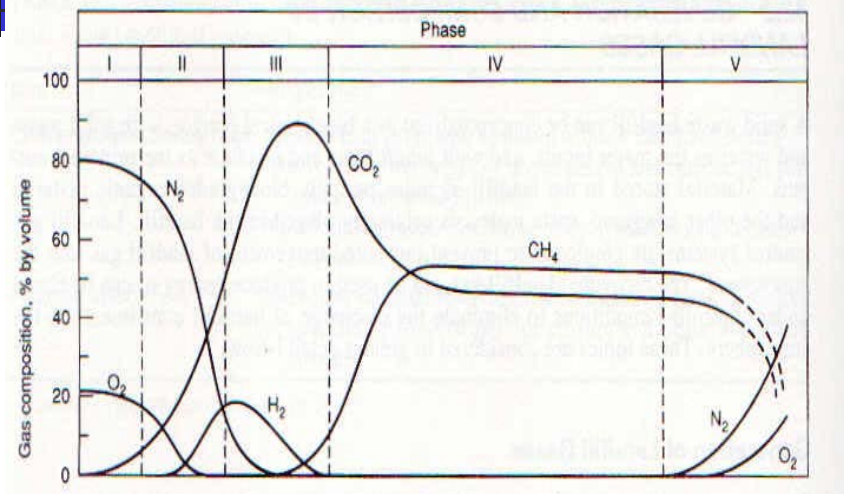
Year	Wastes input (tons)
2006	388,866
2007	392,755
2008	396,682
2009	400,000
2010	404,000

Flaring of biogas- Site data

Yr 2001	400 - 800 m3/hr
Yr 2002	800-1200 m3/hr
Yr 2003	±1200 m3/hr
Yr 2004	>1200 m3/hr

Gas generation patterns

$$C_aH_bO_cN_d + [(4a - b - 2c + 3d) / 4]\ H_2O \longrightarrow [(4a + b - 2c - 3d) / 8]\ CH_4 + d\ NH_3 + [(4a - b + 2c + 3d) / 8]\ CO_2$$



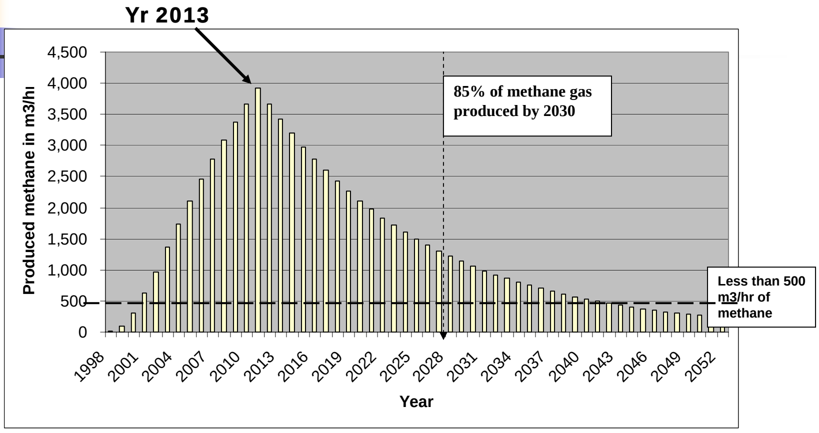
Wastes being placed progressively over a period of 10 years

Models development

- The USEPA equation suitable for sites with known year-to-year waste acceptance rates has been used.
  - $Q_T = 2\ k\ L_o\ Me^{(-kt)}$
- Where:
- Q_T = total amount of landfill gas generated in current year (m3)
- **k= reaction rate (yr^{-1}) = 0.069 yr^{-1}
- *L_o = total methane generation potential = 200 m^3/ton of wastes
- M = mass of solid waste placed in the i^{th} section
- t = No. of years since placement of wastes = age of wastes

- *Since L_o and k values vary widely and depend on local climatic conditions and waste compositions, they have been determined using experimental parameters from Mare Chicose.*

Methane prediction



Power generation potential

Year	Gas Production (Nm3/hr)	Collectable gas (Nm3/hr)	Potential Electric Energy (MWh)
0	0.0	0.0	0.0
1	712.1	427.2	0.7
2	1,383.8	830.3	1.3
3	2,017.9	1210.7	1.9
4	2,617.0	1570.2	2.4
5	3,183.4	1910.1	3.0
6	3,719.6	2231.7	3.5
7	4,227.4	2536.5	3.9
8	4,709.0	2825.4	4.4
9	5,166.1	3099.7	4.8
10	5,600.4	3360.2	5.2
11	6,013.6	3608.1	5.6
12	6,407.0	3844.2	6.0
13	5,979.9	3587.9	5.6
14	5,581.2	3348.7	5.2
15	5,209.0	3125.4	4.8
16	4,861.7	2917.0	4.5
17	4,537.6	2722.6	4.2
18	4,235.1	2541.0	3.9
19	3,952.7	2371.6	3.7
20	3,689.2	2213.5	3.4
21	3,443.2	2065.9	3.2

2010
-
2015

Energy Recovery from landfill gas

- Small modular spark ignition engines of capacities of 1 MW and 2 MW can be used in series to cater for the variability in biogas generation.
- This energy can be used on site in the office or for operation of equipment such as pumps for leachate treatment. It can also be used to supply electricity to the village of Mare Chicose.
- Feasibility study should be carried out based on “status of wastes disposal”.

Energy from Sludge

Sludge

- Produced as a by-product of wastewater treatment.
- Can be Primary, secondary or chemical.
- Is in the form of a liquid or semi-liquid.
- Contains organic matter, pathogens, nutrients, heavy metals.

Typical sludge characteristics

Parameters	Average Composition
pH	7.2
Moisture content (%)	98.14
Total solids	1.86
Volatile solids (% dry sludge)	80.18
Kjeldahl Nitrogen (TKN % dry sludge)	3.30
Phosphorous, P (% dry sludge)	0.064
Potassium, K (% dry sludge)	0.598
Ecoli (No. of colonies/ml raw sludge)	256000
Salmonella (No. of colonies/ml raw sludge)	28800

Estimated quantities of sludge from wastewater treatment plants

Source/ Treatment Plant	Phase 1 (2005)		Phase 2 (2013/2015)	
	Tonnes (25%DS)	Dry Solids t/a	Tonnes (25%DS)	Dry Solids t/a
St. Martin	26,412	6,603	61,640	15,410
Montagne Jacquot	24,820	6,205	51,820	12,955
Grand-Baie	8,395	2,086	8,400	2,100
Baie du Tombeau	-	-	-	-
Central Housing Authority (CHA) Estates	400	98	400	100
Total	60,027	14,992	122,260	30,565

(Source: Environmental Solid Waste Management Programme, Feasibility Report. Fichtner October 2002).

Renewable Energy workshop
Mauritius Research Council
24-25 July 2006

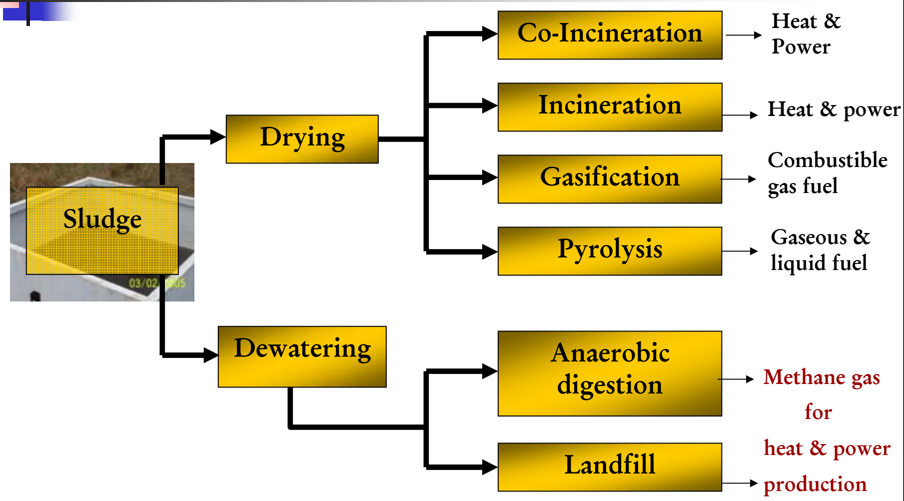
Sludge Management
…traditional methods

- Ocean Dumping
- Land Application

- Composting

Renewable Energy workshop
Mauritius Research Council
24-25 July 2006

Energy Routes



Energy from Sludge

Incineration of sludge

- Incineration or co-incineration (e.g with MSW)
- Technology
  - Rotary Kiln
  - Multiple hearth
  - Fluidised bed
- Calorific Value
  - Raw primary = 26,000 kJ/kg
  - Secondary = 21,000kJ/kg

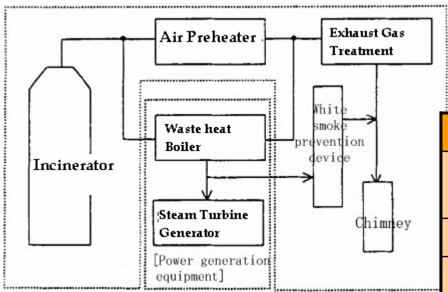
Incineration

Renewable Energy workshop
Mauritius Research Council
24-25 July 2006

Energy from Sludge

Incineration of sludge

- Potential for Mauritius



	Specification
Sludge feed rate	12.5t/h
Calorific Value	21,000 kJ/kg
Steam Turbine	0.824t steam/t sludge
Energy Content	703 x 10^6 MJ
Power	~ 700 kwh

Energy from Sludge

Anaerobic digestion of sludge

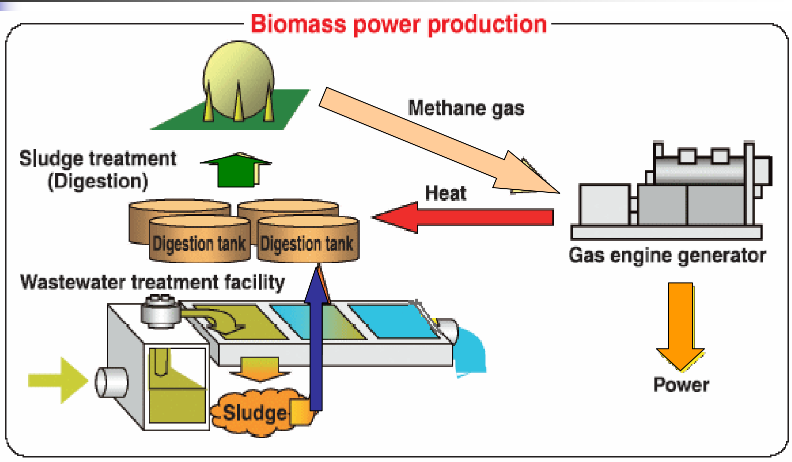
- the bacterial decomposition of organic matter in the absence of oxygen
- mesophilic conditions
  - 20 to 40°C
  - retention time of 15 to 30 days

Anaerobic Digestion

Renewable Energy workshop
Mauritius Research Council
24-25 July 2006

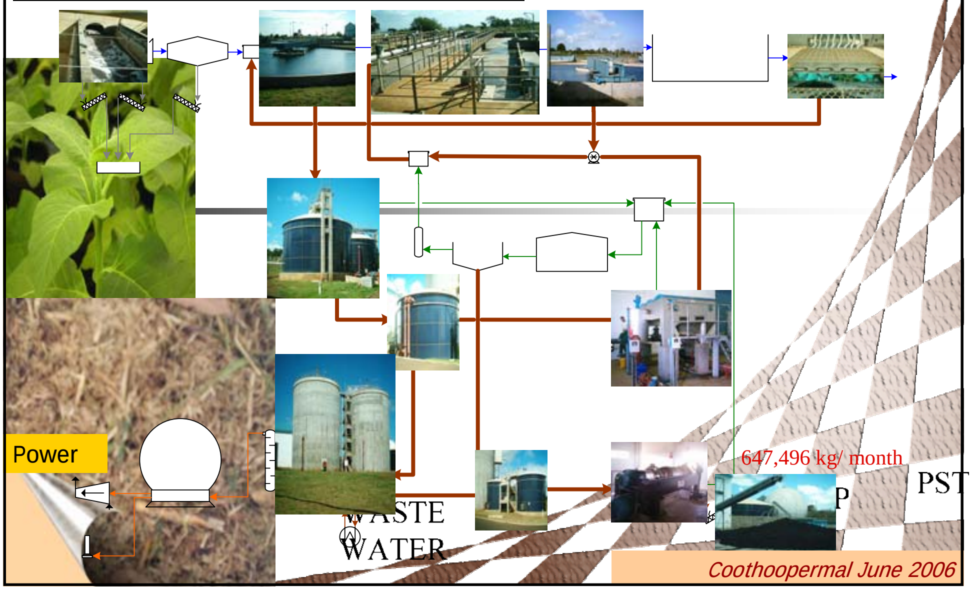
Energy from Sludge

Anaerobic digestion of sludge



Energy from Sludge

St Martin Waste Water Treatment Plant



ACTIVAT
SLUDGE T

Primary
Sludge

SUMP

Acti

SETTL
TAN

TANK

ickened
ary Sludge

GESTOR

Combined
Raw Sludge

Settled

Digested
Sludge

CHP

Energy from Sludge

Anaerobic digestion of sludge

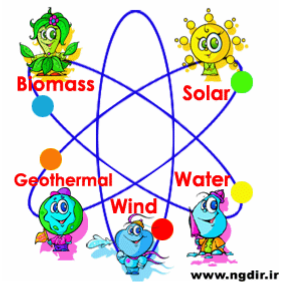
- **Potential for Mauritius**

Amount of dry sludge in 2013 = 30, 565 tonnes (3,489 kg/h)
Volatile solids content = 80%
Amount of Volatile solids destroyed = 40 to 50% (Average 45%)
Biogas yield = 0.8 to 1.2 Nm3/ kg VS destroyed

Motor electricity yield =35% of gas LCV

Lower calorific value of biogas (60% methane) = 6.0 kWh/ Nm3
Hence energy production = **2,638 kWh**

(**Reference:** Gay Jérôme. 2002. *Lutte contre la pollution des eaux: Valorisation énergétique de boues.* Technologies des eaux. Vol G1, dossier G1455



Thank You for your kind attention