National Technical University of Athens

COLUMBIA UNIVERSITY
EARTH ENGINEERING CENTER

"Waste to energy as part of an efficient Integrated Waste Management System"

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Principles of waste management in EU

- According to the principles of solid waste management, waste reduction is top priority. Separation and recycling follow in second place (when they are environmentally and economically feasible). Final disposition of waste in landfills comes last.
- Waste can be a resource. Rather than be disposed in landfills, it should be recovered and serve useful purposes, replacing other resources.
- Remaining materials that cannot be reused or recycled should be treated according to the best environmental practices
- The dominant term in the EU is that of Circular Economy. Only non exploitable waste remains should be disposed in landfills

Basic principles of Solid Waste Management Design in EU

- Some of the EU members have successfully reduced the amount of waste that they dispose into landfills, as a result of recycling, biological treatment (composting and anaerobic digestion) and energy recovery.
- Waste-to-energy technologies can contribute significantly in the reduction of waste that is landfilled, in environmental protection and in energy balance.
- Due to landfill directive 99/31, all member states of EU should divert biodegradable waste from landfill according to specific objectives. This should be done by combining waste treatment methods (eg recycling and waste- to - energy treatment)

Principles of solid waste management

EU Legal framework-Landfill Directive 99/31 EC

- Article 5 of the Landfill Directive states that Member States should set up a national strategy for the implementation of the reduction of biodegradable waste going to landfills
- This strategy should ensure that by 2020 biodegradable municipal waste going to landfills must be reduced to 35% of the total amount of biodegradable municipal waste produced in 1995.

EU Legal framework- Waste Framework Directive (2008/98 EC)

- Consolidates and modernises the existing legislation
- Clarifies the terms "recycling“ and "recovery“
- Introduces the “extended producer responsibility”
- According to this principle, companies that place products on the market, assume financial responsibility for activities relating to the prevention, reuse and recycling and other forms of recovery of waste generated by the use of their products.
- Companies must also inform the public about the extent to which the product can be reused or recycled.

EU Legal framework- Waste Framework Directive (2008/98 EC)

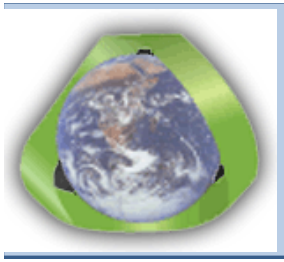
- Recycling target of 50% must be achieved by 2020
- Discrete organic waste management (Separate collection of organic waste at the source) is institutionalized
- Criteria are placed about when the life of a material ends (definition of waste)
- Energy use before landfilling (thermal or anaerobic treatment) is prioritized
- Definition for incineration based on energy efficiency (> 0.65 for new installations)
  - Requires Member States :

    a) to choose management methods that produce the best possible result from an environmental point of view, such as treatment methods accompanied by high material or energy recovery rates,

    b)to develop waste prevention programs, which take into account the entire life cycle of products and materials.

EU Legal framework- Waste Framework Directive (2008/98 EC)

- Member States shall reach the following specific objectives
- (a) by 2020, the preparing for re-use and the recycling of waste materials such as at least paper, metal, plastic and glass from households and possibly from other origins as far as these waste streams are similar to waste from households, shall be increased to a minimum of overall 50 % by weight;
- (b) by 2020, the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70 % by weight.
- (c) The Directive requires that Member States adopt waste management plans and waste prevention programmes, that cover the whole State alone or combined.



Circular economy: The concept

Linear economy

EXTRACT-> PROCESS -> MANUFACTURER ->

CONSUMER -> WASTE DISPOSAL

WASTE

Mixed technical and biological materials

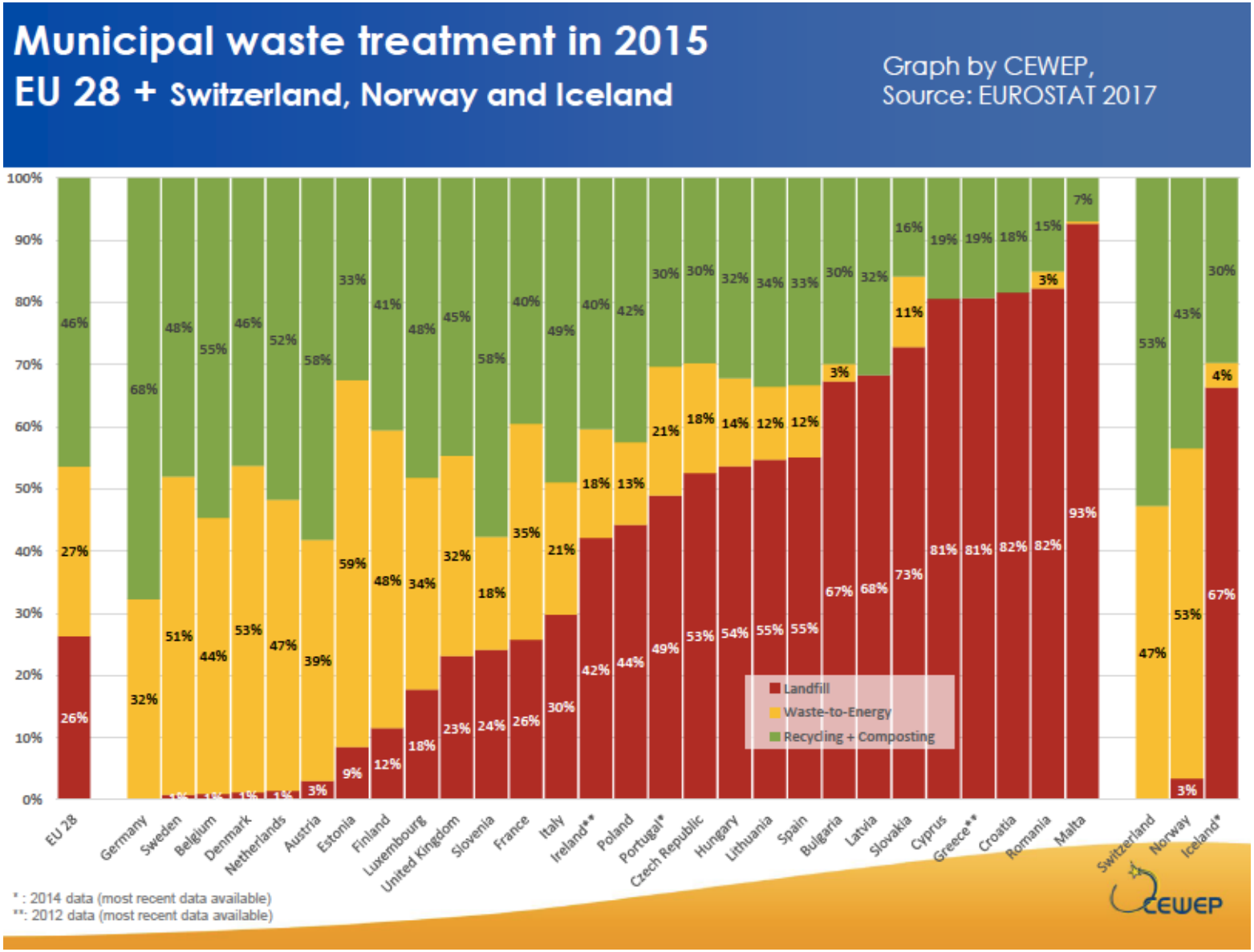
Circular economy

Technical nutrients

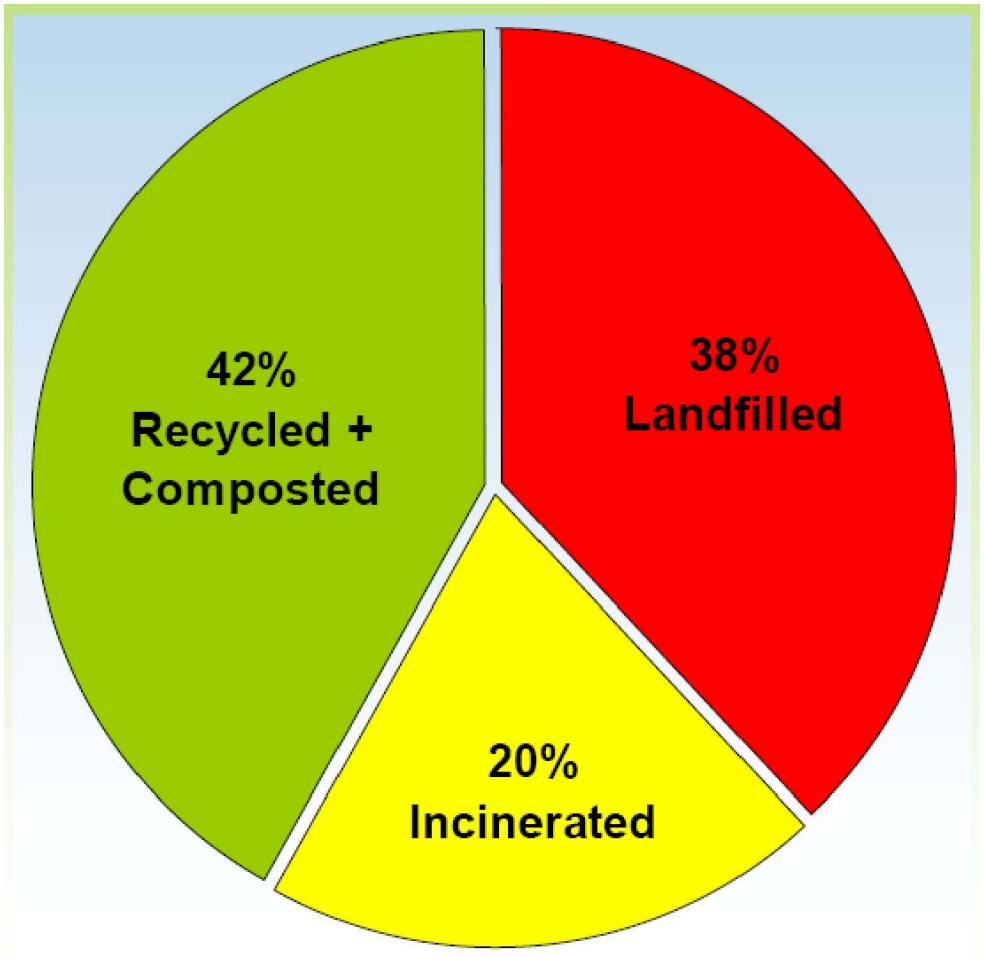
Biological nutrients

The Circular Economy EURequirements

- A common EU target for recycling 65% of municipal waste by 2030;
- A common EU target for recycling 75% of packaging waste by 2030;
- A binding landfill target to reduce landfill to maximum of 10% of municipal waste by 2030;
- A ban on landfilling of separately collected waste;
- Promotion of economic instruments to discourage landfilling ;
- Simplified and improved definitions and harmonised calculation methods for recycling rates throughout the EU;
- Concrete measures to promote re-use and stimulate industrial symbiosis - turning one industry's by-product into another industry's raw material;
- Economic incentives for producers to put greener products on the market and support recovery and recycling schemes (eg for packaging, batteries, electric and electronic equipments, vehicles).
- The new legislation will place a particular focus on waste prevention and introduce important objectives such as reducing by 50% food waste in the EU and halting marine litter with the aim to achieve the UN sustainable development goals in these areas.

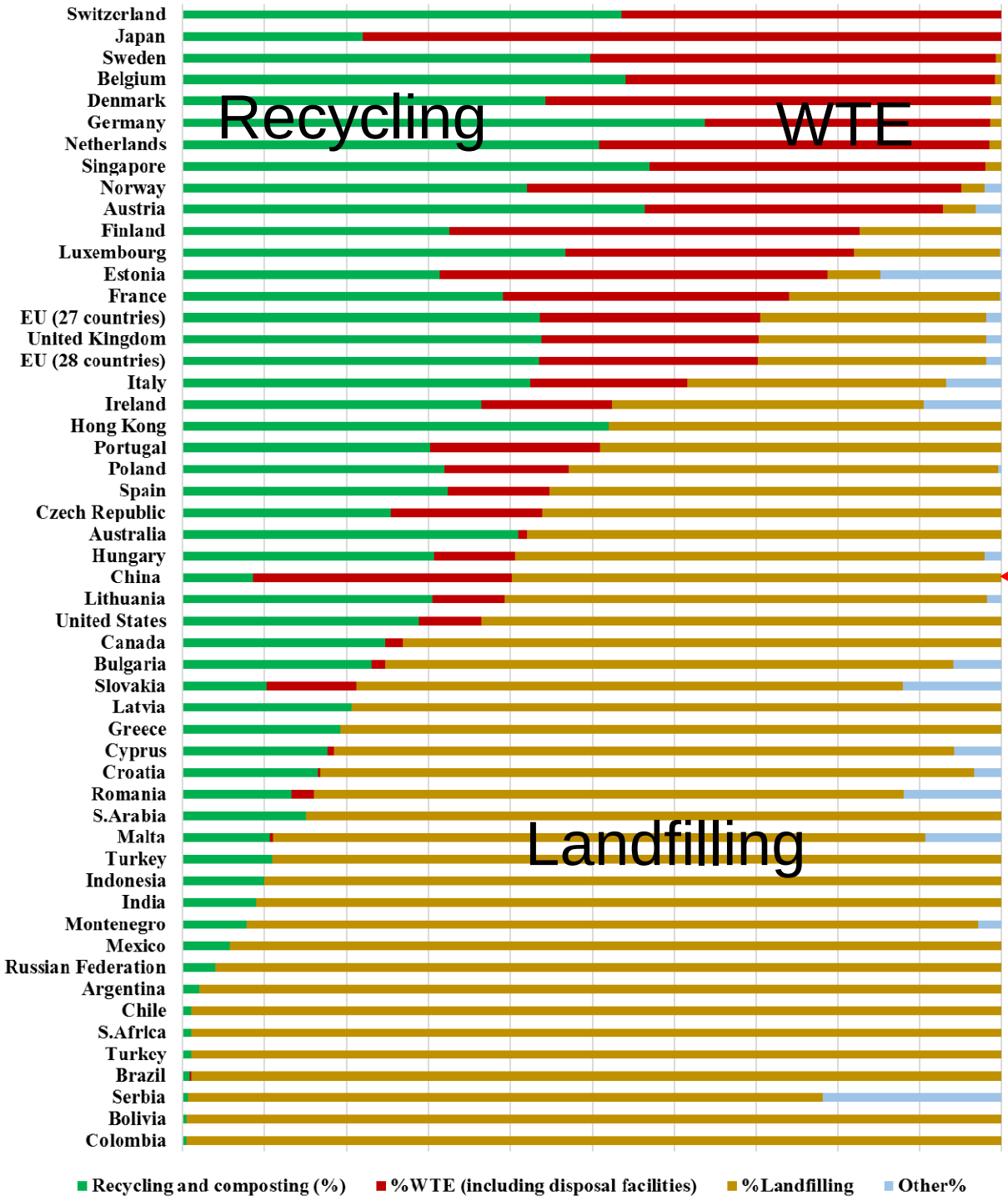

Municipal waste treatment in 2015
EU 28 + Switzerland, Norway and Iceland
Graph by CEWEP,
Source: EUROSTAT 2017
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
EU 28 46% 27% 26%
Germany 68% 32%
Sweden 48% 51%
Belgium 55% 44%
Denmark 46% 53%
Netherlands 52% 47%
Austria 58% 39% 3%
Estonia 33% 59% 9%
Finland 41% 48% 12%
Luxembourg 48% 34% 18%
United Kingdom 45% 32% 23%
Slovenia 58% 18% 24%
France 40% 35% 26%
Italy 49% 21% 30%
Ireland** 40% 18% 42%
Poland 42% 13% 44%
Portugal* 30% 21% 49%
Czech Republic 30% 18% 53%
Hungary 32% 14% 54%
Lithuania 34% 12% 55%
Spain 33% 12% 55%
Bulgaria 30% 3% 67%
Latvia 32% 68%
Slovakia 16% 11% 73%
Cyprus 19% 81%
Greece** 19% 81%
Croatia 18% 82%
Romania 15% 3% 82%
Malta 7% 93%
Switzerland 53% 47%
Norway 43% 53% 3%
Iceland* 30% 4% 67%
Landfill
Waste-to-Energy
Recycling + Composting
* : 2014 data (most recent data available)
**: 2012 data (most recent data available)
CEWEP

Recycling, composting, incineration and landfilling in EU



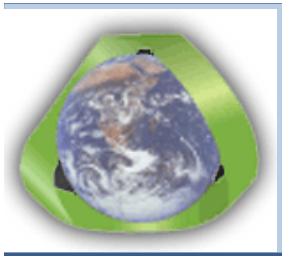
Municipal waste treatment in EU

- Countries with high levels of recycling have also, high levels of incineration
- High levels of recycling and incineration reduce the amount of waste that is disposed in landfills
- With the exception of the Czech Republic and Slovakia, all new EU Member States mentioned dispose more than 80% of the waste in landfills. This applies also for two older Member States, Greece and Ireland.
- Europe, like much of the industrialized world, is using an increasing amount of materials. The average annual use of material resources in EU-27 is around 16 tons/person.



"Ladder of Sustainable Waste Management of nations

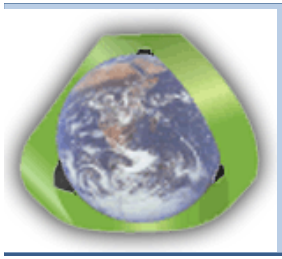
China



Necessary ingredients for successful recycling

- **Communities that are willing to provide separate collection of recyclable materials (principally metals, paper/ cardboard, green wastes)**
- **Citizens who are willing to spend some of their time in separating recyclables at the source (households)**
- **Markets that can use the recyclable materials at a profit to the recyclers (e.g. metal smelters, secondary paper mills)**

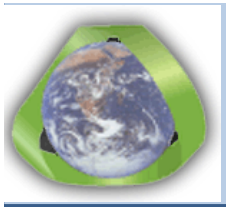
- **In absence of above conditions, government edicts that communities must recycle x% of their solid wastes end up in a waste of money and energy**



Increasing composting

- **Least costly way for municipal government to increase composting: Provide a windrow composting center where municipality and citizens transport their park/ yard wastes and get compost product to be used as soil conditioner**

- **Next and more costly means: Anaerobic Digestion facility where source-separated food wastes from large generators (institutions, food processors) are treated to produce methane and a compost product.**



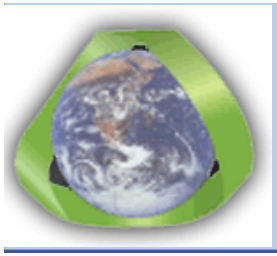
Limitations to recycling: High cost of processing collected recyclables to marketable materials

- For various reasons, it is not possible to collect all recyclables or to process all wastes (E.g. disposable diapers) to marketable materials
- For example, after many efforts to increase recycling in California, less than 10% of the plastic wastes are being recycled
- Therefore, it has been necessary, universally, to develop means for disposing properly the post-recycling wastes

What to do with POST-RECYCLING MSW

- MSW remaining after all possible recycling and composting is called “post-recycling”

- ONLY two ways for sustainable management of post-recycling MSW:
  - Sanitary landfilling
  - Thermal processing with energy recovery (Waste to energy or WTE)



Global generation and disposition of MSW

Estimated global disposition of urban post-recycling municipal solid wastes (total: 1.2 billion tons; 2012)

- **Thermal treatment (WTE): 200 mill. tons**
- **Sanitary landfill, partial CH4 recovery: 200 mill. tons**
- **Landfilled without CH4 recovery: >800 mill. tons**

- Countries with high rates of WTE also exhibit high recycling rates
- All numbers are expected to double by 2030

2015 disposition of post-recycling global MSW

- Combustion with energy recovery (WTE): 230 million tons
- Landfilling: 1,000 million tons (<80% of post-recyling MSW)
  - Sanitary landfilling with partial CH4 recovery: 250 million tons
  - Waste dumps:: >800 million tons (mostly in Asia and Africa)

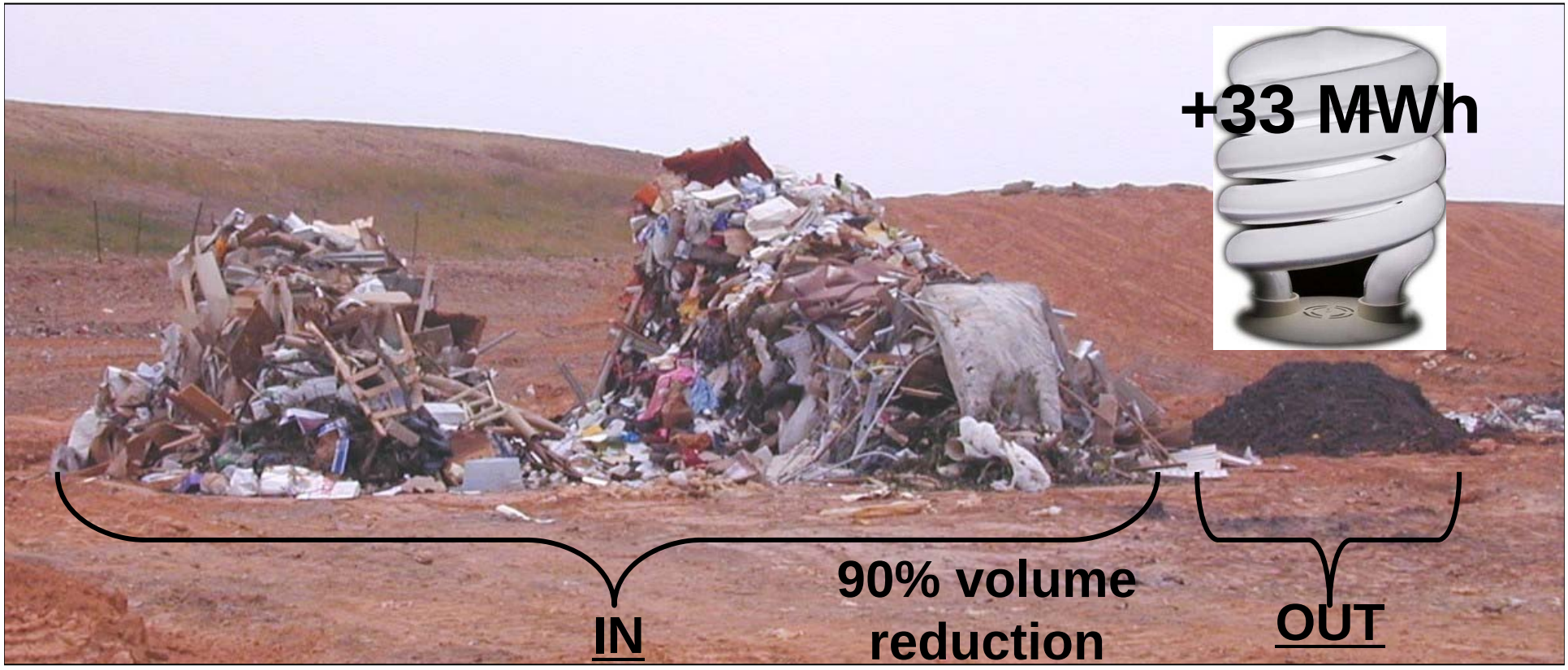
MSW generation is expected to double between 2015 and 2030

Global use of land for landfilling in one year

Estimated average ultimate use of land for proper (sanitary) landfilling of MSW: One square meter used up for ever, for every 10 tons of MSW landfilled

- Current global landfilling in one year converts 100 square kilometers of green fields to landfills
- If all global landfilling were to be done at one global landfill, it would use up a land surface eight times larger than the surface area of metropolitan Milano
-

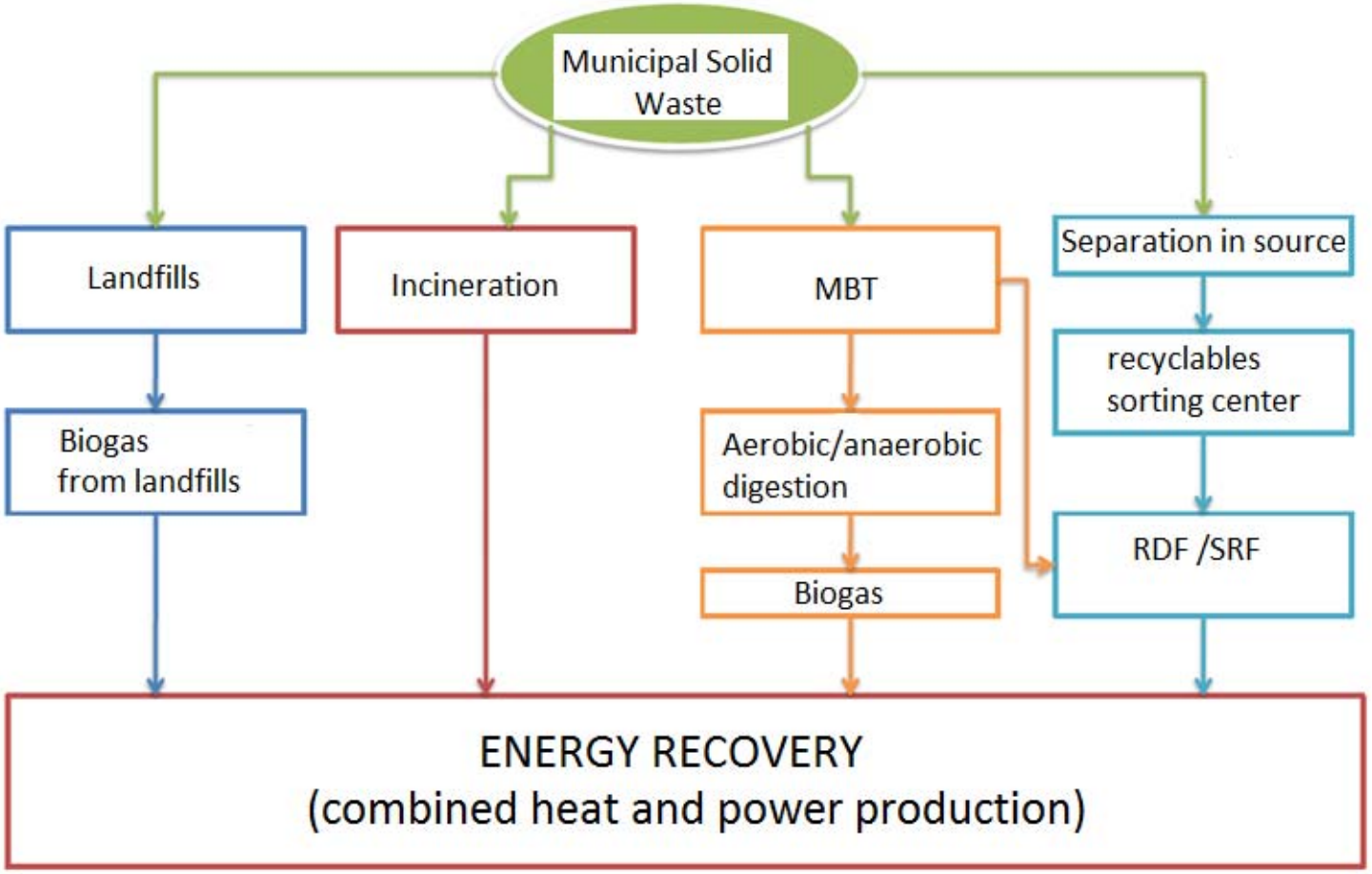
WTE reduces volume of MSW by 90%
Bottom ash is reusable



100 cubic meters of MSW

10 cubic meters of WTE ash

Waste to energy methods



(Καρέλλας, Αγρανιώτης, 2013)

A big problem of WTE 25 years ago: Emission of dioxins and , Hg, and other volatile metals

- The results of **early waste incineration** were an environmental disaster (Brunner and Zobrist, 1983).

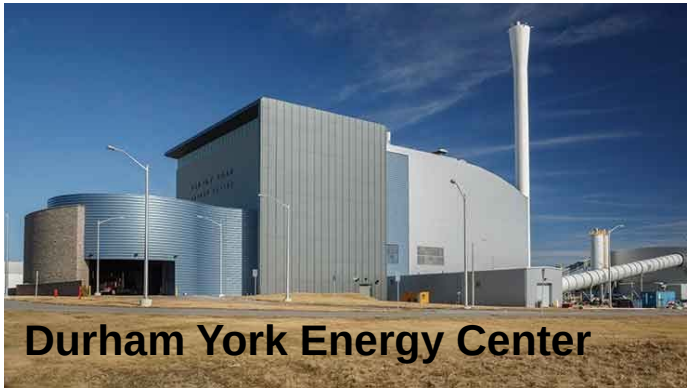
- By 2017, regulation, science, and technology have transformed “incineration” and emissions are below the EU and US standards for high temperature sources

This applies both to developed and developing countries. Example: Dioxins .

The remaining disadvantage of WTE

- Higher initial capital investment, per ton MSW capacity, than sanitary landfilling.

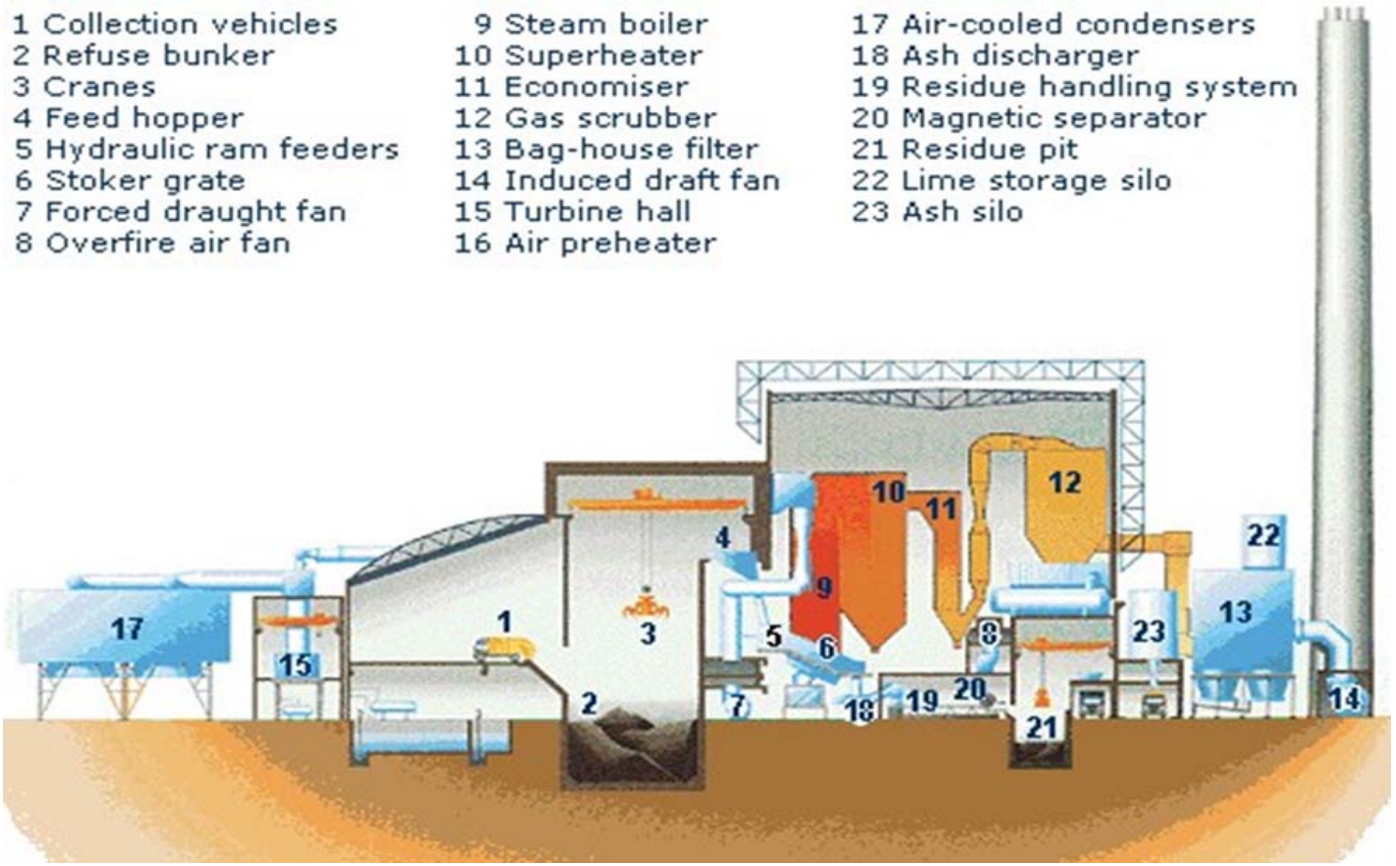
The new Durham County (Ontario) and the Palm Beach (Florida) WTE facilities: CAPEX >$600/annual ton of capacity


Durham York Energy Center


Palm Beach (Florida) WTE

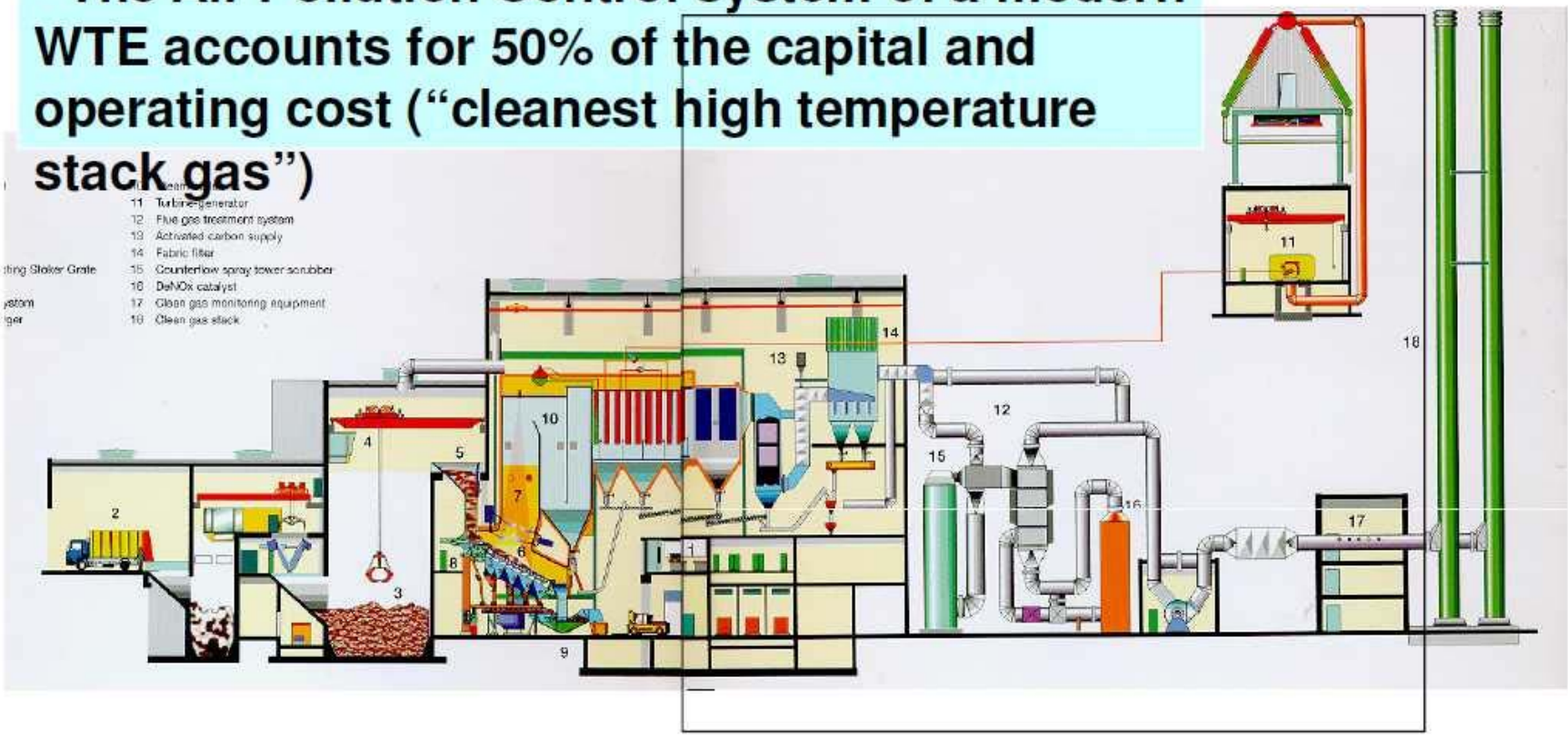
Typical WTE plant

1 Collection vehicles
2 Refuse bunker
3 Cranes
4 Feed hopper
5 Hydraulic ram feeders
6 Stoker grate
7 Forced draught fan
8 Overfire air fan
9 Steam boiler
10 Superheater
11 Economiser
12 Gas scrubber
13 Bag-house filter
14 Induced draft fan
15 Turbine hall
16 Air preheater
17 Air-cooled condensers
18 Ash discharger
19 Residue handling system
20 Magnetic separator
21 Residue pit
22 Lime storage silo
23 Ash silo



The most efficient WTE facilities are co-generators of electricity (> 0.6 MWh per tonne of MSW) and district heating (> 0.5 MWh per tonne of MSW).

- **The Air Pollution Control system of a modern WTE accounts for 50% of the capital and operating cost ("cleanest high temperature stack gas")**



Maximum Achievable Control Technology (EPA's MACT): Dry scrubber, ammonia injection, activated carbon injection, fabric filter baghouse, continuous monitoring

Waste-to-Energy and circular economy

MSW Combustion

Waste to Energy

Flue Gas

Bottom Ash
150-250 kg/ tonne MSW

Air Pollution Control Residues
25-35kg/ tonne MSW

Resources from Waste

A typical Incinerator Bottom Ash processing plant

Non-Ferrous metals (0.5-2%)

IBA Aggregate (85-95%)

Ferrous metals (5-15%)

Coarse fraction (10- 15%)

Medium fraction (40-70 %)

Fine fraction (11- 45 %)

Incineration of waste in EU

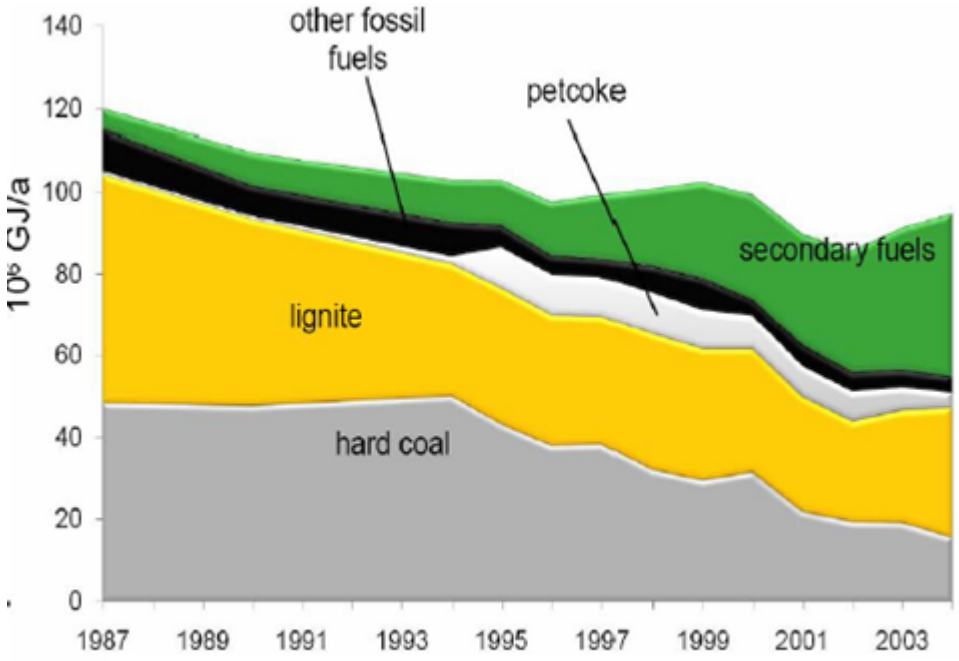
- Since 1995 the total capacity of thermal treatment plants worldwide increased by 16 million tons.
- In EU, there were 406 incineration plants (2010)
- About 54 million tons of waste were incinerated in EU in 2010
- About 60% of EU incineration plants are in Germany, Italy and France
- Denmark, Sweden and Luxembourg incinerate the greater amounts of waste in the EU, 365, 226 and 240 kg / capita respectively

… Energy from waste

Biogas production in EU

- In EU there are 9.243 biogas plants (2010). The total production was about 8.7 million tons of oil equivalent (101,147.6 GWh).
- Germany and United Kingdom produce the largest amounts.
- In Sweden, there are 233 plants with total production of 1.3 TWh/year (2010). In 139 out of 233 plants, the biogas is produced from sludge (0,56 TWh/year), in 70 from landfills (0.46 TWh/year), in 13 from digestion of solid waste (0,16 TWh/year).

Energy recovery in cement industry (EU)

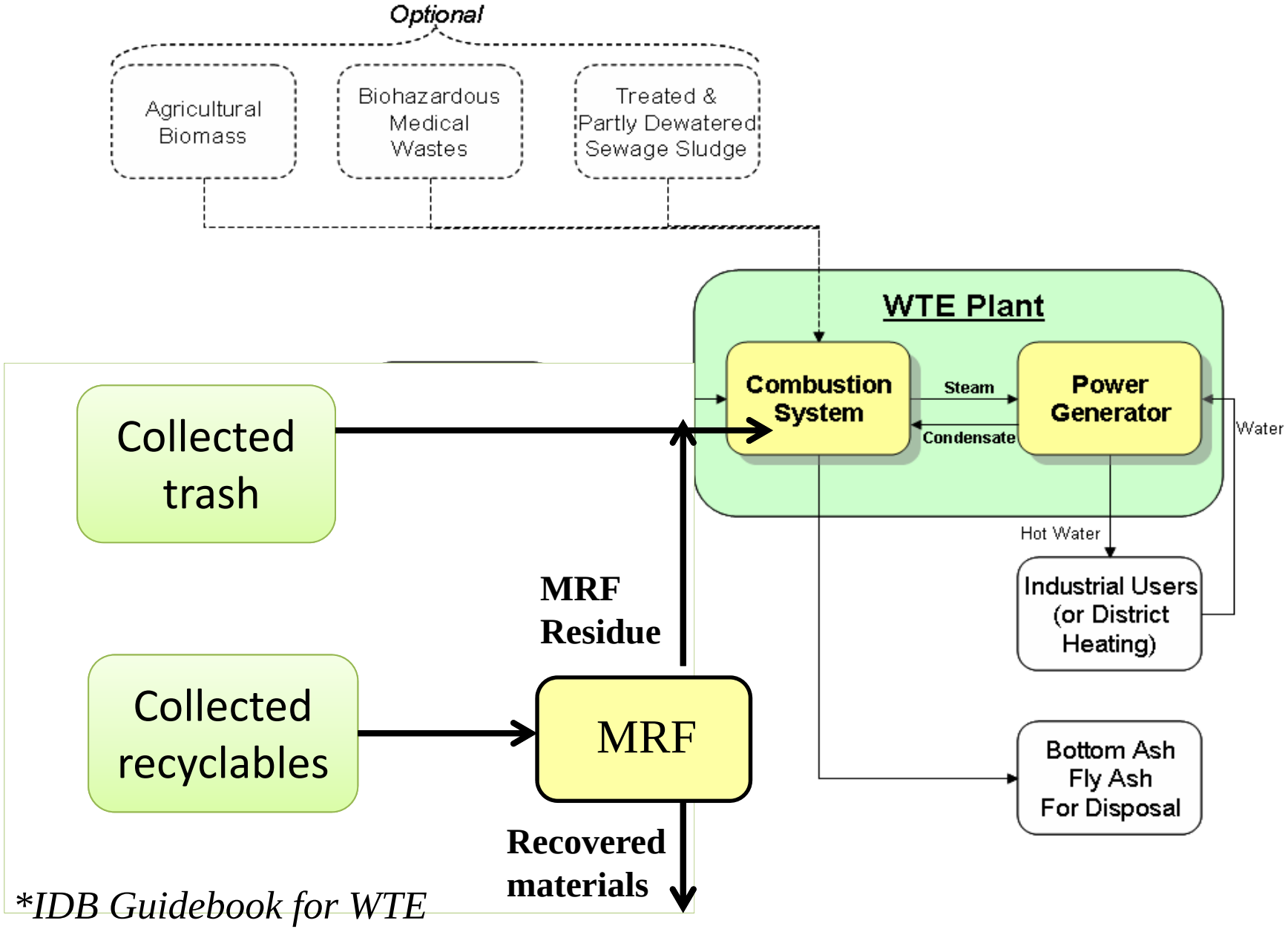


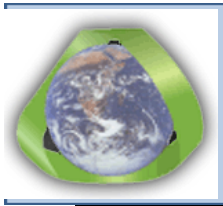
Fuel mixture in German cement industry (Tsobanidis, 2014)

- Quantities of organic waste and biomass (~ 63: 37) [used in the cement industry quadrupled in 15 years (1990-2005), from 3 to 12 m. Tons / year (data CSI, CEMBUREAU) and the EU absorbed most part of the increase.
- 50% of the thermal load of the German cement is covered by organic waste and biomass.
- About 2 million tons/year of SRF are absorbed in the cement industry in Germany

- In Greece, the major problem with the development of similar applications is the lack of standardization, the lack of long-term contracts, the institutional framework and local reactions (tests have been carried out in cement industry companies AGET-Heracles and TITAN).

WTERT Guidebook: Complementary WTE plant and adjacent Materials Recovery Facility (MRF)





Levels of Sustainable Waste Management

Sustainability	Waste management description	Characteristics of the waste management system
Level 6	A fully circular economy with all waste materials re-used as resources	A system and associated economy that is regenerative by design. Materials flows are of two types, with biological materials designed to re-enter the biosphere, and technical materials, designed to circulate with minimal loss of quality. The economy ultimately powered by renewable energy. No waste is generated as they are used as materials and energy resources. Products are designed for deconstruction to enable materials and resource extraction.
Level 5	Optimum industrial sector recycling involving local/national industrial symbiosis with EfW with post combustion recycling	Extensive material recycling and reuse in a system that fully exploits industrial symbiosis to benefit the local/national economy. High efficiency energy extraction from the residual waste using a range of technologies combined with optimised extraction of additional resources from combustion residues. System contains elements of a circular economy.
Level 4	Optimum industrial sector recycling combined with EfW with post-combustion recycling	Extensive recycling and reuse involving extensive export of materials. High efficiency energy extraction from the residual waste using a range of technologies combined with optimised extraction of additional resources from combustion residues. System contains elements of a circular economy.
Level 3	Highly engineered landfill, EfW and industrial sector recycling	Significant levels of recycling completed primarily by the formal sector. Residual waste disposal via a combination of engineered landfill and waste to energy with some extraction and reuse of materials combustion ash.
Level 2	Highly engineered landfill and industrial sector recycling	Highly engineered landfills providing full containment, extraction and treatment of landfill leachate and good landfill gas extraction system with combustion of CH_4 used to generate electricity. Landfills operated to have minimal impact on environment and neighbours. Formal sector recycling and composting systems in operation.
Level 1	Landfill and industrial sector recycling	Landfills provide an intermediate level of environmental protection, involving geological and hydrogeological assessment for site selection, some site management, but no landfill gas or leachate collection. Intermediate level of recycling and materials extraction and local composting schemes.
Level 0	Dumping and informal sector recycling	Uncontrolled dumping of wastes into and onto land with no engineering control to protect the environment from leachate that will contaminate local groundwater. Uncontrolled emissions of landfill gas. Extensive informal sector activity at dumpsite with no or limited use of personal protective equipment. Materials collected from the waste are sold onto local middle men.

Conclusions

- There are many opportunities in development of waste to energy technologies
- Anaerobic digestion, methane collection from landfills, incineration and other waste -to -energy technologies should be examined for streams of municipal solid waste, with regards to technological, financial and environmental criteria.
- Recycling and waste- to- energy treatment can reduce the quantities of industrial and municipal waste that must be disposed to sanitary waste areas. Can be collaborative and not competitive parts of a modern solid waste management system. Current trend is not the juxtaposition of alternative methods, but their combination. Goal: Zero waste society

Thank you for your attention