SAARC ENERGY CENTRE
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WASTE-TO-ENERGY
A case study of Karachi MSW

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SEQUENCE OF PRESENTATION

- Characteristics of MSW
- Selection of WTE Technology for MSW in Karachi
- Economic Analysis
- Conclusion

CALORIFIC OR HEATING VALUE OF MSW

- MSW consists mainly of waste paper, cardboard, food, organic material, mixed plastics and textiles etc.

- In 2016, the worlds' cities generated 2.01 billion tons of solid waste (1.2 kilograms per capita per day, expected to rise by 70% by 2050) (World Bank, 2019)

- Assessment of heating value of MSW is important for efficient design and successful operation and maintenance of WTE facility

- Heating value of MSW depends on percentage of paper, plastic, textiles, organic material, moisture etc.

HEATING VALUES OF MSW

- Heating value of MSW in developing and developed countries

Countries category	Countries	Calorific value (kcal/kg)
Developing	Bangladesh	717
	China	1200-1600
	India	800-1100
	Malaysia	1500-2600
	Sri Lanka	950-1250
	Thailand	500-1500
Developed	Japan	2000-2200
	S. Korea	2600-3000
	UK	2200-3000

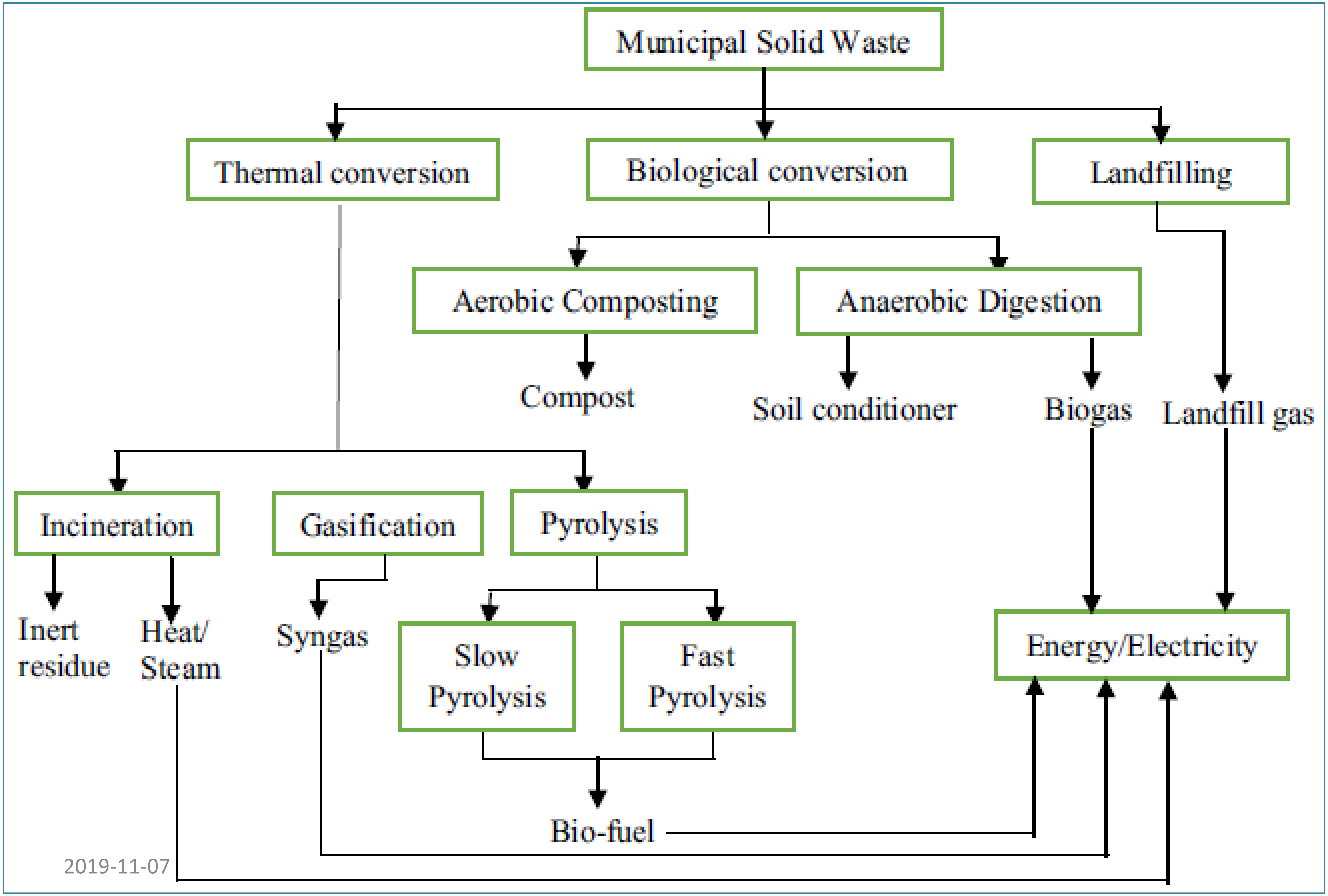
STATUS OF MSW IN KARACHI

- Karachi generates more than 13,500 tons of MSW per day
- Karachi has three landfill sites (LFS)
- Handling one ton of MSW incur a cost of nearly USD 33.4/ton (SSWMB, 2019)
- According to SSWMB, indigenous waste lying open at the landfill sites of Karachi comprises of 54% organic matter

WASTE TO ENERGY (WTE)

- WTE is rapidly growing all over the world
  - ➢ It reduces the demand for landfills
  - ➢ It reduces dependence on fossil fuels
  - ➢ It reduces environmental impacts
  - ➢ It helps develop sustainable cities and achieve sustainable development goals (SDGs)

WTE TECHNOLOGIES



THERMAL TECHNOLOGIES

- Thermal conversion involves thermal treatment of organic matter present in MSW to produce either heat energy, fuel oil or gas

- Thermal conversion technology is generally useful for
  - Dry waste containing lower moisture content
  - Containing high percentage of non-biodegradable organic matter

INCINERATION

- Incineration, which is a controlled combustion of wastes at high temperature is the most widely used thermal technology
- Sometimes auxiliary fuels are used along with MSW, when calorific value of MSW is below 1000 kcal/kg
- Effective incineration process requires average calorific value of MSW
  - At least 1700 kcal/kg (World Bank, 2019)
  - At least 1900 kcal/kg (International Energy Agency)

PYROLYSIS AND GASIFICATION

- In USA, UK, Italy, Germany, Norway and Iceland, gasification has been used to process MSW at small scale
- Gasification process generates less CO_2 than incineration

ANAEROBIC DIGESTION

- Anaerobic digestion (AD) is a process of microbial degradation of organic bio-degradable matter in the absence of oxygen to produce biogas

- Biogas is typically composed of 50–75% methane (CH_4), 25–50% carbon dioxide (CO_2) and 1–15% of other gases and vapors

- The produced sludge can be used as fertilizer

ANAEROBIC DIGESTION

- AD is extensively used for energy recovery from MSW especially in the developing countries, where wastes have high moisture content

- Researcher have found biogas recovered from anaerobic digestion technology to be economically and environmentally sustainable

COSTS OF WTE TECHNOLOGIES

- The costs of different WTE technologies is as under

WTE technologies	Capital cost (USD/ton of MSW/year)	Operational cost (USD/ton of MSW/year)
Incineration	400-700	40-70
Pyrolysis	400-700	50-80
Gasification	250-850	45-85
Anaerobic digestion	50-350	5-35
Landfilling with gas recovery	10-30	1-3

SELECTED WTE TECHNOLOGY (Karachi)

Anaerobic digestion (AD)

- It offers decentralization of energy and power generation
  - Rural and remote communities that are not connected to the electricity grids are able to produce their own electricity
- Once started and stabilized, the plant produces biogas on a continuous basis independently of external factors, such as the sun or wind
- It can produce 2–4 times more methane per ton of MSW in 3 weeks than that of a landfill in 6–7 years

ANAEROBIC DIGESTION

- About 150 kg of methane can be generated from 1 ton of MSW considering 60% organic matter and 40% moisture
- AD produces biogas rich in methane
- The major problem associated with this process is the long duration (typically 20–40 days) of microbial reaction

WHY ANAEROBIC DIGESTION FOR KARACHI MSW

- Effective incineration process requires average calorific value of MSW
    - At least 1700 kcal/kg (World Bank, 2019)
    - At least 1900 kcal/kg (International Energy Agency)

- Waste lying open at the landfill sites of Karachi comprises of 54% organic material

WHY ANAEROBIC DIGESTION FOR KARACHI MSW

- AD is selected for Karachi MSW based on the following factors:

  i. Lower fraction of combustibles and lower heating value due to separation and scavenging
  ii. High moisture content
  iii. High organic fraction

ENERGY RECOVERY FROM MSW

Base-case scenario

- In the absence of any scientific data, the heating/ calorific value of MSW of Karachi is taken as 1400 kcal/kg in the base-case calculations
- For calorific value of 1400 kcal/kg of MSW, methane recovery is computed as 95 kg/ton MSW (or 68 m^3/ton MSW or 5.86 MJ/kg)
- For 500 tons/MSW per day, and for power generation efficiency of 55% (for combined cycle) gives power plant capacity of 16.78 MW

FINANCIAL & ECONOMIC ANALYSIS

Base-case scenario

- Parameters for calculations in the base-case scenario:

Calorific value of MSW	kcal/kg	1,400.00	(Punjab Power Development Board, 2019)
Unit capital cost	USD/ton MSW/year	300.00	(Kumar & Samadder, 2017)
Unit operating cost	USD/ton MSW/year	20.00	(Kumar & Samadder, 2017)
Interest rate	%	0.1325	State Bank of Pakistan
Unit gate fee	USD/ton MSW	10.00	(Tsydenova, et al., 2019)
Electricity generation efficiency	%	0.55	Combined Cycle efficiency ranges between 50-60%

COSTS AND REVENUES

Base-case scenario

- Capital cost of USD 300/ton MSW/year is taken for base-case scenario (Kumar & Samadder, 2017)
- Operating cost of USD 20/ton MSW/year (Kumar & Samadder, 2017)
- For 500 tons/day of MSW and power plant capacity of 16.78 MW, Capital cost comes out to be USD million 54.75 (PKR 8.54 billion for taken 156 PRK/USD)
- Annual operating cost is computed as USD million 3.65/annum (PKR 5.7 billion/year)

COSTS AND REVENUES

Base-case scenario

Unit capital cost	USD/ton/year	300.00
Capital cost	USD million	54.75
Unit operating cost	USD/ton/year	20.00
Annual operating cost	USD million/year	3.65
Unit MSW collection fee	USD/ton	0.00
Annual MSW collection fee	USD	0.00
Total annual operating costs	USD million/annum	3.65
Total annual operating costs	PKR million/annum	569.40

COSTS AND REVENUES

Base-case scenario

Tariff of NEPRA	US¢/KWh	10.00
Daily electricity sales	USD/day	40,271.00
Annual electricity sales	USD million/annum	14.70
Sale of compost as a % of sale of electricity	%	0.25
Annual compost sales	USD million/annum	3.67
Unit gate fee	USD/ton MSW	10.00
Earning from gate fee	USD million/annum	1.83
CO_2 avoided per ton MSW	Tons CO_2/ton MSW	0.73
CO_2 avoided per annum	Tons/year	133,225.00
carbon credit	USD/ton CO_2	0.00
Total carbon credit per annum	USD/year	0.00
Total revenues per year	USD million/annum	20.20
Total revenues per year	PKR million/annum	3.15

Empirical results of financial analysis

Base-case scenario

- Benefit Cost Ratio (BCR) computed as 1.18 which shows the higher present value of the revenues than the present value of the costs incurred

- The project also indicates positive NPV with Internal Financial Rate of Return (I.F.R.R.) of 15.95% which is higher than the applicable discount rate of 13.25%

Empirical results of financial analysis

Base-case scenario

I.F.R.R. at discount rate of 13.25% for the base-case scenario				
P.W. of total cost	USD million	54.75	8.76	PKR billion
P.W. of net revenues	USD million	64.58	10.33	PKR billion
NPV	USD million	9.83	1.57	PKR billion
Benefit cost ratio		1.18	1.18	
I.F.R.R.	%	15.95%	15.95%	%

Sensitivity analysis of the project

- Parameter for sensitivity analysis (range of ±20% with respect to the parameters taken in the base-case scenario)

Parameters for Sensitivity analysis	Unit	lower value	upper value
Calorific value of MSW	kcal/kg	1,260.00	1,540.00
Unit capital cost	USD/ton MSW/year	270.00	330.00
Unit operating cost	USD/ton MSW/year	18.00	22.00
Unit gate fee	USD/ton MSW	9.00	11.00
Electricity generation efficiency	%	0.50	0.61

Sensitivity analysis of the project

Effect of calorific value of MSW

For the taken lower value (1260 kcal/kg) of calorific value, the project is unfeasible whereas for upper value (1540 kcal/kg) of calorific value the project is feasible

P.W. of total cost	**USD million**	**54.75**	**54.75**
P.W. of net revenues	USD million	51.33	77.83
NPV	USD million	-3.42	23.08
Benefit cost ratio		0.94	1.42
I.F.R.R.	%	0.12	0.19

Sensitivity analysis of the project

Effect of capital cost

For the taken lower value (270 USD/ton MSW/year) of capital cost, the project is feasible whereas for upper value (330 USD/ton MSW/year) of capital cost the project is unfeasible

P.W. of total cost	**USD million**	**49.28**	**60.23**
P.W. of net revenues	USD million	70.05	59.10
NPV	USD million	20.78	-1.12
Benefit cost ratio		1.42	0.98
I.F.R.R.	%	19.00%	13.00%

Sensitivity analysis of the project

Effect of operating cost

For the taken lower value (18 USD/ton MSW/year) and upper value (22 USD/ton MSW/year) of operating cost, the project is feasible

P.W. of total cost	**USD million**	**54.75**	**54.75**
P.W. of net revenues	USD million	67.21	61.95
NPV	USD million	12.46	7.20
Benefit cost ratio		1.23	1.13
I.F.R.R.	%	17.00%	15.00%

Sensitivity analysis of the project

Effect of gate fee

For the taken lower value (9 USD/ton MSW) and upper value (11 USD/ton MSW) of field gate fee, the project is feasible

P.W. of total cost	**USD million**	**54.75**	**54.75**
P.W. of net revenues	USD million	63.26	65.89
NPV	USD million	8.51	11.14
Benefit cost ratio		1.16	1.20
I.F.R.R.	%	15.60%	16.31%

Sensitivity analysis of the project

Effect of electrical generation efficiency

For the taken lower value (49.5%) of electrical efficiency, the project is unfeasible whereas for upper value (60.5%) of electrical efficiency, the project is feasible

P.W. of total cost	**USD million**	**54.7500**	**54.7500**
P.W. of net revenues	USD million	51.3300	77.8277
NPV	USD million	-3.4200	23.0777
Benefit cost ratio		0.9375	1.4215
I.F.R.R.	%	12.28%	19.48%

Sensitivity analysis of the project

Effect of MSW collection fee

- Project is feasible if the project developer pays MSW collection fee to a maximum of 20% of USD 33.4/ton MSW, otherwise the project becomes unfeasible

MSW collection fee	USD/ton MSW	3.35	6.70	10.05
P.W. of total cost	USD million	54.75	54.75	54.75
P.W. of net revenues	USD million	61.03	57.48	53.93
NPV	USD million	6.2781	2.7274	-0.82
Benefit cost ratio		1.12	1.05	0.98
I.F.R.R.	%	14.99%	14.01%	13.02%

Sensitivity analysis of the project

Effect of Carbon Credit

- Carbon certificates make the project more attractive

Carbon credit	**USD/ton CO_2**	**0.00**	**5.00**	**10.00**
P.W. of total cost	USD million	54.750	54.750	54.750
P.W. of net revenues	USD million	64.579	69.382	74.185
NPV	USD million	9.829	14.632	19.435
Benefit cost ratio (BCR)		1.180	1.267	1.355
I.E.R.R.	%	16%	17.2%	18.5%

Conclusions

- Effective management of MSW is not only a social responsibility, but also an essential requirement to avoid environmental and health impacts
- Worldwide, often municipalities supply MSW to the WTE plant free of cost while in some cases they are also required to pay certain fee per ton of MSW treated by the plant operator in environment friendly manner (called as gate fee)
- WTE technologies provide an effective management of MSW in environment friendly manner which has become essential to build sustainable and livable cities and achieve sustainable development goals

Thank you