USDN Waste Innovation Research

New Waste Technology Tool - An Innovation Fund Project

Webinar
Tuesday, November 12, 2013

Green Houston

C40 CITIES CLIMATE LEADERSHIP GROUP

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Contents

- Overview of research
- The future of waste management

USDN Waste Innovation Research - Purpose

- Identify technologies
- Look at costs
- Assess Greenhouse Gas impacts
- To produce general guidelines for implementing an integrated waste management strategy

The Tool

Urban Sustainability Directors Network:
Waste Innovation Partnership
Technology Tool
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What the tool presents

- A list of suppliers relating to the following technology groups:
  - Materials Recovery Facilities (Single and Mixed Stream)
  - Advanced Thermal Treatment Systems
  - Anaerobic Digestion
  - Composting
  - Waste to Fuel
- A set of hypothetical waste management scenarios for each city
- A hypothetical interactive flow diagram for each city
- GHG Emissions Assessment
- ROM Cost Benefit Analysis

What the tool is intended to do

It's a guide to help:

- support your decision making process
- assess how you can maximize landfill diversion
- you assess what technologies are right for your situation
- you target individual goals
- you assess the rough costs associated with waste technologies
- you assess the Greenhouse Gas impacts associated with waste technologies
- you talk to technology suppliers with increased knowledge

What the tool should not be used for

- As a basis for a final decision on which technologies/scenarios would be suitable for your city.
- As a substitute for the advice of a qualified waste management professional.
- As a complete mass balance assessment tool for assessing waste flows.

The Tool

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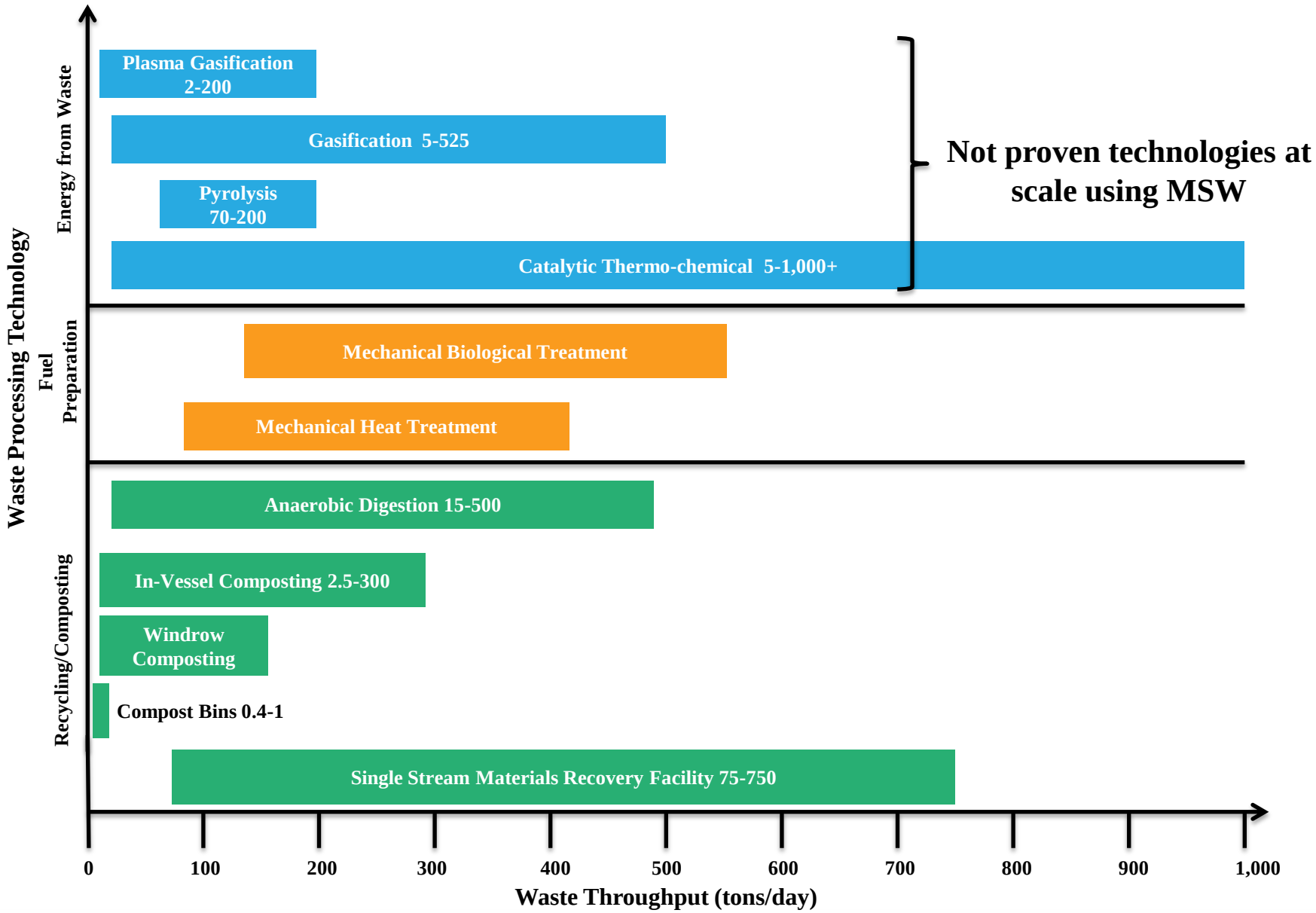
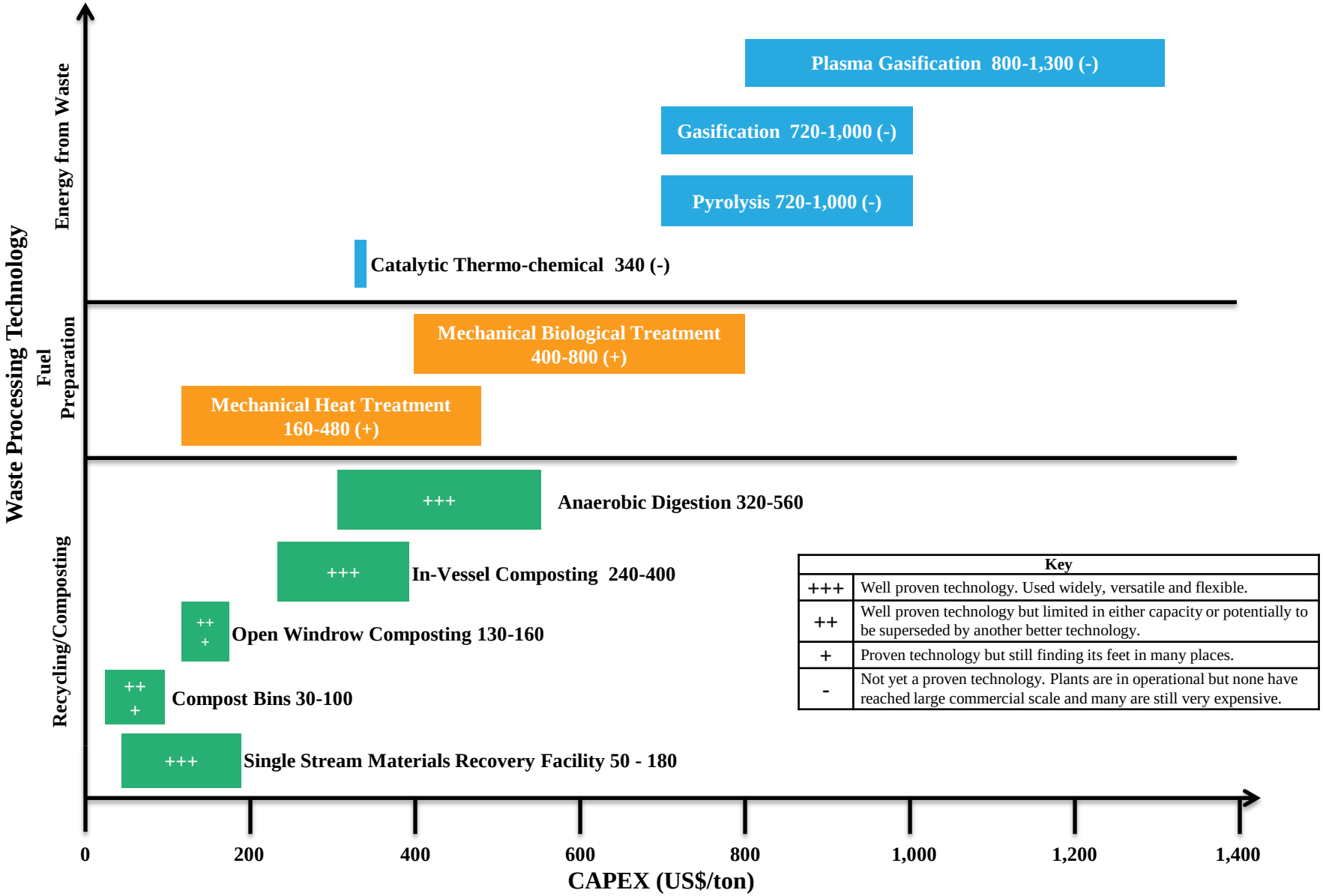
At what scale do they optimize?

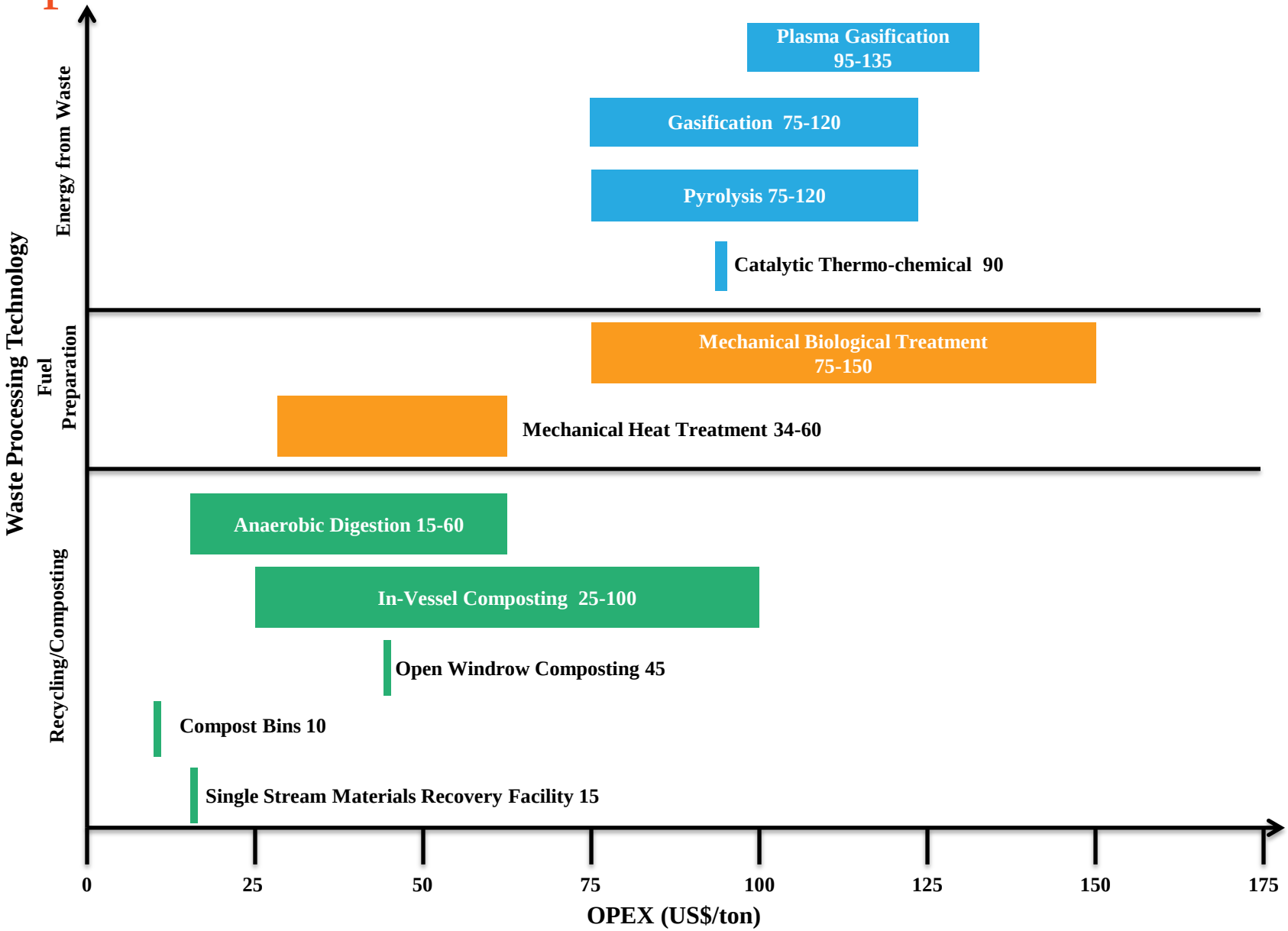


First Costs

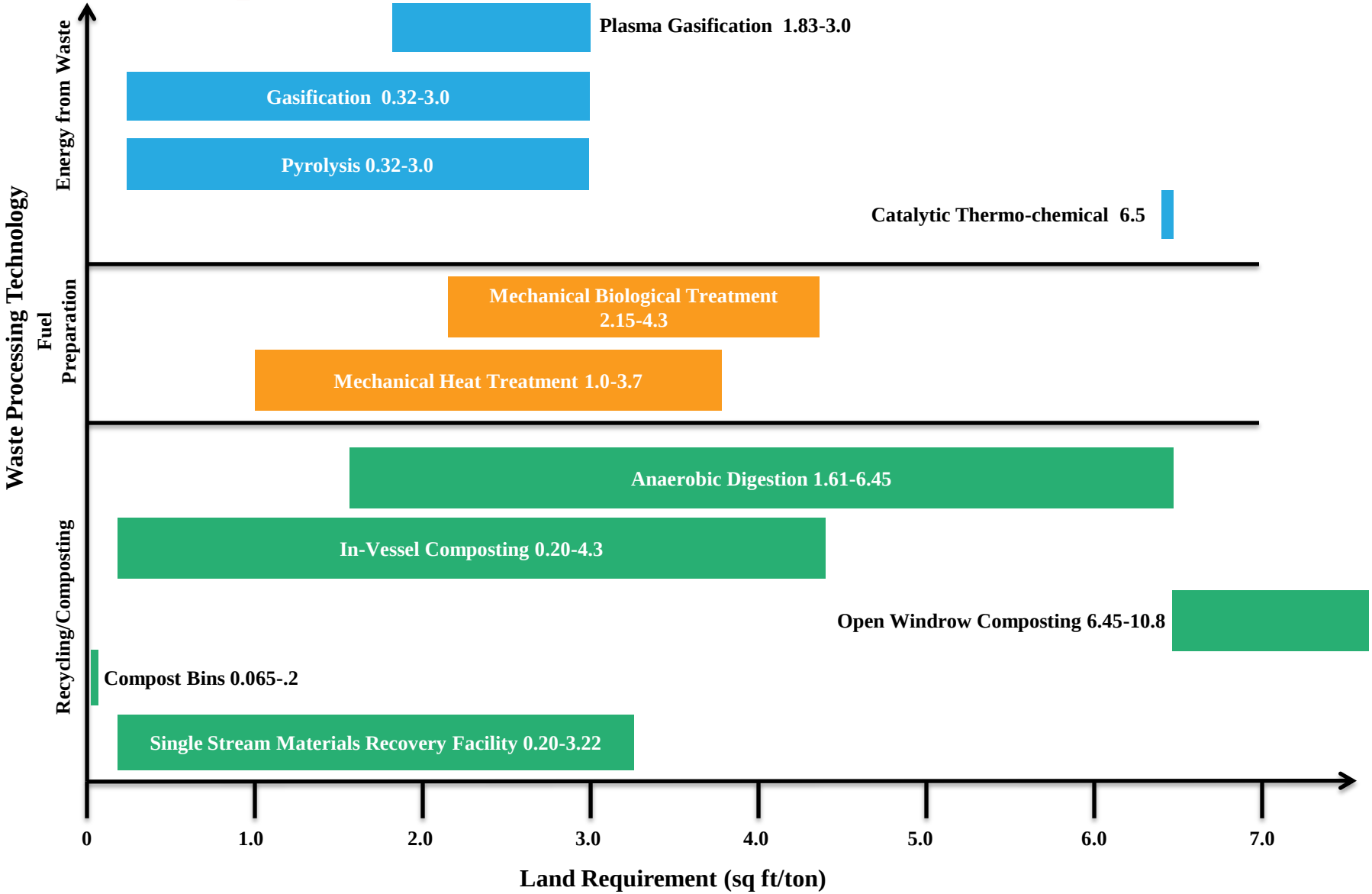


Key	
+++	Well proven technology. Used widely, versatile and flexible.
++	Well proven technology but limited in either capacity or potentially to be superseded by another better technology.
+	Proven technology but still finding its feet in many places.
-	Not yet a proven technology. Plants are in operational but none have reached large commercial scale and many are still very expensive.

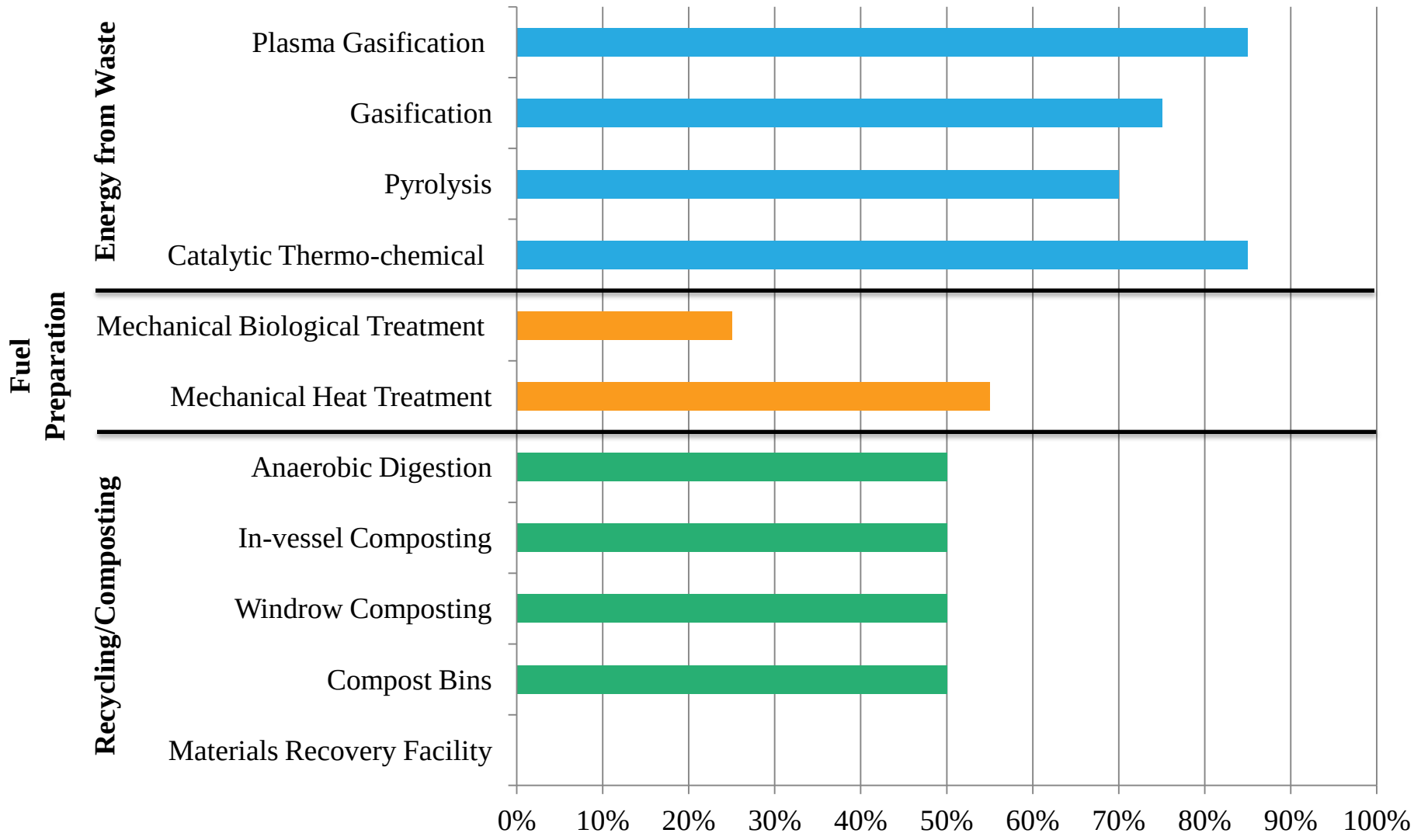
Operational Costs



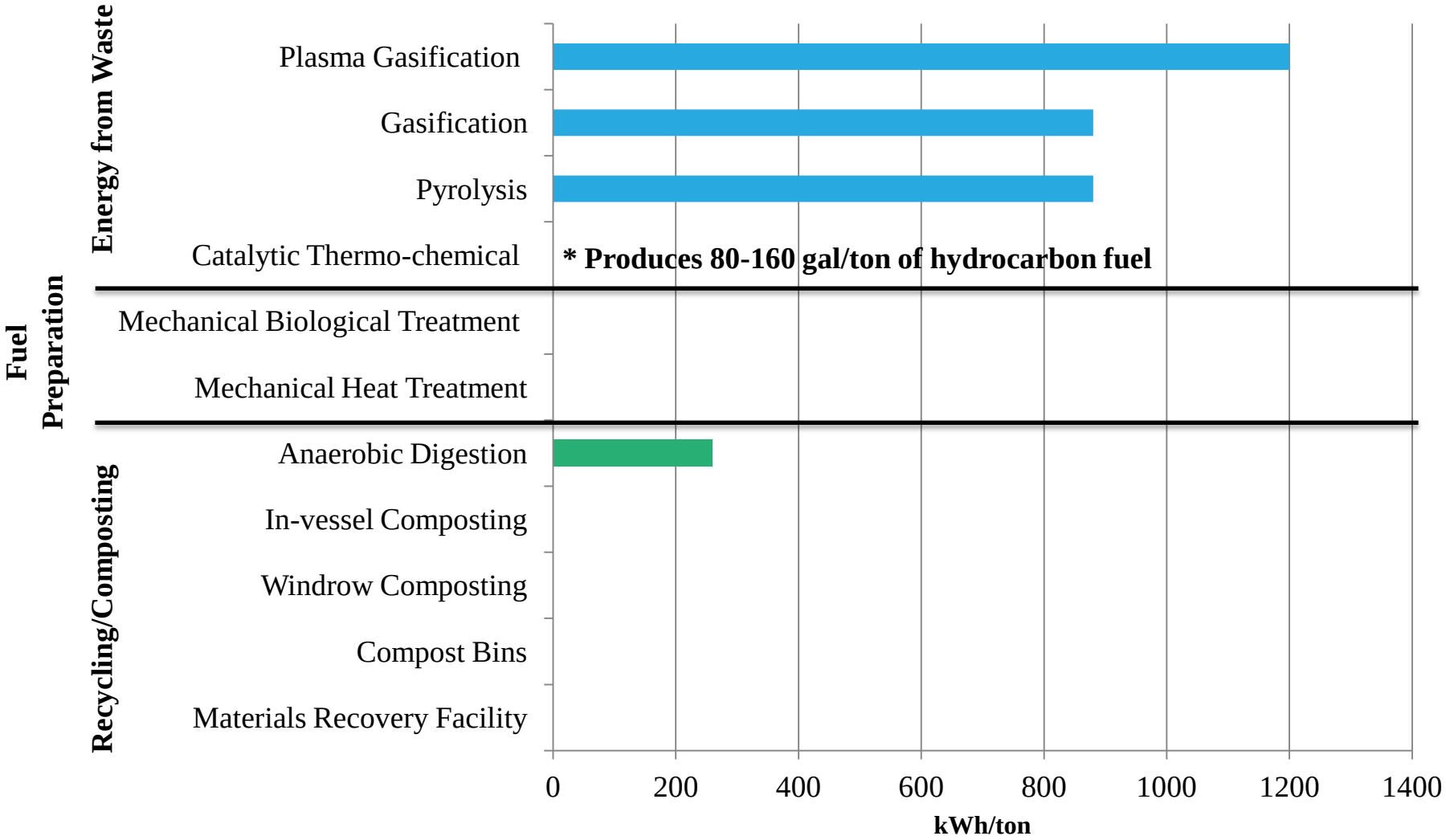
Land Requirement



Mass Reduction



Electricity Generation



What is happening around the world

Leaders

- Western Europe
- West Coast America
- Japan
- Canada
- Australia
- New Zealand

Changing

- East Coast America
- Eastern Europe
- Russia
- China
- India
- South Africa
- Nigeria
- Kenya
- C40 cities

Thinking

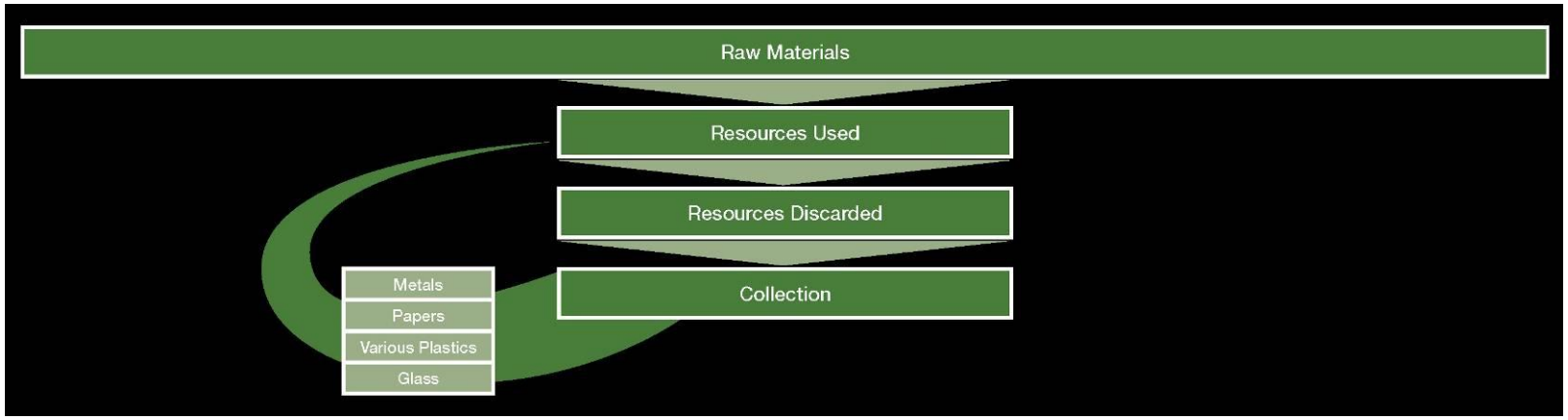
- South America
- Other African nations

Possible ways forward - Options

Waste Treatments	Waste Treatment Technologies
Landfill	• None
Collect the waste	
Disposal	• Landfill with landfill gas electricity
Pre-treatment/Fuel Preparation	• Mechanical Pre-treatment • Mechanical Heat Treatment • Mechanical Biological Treatment
Biological Treatment	• Composting • Anaerobic Digestion • Mechanical Biological Treatment
Advanced Thermal Treatment	• Gasification and Pyrolysis • Plasma Gasification
Combination of Technologies	• Integrated Waste Management Facility

Integrated solution

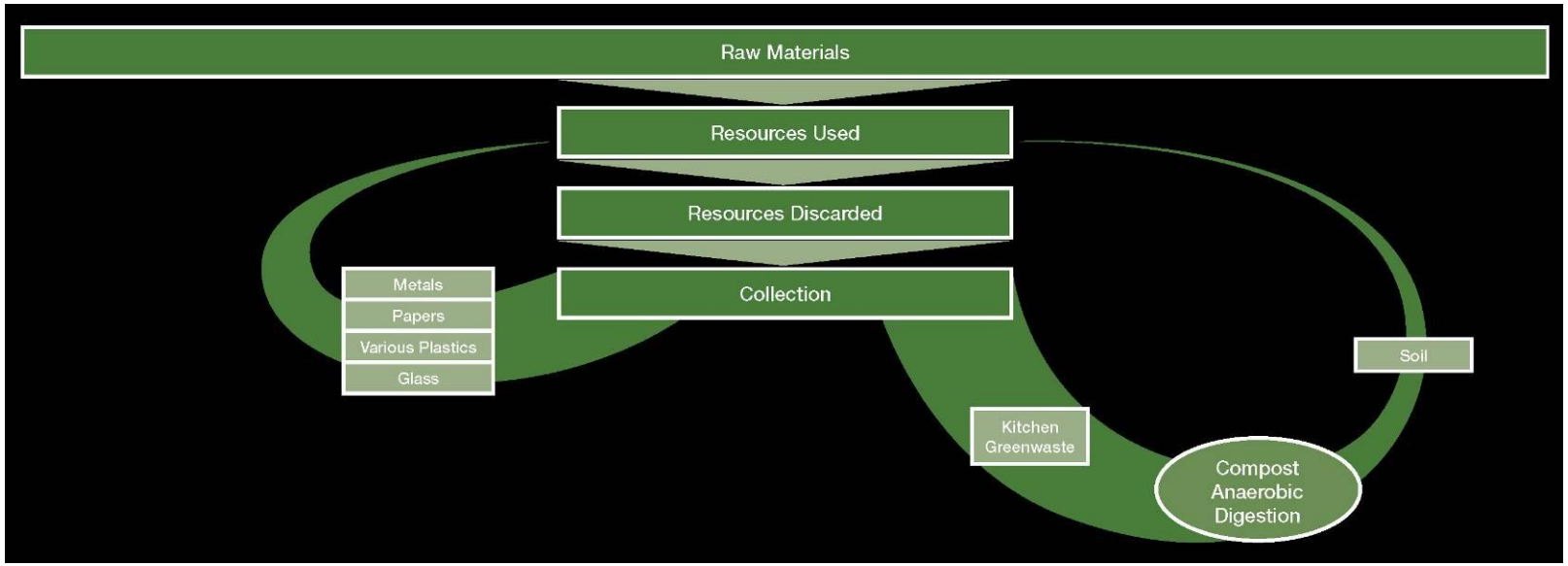
Integrated solution



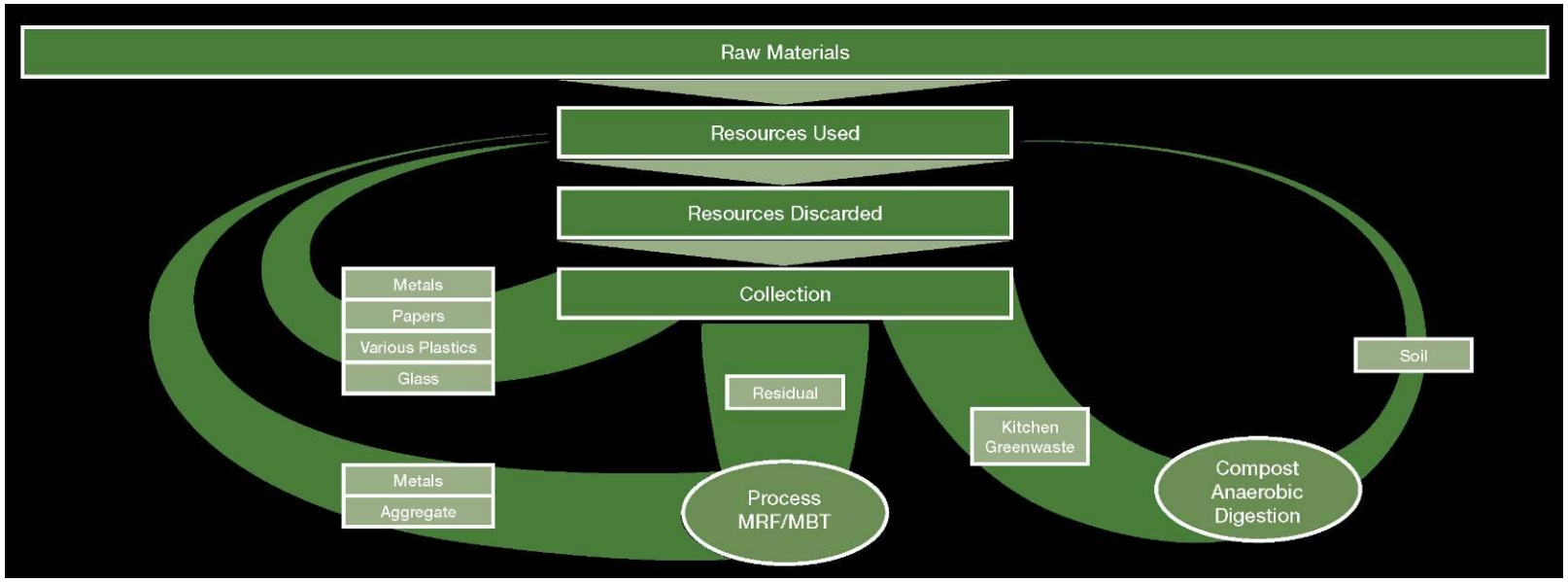
GLASS
FOOD
GENERAL

Ensure you have a market for the materials

Integrated solution



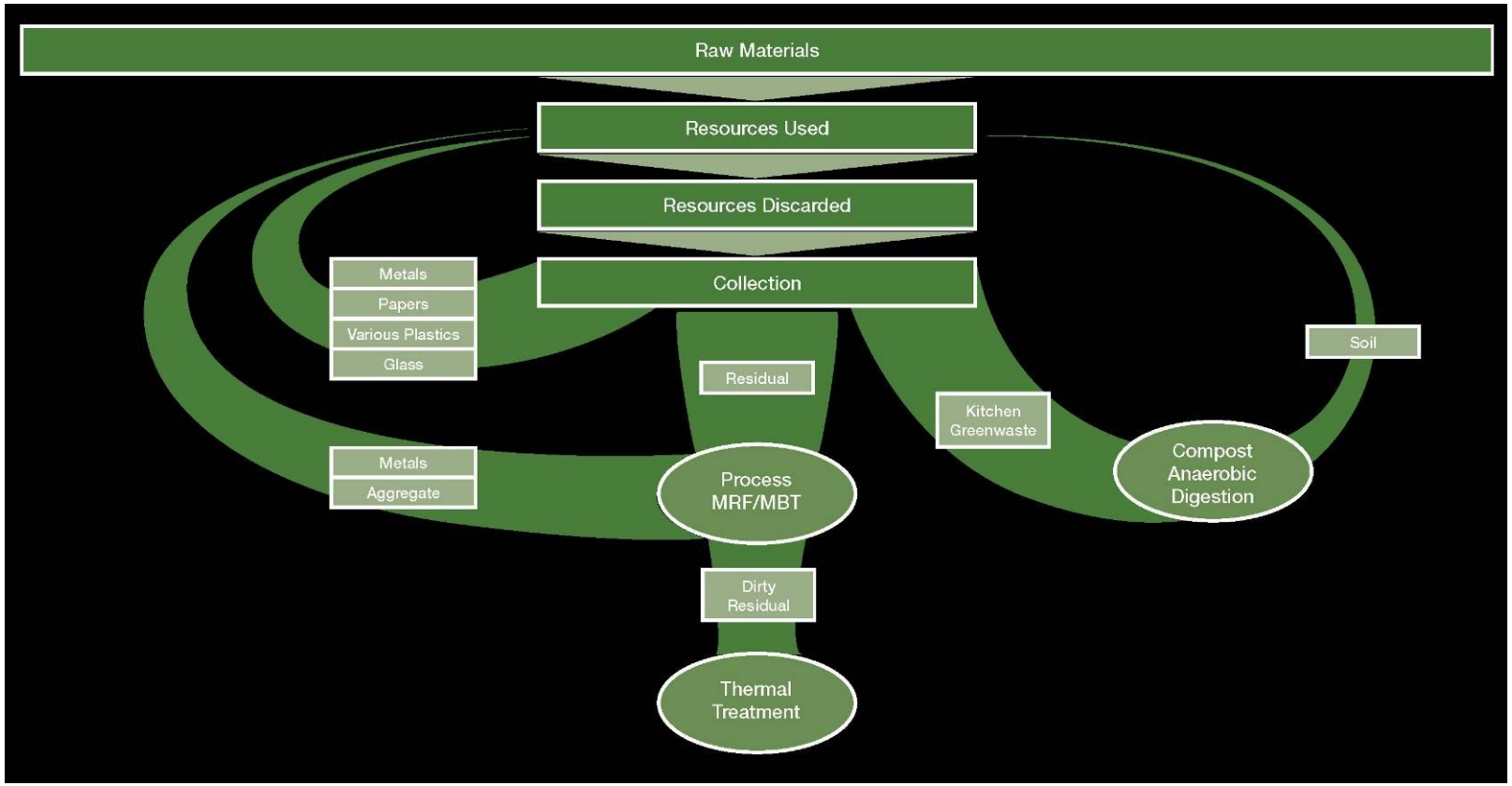
Integrated solution



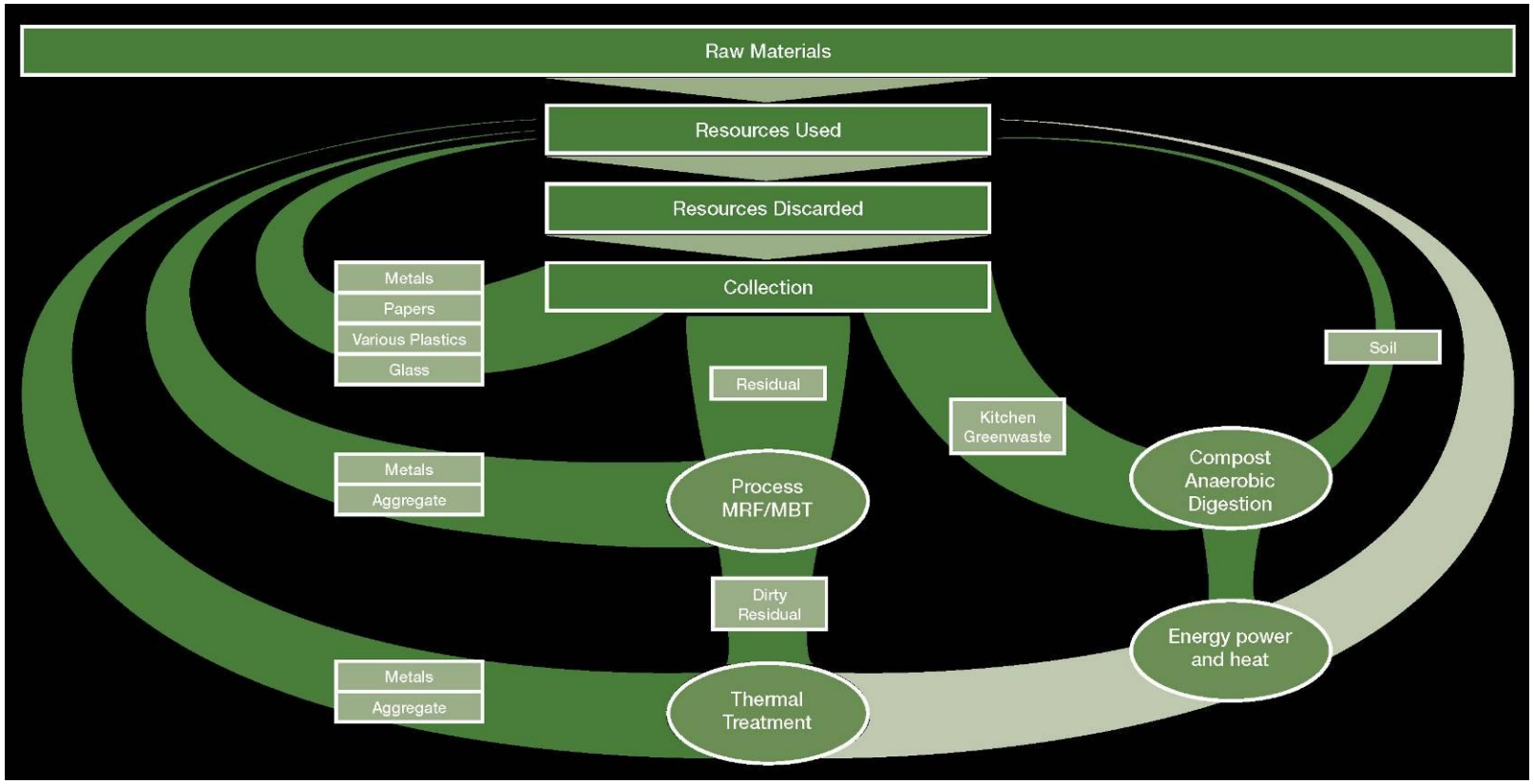
Materials Recovery

- Recycling in sites
- Separation of residual fraction:
  - Metals
  - PET
  - HDPE
  - PP
  - Paper / card
  - Plastic film
  - Solid recovered fuel to thermal treatment
  - Compost of fine fraction

Integrated solution



Integrated solution



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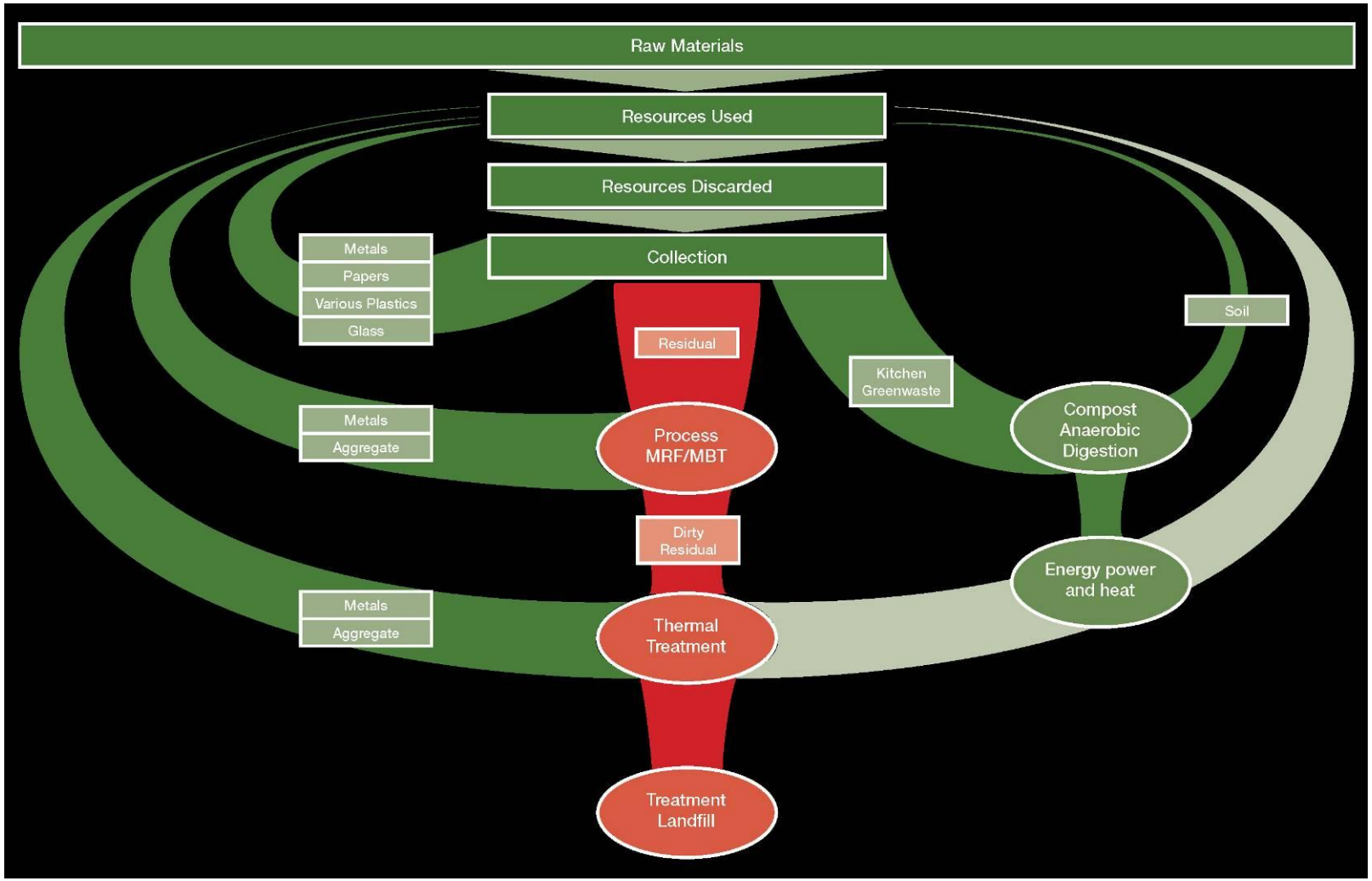
Integrated solution



So what can you do with the residual?

So what can you do with the residual?

- Remember matter cannot be created or destroyed
- And its the contents of your garbage bin
- You just decide on the products you make and the routes / markets

Options depend on local conditions, markets for products and your view of risk.

Japan 32 streams (zero?)

- Imaging that in a City

Recycle

- But market for dirty paper / plastic and fine fraction

Soils

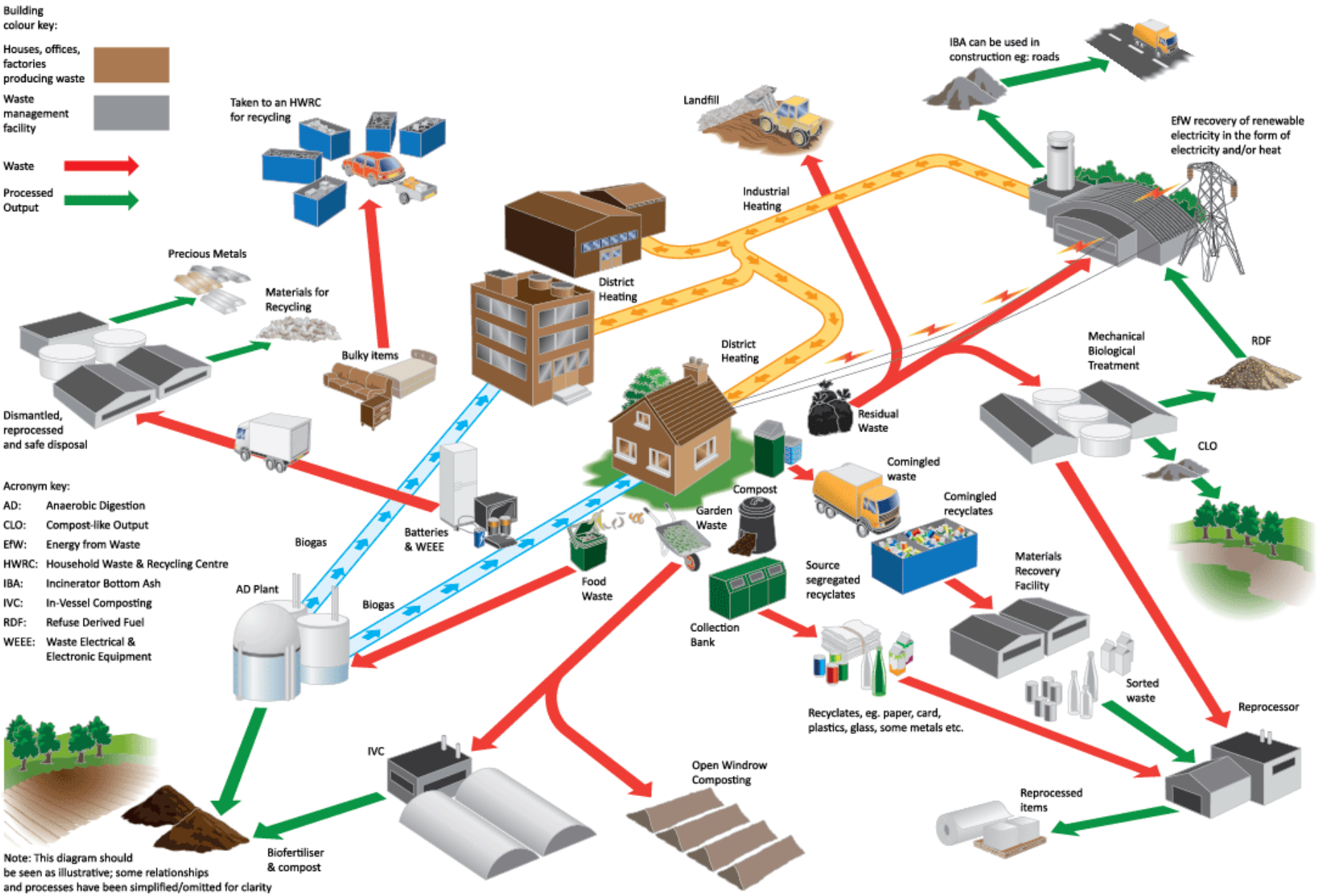
- Accept the contamination risk for years

Fuel from Energy

- Ash and public perception

Repository

- How


Building colour key:
Houses, offices, factories producing waste
Waste management facility
Waste
Processed Output
Taken to an HWRC for recycling
Landfill
IBA can be used in construction eg: roads
EfW recovery of renewable electricity in the form of electricity and/or heat
Industrial Heating
District Heating
District Heating
Precious Metals
Materials for Recycling
Bulky items
Dismantled, reprocessed and safe disposal
Residual Waste
Mechanical Biological Treatment
RDF
CLO
Comingled waste
Comingled recyclates
Compost
Garden Waste
Food Waste
Batteries & WEEE
Biogas
Biogas
AD Plant
Source segregated recyclates
Materials Recovery Facility
Collection Bank
Sorted waste
Recyclates, eg. paper, card, plastics, glass, some metals etc.
Reprocessor
Reprocessed items
IVC
Open Windrow Composting
Biofertiliser & compost
Acronym key:
AD: Anaerobic Digestion
CLO: Compost-like Output
EfW: Energy from Waste
HWRC: Household Waste & Recycling Centre
IBA: Incinerator Bottom Ash
IVC: In-Vessel Composting
RDF: Refuse Derived Fuel
WEEE: Waste Electrical & Electronic Equipment
Note: This diagram should be seen as illustrative; some relationships and processes have been simplified/omitted for clarity

Urban Sustainability Directors Network: Waste Innovation Partnership Technology Tool

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Interactive Index

1. Introduction
- Introduction to the project
- Guidance on how to use this document

2. City Information
- Details of waste generation rates and composition from participating cities

3. Scenarios
- Potential treatment scenarios for each participating city
- Different treatment technology combinations presented

4. Flow Diagrams
- Diagrammatic representation of waste flow and treatment options

5. Technology Summary
- Summary table of all relevant technology types
- Includes information on capital cost, operational cost, and design throughput

6. Materials Recovery Facility (MRF)
- Overview and comparison of single stream and mixed waste MRF technology
- List of technology suppliers and reference facilities

7. Advanced Thermal Treatment (ATT)
- Overview and comparison of Gasification, Pyrolysis and Plasma Gasification
- List of technology suppliers and reference facilities

8. Bio Anaerobic Digestion (AD)
- Overview of Anaerobic Digestion technology
- List of technology suppliers and reference facilities

9. Bio - Composting
- Overview of Bio-Composting technology
- List of technology suppliers and reference facilities

10. Waste-to-Fuel
- Overview of Waste-to-Energy technology
- List of technology suppliers and reference facilities

11. Greenhouse Gas Emissions
- Interactive tool to estimate greenhouse gas emissions from various waste treatment scenarios

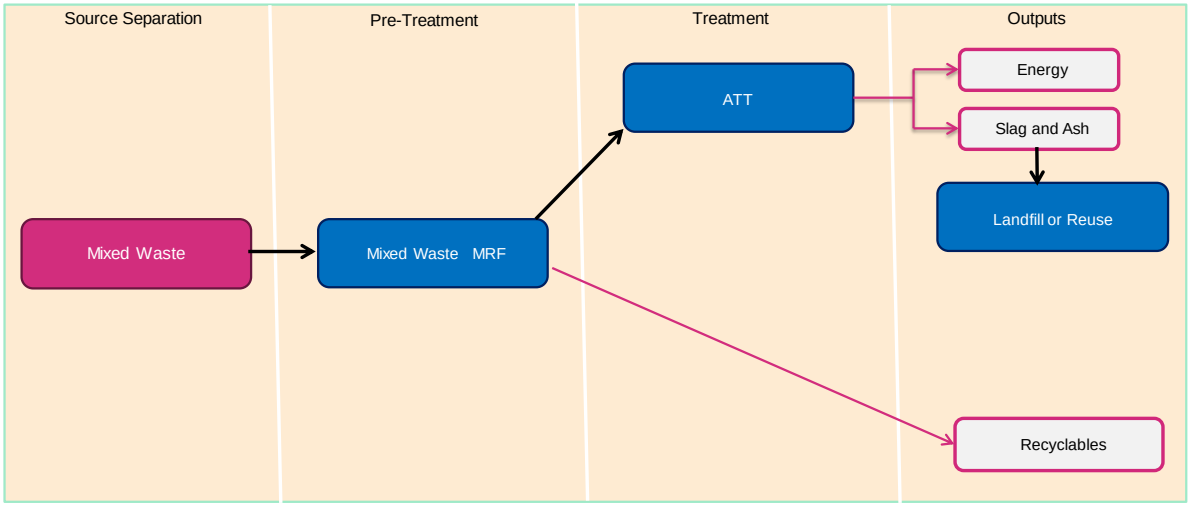
12. Cost-Benefit Analysis
- Summary table of costs and benefits associated with ATT and AD technologies

City	Collection Method					Waste Source	Composition	Mass (tons)	Description	Mass Burn Allowed	Advanced Thermal Treatment OK?
	Residual	Recyclables	Food	Mixed	Yard						
San Jose	Yes	Yes	No	No	Yes	Residential City Buildings C&D	Single Family Homes Recyclables 31% (Mixed Paper 7%, Compostable Paper 7%, Plastic 4%, Recyclable Paper 3%, Metal 2%, Glass 2%, Textiles 2%, Yard Trimmings 2%, wood 1%, Other Potentially Recyclable 1%) Food Scraps 42% Residual 27%	146,000	**Single Family Home** 146,000 tons of trash from Single family homes 97,000 tons (16,000 tons residue) **Multi Family Homes** 74,000 tons garbage (processed and composted, yields 20,000 tons residue) + 17,000 tons recycling (1,000 tons residue) **Yard waste from both** 133,000 tons (2,000 tons residue) **City Buildings**	No	Unclear

Waste Treatment Scenarios

City	Collection Method					Waste Source	Composition	Mass (tons)	Description	Mass Burn Allowed	Advanced Thermal Treatment OK?	Current Diversion rate
	Residual	Recyclables	Food	Mixed	Yard							
Houston	No	No	No	Yes	No	Residential	Plastics 13% Metals 8% Glass 5% Food 14% Yard 14% Wood 7% Paper and card 28% Textiles 8% C&D 2% Exwaste 1%	443,000	City collected 443,000 tons in 2011	No	Yes	14%

Scenario 1



Key Strategies:

Mixed waste would be sent through a MRF to recover recyclables.

The residual waste component would be sent to an ATT facility to decrease the disposal of waste at landfill.

Mixed Waste
Revenue/offset generating products
Organic Waste

Waste Treatment Scenarios

City	Collection Method					Waste Source	Composition	Mass (tons)	Description	Mass Burn Allowed	Advanced Thermal Treatment OK?	Current Diversion rate
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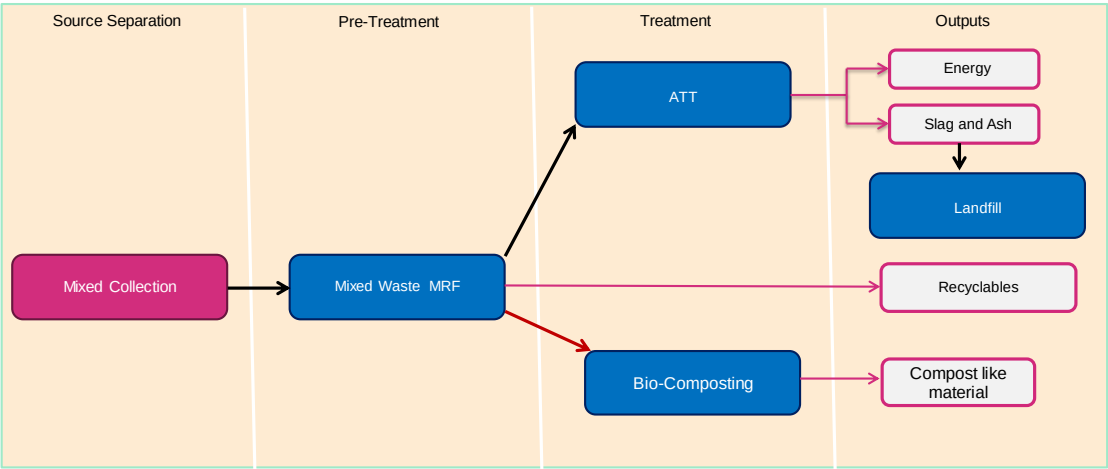
Scenario 2a - Bio-composting



Key Strategies:

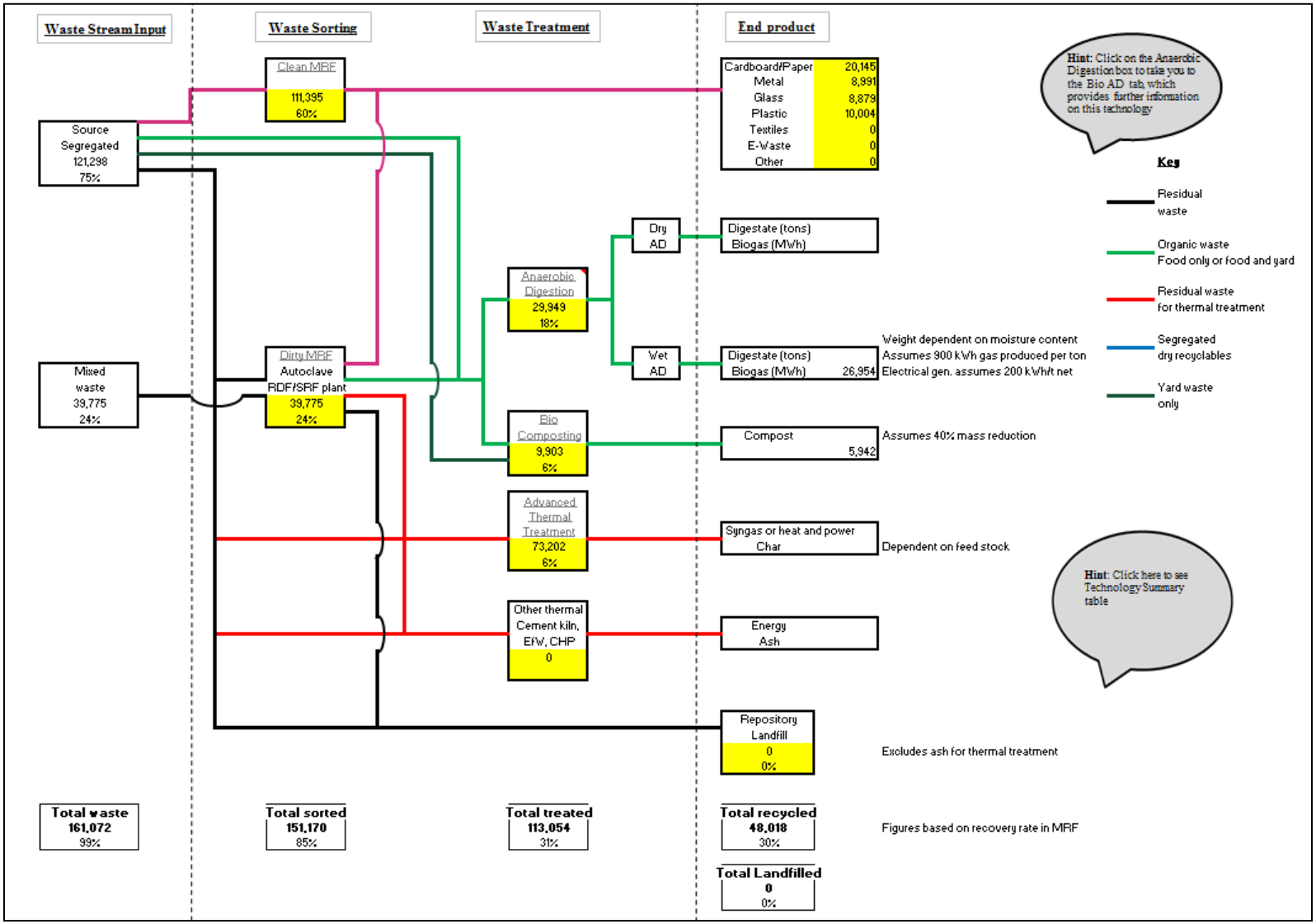
Mixed waste would be sent through a MRF to recover recyclables.

The organic fraction (primarily yard and food waste) will be recovered by MRF and sent to biocomposting facility.

The residual waste component from the MRF would be sent to an ATT facility to decrease the disposal of waste at landfill.

Mixed Waste
Revenue/offset generating products
Organic Waste

Process Flow Diagrams



Technology Summary

Index

Parameter	RECYCLING / COMPOSTING					FUEL PREPARATION		WASTE TO ENERGY				
	Materials Recovery Facility	Compost Bins/ Wormeries	Windrow Composting	In-vessel Composting	Anaerobic Digestion	Mechanical Heat Treatment	Mechanical Biological Treatment	Moving Grate Incinerator	Fluidized Bed Incineration	Pyrolysis	Gasification	Plasma Gasification
Ideal calorific value of waste (MJ/kg)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	6.6-18	6-20	10-25	10-25	10-25
Typical range of waste throughput (t/day)	75-6,000	0.4-1	2.5-150	2.5-300	0.5-500	80-410	137-548	180-900	70-900	70-200	5-525	2-200
Typical Feedstock(s)	Dry mixed recyclables Mixed MSW	Food waste Yard waste Paper/Cardboard	Yard waste	Food/catering waste, Yard waste, Poultry waste	Food waste Yard waste Sewage sludge	Mixed MSW Clinical waste Slaughterhouse waste	Mixed MSW	Mixed MSW	Pre-treated MSW Sewage sludge	Pre-treated MSW SRF Shredded tires Biomass	Pre-treated MSW SRF Shredded tires Biomass	Mixed MSW SRF Shredded tires Biomass
Typical land requirement (ft^2/t)	0.20 - 3.22	0.065 - 0.2	6.45 – 10.8	0.20 – 4.3	1.61 – 6.45	1.0 – 3.7	2.15 – 4.3	0.53 – 1.0	0.53 – 1.0	0.32 – 3.0	0.32 – 3.0	1.83 – 3.0
CAPEX (US$/t)	50-180	30-100	130-175	240-400	320-560	160-480	400-800	450-750	580-840	720-1,000	720-1,000	700-1,300
OPEX (US$/t)	15	10	45	25-100	15-60	34-60	75-150	45-100	60-110	75-120	75-120	90-135
Mass reduction	–	50%	50%	50%	50%	55%	25%	75%	75%	70%	75%	85%
Main outputs	Recyclables Rejects	Compost Rejects	Compost Rejects	Compost Rejects	Liquid and solid digestate Biomethane Electricity & Heat Rejects	Recyclables SRF Rejects	Recyclables SRF Low grade compost Metals Rejects	Electricity & Heat Rejects IBA APC residues Metals	Electricity & Heat Rejects Ash APC residues Metals	Syngas Electricity & Heat APC residue Char	Syngas Electricity & Heat APC residue Ash Slag	Syngas Electricity & Heat Vitreous silicate slag Salts
Typical energy outputs (per ton)	N/A	N/A	N/A	N/A	$300kWh_{th}$ $260kWh_{el}$	N/A	N/A	$1,450kWh_{th}$ $550kWh_{el}$	$1,800kWh_{th}$ $450kWh_{el}$	$3,200kWh_{th}$ $880kWh_{el}$	$3,200kWh_{th}$ $880kWh_{el}$	$2,000kWh_{th}$ $1,200kWh_{el}$
Is it a proven technology?	+++	++	++	+++	+++	--	+	+++	++	-	-	-

Key

CAPEX	Typical capital expenditure for the plant. This a general estimate only and is based on information received from technology suppliers and operational plants.
OPEX	Operational expenditure required to run the plant. This a general estimate only and is based on information received from technology suppliers and operational plants.
MSW	Municipal Solid Waste. Typically includes household and commercial waste.
SRF	Solid Recovered Fuel. Residual waste with a high calorific value. SRF can be treated in advanced thermal treatment plants or co-fired e.g. cement kilns, power stations and steel mills.
APC	Air Pollution Control residues (e.g. by products from the cleaning of flue gases from the thermal treatment of waste)
IBA	Incinerator Bottom Ash. (e.g. residue from the combustion of waste)
+++	Well proven technology. Used widely, versatile and flexible.
++	Well proven technology but limited in either capacity or potentially to be superseded by another better technology.
+	Proven technology but still finding its feet in many places.
-	Not yet a proven technology. Plants are in operational but none have reached large commercial scale and many are still very expensive.

Technology Overview

1. Definitions of Anaerobic Digestion

Anaerobic Digestion (AD): AD is the natural decomposition (digestion) of organic waste in an oxygen-free (anaerobic) environment. The process generates approximately 60% methane and 40% carbon dioxide. This biogas can be burnt to generate combined heat and power (CHP) or the biogas can be upgraded (injection in to the gas grid or for use as a vehicle fuel. A solid and liquid digestate is also generated from the process that can be used as an organic fertilizer

2. Key Features of AD

	Anaerobic Digestion
CAPEX (US$/t)	450
OPEX (US$/t)	15-60
Land take (m^2/t)	0.84 (<10,000tpa capacity); 0.42 (10,000 to 25,000tpa capacity) 0.20 (30,000 to 50,000tpa capacity) 0.16 (≥100,000tpa capacity)
Capacity (t/day)	15-500
Input material	Food and yard waste, Sewage sludge
Main by-products	Liquid and solid digestate, Biomethane, Electricity, Heat, Rejects
Energy output	$300kWh_{th}$ $260kWh_{el}$
Mass reduction	50%

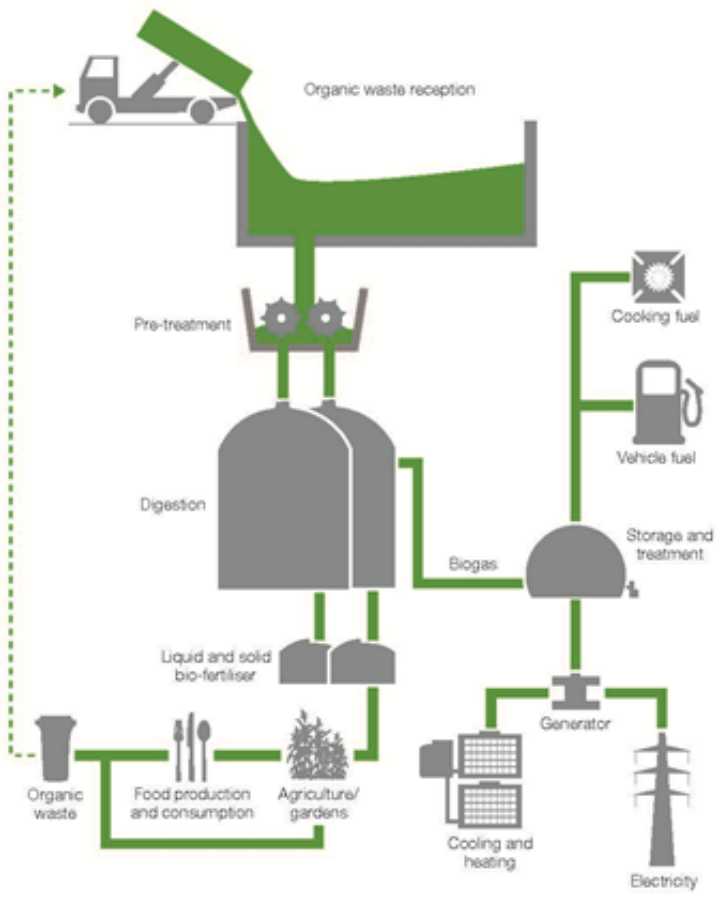
Technology Overview

3. Strengths & Weaknesses of AD Technologies

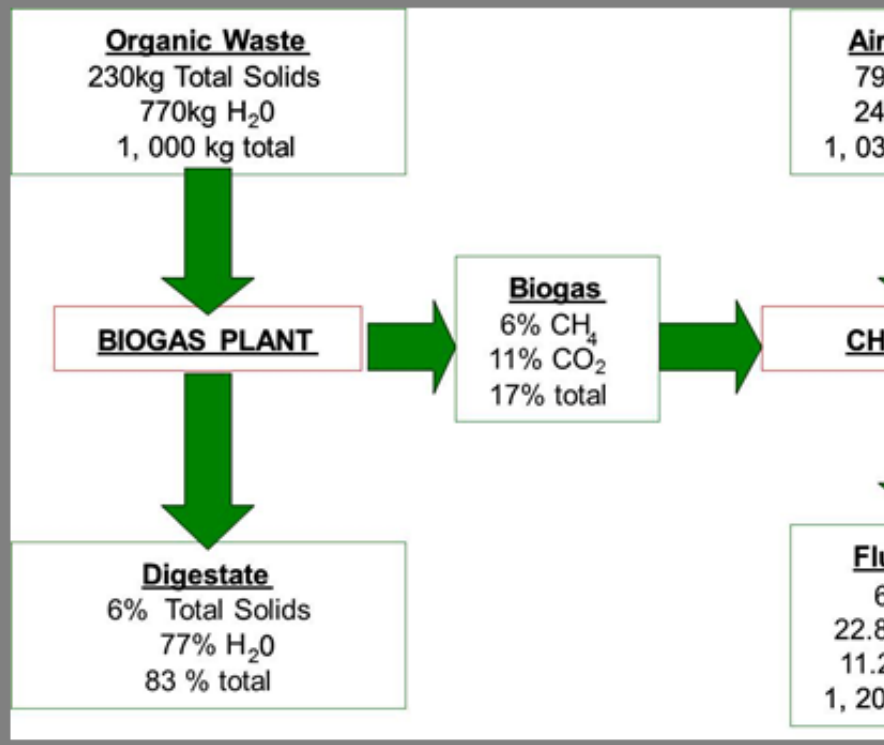
Strengths	Weaknesses
Diverts biodegradable waste from landfill, reducing the environmental effects of leachate and methane production.	High Initial cost
Emissions from AD plants are generally lower than other forms of WtE	High management skills required-precise monitoring must be carried out
Produces and organic fertilizer and soil improver (digestate), which may generate some revenue if a market is identified	Financing often requires a long term contract
Reduces climate change impacts of waste and energy	The co-digestion of organic MSW with biosolids is likely to increase cost and land-take requirements, and may also adversely affect the quality of the digestate output
Sustainable farming and diversification	
If built and managed correctly AD is a bankable technology	
The process is energy self-sufficient and generates surplus energy	

4. Process Diagrams for AD

AD process diagram

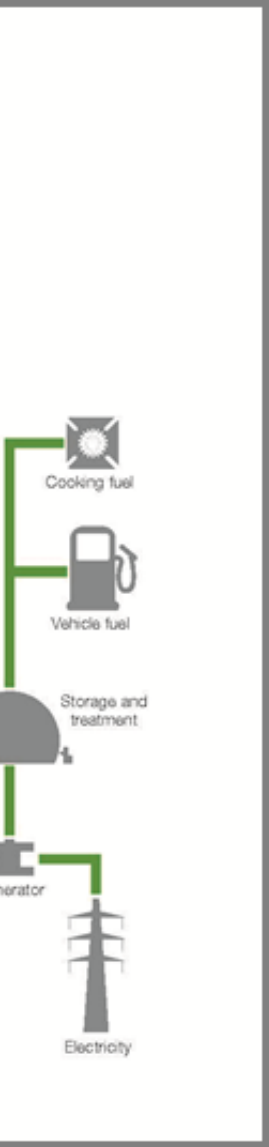


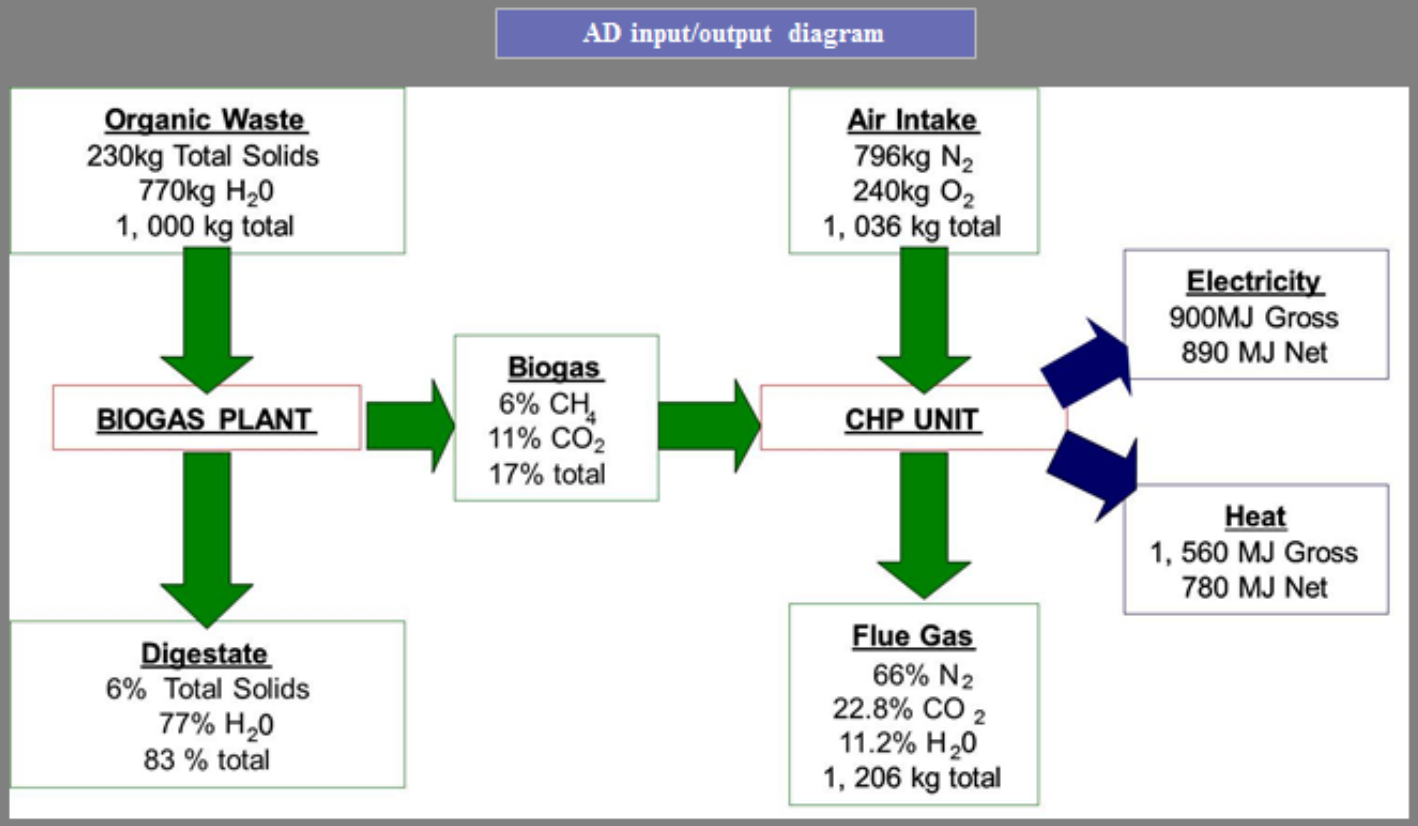
AD input/output diagram



5. AD Technology Suppliers

Company	Process	Number of Facilities	Comments	Case Study





Number of Facilities	Comments	Case Study	Contact Details

5. AD Technology Suppliers

Company	Process	Number of Facilities	Comments	Case Study	Cont
Linde Engineering Dresden GmbH	Wet and Dry AD	8	Dry single stage, mesophilic and wet two stage thermophilic operation Throughput capacities of reference facilities range from 15,000 tpa to 150,000 tpa	Where: Lille, France Year Commissioned: 2007 Throughput: 62,000 tpa CAPEX: NA Facility type: Dry AD	Linde Eng GmBh, Bode 012 G Tel: +49 Fax: +49 (ledd.dresd www.li
Organic Waste Systems (DRANCO)	Dry AD	17	Single stage, dry anaerobic systems, under thermophilic conditions Footprint data (5,000tpa - 3,000m^2, 50,000tpa - 10,000m^2, 100,000tpa - 15,000m^2) Typical biomethane production is 100-200m^3 of biomethane/ton and 0.2-0.4MWh/ton	Where: Brecht, Belgium Year Commissioned: 2000 Throughput: 50,000 tpa CAPEX: $19 million Footprint: 10,000m^2 Electricity generation: 10,000MWh	C Dol B-9 E Tel. +32 Fax +32 mai ww
Zero Waste Energy	Dry AD	NA	Facility to be built in San Jose will be the largest dry AD facility in the world. Uses Zero Waste Energy's patented Kompoferm Plus technology and state-of-the-art manufactured Kompoferm Modular System.	Where: San Jose, CA Year Commissioned: December 2013 Throughput: 67,000 tpa CAPEX: NA	3470 Mt. I A215 Ph. (97
Axpo Kompogas	Dry AD	70	Dry thermophilic AD in single horizontal plug flow digester Design throughput ranges from <5000 to 100,000tpa General footprint for a typical 50,000tpa and digester facility is 12,000m^2 Process produces approximately 105-130m^3 of biomethane per ton.	Where: Montpellier, France Year Commissioned: 2008 Throughput: 105,000 tpa CAPEX: $88 million Footprint:16,000m^2 Energy Output: 30,000,000 kWh/a electricity	Axpo K Flugh 8152 Sw Phone: +41 Fax: +41 4 www.axp
					VALORGA I

Technology Overview

Definitions | Key Features | Strengths & Weaknesses | Process Diagrams | Technology Suppliers

1. Definitions of Waste-to-Fuel Technology

Waste-to-Fuel: Any process that produces fuel (e.g. ethanol, diesel, biofuel) from the treatment of waste.

2. Key Features of Waste-to-Fuel Technologies

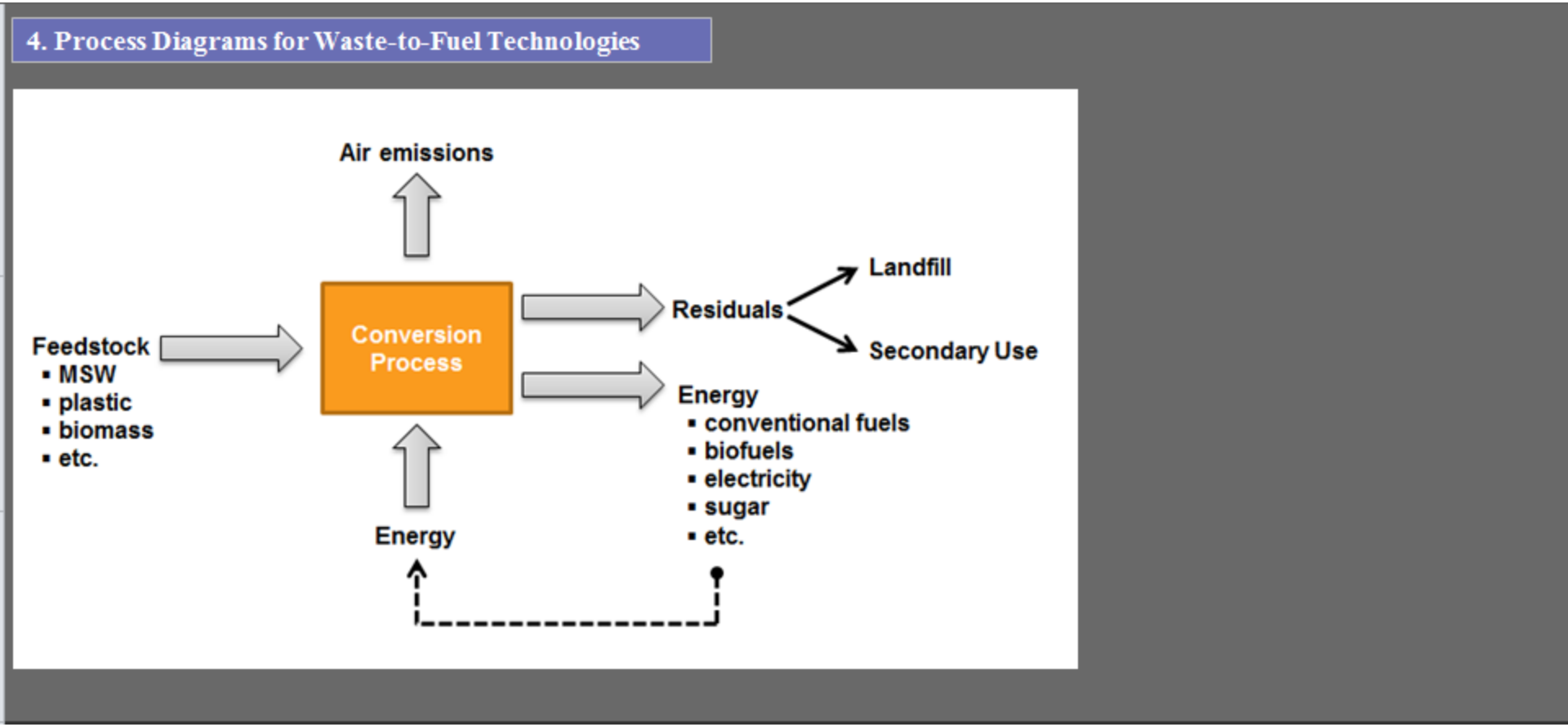
	Waste-to-Fuel
Capital costs (US$ million)	5-175
Land requirement (ft^2)	610-50,000
Typical capacity (t/year)	1,000-90,000
Input material	MSW, biomass, plastics, fat, grease, oil
Energy outputs	Syngas, gasoline, biofuels, synthetic oil, ethanol, electricity, sugar

Technology Overview

3. Strengths & Weaknesses of Waste-to-Fuel Technologies

Waste-to-Fuel	
Strengths	**Weaknesses**
Ability to recovery energy from waste	It is often unclear exactly what emissions will be involved and what sort of ash or other residue will be produced
Significantly reduces amount of waste sent to landfill	Emerging technologies that are relatively unproven on commercial scale
Produces useful product s that can be used as fuels or as feedstock for other petro-chemicals applications	MSW can require significant pre-treatment
Plants are often modular and can be adjusted as waste streams or volumes change	High skill level required to operate the plant
Facilities can be integrated with other technologies such as MRFs	Often limited to certain waste feedstocks; many technologies only process one waste type
Reduces reliance on imported fuels	High operation/maintenance costs
Shields municipality from energy and fuel price increases	Requires internal and/or external demand for fuels that are produced
	Public concern over air pollution and health impacts

Technology Overview



5. Waste-to-Fuel Technology Suppliers

Company	Process	Plants Developed	Case Study	Contact Details
2OC	Fat, oil and grease to electricity	1 commercial plant under construction	Where: East London, UK Commissioned: 2015 (expected) Throughput: 66 tons/day CAPEX: US$110 million Footprint: No data Material Input: fat, oil and grease Energy Output: 130 gigawatt-hours of electricity per year	20C Limited Solsbury Hill Bath, UK BA17AB 01225 851115 info@2oc.co.uk
Alphakat	Waste to diesel	Several demonstration and commercial plants	Where: Boston, MA Commissioned: 2008 Throughput: 20,000 ton/yr CAPEX: US$ 10.7 million Footprint: 6,500 sf Material Input: MSW Energy Output: 700 liters synthetic diesel/hr	Schulstrasse 8 Buttenheim (Germany · Tel +49 9545 208, Fax +49 325 mail@alphakat.de
Cool Planet Biofuels	Waste to fuel	1 pilot plant	Where: Camarillo, CA Commissioned: No data Throughput: No data CAPEX: No data Footprint: No data Material Input: biomass Energy Output: 200,000 gallons gasoline/yr	460 Calle San Pablo Camarillo, CA 93012 info@coolplanet.com
CRI Catalyst Company	Biomass to liquid hydrocarbon fuel (integrated hydropyrolysis and hydroconversion)	1 pilot plant + 11 demonstration plants in development + 1 commerical plant in development	Where: Chicago, IL Commissioned: 2012 Throughput: 50 kg/day CAPEX: No data Footprint: No data Material Input: woody biomass and aquatic plant residues Energy Output: gasoline, kerosene and diesel	CRI Catalyst Company One Shell Plaza 910 Louisiana Street – 29th Houston, Texas 77002 Tel: 713-241-3000 information@cri-criterion.c

GHG Emissions Calculator

1) Select city | 2) Input avg. miles material travels to | 3) Check to include MRF ☑ | 4) Input avg. miles material travels to Thermal | 5) Select Thermal | 6) Check to include Thermal Treatment ☑ | 7) Input avg. miles material travels to Biological Treatment | 8) Select Biological Treatment | 9) Check to include Biological Treatment ☑ | 10) Input avg. miles material travels to Landfill

Scenario 1		MRF				Recycling		Thermal Treatment					Biological Treatment					Landfill				Recovered			Total
Iowa City	Waste	100						100	Pyrolysis				100	Anaerobic Digestion				100							
	tons	Transport GHG mtonsCO2e	Net Energy Use kWh/ton	Net Energy Use kWh	Energy GHG mtonsCO2e	GHG mtonsCO2e/to	Net GHG mtonsCO2e	Transport GHG mtonsCO2e	Net Energy Use kWh/ton	Net Energy Use kWh	Process GHG mtonsCO2e/tor	Process+ Energy GHG mtonsCO2e	Transport GHG mtonsCO2e	Net Energy Use kWh/ton	Net Energy Use kWh	Process GHG mtonsCO2e/tor	Process+ Energy GHG mtonsCO2e	Transport GHG mtonsCO2e	To Landfill tons	GHG mtonsCO2e/to	Process GHG tonsCO2e	To Recycle tons	To Thermal tons	To Bio tons	mtonsCO2e
Plastics	21,775	305	600	13,065,000	9,691	-0.98	-10,670	152	-571	-6,216,763	1.25	8,373	0	-200	0	0.000	0	8	544	0.000	0	10,888	10,888	0	8,460
Metals	6,500	91	600	3,900,000	2,893	-3.97	-21,934	14	-571	-556,725	0.00	-413	0	-200	0	0.000	0	1	49	0.000	0	5,525	975	0	-19,349
Glass	1,950	27	600	1,170,000	868	-0.28	-355	10	-571	-389,708	0.00	-289	0	-200	0	0.000	0	0	34	0.000	0	1,268	683	0	261
Food	17,290	242	600	10,374,000	7,695	0.00	0	0	-571	0	0.02	0	242	-200	-3,458,000	-0.326	-8,205	0	0	0.276	0	0	0	17,290	-26
Yard	5,980	84	600	3,588,000	2,661	0.00	0	0	-571	0	0.02	0	84	-200	-1,196,000	-0.140	-1,723	0	0	0.131	0	0	0	5,980	1,106
Wood	0	0	600	0	0	0.00	0	0	-571	0	0.02	0	0	-200	0	0.000	0	0	0	0.263	0	0	0	0	0
Paper/Cardboard	32,760	459	600	19,656,000	14,580	-3.52	-57,658	229	-571	-9,352,980	0.02	-6,640	0	-200	0	-0.326	0	11	819	0.311	255	16,380	16,380	0	-48,764
Textiles	5,330	75	600	3,198,000	2,372	-2.37	-6,316	37	-571	-1,521,715	1.24	2,176	0	-200	0	0.000	0	2	133	0.000	0	2,665	2,665	0	-1,654
C&D	30,940	0	600	0	0	-0.24	0	0	-571	0	0.23	0	0	-200	0	0.000	0	433	30,940	0.000	0	0	0	0	433
E-waste	2,990	42	600	1,794,000	1,331	-2.35	-3,513	21	-571	-853,645	0.27	-225	0	-200	0	0.000	0	1	75	0.000	0	1,495	1,495	0	-2,343
Total	125,515	1,324		56,745,000	42,092		-100,446	463		-18,891,535		3,582	326		-4,654,000		-9,928	456	32,594		255	38,220	33,085	23,270	-61,876

11) Input avg. miles material travels to | 12) Check to include MRF ☑ | 13) Input avg. miles material travels to Thermal | 14) Select Thermal Treatment | 15) Check to include Thermal Treatment ☑ | 16) Input avg. miles material travels to Biological Treatment | 17) Select Biological Treatment | 18) Check to include Biological Treatment ☑ | 19) Input avg. miles material travels to Landfill

Scenario 2		MRF				Recycling		Thermal Treatment					Biological Treatment					Landfill				Recovered			Total
Iowa City	Waste	100						100	Massburn				100	Anaerobic Digestion				100							
	tons	Transport mtonsCO2e	Net Energy Use kWh/ton	Net Energy Use kWh	GHG mtonsCO2e	GHG mtonsCO2e/to	Net GHG mtonsCO2e	Transport GHG mtonsCO2e	Net Energy Use kWh/ton	Net Energy Use kWh	Process GHG mtonsCO2e/tor	Process+ Energy GHG mtonsCO2e	Transport GHG mtonsCO2e	Net Energy Use kWh/ton	Net Energy Use kWh	Process GHG mtonsCO2e/tor	Process+ Energy GHG mtonsCO2e	Transport GHG mtonsCO2e	To Landfill tons	GHG mtonsCO2e/to	Process GHG tonsCO2e	To Recycle tons	To Thermal tons	To Bio tons	mtonsCO2e
Plastics	21,775	305	600	13,065,000	9,691	-0.98	-10,670	152	-544	-5,922,800	1.25	9,191	0	-200	0	0.000	0	8	544	0.000	0	10,888	10,888	0	8,678
Metals	6,500	91	600	3,900,000	2,893	-3.97	-21,934	14	-544	-530,400	0.00	-393	0	-200	0	0.000	0	1	49	0.000	0	5,525	975	0	-19,329
Glass	1,950	27	600	1,170,000	868	-0.28	-355	10	-544	-371,280	0.00	-275	0	-200	0	0.000	0	0	34	0.000	0	1,268	683	0	275
Food	17,290	242	600	10,374,000	7,695	0.00	0	0	-544	0	0.02	0	242	-200	-3,458,000	-0.326	-8,205	0	0	0.276	0	0	0	17,290	-26
Yard	5,980	84	600	3,588,000	2,661	0.00	0	0	-544	0	0.02	0	84	-200	-1,196,000	-0.140	-1,723	0	0	0.131	0	0	0	5,980	1,106
Wood	0	0	600	0	0	0.00	0	0	-544	0	0.02	0	0	-200	0	0.000	0	0	0	0.263	0	0	0	0	0
Paper/Cardboard	32,760	459	600	19,656,000	14,580	-3.52	-57,658	229	-544	-8,910,720	0.02	-6,312	0	-200	0	-0.326	0	11	819	0.311	255	16,380	16,380	0	-48,435
Textiles	5,330	75	600	3,198,000	2,372	-2.37	-6,316	37	-544	-1,449,760	1.24	2,229	0	-200	0	0.000	0	2	133	0.000	0	2,665	2,665	0	-1,601
C&D	30,940	0	600	0	0	-0.24	0	0	-544	0	0.23	0	0	-200	0	0.000	0	433	30,940	0.000	0	0	0	0	433
E-waste	2,990	42	600	1,794,000	1,331	-2.35	-3,513	21	-544	-813,280	0.27	-195	0	-200	0	0.000	0	1	75	0.000	0	1,495	1,495	0	-2,313
Total	125,515	1,324		56,745,000	42,092		-100,446	463		-17,998,240		4,245	326		-4,654,000		-9,928	456	32,594		255	38,220	33,085	23,270	-61,213

20) Input avg. miles material travels to | 21) Check to include MRF ☑ | 22) Input avg. miles material travels to Thermal | 23) Select Thermal Treatment | 24) Check to include Thermal Treatment ☑ | 25) Input avg. miles material travels to Biological Treatment | 26) Select Biological Treatment | 27) Check to include Biological Treatment ☑ | 28) Input avg. miles material travels to Landfill

Scenario 3		MRF				Recycling		Thermal Treatment					Biological Treatment					Landfill				Recovered			Total
Iowa City	Waste	100						100	Conventional				100	Bio Compostin				100							
	tons	Transport mtonsCO2e	Net Energy Use kWh/ton	Net Energy Use kWh	GHG mtonsCO2e	GHG mtonsCO2e/to	Net GHG mtonsCO2e	Transport GHG mtonsCO2e	Net Energy Use kWh/ton	Net Energy Use kWh	Process GHG mtonsCO2e/tor	Process+ Energy GHG mtonsCO2e	Transport GHG mtonsCO2e	Net Energy Use kWh/ton	Net Energy Use kWh	Process GHG mtonsCO2e/tor	Process+ Energy GHG mtonsCO2e	Transport GHG mtonsCO2e	To Landfill tons	GHG mtonsCO2e/to	Process GHG tonsCO2e	To Recycle tons	To Thermal tons	To Bio tons	mtonsCO2e
Plastics	21,775	305	600	13,065,000	9,691	-0.98	-10,670	152	-685	-7,457,938	1.25	8,053	0	50	0	0.000	0	8	544	0.000	0	10,888	10,888	0	7,539
Metals	6,500	91	600	3,900,000	2,893	-3.97	-21,934	14	-685	-667,875	0.00	-495	0	50	0	0.000	0	1	49	0.000	0	5,525	975	0	-19,431
Glass	1,950	27	600	1,170,000	868	-0.28	-355	10	-685	-467,513	0.00	-347	0	50	0	0.000	0	0	34	0.000	0	1,268	683	0	204
Food	17,290	242	600	10,374,000	7,695	0.00	0	0	-685	0	0.02	0	242	50	864,500	-0.200	-2,817	0	0	0.276	0	0	0	17,290	5,362
Yard	5,980	84	600	3,588,000	2,661	0.00	0	0	-685	0	0.02	0	84	50	299,000	-0.200	-974	0	0	0.131	0	0	0	5,980	1,855
Wood	0	0	600	0	0	0.00	0	0	-685	0	0.02	0	0	50	0	0.000	0	0	0	0.263	0	0	0	0	0
Paper/Cardboard	32,760	459	600	19,656,000	14,580	-3.52	-57,658	229	-685	-11,220,300	0.02	-8,026	0	50	0	0.000	0	11	819	0.311	255	16,380	16,380	0	-50,149
Textiles	5,330	75	600	3,198,000	2,372	-2.37	-6,316	37	-685	-1,825,525	1.24	1,950	0	50	0	0.000	0	2	133	0.000	0	2,665	2,665	0	-1,880
C&D	30,940	0	600	0	0	-0.24	0	0	-685	0	0.23	0	0	50	0	0.000	0	433	30,940	0.000	0	0	0	0	433
E-waste	2,990	42	600	1,794,000	1,331	-2.35	-3,513	21	-685	-1,024,075	0.27	-351	0	50	0	0.000	0	1	75	0.000	0	1,495	1,495	0	-2,470
Total	125,515	1,324		56,745,000	42,092		-100,446	463		-22,663,225		784	326		1,163,500		-3,791	456	32,594		255	38,220	33,085	23,270	-58,537

GHG Emissions Calculator

1) Select city

2) Input avg. miles material travels to

3) Check to include MRF ☑

Scenario 1		MRF				Recycling	
Iowa City	Waste	100					
		Transport GHG	Net Energy Use		Energy GHG	GHG	Net GHG
	tons	mtonsCO2e	kWh/ton	kWh	mtonsCO2e	mtonsCO2e/ton	mtonsCO2e
Plastics	21,775	305	600	13,065,000	9,691	-0.98	-10,670
Metals	6,500	91	600	3,900,000	2,893	-3.97	-21,934
Glass	1,950	27	600	1,170,000	868	-0.28	-355
Food	17,290	242	600	10,374,000	7,695	0.00	0
Yard	5,980	84	600	3,588,000	2,661	0.00	0
Wood	0	0	600	0	0	0.00	0
Paper/Cardboard	32,760	459	600	19,656,000	14,580	-3.52	-57,658
Textiles	5,330	75	600	3,198,000	2,372	-2.37	-6,316
C&D	30,940	0	600	0	0	-0.24	0
E-waste	2,990	42	600	1,794,000	1,331	-2.35	-3,513
Total	**125,515**	**1,324**		**56,745,000**	**42,092**		**-100,446**

4) Input avg. miles material travels to Thermal Treatment

5) Select Thermal Treatment

6) Check to include Thermal Treatment ☑

Thermal Treatment				
100	Pyrolysis			
Transport GHG	Net Energy Use		Process GHG	Process+ Energy GHG
mtonsCO2e	kWh/ton	kWh	mtonsCO2e/ton	mtonsCO2e
152	-571	-6,216,763	1.25	8,973
14	-571	-556,725	0.00	-413
10	-571	-389,708	0.00	-289
0	-571	0	0.02	0
0	-571	0	0.02	0
0	-571	0	0.02	0
229	-571	-9,352,980	0.02	-6,640
37	-571	-1,521,715	1.24	2,176
0	-571	0	0.23	0
21	-571	-853,645	0.27	-225
463		**-18,891,535**		**3,582**

GHG Emissions Calculator

7) Input avg. miles material travels to Biological Treatment

8) Select Biological Treatment

9) Check to include Biological Treatment ☑

Biological Treatment

100	Anaerobic Digestion			
Transport GHG mtonsCO2e	Net Energy Use kWh/ton	Net Energy Use kWh	Process GHG mtonsCO2e/ton	Process+ Energy GHG mtonsCO2e
0	-200	0	0.000	0
0	-200	0	0.000	0
0	-200	0	0.000	0
242	-200	-3,458,000	-0.326	-8,205
84	-200	-1,196,000	-0.140	-1,723
0	-200	0	0.000	0
0	-200	0	-0.326	0
0	-200	0	0.000	0
0	-200	0	0.000	0
0	-200	0	0.000	0
326		**-4,654,000**		**-9,928**

10) Input avg. miles material travels to Landfill

Landfill				Recovered			Total
100							
Transport GHG mtonsCO2e	To Landfill tons	GHG mtonsCO2e/ton	Process GHG tonsCO2e	To Recycle tons	To Thermal tons	To Bio tons	mtonsCO2e
8	544	0.000	0	10,888	10,888	0	8,460
1	49	0.000	0	5,525	975	0	-19,349
0	34	0.000	0	1,268	683	0	261
0	0	0.276	0	0	0	17,290	-26
0	0	0.131	0	0	0	5,980	1,106
0	0	0.263	0	0	0	0	0
11	819	0.311	255	16,380	16,380	0	-48,764
2	133	0.000	0	2,665	2,665	0	-1,654
433	30,940	0.000	0	0	0	0	433
1	75	0.000	0	1,495	1,495	0	-2,343
456	**32,594**		**255**	**38,220**	**33,085**	**23,270**	**-61,876**

High-level Cost-Benefit Analysis

Cost Benefit Analysis

	Landfill[1]	Mass Burn Incineration	Anaerobic Digestion	Pyrolysis	Gasification	Plasma Gasification
Costs						
CAPEX (US$/ton)	10-25	180-900	320-560	720-1,000	720-1,000	700-1,300
OPEX (US$/ton)	15-75	45-100	15-60	75-120	75-120	90-135
Staff requirements	5-15	25-35	5-10	5-20	5-20	10-30
Land take (ft^2/ton)	0.5-30	0.53-1.0	1.61 – 6.45	0.32 – 2.1	0.32 – 2.1	1.83 – 2.36
Permitting complexity	Medium	Medium	Medium	High	High	High
Utility interaction	Low	Medium	Medium	Medium	Medium	Medium
Environmental impact	High	Medium	Low	Low	Low	Low
Construction risk	Low	Low	Medium	High	High	High
Technology risk	Low	Low	Low	Medium-High	Medium-High	Medium-High
Investment financial risk	Low	Low	Medium-High	Medium-High	Medium-High	Medium-High
Benefits						
Energy output (kWh/ton MSW)	N/A	550	260	880	880	1,200
Compost output (lbs/ton MSW)	N/A	N/A	500-800	N/A	N/A	N/A
Eligible for incentives/credits	No	Yes	Yes	Yes	Yes	Yes
Mass reduction	0%	75%	50%	70%	75%	85%

[1]Landfill gas-to-energy not included

Thank you for the opportunity

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