Could waste to energy help to close the loop?

Prof. dr.sc. Daniel R. Schneider

University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture,
Department of Energy, Power Engineering and Environment
Zagreb, Croatia

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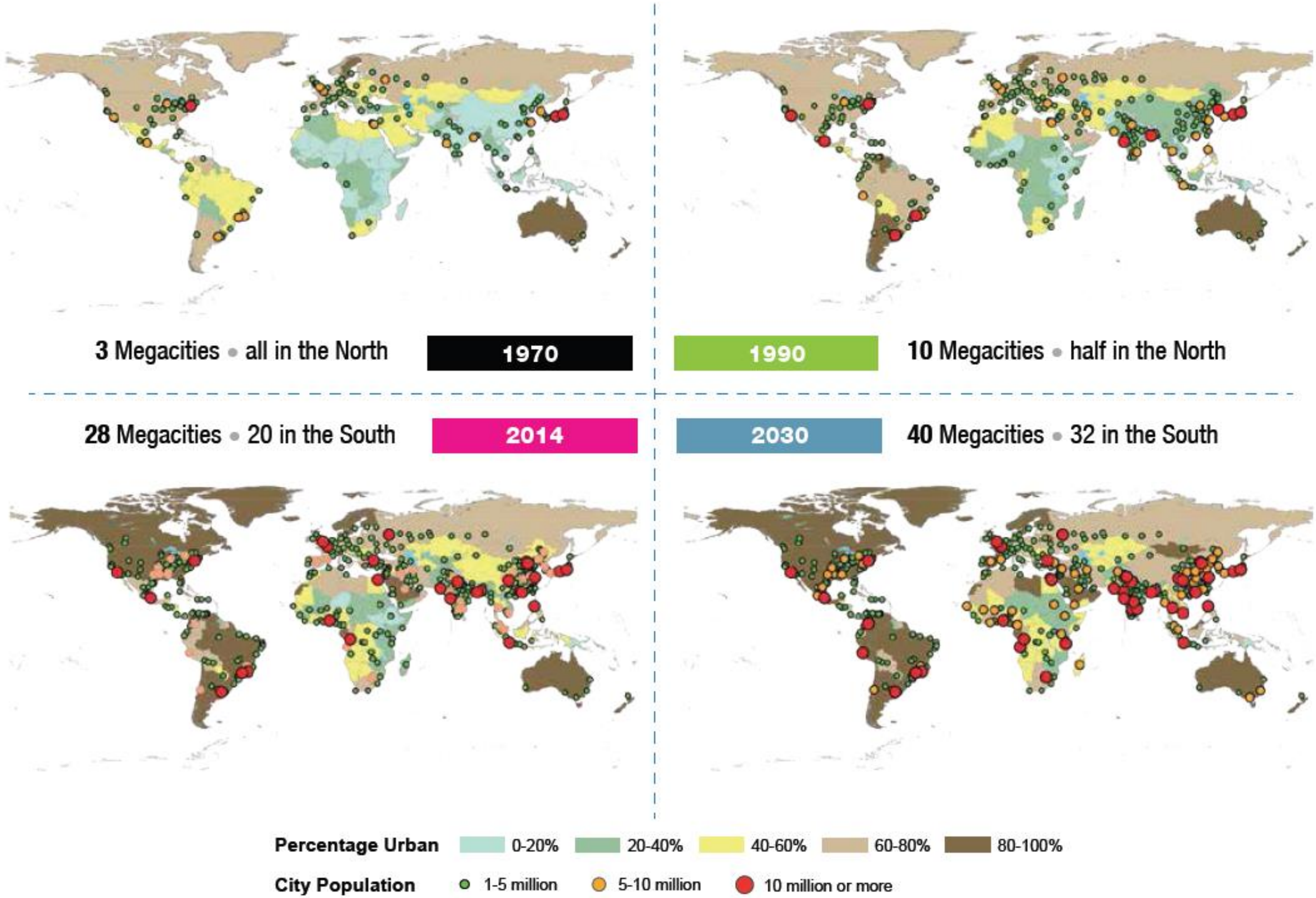
Global problem

- The global population, currently at **7.6 billion** (December 2017), will grow in the coming decades to **9 billion** (and perhaps 11.8 billion by the end of the 21st century).
- Some **80%** of this growing population **will live in cities**, most of which are yet to be built. (Figure1)
- Of this projected 9 billion people, **3 billion** will belong to the **middle class**, with sufficient income to purchase the consumer goods[1].
- In 2012 about 3 billion residents generated **1.2 kg** per person per day, which made for **1.3 billion** tonnes per year[2].
- By 2025 this will likely increase to 4.3 billion urban residents generating about **1.42** kg/capita/day of municipal solid waste, which makes for **2.2 billion** tonnes of MSW per year. (Figure2)

[1]Global Waste Management Outlook (GWMO), UNEP, ISWA.
[2]World Bank's report What a Waste: A Global Review of Solid Waste Management.

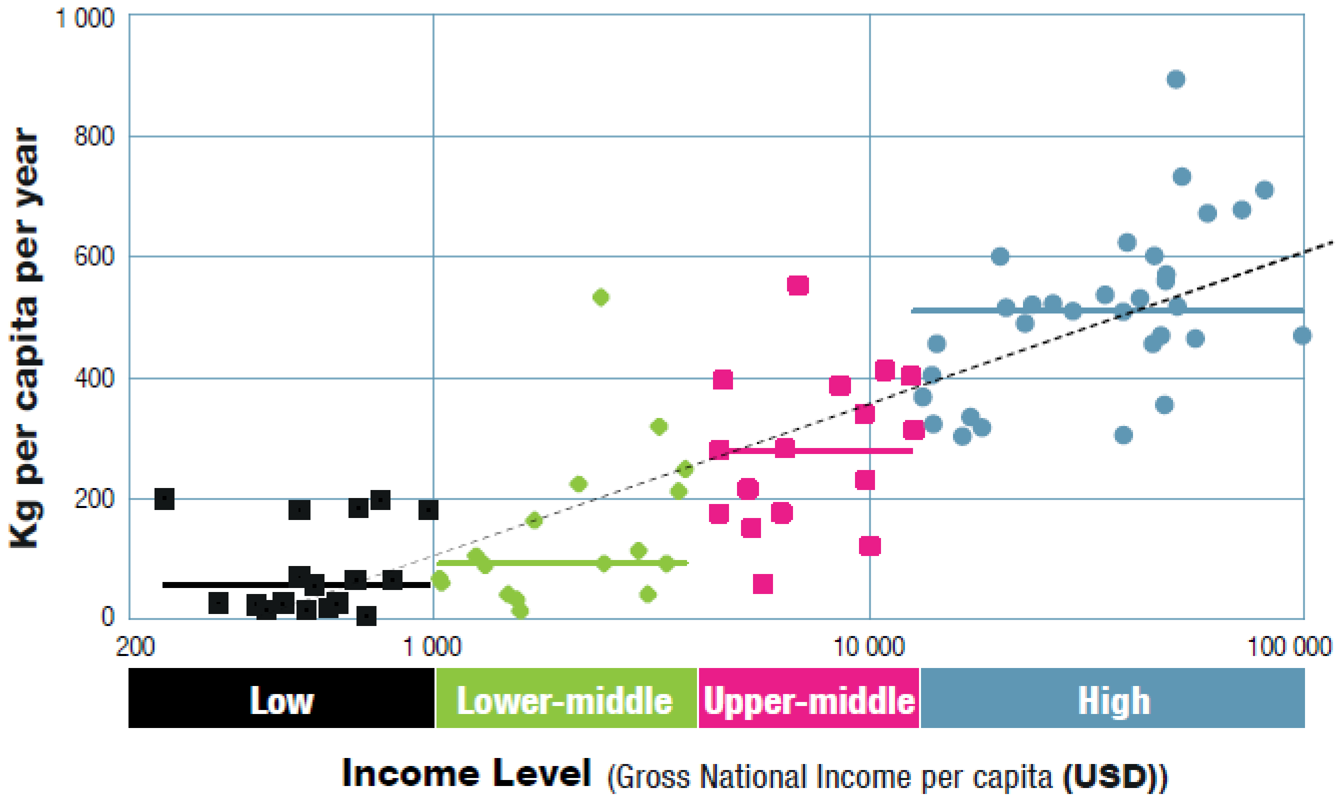
Percentage of urban population and locations of large cities, 1970 – 2030



UN disclaimer: Designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country territory or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Source: UNDESA, Population Division (2014). World Urbanization Prospects, the 2014 Revision. New York. http://esa.un.org/unpd/wup/

Global problem



Source:
Global Waste Management Outlook (GWMO), UNEP, ISWA

Notes: Based on data from 82 countries using the latest available data within the period 2005-2010. For 12 countries, the latest available data was older than 2005.

Regression: $y = 109.67\ln(x) - 651.45$, $R^2 = 0.72$

Data sources: EMC's Master Country Database (n.p., 2014) using primarily data from the EU, OECD and World Bank; Lawless (2014), Waste Atlas: Recycling and resource recovery around the world (Unpublished master's thesis). University of Leeds, Leeds, UK. Both were prepared for the GWMO (see Annex B, under Waste databases).

Global problem

- Among the biggest waste producers (absolute quantity) in the world are the United States, China, Brazil, Japan and Germany. (Figure 3)
- Furthermore, the UNEP predicts that the amount of waste will probably **double** in lower-income African and Asian cities within next 15-20 years because of population growth, urbanization and rising consumption.
- The amount of urban waste being produced is growing faster than the rate of urbanisation[3].
- It is estimated that global waste generation will double by 2025 to over 6 million tonnes of waste per day and the rates are not expected to peak by the end of this century.
- OECD countries will reach 'peak waste' by 2050, and East Asia and Pacific countries by 2075, waste will continue to grow in Sub-Saharan Africa.

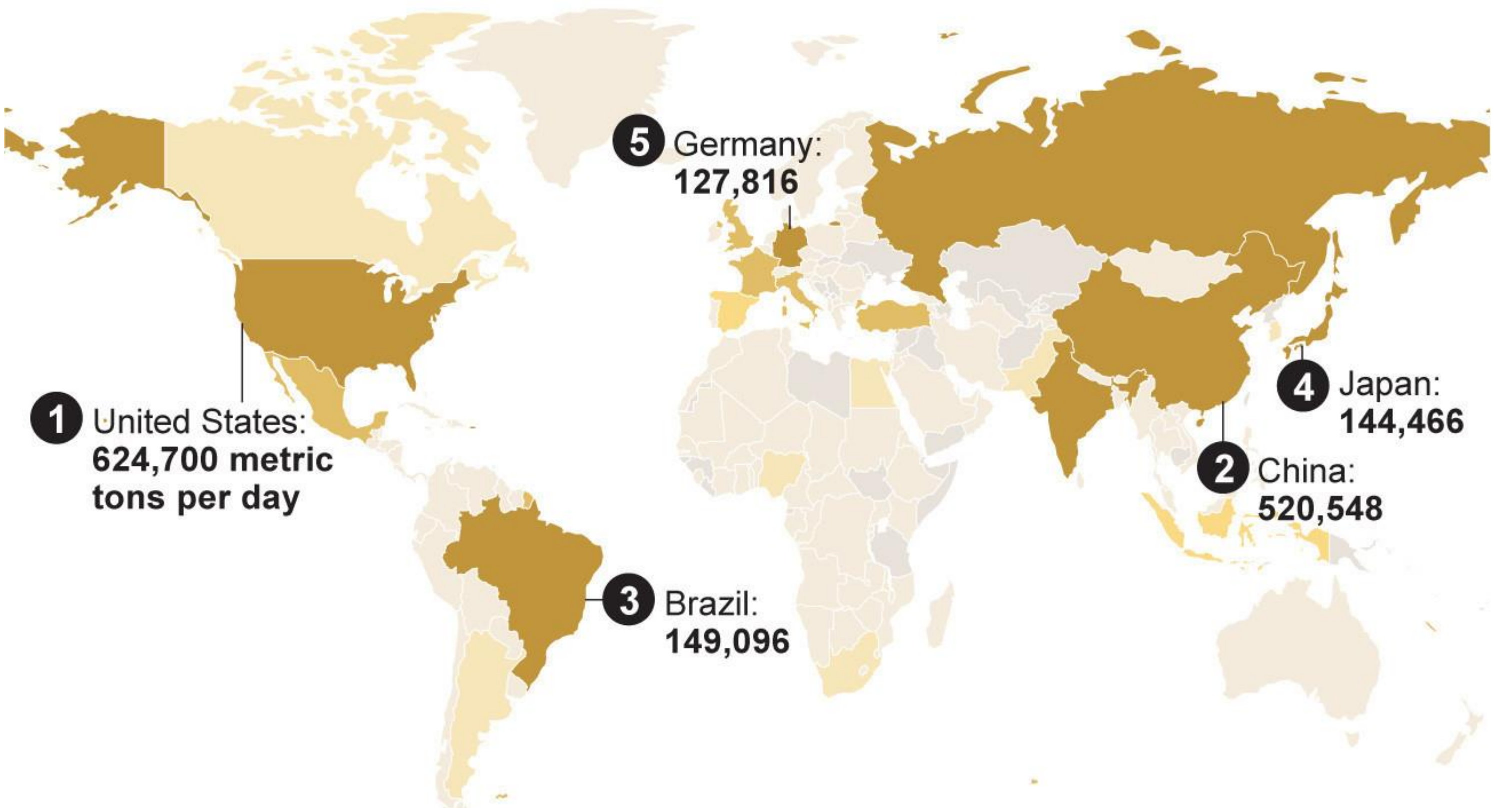
[3] World Bank's report What a Waste: A Global Review of Solid Waste Management.

Who generates the most waste?

Metric tons of solid waste generated each day*

(In thousands)

- Less than 40
- 40 - 60
- 60 - 80
- 80 - 100
- More than 100
- No data available



*Figures are from a 2011 report that compiled data from earlier years.

Source: World Bank

Angelica Quintero / @latimesgraphics

Global problem

- A percentage of **urban population** is steadily increasing;

  In 2016 the percentage of the population in cities was **54% of the total world population**, while for **2050** increase to **66%** is forecasted[4].
- In **EU** about **75% population** lives in urban areas [EEA].
- Such migration trends put significant problems on management of cities in terms of meeting the needs for **housing, food, water, energy, transport** and **other infrastructure**, and addressing **waste and emissions** as well as the **quality of life of residents**.

- **Cities** today spend **three quarters** of the total energy and at the same time generate **80%** of global carbon dioxide emissions

  which makes their organization and sustainable management **one of the largest challenges of environmental policy**.

[4]The United Nations Population Division's World Urbanization Prospects.

Urban metabolism

- **Urban metabolism** as the „Sum of the total technological and socio-economic processes that take place in cities and result in **growth**, **energy** generation and **waste** elimination" [Kennedy 2007, 2011]
- Cities within their borders are still dependent on the import of energy and fuel or the export of waste generated in them.
- Two main approaches to the modelling of urban metabolism are recognized: models based on **material and energy flows** and "**emergy**" **models.** In this second approach all processes and measures are reduced to a standard unit based on solar energy.
- The first approach, which includes an analysis of material flows to describe the flows of energy and matter showed much more appropriate in engineering applications so that today it is the most used.
- This approach includes energy of transformation of raw materials and energy (fuels) in the final material goods, as well as associated waste streams.

Local energy resources

- In **urban** areas energy from renewable sources as well as locally available resources can be used (e.g. waste, biomass, sludge) can be used.
- In an urban context (urban area in the narrow sense) it is possible to identify a whole range of potential sources of energy:
  - **Biodegradable fraction of municipal waste** (paper, cardboard, textiles of organic origin, food waste, wood, etc.),
  - **Non-biogenic fraction of municipal waste** (a fraction that is not possible (or not wanted) to materially recover (recycle), e.g. plastics,
  - **Urban "green" biomass** such as three trimmings, branches, leaves, shrubs, grass cuttings from public green spaces, parks, tree alleys and private gardens, construction wood waste (demolition), waste from wood industry
  - **Waste edible oil** from restaurants
  - **Sewage sludge** from the waste water treatment plant

Local energy resources

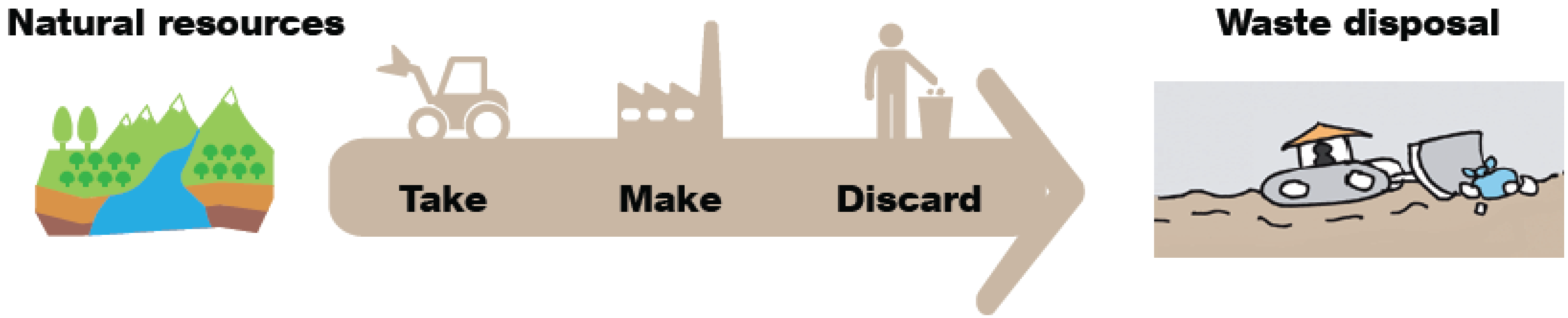
- In the peri-urban (immediate proximity to the city) area are also available:
  - **other types of biomass** such as waste from agriculture and forestry, wood industry (if present in these urban areas), wood chips, energy crops,
  - **organic** (biomethanogenic) **waste** from the farms,
  - **landfill gas** is present at the landfills.

- The greatest potential makes available **municipal waste** and especially interesting is its biodegradable fraction.

- Not only the waste generated daily in cities but also the existing landfill, i.e. historical waste, dealt with in the past years and even decades (Landfill Mining).

Circular economy

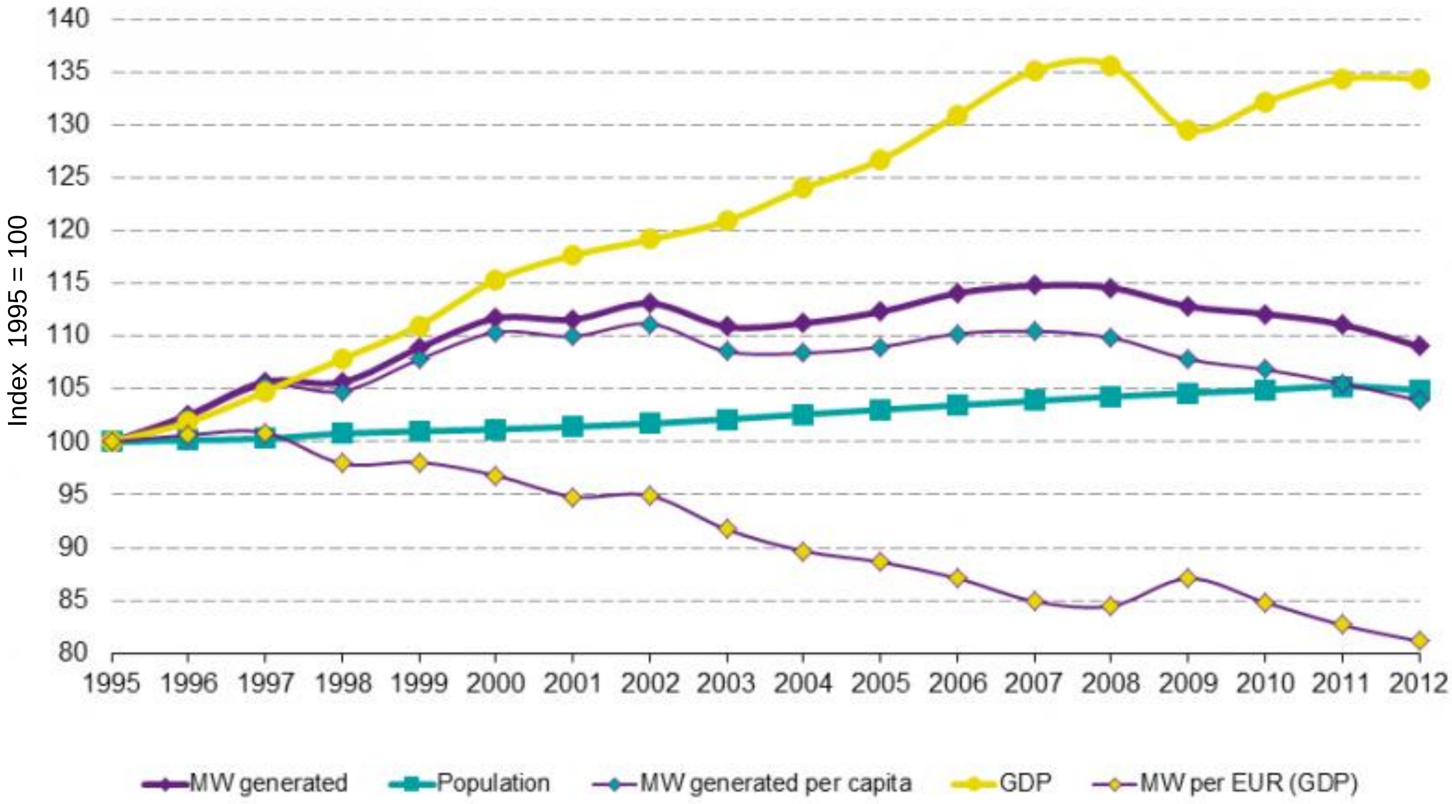
- The goal is to move the thinking away from "waste disposal” to „**waste management**” and from „waste” to „**resources**”
- The circular economy is regenerative.
- It entails gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system. (Figure A)
- Moving from the linear economy and waste management:



Source: Global Waste Management Outlook (GWMO), UNEP, ISWA.

The situation with waste management in the EU

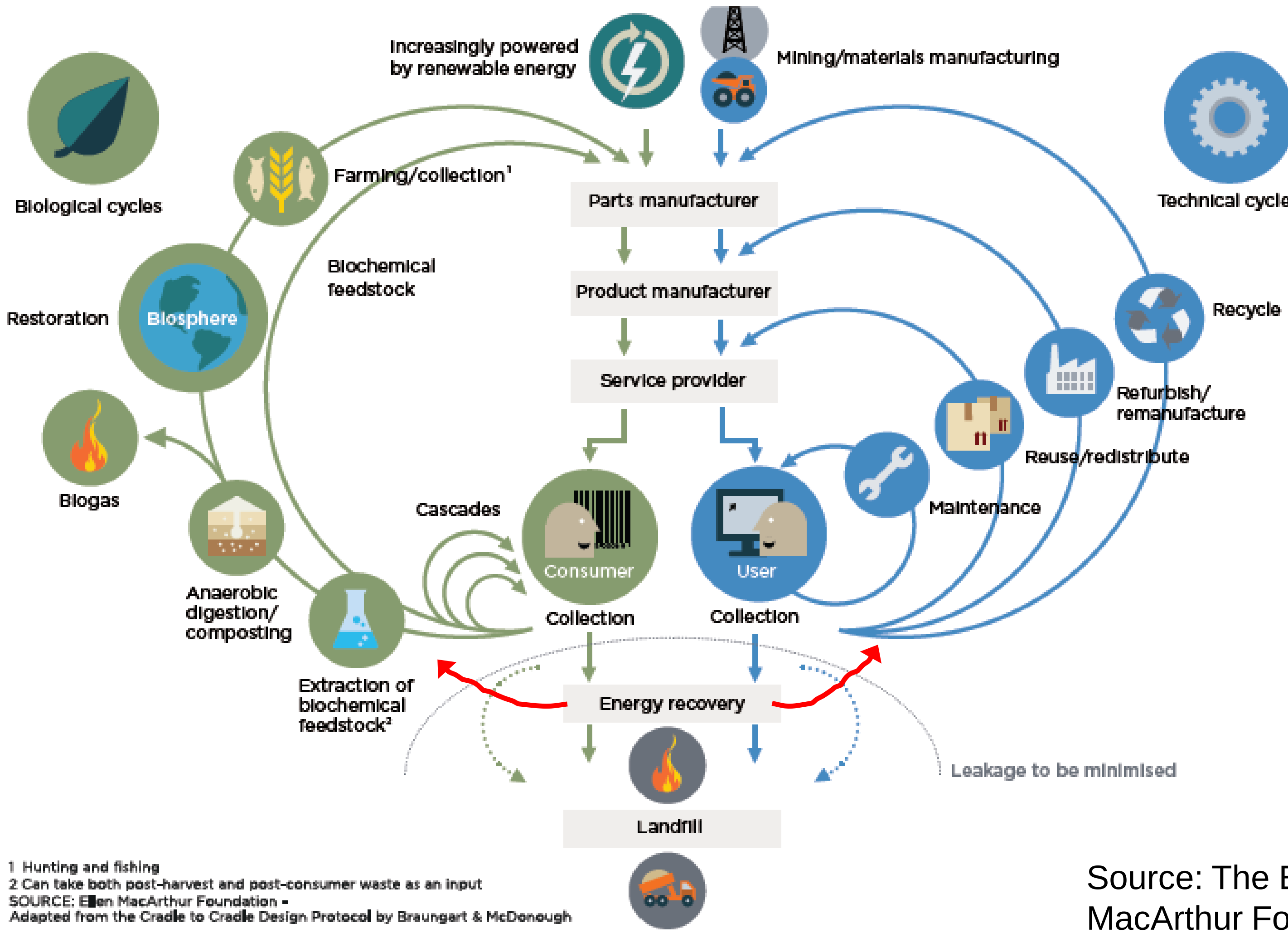
Generated waste in EU vs. GDP (comparison to 1995)



Source: Eurostat

- to the resource management within a circular economy:

Circular economy – an industrial system that is restorative by design



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input
SOURCE: Ellen MacArthur Foundation –
Adapted from the Cradle to Cradle Design Protocol by Braungart & McDonough

Source: The Ellen MacArthur Foundation (adapted)

- Waste (and energy) issue could fall into several categories of Global Sustainable Goals:

Source: UN Sustainable Development Goals, 2015

Material recovery of waste

- In the last decade in the EU, a great emphasis has been put on the material recovery (shortage of resources):
  - Waste Framework Directive (2008/98/EC) (WFD)
  - The Circular Economy Package (CEP)
  - Packaging and packaging waste directive (1994/62/EC)
- New very ambitious targets (December 18, 2017), under CEP
- Increase in **recycling** of municipal waste (preparation for recycling and reuse) to:
  - **50%** by **2020** (WFD)
  - **55%** by **2020**
  - **60%** by **2030** (CEP)
  - **65%** by **2035**
- The establishment of a **uniform formula** for calculating the municipal waste target, and new **targets for recycling** municipal and packaging waste.

Material recovery of waste

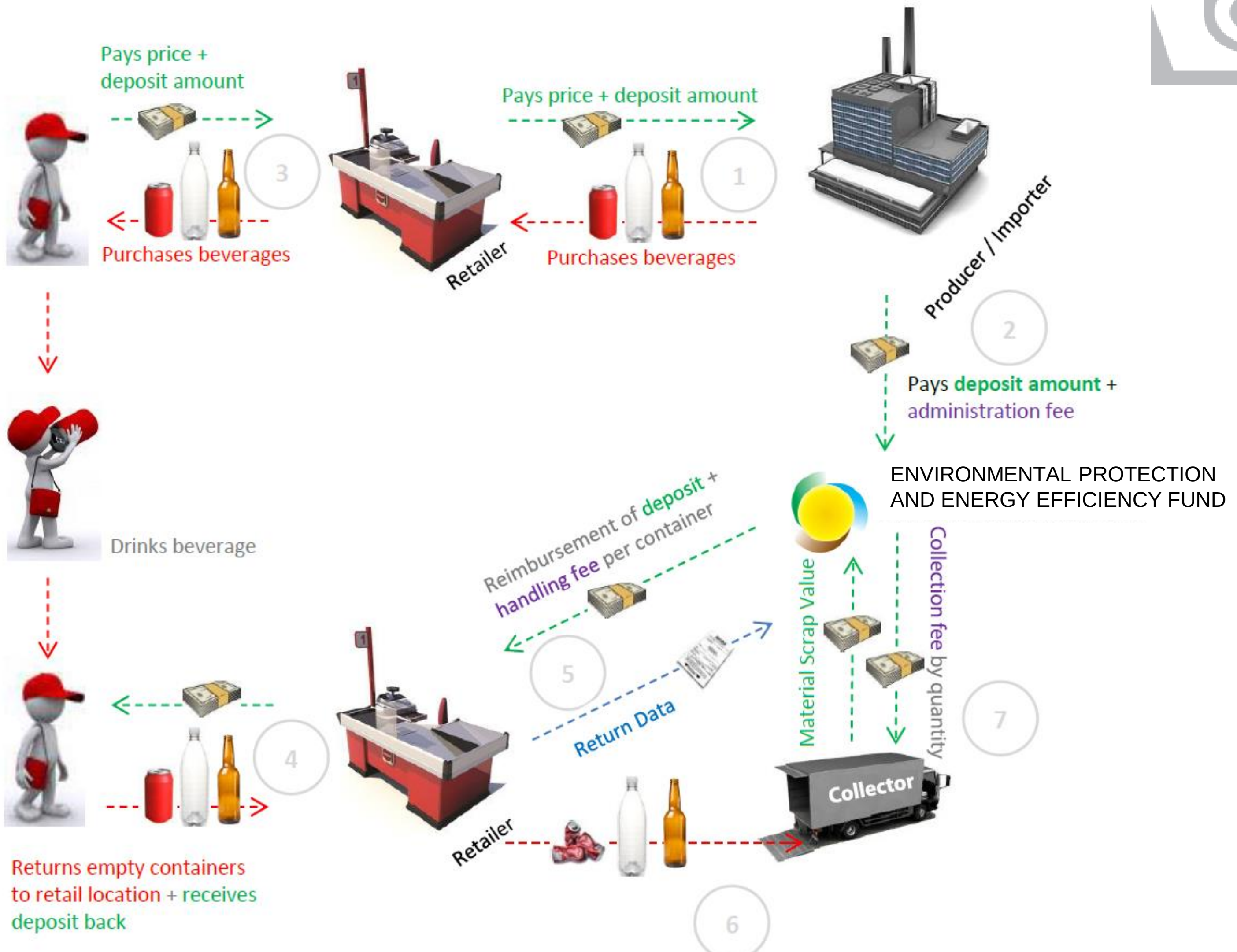
- Recycling/reuse of **packaging waste** to **70%** by **2030** (CEP)

- A new Europe-wide **EU Strategy for Plastics in the Circular Economy** (January 16, 2018)
  - by **2030**, **all plastics packaging** should be reusable or recyclable.
  - the impact of **single-use** plastics should be reduced (example deposit)

- **Landfiling** limited to maximum **10%** of total municipal waste by **2035**.
- Ban of waste disposal that has a **total organic carbon** (TOC) of more than **5%** or a **loss of ignition** (LOI) of more than **3%**.
- Ban of landfiling of **separately collected waste**.

- **QUESTION: Is there any place for energy recovery in the new concept of a circular economy?**

Deposit refund system in Croatia



Interactions of stakeholders in the packaging waste deposit system, for metal, plastic and glass packaging waste

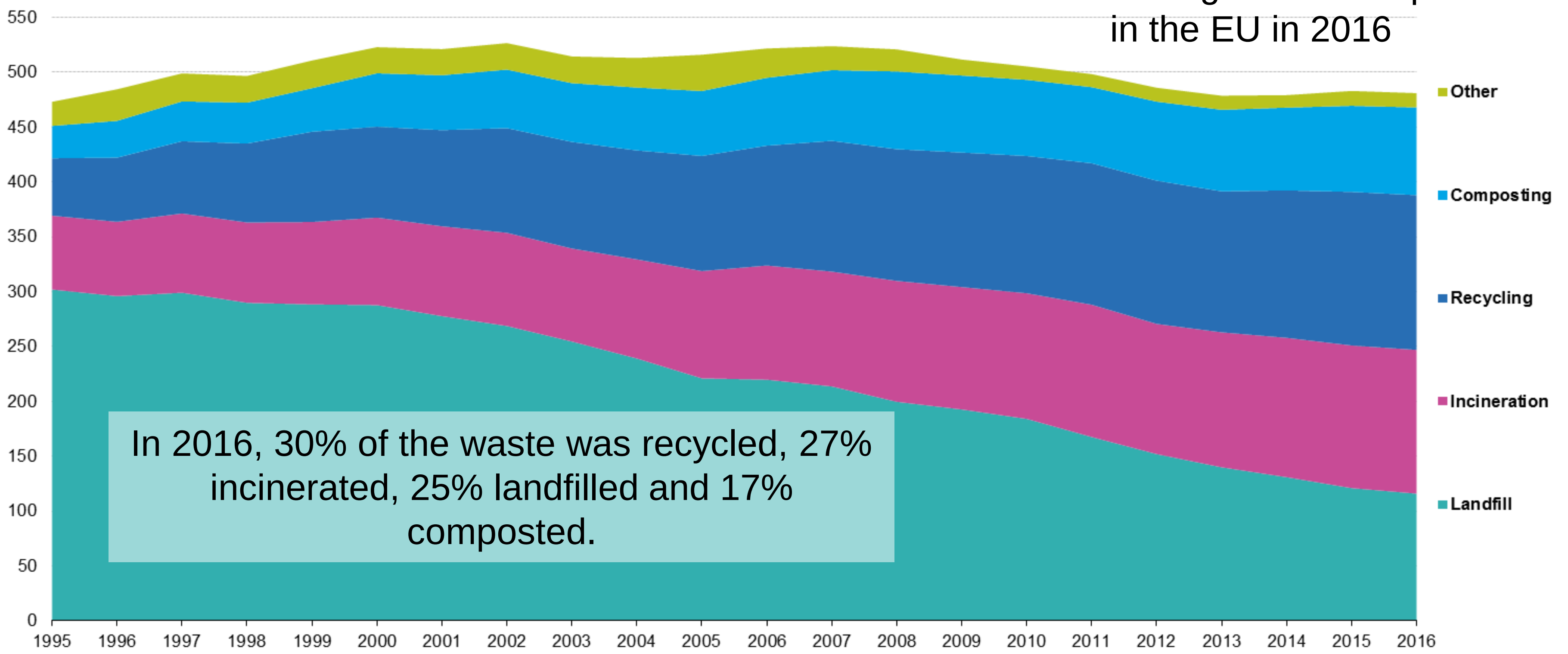
Table: Comparison of characteristics of different deposit systems

	Croatia	Norway	Finland	Estonia	Sweden	Germany
Operator (ownership structure)	State (state fund)	Industry (MFP, BP, W)	Industry (BP,BV, LC, M)	Industry (BP,BI, M)	Industry (BP, M)	Industry (M, MFP)
Clearing system	Centralised	Centralised	Centralised	Centralised	Centralised	Decentralise d
Manages unredeemed deposits	Operator	Operator	Operator	Operator	Operator	Producer
Deposit value dependent on packaging volume	NO	YES	YES	NO	YES	NO
Deposit value dependent on packaging material	NO	NO	YES	NO	YES	NO
Difference in administrative fees depending of barcode type (domestic/international)	NO	YES	YES	YES	NO	NO
Null rate of administrative costs for aluminium packaging	NO	NO	NO	YES	YES	NO
On-line clearing	NO	YES	YES	YES	YES	YES
Compensation for manipulative costs	YES	YES	YES	YES	YES	NO
The owner of the material	Operator	Operator	Operator	Operator	Operator	Retailer
Automated collection share >80%	NO (< 5%)	YES (95%)	YES (95%)	YES (94%)	YES (95%)	YES (80%)
Return rate (%)	87	96	93	82	88	97
Separate transport fee	YES	NO	NO	NO	NO	NO
Glass collection	YES	NO	YES	YES	NO	YES
MFP - Manufacturers of food products; BP - Beverage producers; W - wholesalers; BV - Beverage vendors; LC - Logistics companies; BI - Beverage importers; M - Merchants						

Source: Schneider and Tomić, 2017

The situation with waste management in the EU

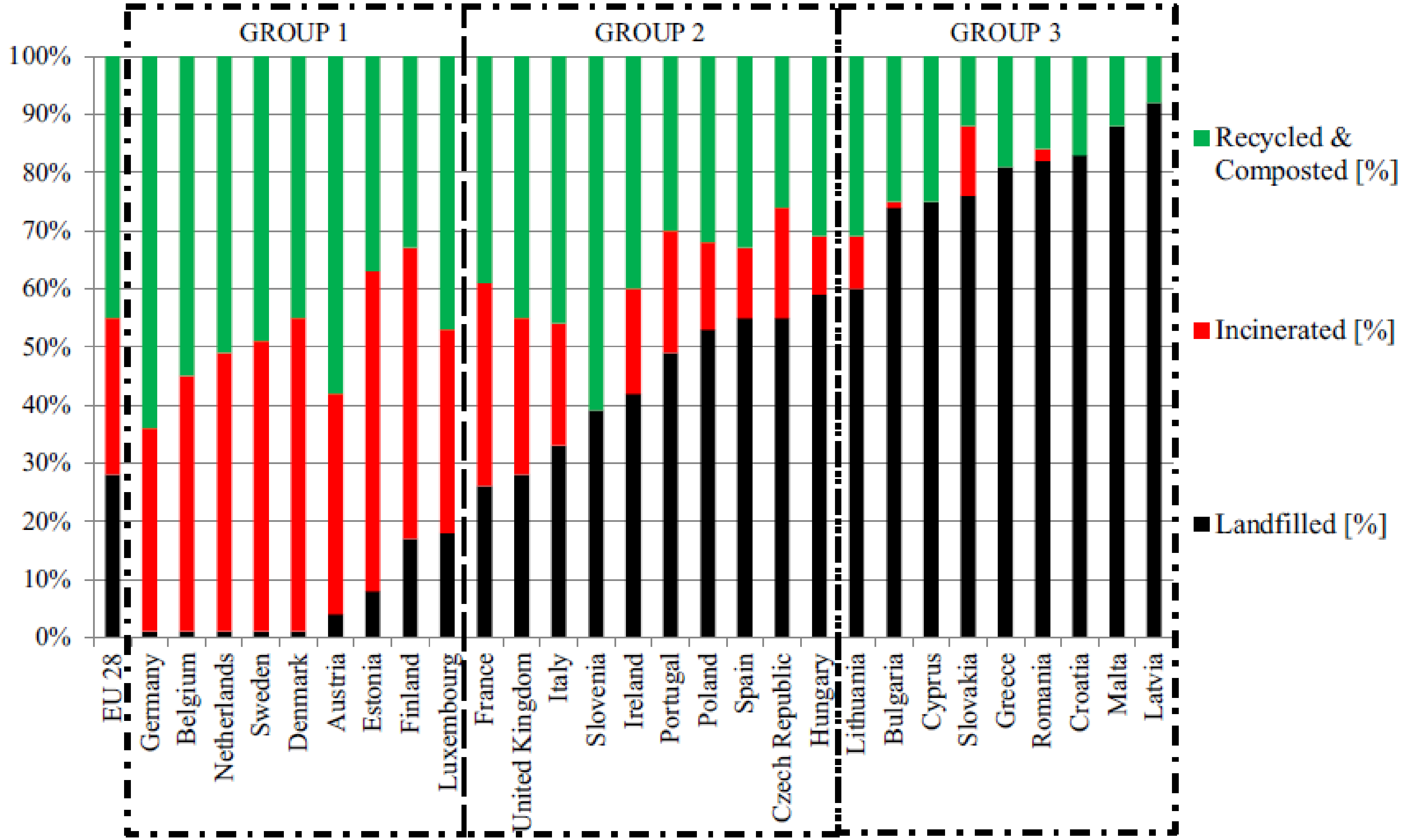
480 kg of MSW/cap in the EU in 2016



Trends in municipal waste management methods in Europe, 1995 – 2016

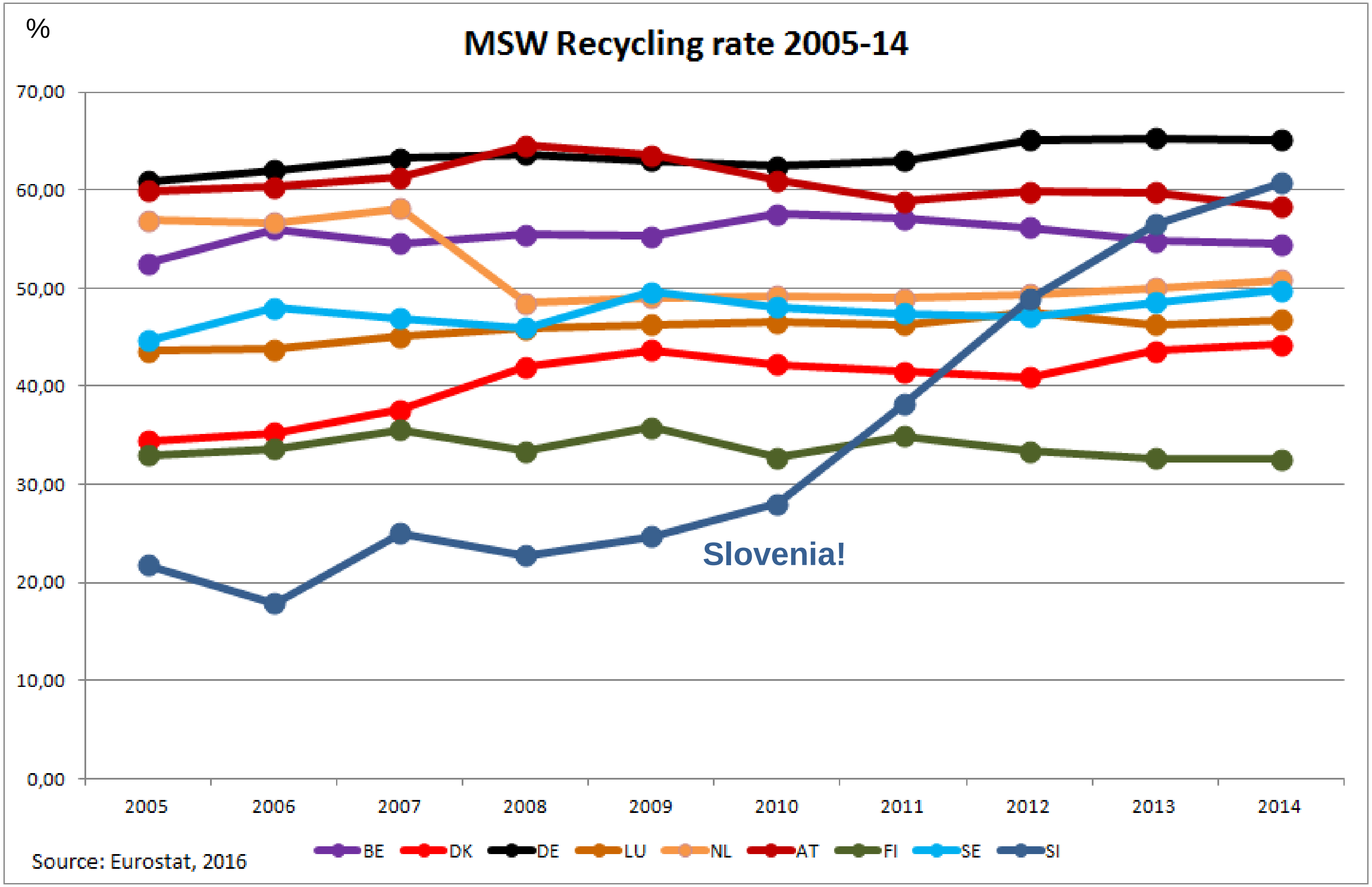
Source: Eurostat

Methods of waste management in EU28, in %, data for 2014 (Eurostat, 2016.)[9]



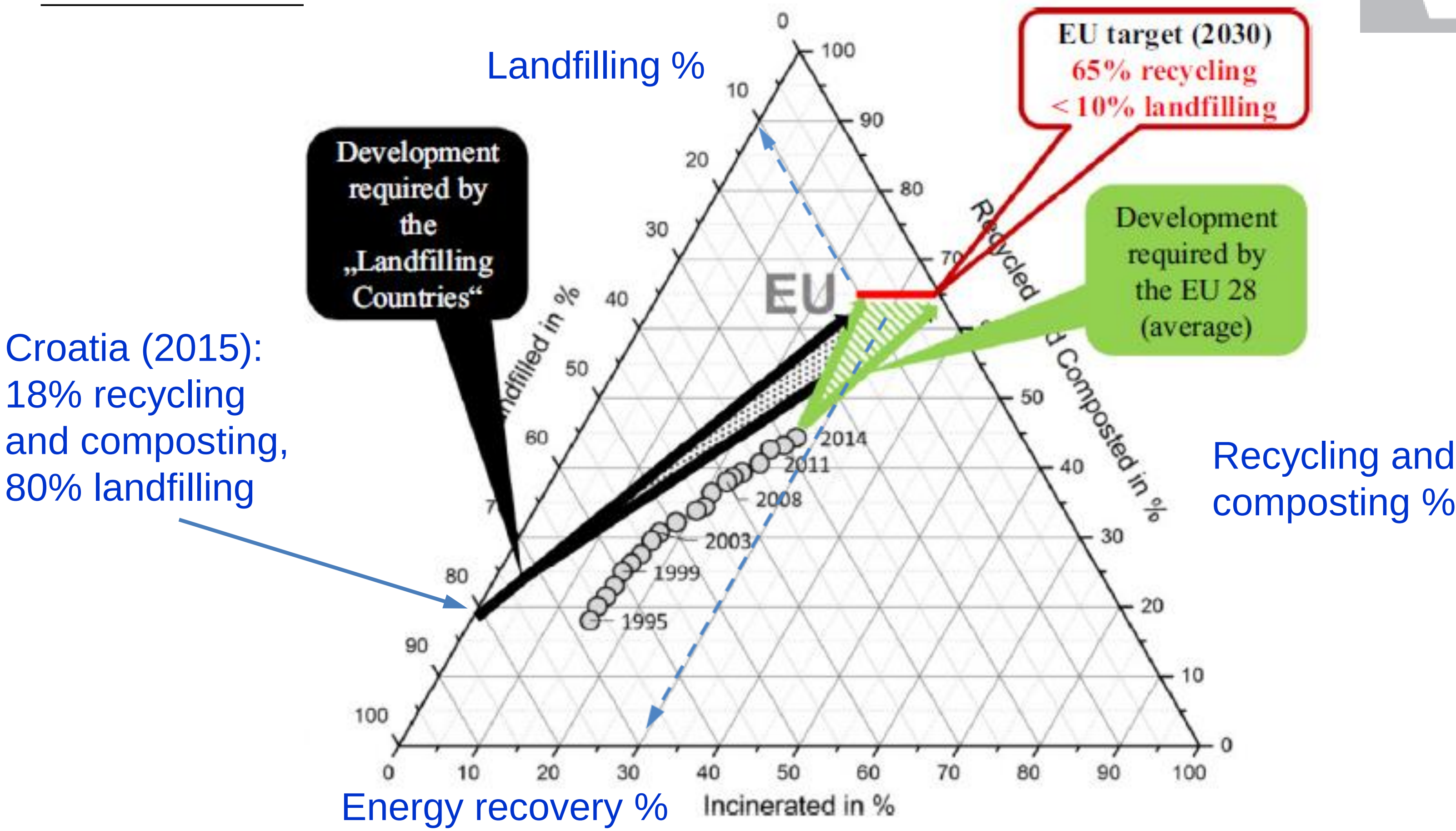
[9]Taken from: „Dynamic visualisation of municipal waste management performance in the EU using Ternary Diagram method", R. Pomberger, R. Sarc, K.E. Lorber, Waste Management 61 (2017) 558–571

Trends in recycling rates in selected EU countries (2005-2014)



Source: Eurostat, 2016

Waste management in the EU28



Waste management development in the EU 28 to 2014, as well as the effort needed to meet the goals of the Circular Economy Package (additionally (black bold arrows) for countries that base their waste management on landfilling)

Adapted from Source: *„Dynamic visualisation of municipal waste management performance in the EU using Ternary Diagram method"*, R. Pomberger, R. Sarc, K.E. Lorber, Waste Management 61 (2017) 558–571

Problems ahead

- Recently (January 1, 2018) China banned imports of 24 categories of solid waste, including certain types of plastics, paper and textiles (recyclables)
- In 2015, China imported nearly **50 million** tonnes of waste.
- The European Union exports **50%** of its collected and sorted plastics, **85%** of which goes to China (e.g. Ireland exported 95% of its plastic waste to China in 2016).
- The US exported 16 million tonnes of waste to China (in 2016) worth more than $5.2 billion.
- Global plastic exports to China could drop from **7.4 million** tonnes in 2016 to **1.5 million** tonnes in **2018**.
- The decrease will be partly due to a fall in the threshold of impurities China is willing to accept - higher standards that most countries currently cannot meet.
- Looking for other countries to export: India, Pakistan or southeast Asia, but it could be more expensive than shipping waste to China.

Problems ahead

- The ban risks causing a severe environmental problem as recyclable waste is instead incinerated or landfilled.
- Collectors of recyclables in US and EU are already reporting "significant stockpiles" of materials.
- The ban has also created challenges for Chinese companies dependent on foreign waste.
- More than **half** their plastics were imported, and as prices for such raw materials go up, production will be reduced by at least a **third**, (some companies alreday let go employees, or exited from business).
- In Europe, the ban could also have the positive effect of prompting countries to focus on developing domestic recycling industries (Jean-Marc Boursier, president of the European Federation of Waste Management and Environmental Services)

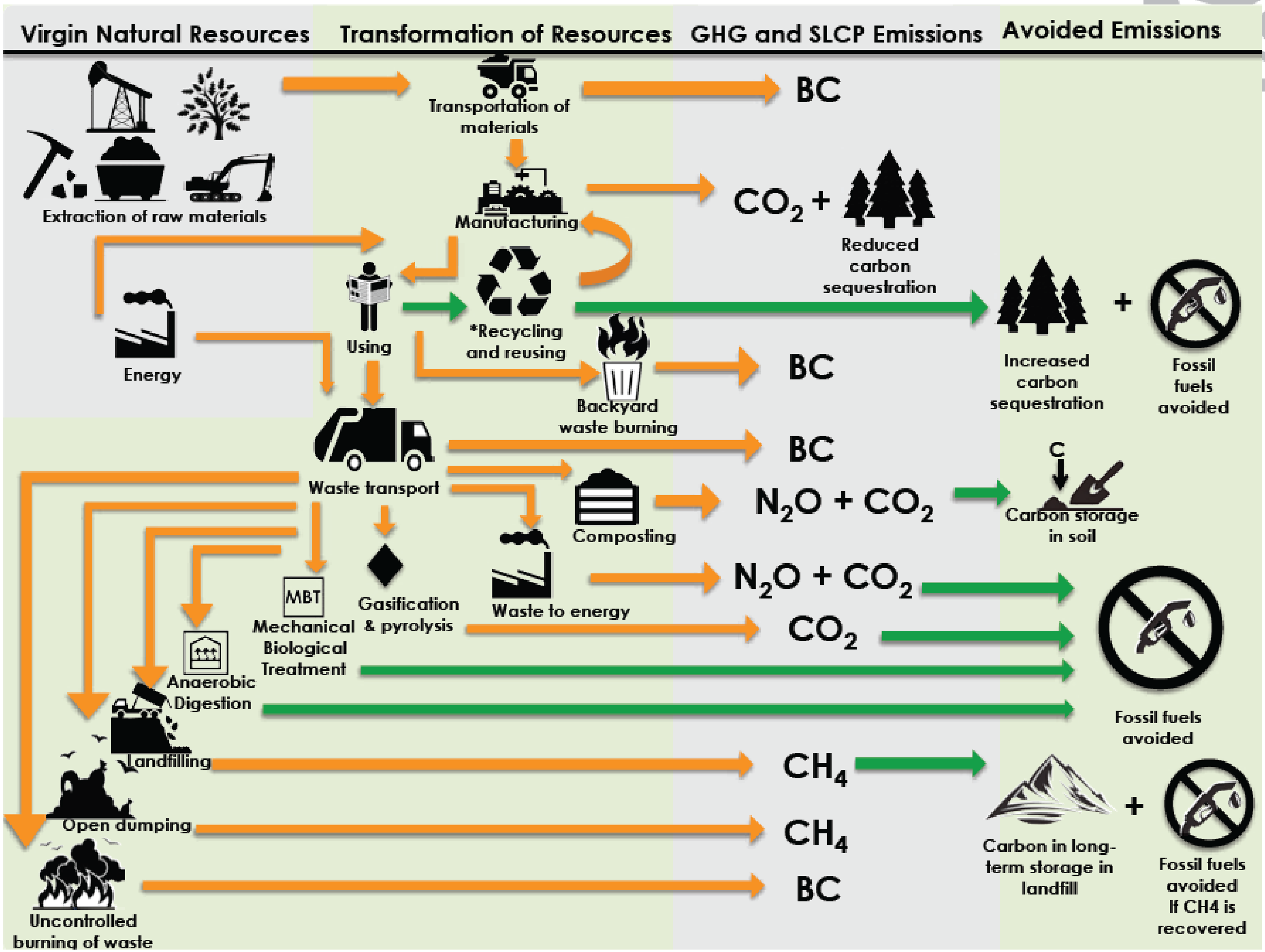
Sinergy

- Energy recovery of waste and waste materials can help to meet the goals of:
  - Energy Union Strategy (energy)[5]
  - the Paris Agreement (climate)[6] Figure 4
- Energy production from waste is a much wider concept than mere waste incineration. It refers to the various processes of treatment of waste (and waste materials) in which energy is generated (e.g. in form of electricity, heat or fuel). Figure 5
- It is necessary to ensure compliance with the **waste management hierarchy**.
- EfW through the use of proven energy-efficient technologies can help in generating high-quality jobs.
- It opens space for **innovation**.

[5] http://ec.europa.eu/priorities/energy-union-and-climate/state-energy-union_en
[6] http://unfccc.int/paris_agreement/items/9485.php

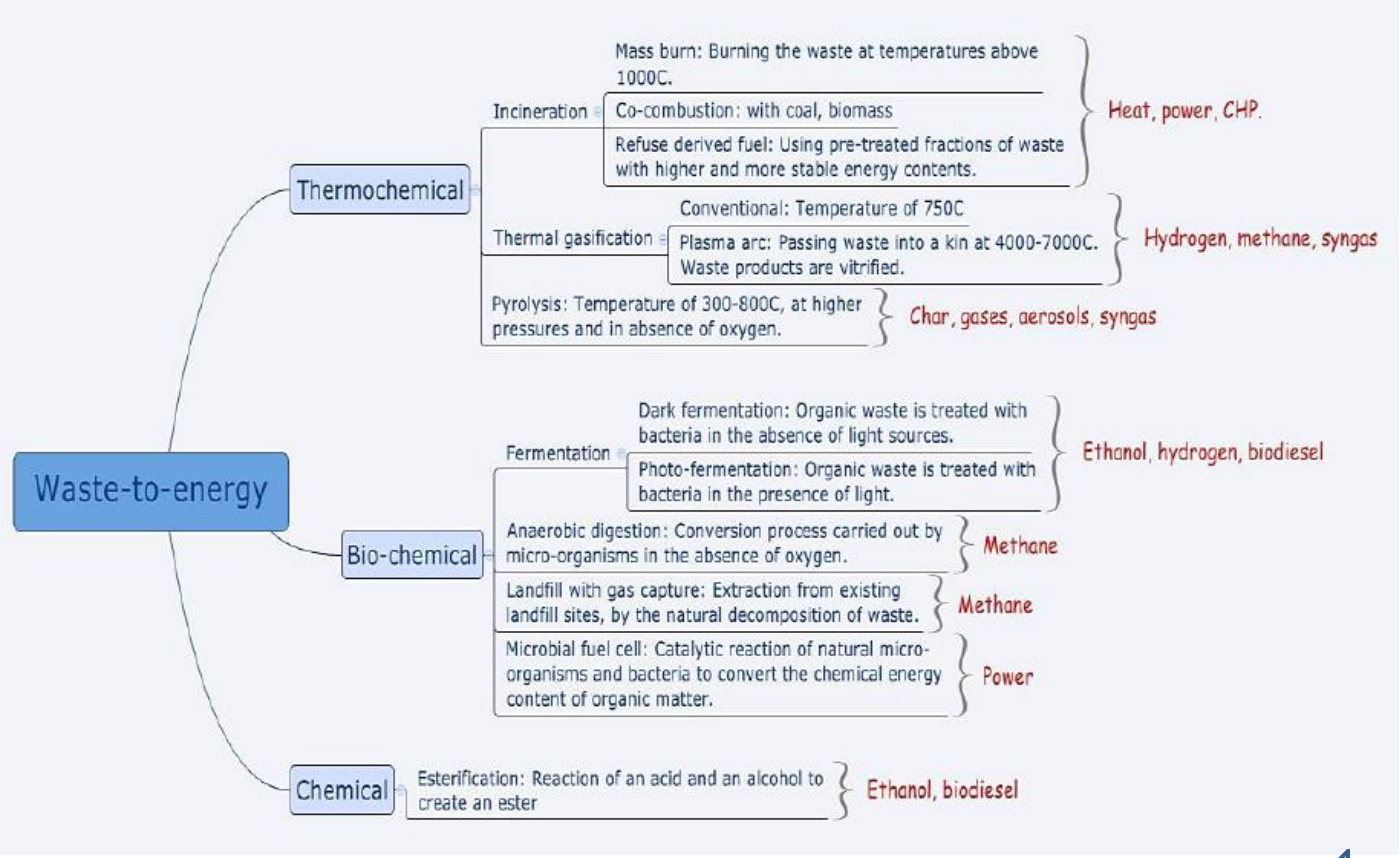
Climate synergy

Simplified schematic of waste management and climate change (excluding prevention)



Source: Global Waste Management Outlook (GWMO), UNEP, ISWA, figure by Natalia Reyna, Imperial College London. Inspired by an earlier figure published by USEPA, available at http://www.epa.gov/region9/climatechange/waste.html

Current WtE technologies



Source: World Energy Resources - Waste to Energy 2016, World Energy Council

Energy from waste

- The latest EU communication on the **role of energy from waste in the circular economy**[8] lists the following technologies as recommended[7]:
  - Waste co-incineration (in fossil/biomass thermal power plants or cement plants, steel furnaces, other industrial furnaces),
  - Incineration in dedicated plants (waste-to-energy plants),
  - Anaerobic digestion of biodegradable waste,
  - Solid, liquid or gaseous fuels from waste, and
  - Indirect energy recovery (after pyrolysis and gasification),
  - Landfill gas plants on landfills (*author added*).

[7]Communication on the Role of Energy from Waste in the Circular Economy, European Commission, COM(2017) 34 final, Bruxelles, 26.01.2017.
[8]Towards a better exploitation of the technical potential of waste-to-energy, European Union, 2016, http://publications.jrc.ec.europa.eu/repository/bitstream/JRC104013/wte%20report%20full%2020161212.pdf

Role of from Waste-to-Energy processes in the Circular Economy

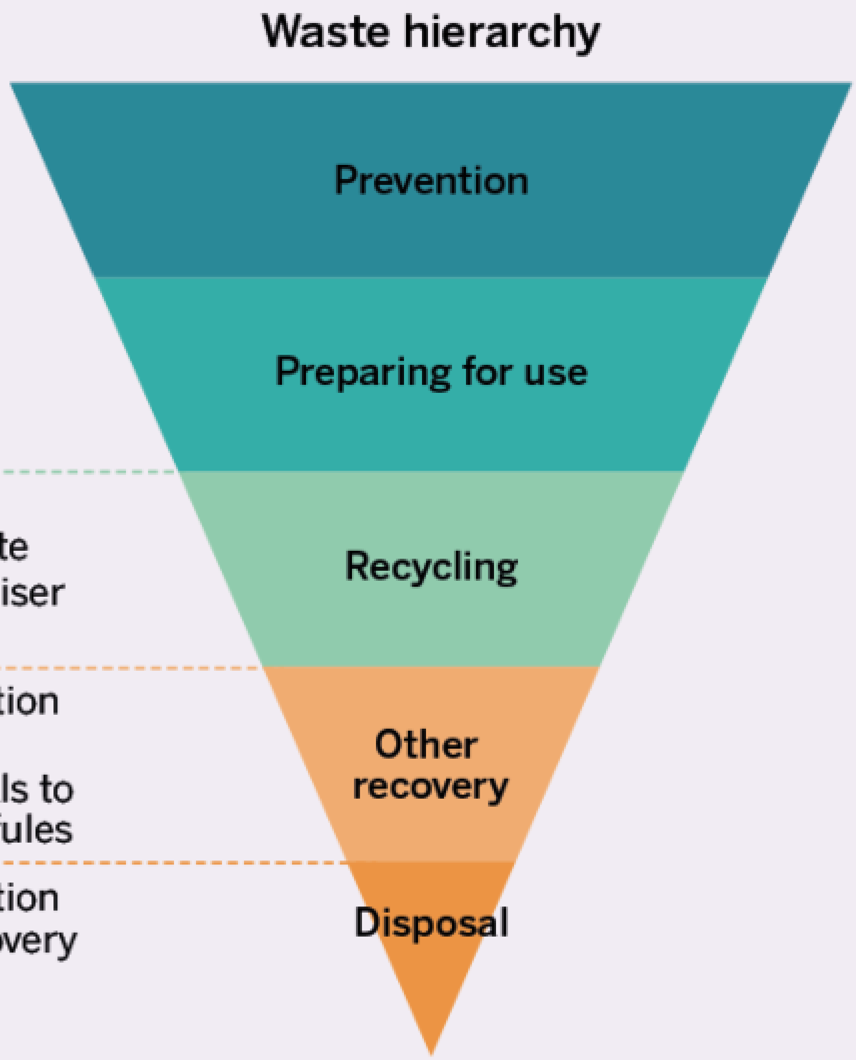
*Incineration of waste will be considered as **recovery** if the energy conversion efficiency exceeds **65%** for plants license issued after 31 December 2008, or **60%** with a permit before 1.1.2009

Examples of EfW processes

- Anaerobic digestion of organic waste where digestate is recylced as fertiliser

- Waste incineration and co-incineration with a high level of energy recovery
- Reprocessing of waste into materials to be used as solid, liquid or gaseous fules

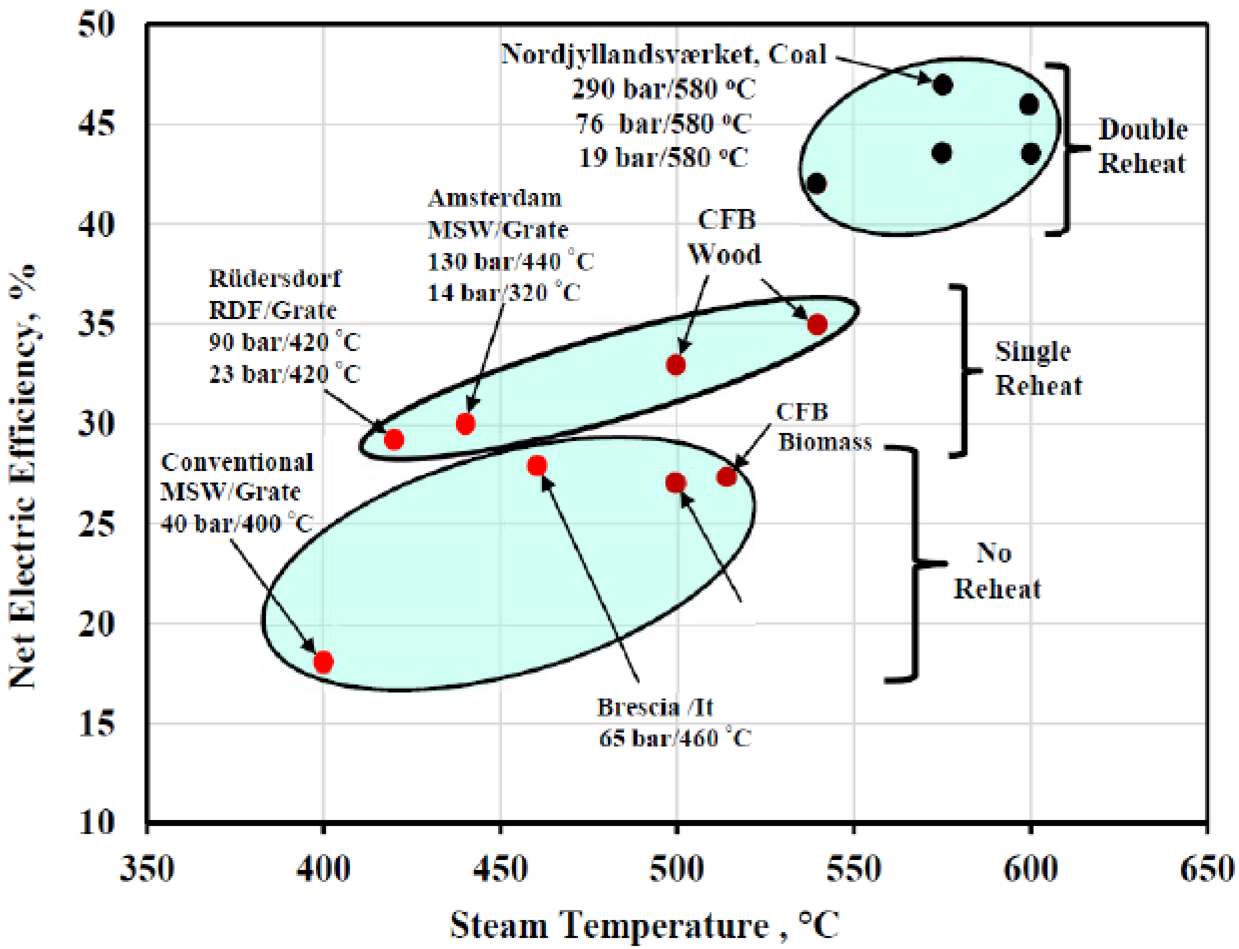
- Waste incineration and co-incineration operations with limited energy recovery
- Utilisation of capture landfill gas



Source: European Commission

Role of waste-to-energy

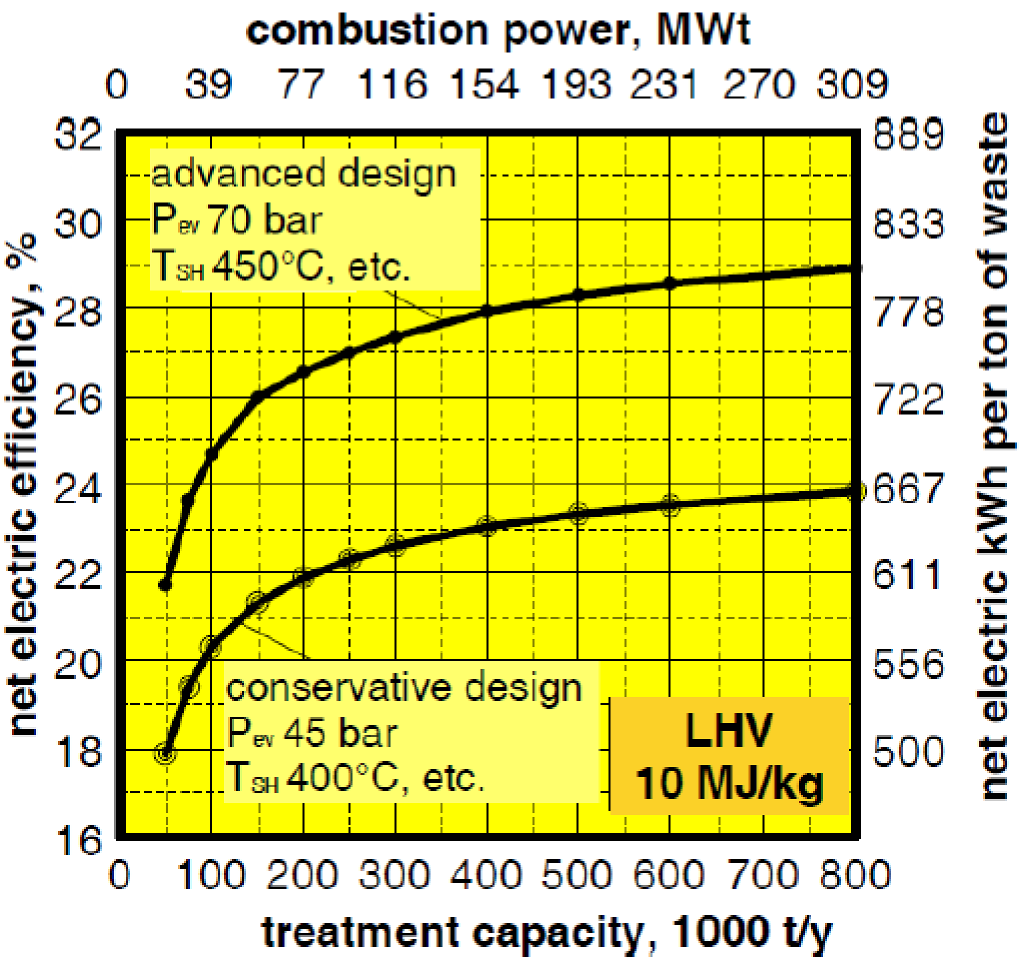
Net electric efficiency of WtE plants compared to modern biomass and coal fired power plants



Source: Hunsinger (2011) & Vainikka et.al (2013)

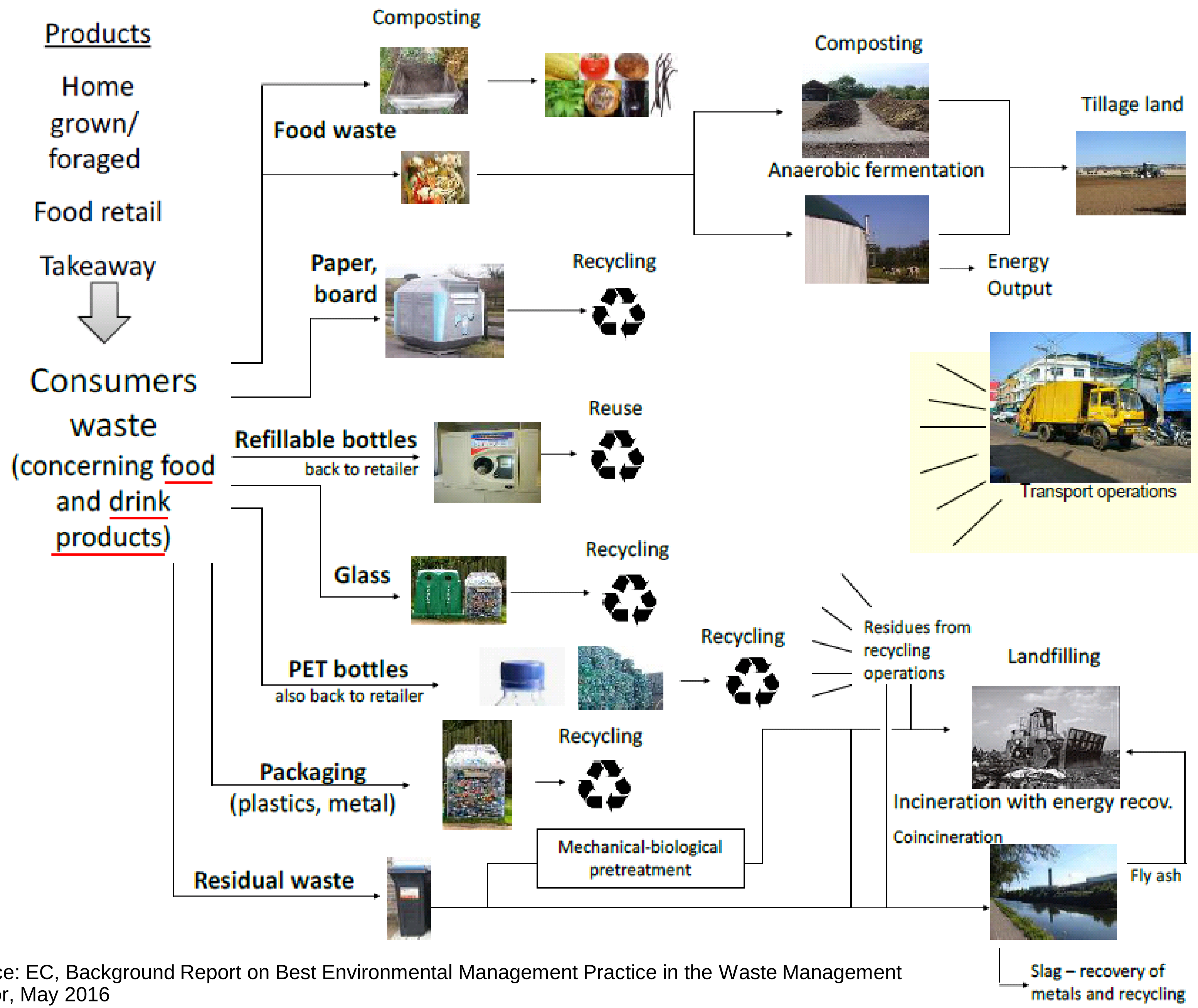
Role of waste-to-energy

Effect of steam parameters and scale



Source: Consonni, Viganò and Bogale (2014)

Recommended practices in waste management in the EU

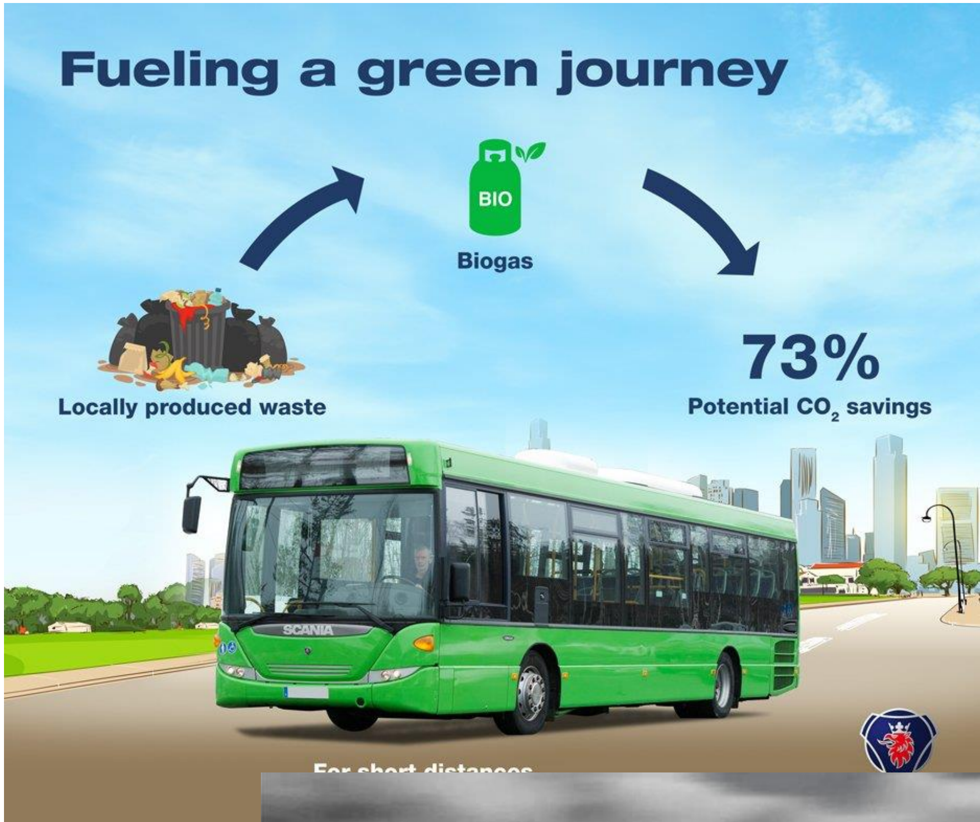


Source: EC, Background Report on Best Environmental Management Practice in the Waste Management Sector, May 2016

Energy from waste

- A great potential of **biodegradable waste** in energy and fuel production. The EEA study of 2013 shows that **40% of biodegradable waste** in EU28 level (in 2010) **ended at landfills**.
- Processes in which recycling of materials combines with energy recovery, such as **anaerobic digestion** of biodegradable waste, whereby biogas and digestate are produced are especially recommended.
- **Biogas** is used as a fuel for the production of electrical and thermal energy, however, biogas installations are often located at distant locations where heat is not needed and cannot be utilized.
- As **biomethane** (biogas that is upgraded to the biomethane quality) it can be injected into the natural gas network and used in conventional cogeneration plants in urban areas where all the heat from the process can be used, or in households for heating and cooking, or as a **fuel for transport** (e.g. in compressed natural gas (CNG) vehicles).
- CO_2 from biogas upgrading can even go to greenhouses for fruit and vegetable cultivation.

Biomethane from waste

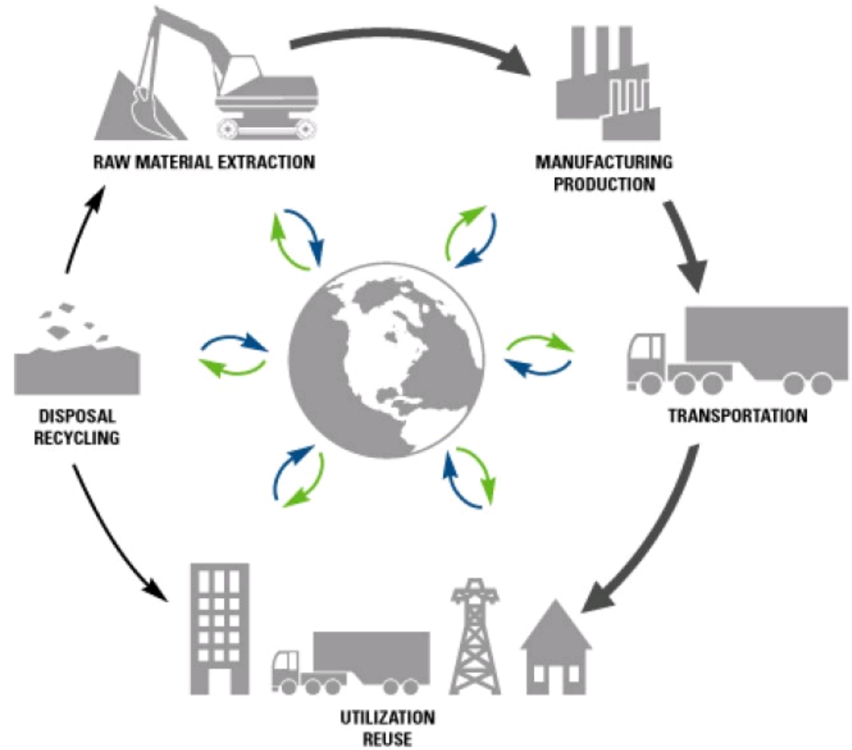


Targeted waste management system

Source: Shanks Waste Management, http://www.shanks.co.uk/

Energy from waste

- EU Member States have a certain flexibility in the implementation of the hierarchy, as the ultimate goal is to encourage those waste management options that give the best environmental outcome, → assisted by various methods such as Multicriteria Analysis (MCA) and Life Cycle Analysis (LCA), Embodied Energy, etc.
- Also due to e.g. technical feasibility, economic viability and environmental protection.
- in certain justified and special cases (e.g. materials containing certain hazardous substances) disposal or energy recovery (incineration) may be a better solution than recycling.



LCA analysis

Source: BioFuelNet Can.

Recycling vs. Incineration

- Furthermore, the new Circular Economy Package gives emphasize on the quality, i.e. obtaining quality recyclable materials (in short **Quality Recycling**) and sustainable recycling.
- Some materials, after a large number of recycling cycles, become unsuitable for further use in production processes and ultimately end up in landfills.
- The separation of recyclables from mixed municipal waste that comes in sorting plants is very difficult (increasing complexity in the composition of products and materials) and is not always economically viable (insufficient quality or purity of the obtained material).

Recycling vs. Incineration

- Such materials, which are often contaminated and contain pollutants (such as discarded material from sorting and recycling plants) can be efficiently thermally treated (with energy recovery) by which the pollutants are permanently removed from the production cycle.

- Without energy recovery, the high targets set by EU directives on recycling will be difficult to achieve, especially after the new criteria for quality and efficiency of recycling have been defined (similar to what is being done in waste incineration through the R1 formula for energy efficiency of the process, which will be harmonized for all 28 EU members).

$$\text{Energy Efficiency} = \frac{(E_p - (E_f + E_i))}{(0.97 * (E_w + E_f))}$$

In which:

E_p	The annual energy produced as heat or electricity. It is calculated with energy in the form of electricity being multiplied by 2.6 and heat produced for commercial use multiplied by 1.1 (GJ/year)
E_f	The annual energy input to the system from fuel contributing to the production of steam (GJ/year)
E_i	The annual energy imported excluding ,E-w and E-f (GJ/year)
E_w	The annual energy contained in the treated waste calculated using the net calorific value of the waste (GJ/year)
0.97	The factor accounting for energy losses due to bottom ash and radiation

Environmental sustainability - Methodology

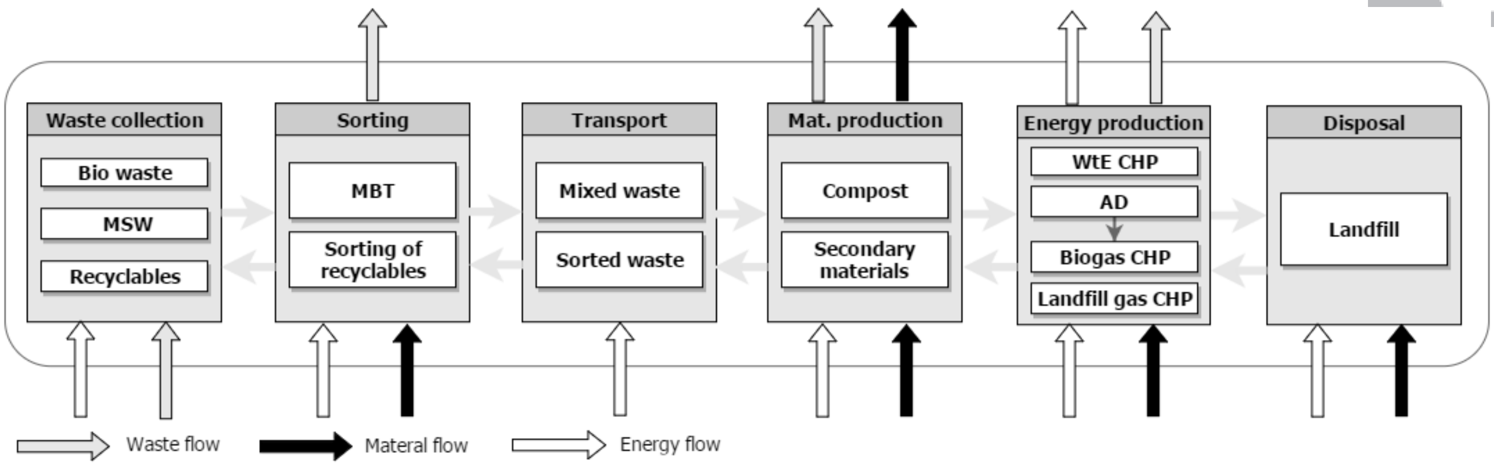
- Sustainability analysis:
  - EC emphasized importance of LCA analysis
  - LCA can be too complicated and too slow for some applications
  - Single-score LCIA methodologies
- **Cumulative Energy Demand (CED)** factor - Life Cycle Impact factor
  - Proxy to assess the environmental impact
  - Correlates with more complex single-score LCIA methodologies
  - Simple, scientifically robust and better suitable for some applications
- It is based on **Mass and energy flow** tracking.
- Each **technology** input and output flows are defined <u>through Unit Process Data (UPR)</u> from LCA databases.
- Answer the question:

  Which of the considered WMS leads to higher overall benefits i.e. which is more sustainable?

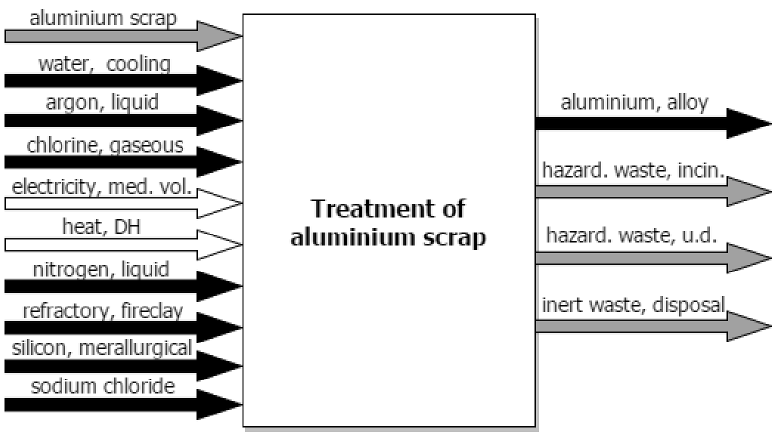
  - Through **primary energy (PE) consumption** and **return** approach

Methods

Stages of analysis and boundary



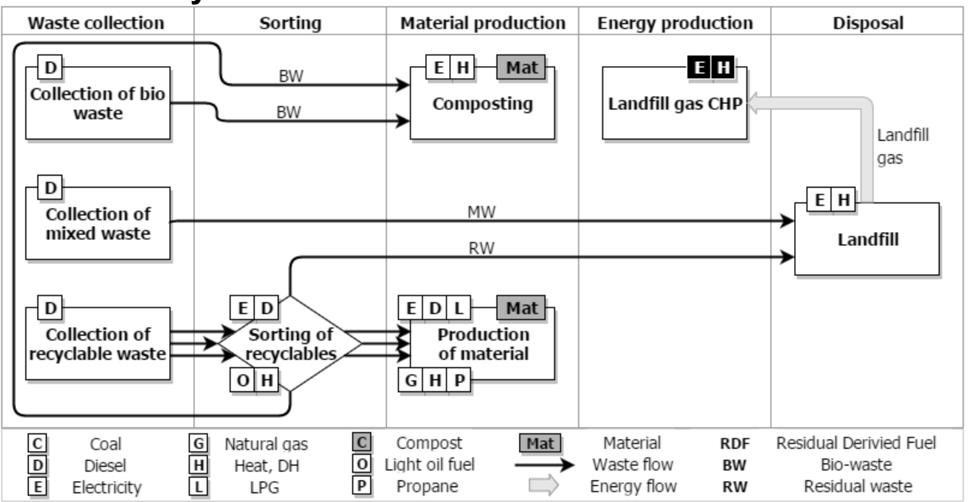
- Identification of stages and technologies that are part of WMS
- Identification of material and energy flows using UPR data
- Reducing external flows to PE equivalents using CED values
  - For marketable goods: to PE values for market activities
  - For waste flows: to PE needed for their disposal/treatment



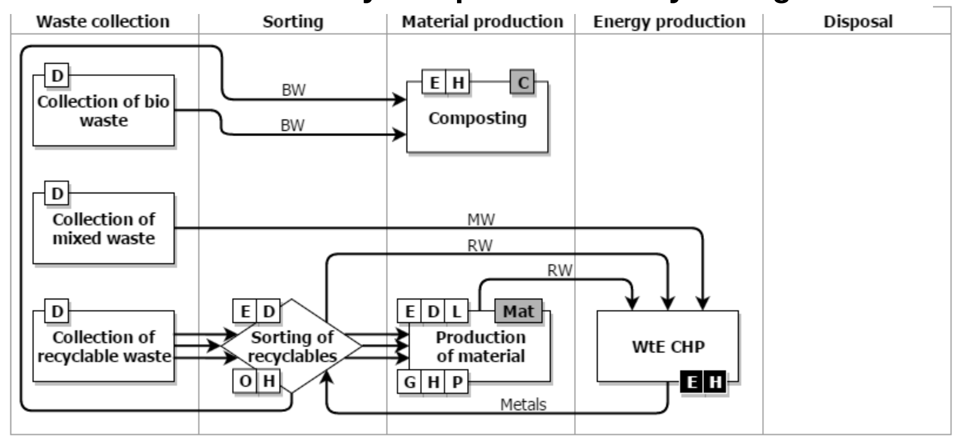
Each stage consists of different technologies represented by UPR data (example of Alu scrap)

Scenarios

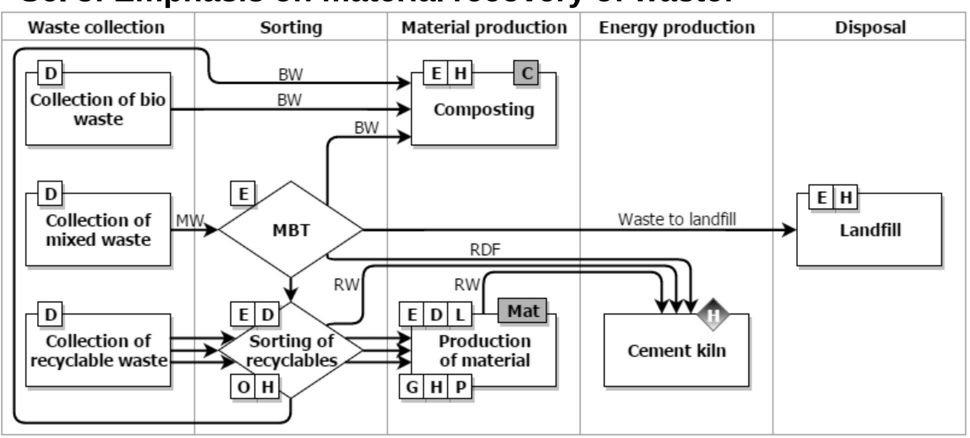
Sc. 1: Today's situation:



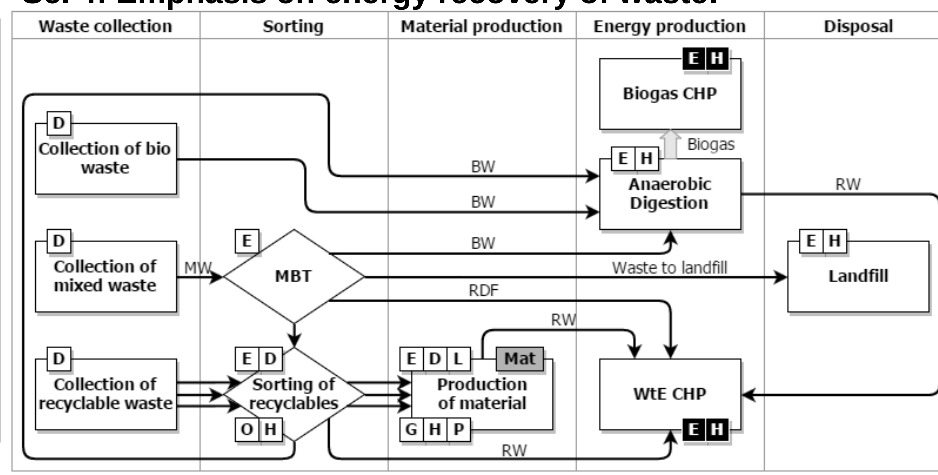
Sc. 2: Planned WMS by WM plan of the City of Zagreb:



Sc. 3: Emphasis on material recovery of waste:



Sc. 4: Emphasis on energy recovery of waste:



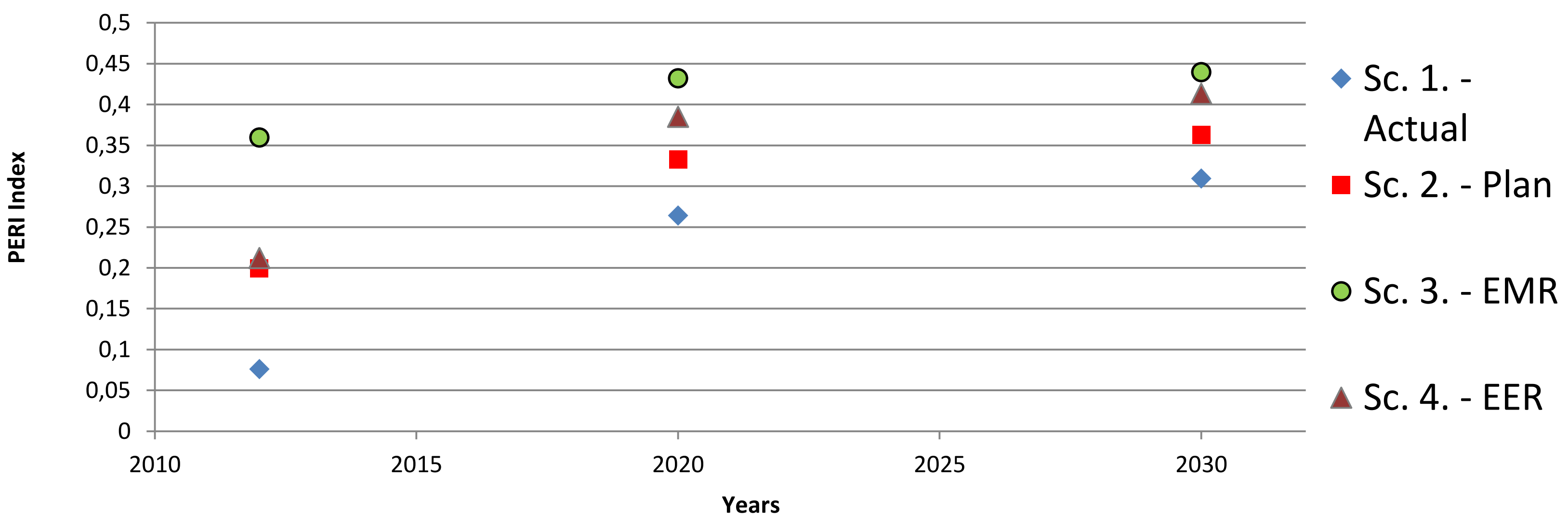
White marks denote input streams that intersects analysis boundary
Black marks denote output streams that intersects analysis boundary
Product flow that intersects analysis boundary – grey mark

Results

PERI index

- Comprehensive screening indicator for comparison of sustainability of different WM solutions
- Calculated by dividing resulting **primary energy return** with **primary energy** used **for production of discarded materials** which entered observed WMS.

$$PERI = \frac{PER}{\sum_{i=1}^{n}(W_i \times CED_i)}$$

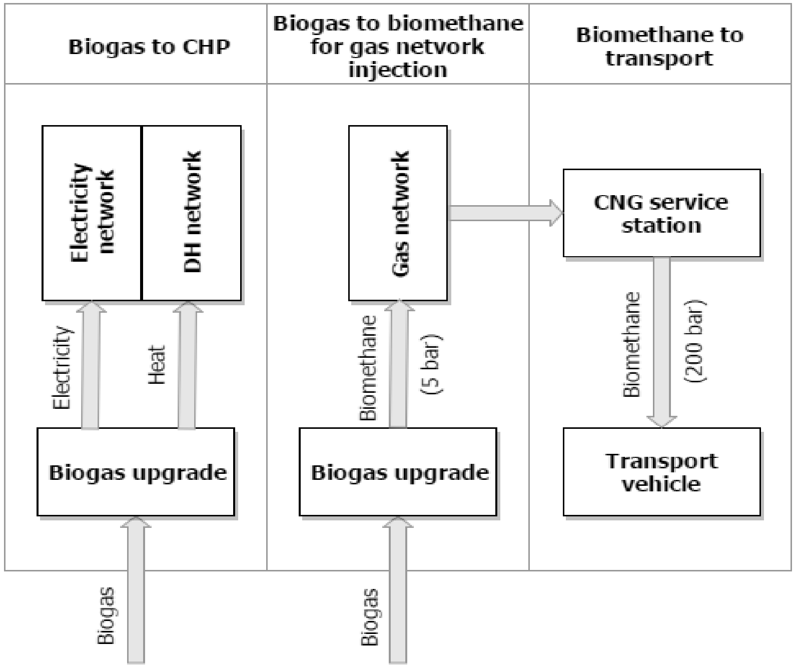


Closing the loop - More Scenarios

- To <u>what extent</u> can the "**closing the loop**" of the waste disposal and recovery system from the energy side be achieved.
- This is done by analysing the <u>degree</u> to which <u>energy</u> generated <u>from</u> <u>waste</u> can <u>satisfy waste</u> management and recovery systems energy needs (energy consumption/generation of <u>collection</u>, <u>sorting</u>, <u>transport</u>, <u>material production (recycling)</u>, <u>energy recovery/transformation</u> and final disposal stages were tracked separately from material recovery) at the local and wider level.

Energy and energy carriers produced from waste and waste materials are a part of urban energy systems:

- DH, electricity, natural gas and also transport system.
- replace other energy carriers produced from other primary fuels which lead to partial fuel shift

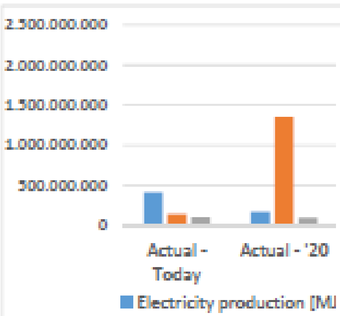


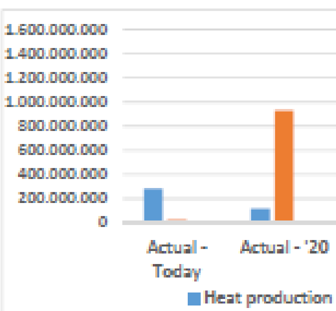
- Three alternative biogas transformations were analysed

Results

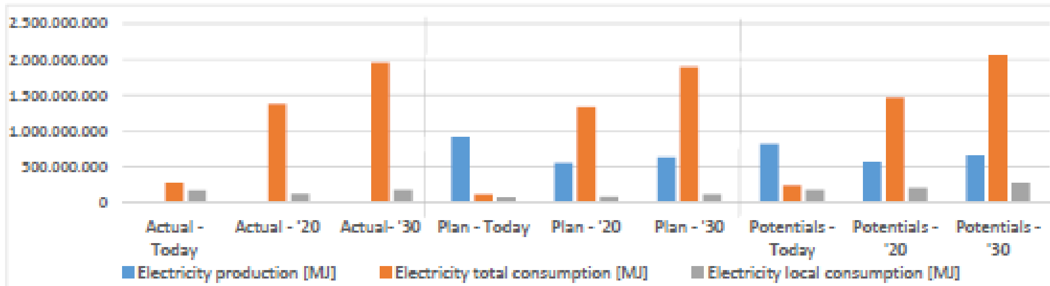
RESULTS – Consumption coverage

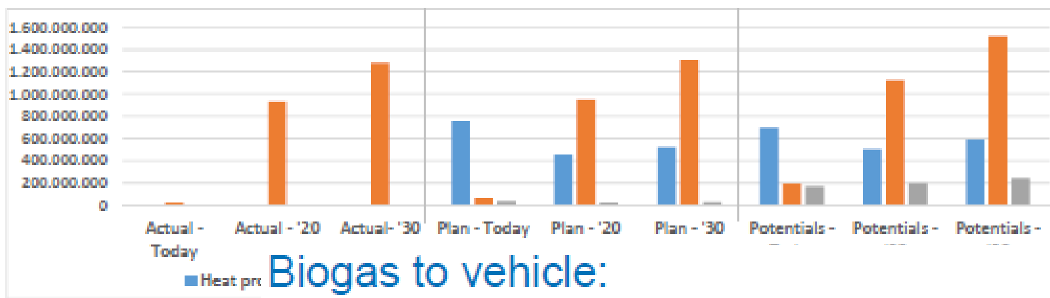
Biogas to CHP:

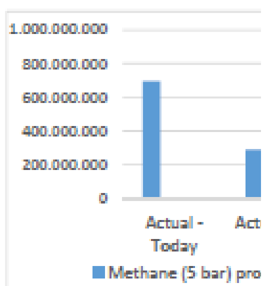




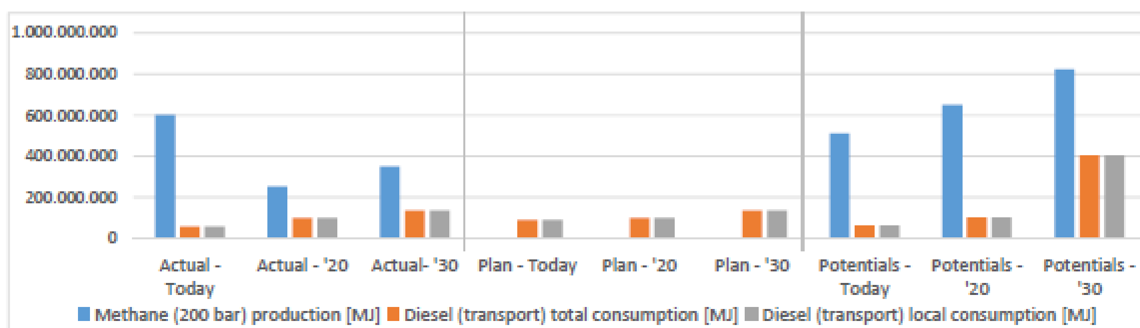
Biogas to grid:







Biogas to vehicle:

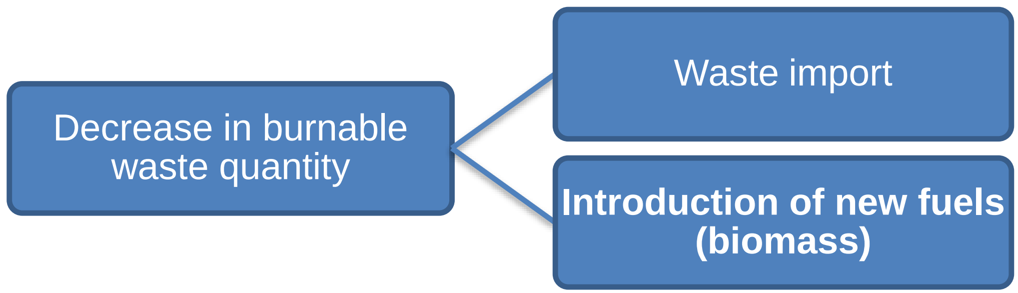


Energy from waste

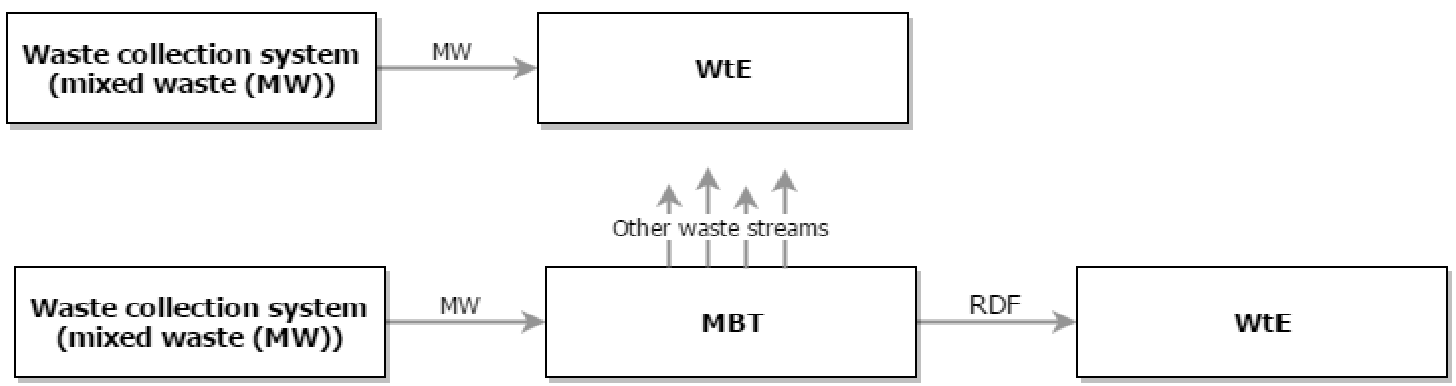
- The share of mixed waste as fuel for waste-to-energy (mass burn) generation systems will decrease due to the obligation of separate collection and more ambitious EU targets in terms of recycling.
- The capacity of WtEs in the EU has so far been steadily increasing.
- EEA data show that there is currently no overcapacity in waste incinerators in the EU although there is an uneven distribution by Member States.
- Significant cross-border traffic of waste (mostly RDF).
- Public funding should not be used for creating excess capacity of incinerators for waste that can be otherwise recycling.
- For these reasons, member states are advised to gradually abolish public support for energy recovery of mixed waste. (this does not mean for RDF, SRF).

More Scenarios - Economic sustainability

- Quantity of residual waste decreases => Economic viability?
- Solving the waste management problem => Capacity of WtE plant

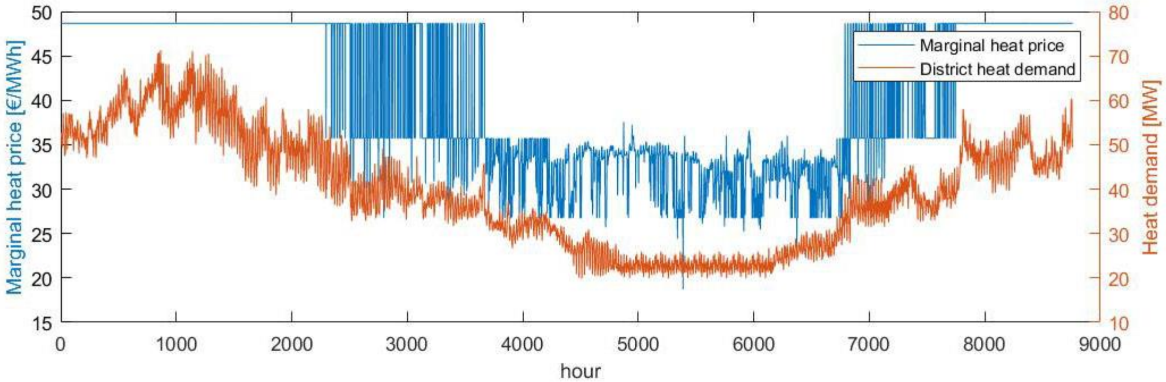


- Two cases were analysed:



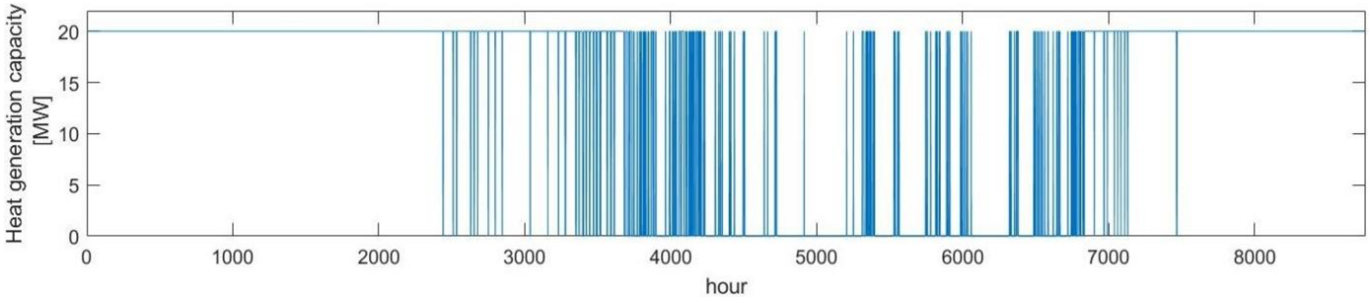
More Scenarios - Economic sustainability

- Sønderborg – Two energy markets
  - Heat market simulated in Matlab and power in EnergyPLAN
  - Heat market was assumed to operate after power market
  - Marginal heat prices and DH demand:



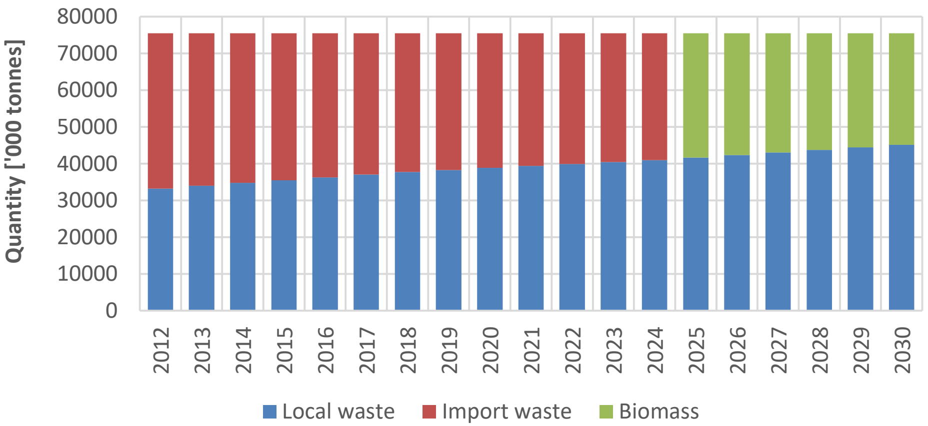
- During the time of the high demand - constant operation
- Lower demand – not constant operation due to large generation of plants with lower marginal cost or due conditions on power market very dependent on the achieved power price on the el-spot market.
- Dispatching of the WtE plant on the heat market:

  - During the time of high demand the heat prices were high
  - Due to the marginal heat day-ahead market, the WtE plant was not dispatched during all the hours of the year on the heat day ahead market.
    - Needed higher gate fee to recover investments and running costs

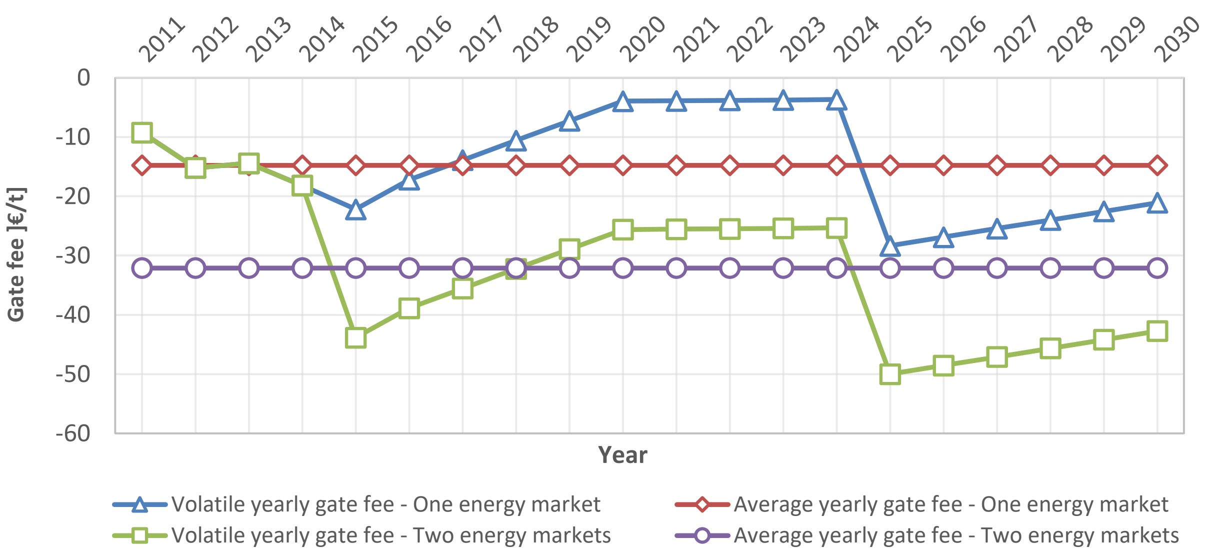


More Scenarios - Economic sustainability

- Sønderborg – One energy market
  - Quantity of waste increases
    - Socio - economic movements
  - Waste compensation with biomass



  - Gate fee volatility:

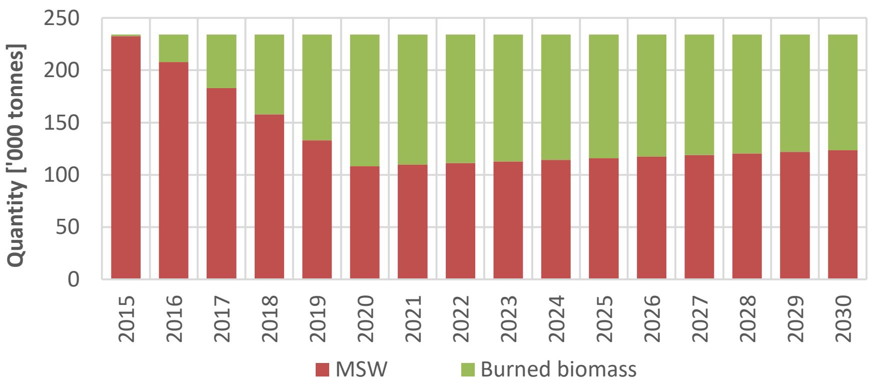


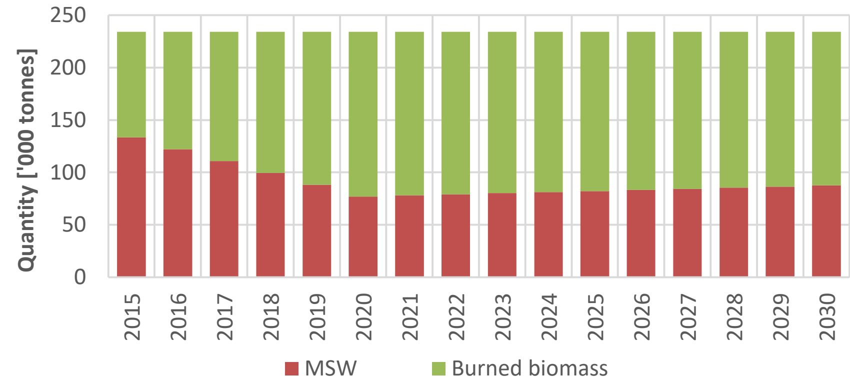
- One energy market:
  - Average: 14.8 €/t
  - Volatile: 9.2 to 28,34 €/t
- Two energy markets:
  - Average: 32.1 €/t
  - Volatile: 9.2 to 49,99 €/t

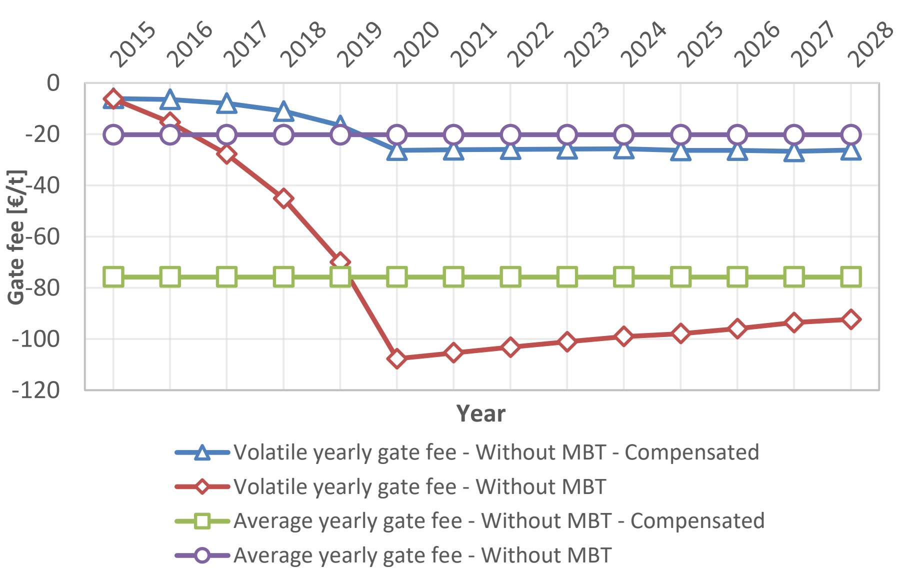
Tomić, T., Dominković, D.F., Pfeifer, A., Schneider, D.R., Pedersen, A.S., Duić, N. Waste to energy plant operation under the influence of market and legislation conditioned changes. Energy. 137, 1119-1129 (2017).

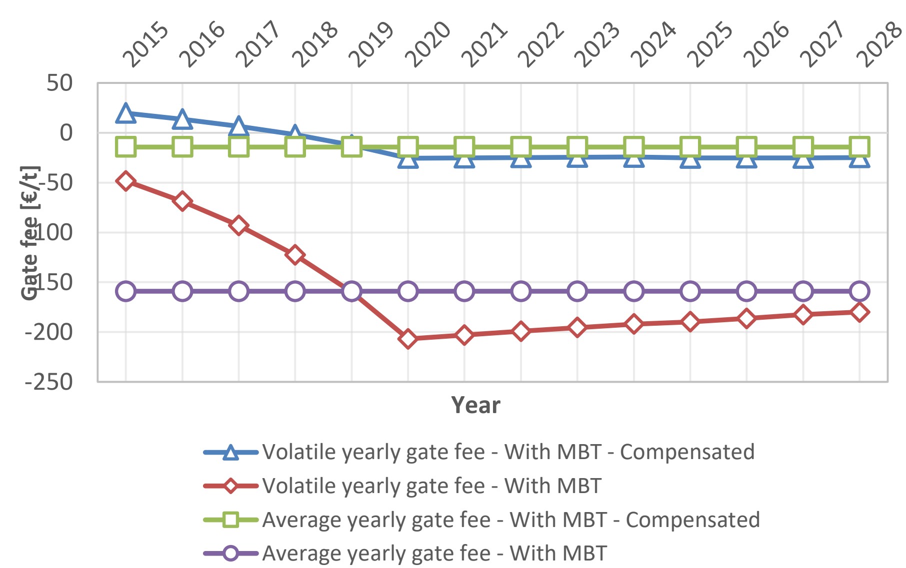
More Scenarios - Economic sustainability

- Zagreb – Without and with MBT:





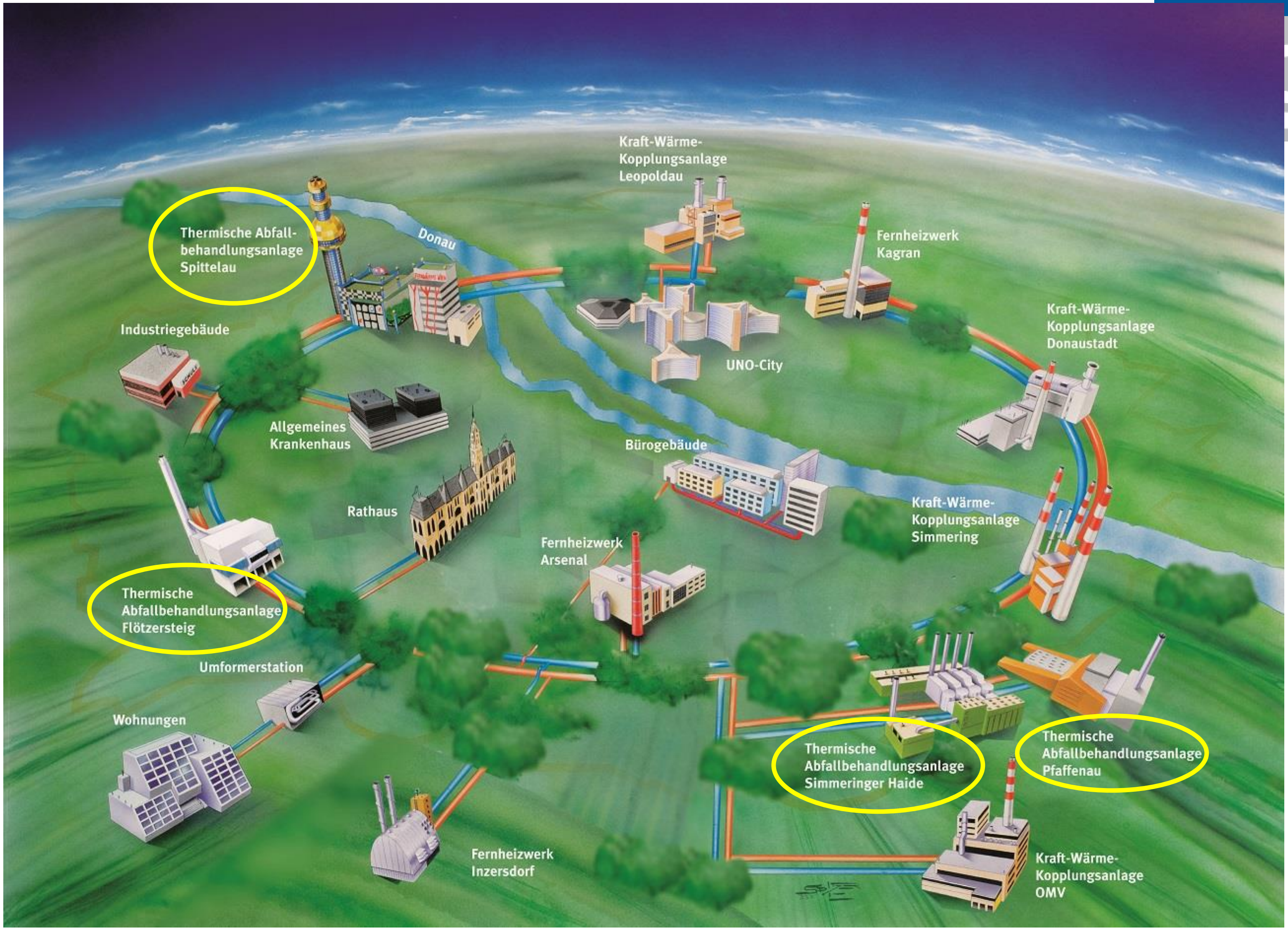




Tomić, T., Dominković, D.F., Pfeifer, A., Schneider, D.R., Pedersen, A.S., Duić, N. Waste to energy plant operation under the influence of market and legislation conditioned changes. Energy. 137, 1119-1129 (2017).

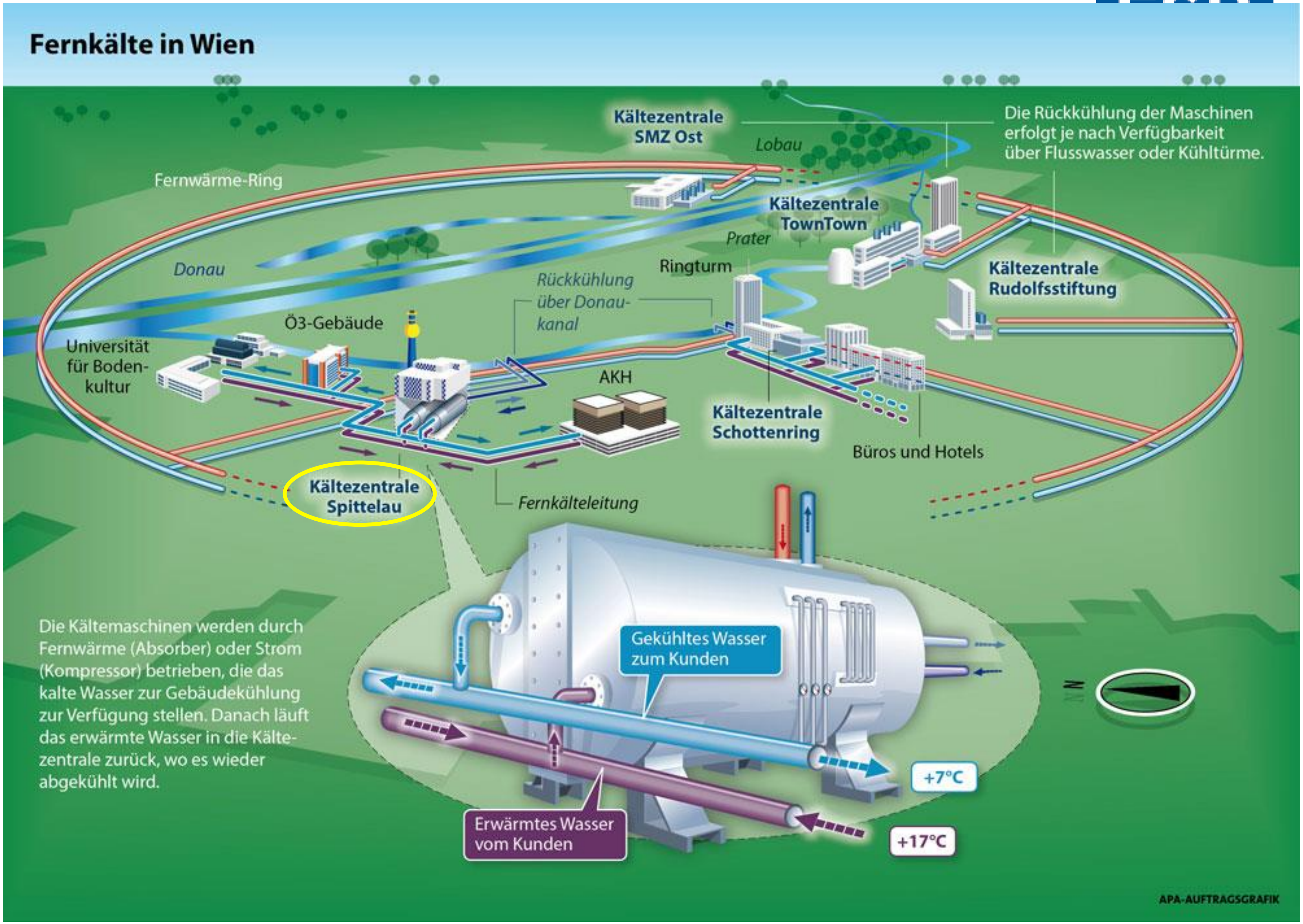
Energy from waste

- Energy from waste is still heavily used in Europe, especially in the production of heat energy for district heating and process needs:
- At present, **50 TWh** per year of heat is used with estimated potential to 2050 that is four times bigger (HRE, 2013).
- Some of the European cities **more than 50% of their district heating** energy obtain from **waste**, which makes this fuel a local resource, reducing the EU's dependence on imported fossil fuels. (Figure H1)
- Often the **cost of heat** produced **from waste** is the lowest of all sources used today for the production of (**thermal**) energy (UNEP, 2015). (Figure H2)
- Of course here are not taken into account the external costs of the environment but only the levelized cost of energy production, whereby the **price of fuel**-waste **is negative**.

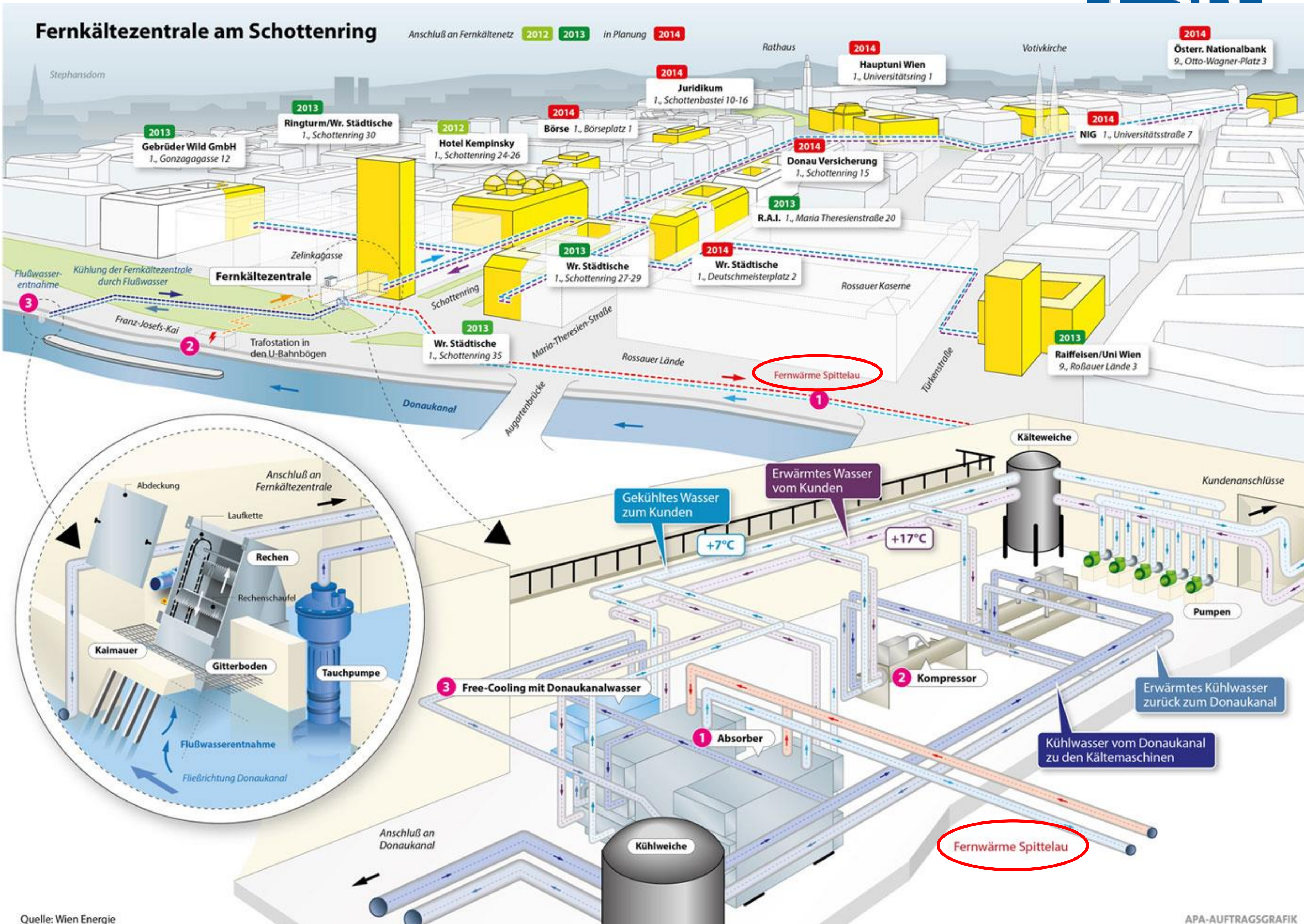


„Vienna ring” of district heating

Source: Spittelau. The thermal waste treatment plant, WIEN ENERGIE Fernwärme

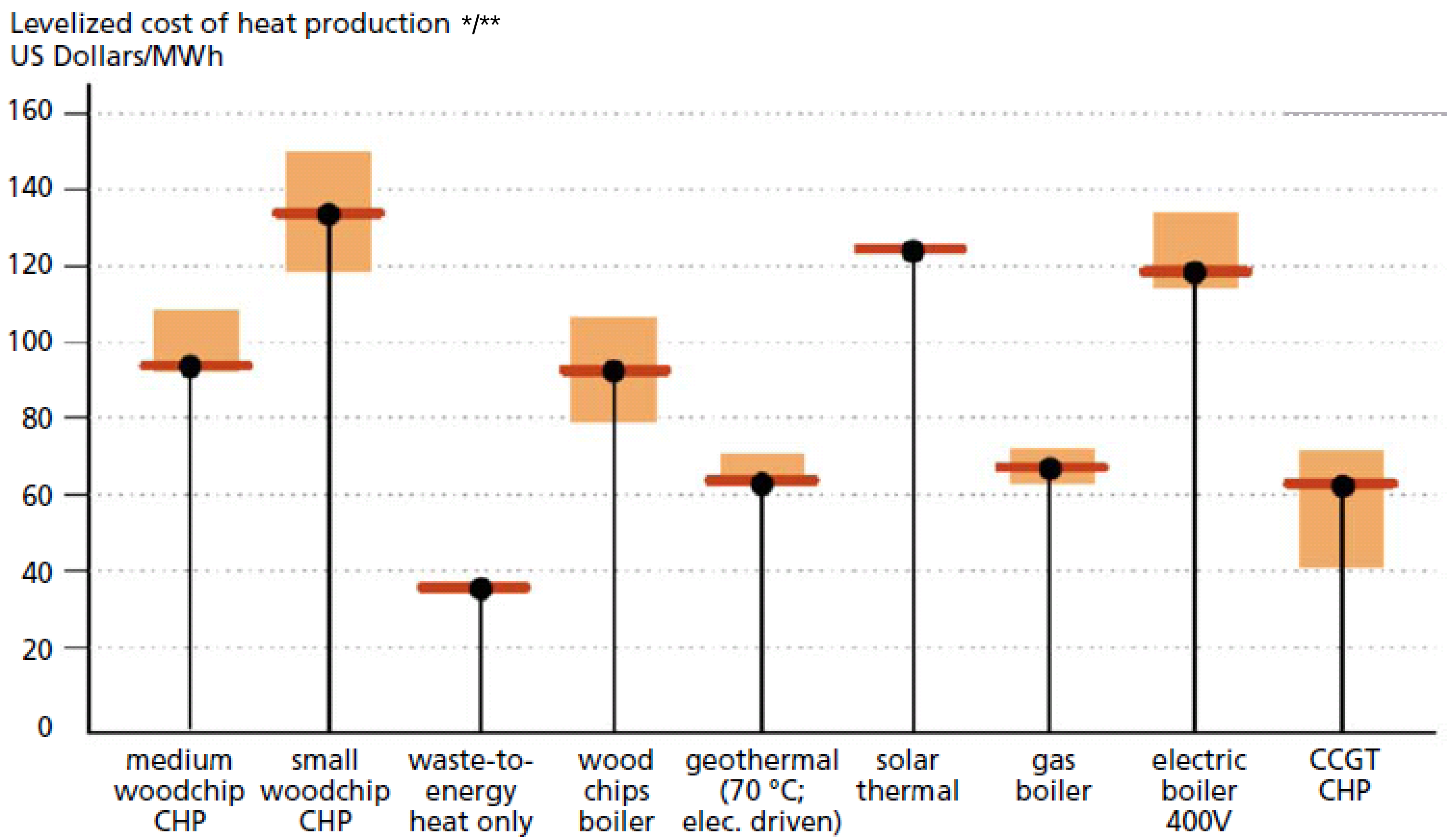


Introducing district cooling to the "Vienna ring"



Introducing district cooling to the "Vienna ring"

Comparison of heat production costs for district heating from different sources

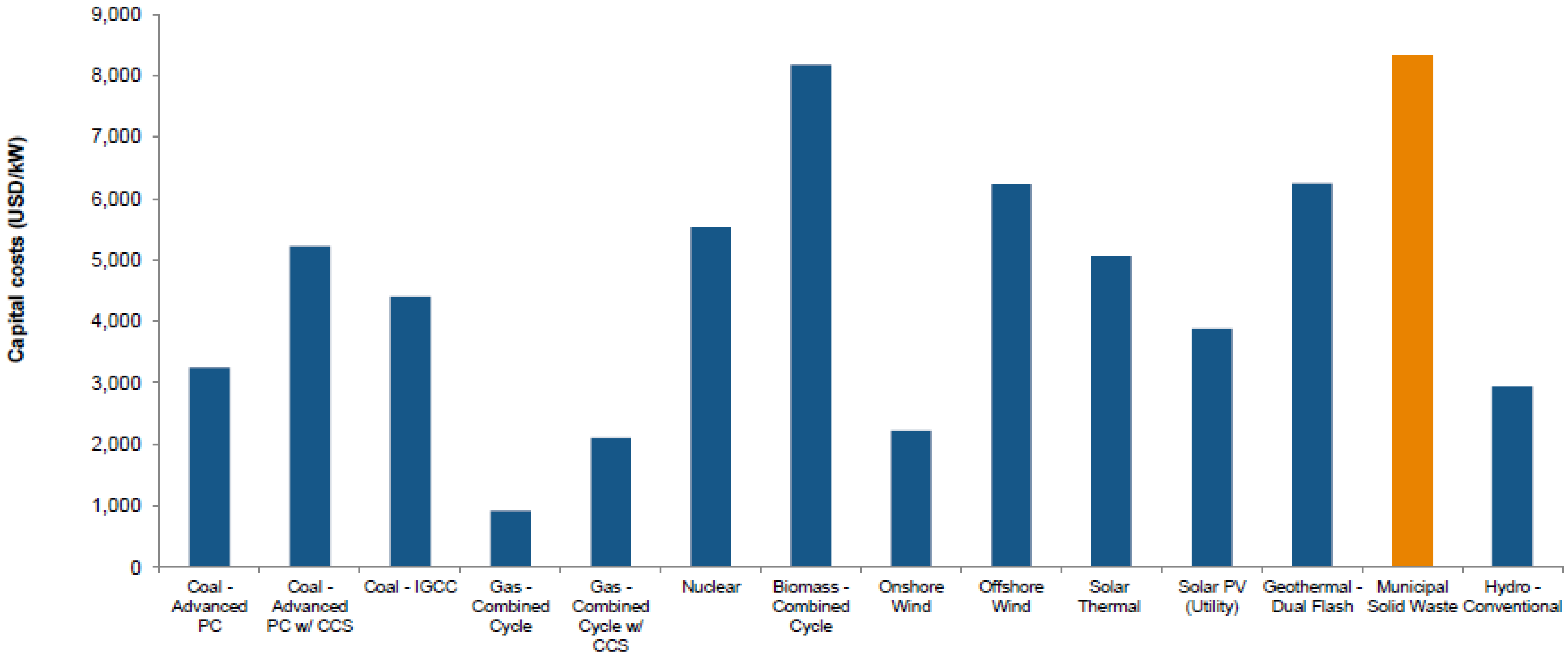


*UNEP has calculated CHP and waste-to-energy heat prices based on the lowest heat price possible based on fuel prices and electricity price received as well as on CAPEX and OPEX payments (additional details on the next slide)

**this cost does not take into account the external costs and benefits for environment

Source: UNEP – District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable, 2015: http://unep.org/energy/portals/50177/DES_District_Energy_Report_full_02_d.pdf

Capital cost estimates for utility scale **power** generation plants (electricity) in the United States



Source: EIA (2013)

- In comparison of capital costs (USD/kW) WtE shows the highest cost

Energy from waste

- There is potential for **improving energy efficiency** in energy recovery in EU and it is estimated that the amount of energy recovered from the same amounts of waste (incinerated today) could be **increased by 29%**, to 872 PJ/yr, if the proven techniques and support measures are properly implemented.
- **Europe** is the largest market for WtE technologies, accounting for **47.6%** of total market revenue in 2013.
- The Asia-Pacific market is dominated by **Japan**, which uses up to **60%** of its solid waste for incineration.
- However, the fastest market growth has been witnessed **in China**, which has more than doubled its WtE capacity in the period 2011-2015.

Energy from waste in China

- Waste is a subject of growing concern in China, as is the case in many emerging economies.
- **China** generates about **300 million** tonnes of **MSW** annually, and this figure is expected to exceed **500 million** t/a by 2025[10].
- Simple landfilling of waste is leading to secondary pollution – either through methane leakage or by the contamination of groundwater.
- China has made an effort to utilise WtE as a part of its waste management strategy.
- However, MSW in China has a high proportion of food waste, resulting in high moisture content and a relatively low net calorific value (**3-5 MJ/kg** on average, compared to **8-11 MJ/kg** in Europe).
- The waste also has seasonal variations, giving it complicated heating properties.

[10]Coolsweep, 2014, Global analysis of the waste-to-energy field

Energy from waste in China

Fuel	Calorific Value (MJ/kg)
Natural gas	36-50
Diesel	46
Black coal, various types	29-32.7
Lignite briquettes	21
Refuse derived fuel, in Germany	13-23
Wood	15
Crude lignite	10
Residual waste, unsorted, in Austria	8-12
Residual waste, unsorted, in China	3.5-5

Source: Ecoprog (2015)

- Incineration technology originated in Europe is not well suited to treat waste with the mentioned properties.
- Therefore, in China they developed new incineration plants based on circulating fluidised bed (CFB) technology to recover energy from its waste.

Energy from waste in China

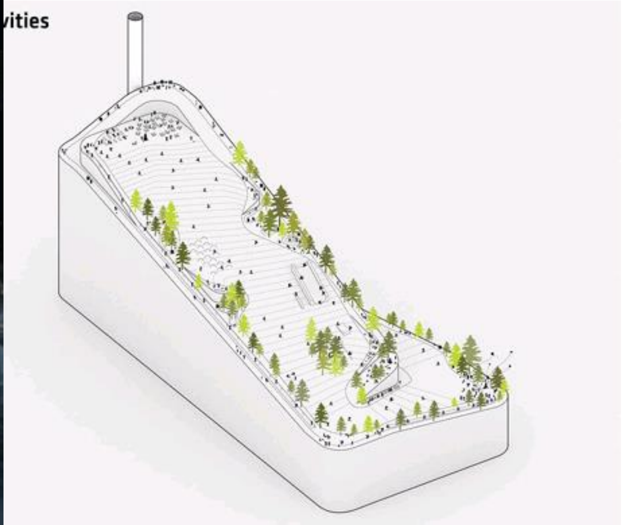
- CFB technology is proven to be better suited for high moisture content waste, hence making it potentially attractive for implementation in other emerging economies.
- Dioxin levels reported from these new plants are lower than EU standards.
- The plants are also capable of processing sewage sludge and other waste sludges, of which China produces **40 million tonnes** a year, once the waste is pre-dried.
- Ongoing research is targeted towards reducing the amount of sewage-sludge ash produced from incineration, and integrating the pre-dried sludge with MSW to produce more fuel for the plant.
- There are currently **28 CFB WtE plants** in operation in China, the largest of which was built in 2012 and processes 800 tonnes of waste per day[11]

[11] Zhejiang University, 2015

Process Parameters	Values
R1 value	0,8
Waste capacity (MCR)	5616 t/day
Heat value, lower (MCR)	8792 KJ/kg
Steam temperature	450 °C
Steam pressure	65 bar(a)
Gross electric output	165 MW
Boiler outlet flue gas temperature	180-200 °C
Feed water temperature	130 °C

Shenzhen East Waste-to-Energy Plant (China)

Capacity: **5,000 tonnes** of waste **per day** (corresponding to one third of the waste generated by Shenzhen's 20 million inhabitants)



Source: Dezeen Magazine, http://www.dezeen.com/

ARC WtE Plant, Copenhagen (Denmark)

- Provide electricity for 62,500 homes and heat up to 160,000 homes throughout the district through cogeneration
- Capacity: **400.000 t/y** waste
- Investment: 470 million EUR, commercial operation in 2018.
- Ski slope on the roof and climbing wall on the side

Plant design data (per line)		
Process parameters	**Guaranteed Values***	**Units**
Waste capacity	35	t/h
Heat value, lower	11.5	MJ/kg
Steam output	141.1	t/h
Steam temperature	440	°C
Steam pressure	70	bar
Boiler outlet flue gas temp.	160	°C
Feed water temperature	130	°C

Flue gas values: After cleaning	Guaranteed Values*	Units
NOx**	15	mg/ Nm³
CO***	50	mg/ Nm³
NH3**	3	mg/ Nm³
TOC	5	mg/ Nm³

* All values refer to 11% O2 dry gas
** 24-hour average
*** Half-hour average

Source: Babcock & Wilcox Vølund A/S

Energy from waste

- **Sludge** arising from the wastewater treatment processes sometimes contains toxic as well as pathogenic substances (heavy metals, inorganic and organic pollutants, pathogens, and other chemical compounds such as drugs, byproducts of detergents, etc.) and often not suitable for agricultural food production.
- Organic compounds in sludge represent significant energy potential.
- In Croatia there are two most common modes of energy recovery sludge applicable:
  - **digestion of a raw sludge** with biogas production (e.g. at the site of the wastewater treatment plant) and
  - **thermal recovery** with energy recovery (incineration in WtE plants or co-incineration in thermal power plants and rotary kiln of cement plants).

Fuels from waste

- **Waste edible oils and fats**; there is room to improve the efficiency of collection and processing systems to produce products such as **biodiesel** and **hydrogenated vegetable oils**.
- The resulting biofuel can be directly used **in traffic** including the use of hydrogenated vegetable oils **in aviation**.
- Conversion of **plastic** (non-recyclable/polluted) **waste into fuel** (e.g. Pyrolysis/Catalytic degradation/Gasification, De-polymerization, etc.) to Diesel (and similar to diesel), heating oil, chemicals, monomers, etc.
- **Wood waste** today is a common fuel for incineration.
- Circular Economy Action Plan emphasizes multiple uses of renewable sources such as wood in several cycles of reuse and recycling whenever possible.
- If re-use or recycling is not possible, **exploitation** of wood waste **for energy** is a desirable way of replacing fossil fuels and avoiding disposal at landfills. -- also can be used for production of for biofuels (through fermentation).
- There is a number of other waste materials that can be energetically recovered (e.g. from fruit and vegetable production, such as olive and grape pomace, tomato waste). - **in peri-urban** belt

Klemetsrudanlegget AS, Oslo (Norway)

- **First CO_2 negative carbon capture from waste** (CCR/CCS)
- CO_2 post combustion can be captured
- Norway's **largest** WtE plant
- Capacity: **350,000 t/y** (40 t/h)
- Norwegian and international waste
- Direct incineration of special waste
- Electricity production: 104 GWh (2016)
- Heat production: 806 GWh (2016)
- Large investments to increase production, 2014-2017

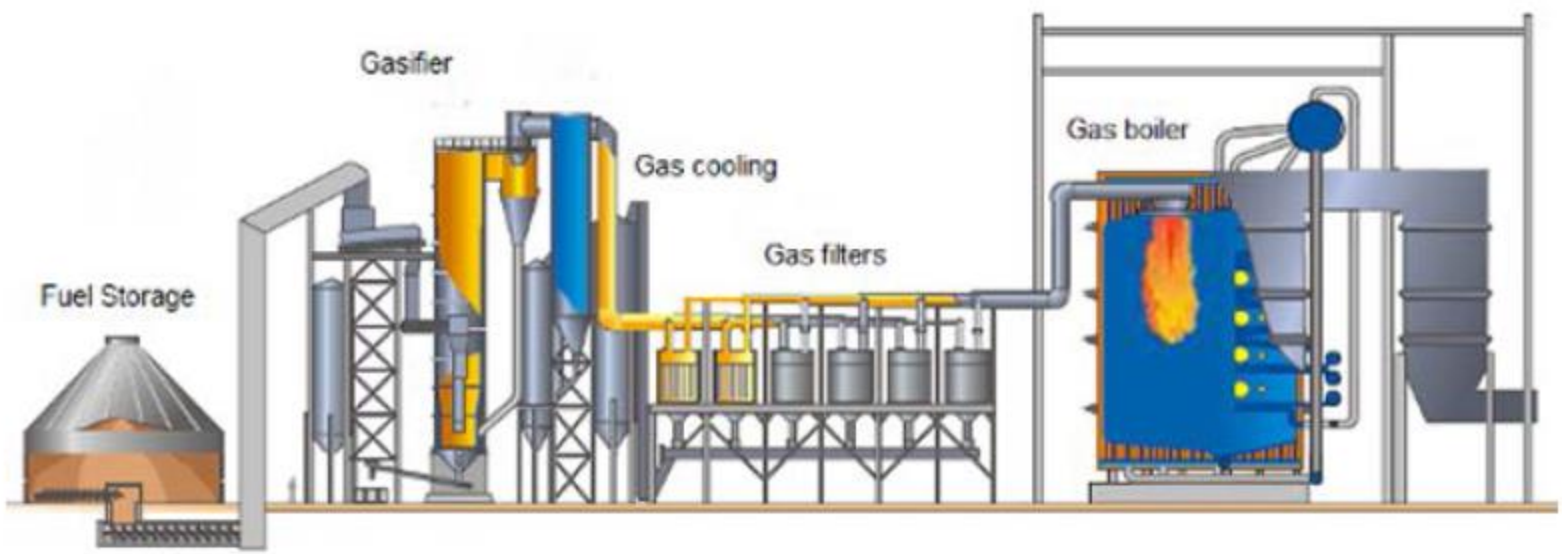
This WtE is an integral part of Oslo's cycle based waste system

- Extensive source sorting (City of Oslo)
- Two optical sorting plants (CoO)
- One biogas plant (CoO)
- Two WtE plants (CoO /KEA AS)
- District heating system (Hafslund)

- Tests show stabile cleaning of CO_2 with **90% capture**
- Strong similarities with flue gas from coal - transfer of experience
- Removes **both fossil and biological CO_2** (60% bio CCS)
- About **400,000 tons CO_2** yearly from KEA, potential app. 600,000 t
- Another 150,000 tons CO_2 from plants at Haraldrud

Lahti Energy's Kymijärvi II (Finland)

- **First gasification** power plant in the world to efficiently generate electricity and district heat from Solid Recovered Fuel (**SRF**). Investment: 157 million EUR.
- In operation since 2012, good track record.
- Two Metso circulating fluidized bed gasifiers.
- Produces **50 MW** electricity and **90 MW** of heat for district heating.
- Capacity **250,000 t/y** of SRF (CEN/TC 343 SRF standard): shredded, source-separated solid waste mixture of wood, and non-recyclable paper, cardboard and (non PVC) plastic.
- Gas conditioning reduces the potential for boiler tube corrosion which allows for higher steam pressure and temperature (**120 bar** and **540°C** compared to 65 bar and 480°C typically) → improved steam cycle energy efficiency.



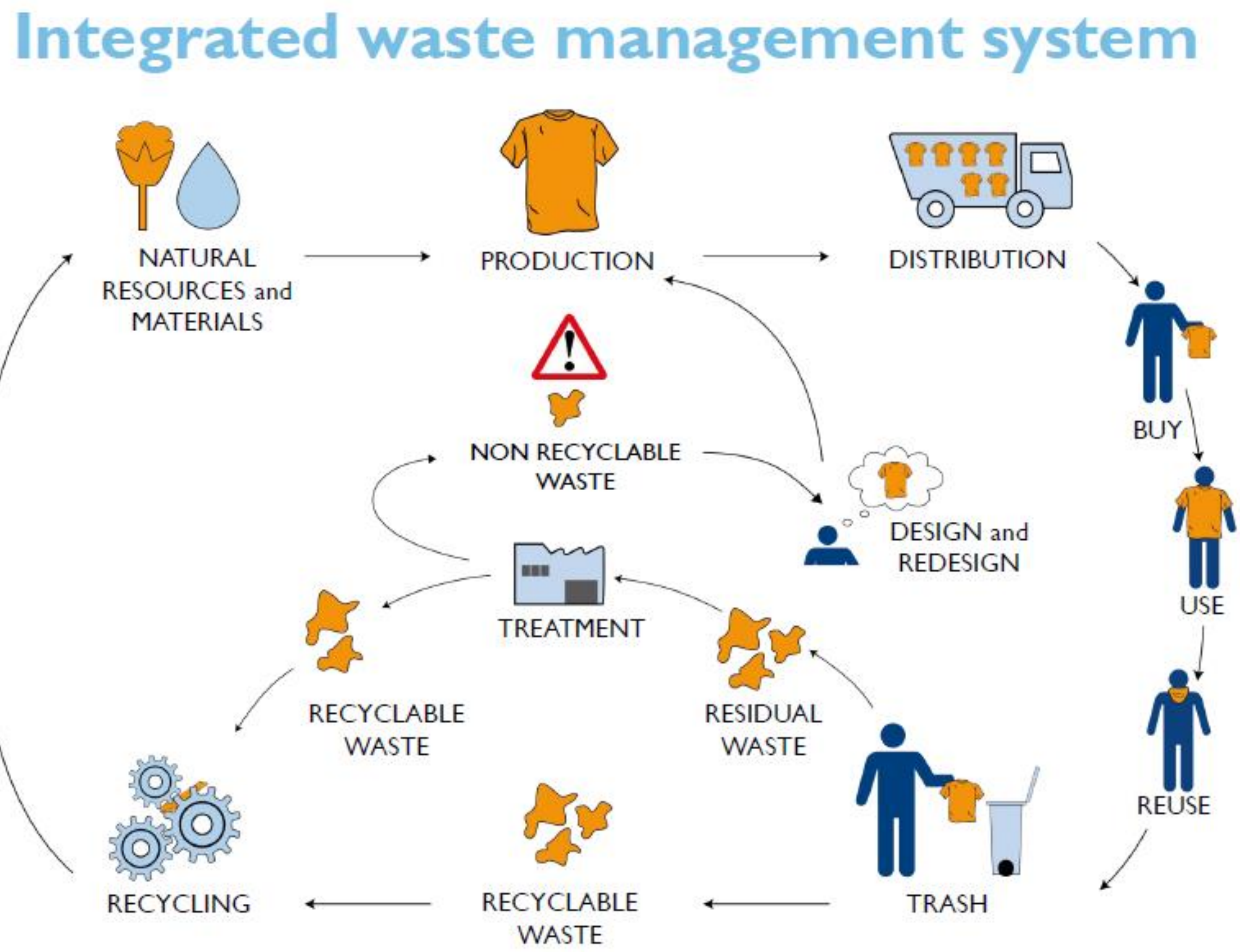
Tees Valley Renewable Energy Facility, TV1 and TV2 (UK)

- **Largest WtE plasma gasification plant**, Teesside, North East England.
- The integrated-gasifier-combined-cycle (IGCC) facility use a single large Westinghouse Plasma oxygen-blown plasma gasifier.
- Capacity of TV1: **350,000 t/a of RDF** (1100 t/d), non-recyclable MSW: pre-processed municipal, commercial and industrial waste.
- Electricity production: **50 MW**.
- The product gas cooled and cleaned to remove particulate matter, HCl and other acid gases, ammonia, sulfur, and mercury. The gas fuels two combustion gas turbine-generators with exhaust heat recovered in a heat recovery steam generator. The steam runs a steam turbine-generator for additional electricity.

Project stopped near completion in 2016!

Source: ALTER NRG

Zero Waste principle – final goal?



The integrated waste management system starts from the design of objects and packaging, in consideration of the entire life cycle, with the goal to be sustainable in all its phases.

Source: http://www.contarina.it/en

Conclusion

- **Energy recovery of waste** can play an important role in transition to a circular economy, provided that the principle of the waste management hierarchy is respected and the decisions taken do not prevent higher levels of **prevention, reuse and recycling**.
- Only that way waste-to-energy will have a synergistic effect on **energy and climate policies**.
- Although data show that there is currently no overcapacity at EU-wide level, it is recommended that the role of incineration of waste, at present the dominant mode of WtE, needs to be redefined in order to ensure an undeterred increase of recycling and re-use rates and to avoid overcapacity in the treatment of residual waste.
- In the future, more attention should be given to the processes in which recycling of materials combines with energy recovery, such as **anaerobic digestion** of biodegradable waste.

"Waste is merely a resource in the wrong place"
(Mahatma Gandhi/ Buckminster Fuller)

Thank you for attention!

1st Latin American sdewes Conference
RIO DE JANEIRO
2018

Prof. dr.sc. Daniel R. Schneider
University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture,
Department of Energy, Power Engineering and Environment
Ivana Lucica 5,
HR-10002 Zagreb, Croatia
e-mail: daniel.schneider@fsb.hr

FSB

Levelized cost of heat production

Note: Centralized plant costs are estimates based on available data and will vary significantly by country. Such variance is caused by (but is not limited to): load factor; local fuel prices currently and in the future; fuel prices at point of consumption (i.e., electricity consumed may have higher price than average annual electricity price); installation and labour costs; capacity of installation; land prices; cost of finance; development costs; any subsidies and tax incentives.

UNEP has calculated CHP and waste-to-energy heat prices based on the lowest heat price possible based on fuel prices and electricity price received (prices detailed below) as well as on CAPEX and OPEX payments.

Waste cost: – US$26/ton (negative).
Wood chips: US$169/ton.
Gas: US$38/MWh.
Electricity price received for CHP/Incinerators: US$102/MWh.
Electricity price for cooling: US$127–US$165/MWh.
Discount rate: 10 per cent.
Waste incinerator load factor: 80 per cent.
All CHP plants load factor: 40 per cent.
District heat gas/electric boiler load factor: 10 per cent.
District heat wood chip boiler load factor: 40 per cent.
Geothermal load factor: 80 per cent

Source: UNEP analysis based on: Pöyry and AECOM, 2009; Swedblom et al., 2014; Danish Energy Agency and Energinet.dk, 2012; Danfoss, 2014; Gudmundsson and Thorsen, 2013; Zabala, 2009; Euroheat & Power, 2008.

Source document:
Source : UNEP – District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable, 2015:
http://unep.org/energy/portals/50177/DES_District_Energy_Report_full_02_d.pdf

Accesed 13.10.2016. at:
http://www.unep.org/newscentre/Default.aspx?DocumentID=2818&ArticleID=11153&l=en