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Session XVII

# Assessing the 3T method as a replacement to R1 formula for measuring the efficiency of waste-to-energy plants

Stergios Vakalis, Konstantinos Moustakas and Maria Loizidou

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# What is “waste-to-energy”

- It is the term that addresses the energy production by means of thermal treatment of waste.
- It primarily refers to combustion of municipal solid waste.
  - Commercial and Industrial waste are also considered
  - Thermal processes like gasification and pyrolysis are becoming more popular.
- The term should not ne confused with “energy from waste”, which is a more general term that includes a broader ranger of technological possibilities.

# Waste-to-energy data

- In 2014 more than 88 million tons of waste were thermally treated in waste-to-energy plants (Ella Stengler - C.E.W.E.P., 2016)
- For the production of:
  - 38 billion KWh electricity
  - 88 billion KWh heat
- After thermal treatment there are solid residues of approximately 30 % by weight and 10 % by volume that are primarily disposed to landfills.

# The dual nature of waste-to-energy

- Historically, all the “Waste Framework Directives” that have been issued by the European Commission, separate the waste management strategies into Recovery Operations and Disposal Operations.
- Waste-to-energy technologies have the inherent problem that they do not belong entirely on the one category or the other.
  - Directive 2008/98/EU of the European parliament and of the council of 19 November 2008 on waste
  - waste is used principally as a fuel for energy generation and thus they belong to category 1 of the Recovery Operations (ANNEX I), i.e. R 1.
  - the residues of the treatment are landfilled on land and thus they belong to category 10 of the Disposal Operations (ANNEX II), i.e. D 10.

# Issues that derive from the “duality”

- The issue of “duality” has been of high importance because each waste-to-energy facility could be considered an energy production or a disposal facility according to the category that is assigned.

- This influences the level of the gates fees but also the overall taxation of the waste-to-energy facilities.

# Introduction of the R1 formula

- In order to address this issue European Commission integrated the R1 formula (that was developed by Dieter Reimann) in the second revision of the Waste Framework Directive of 2008.

- $R1 = \frac{(\mathrm{Ep}-(\mathrm{Ef}+\mathrm{Ei})}{0.97 * (\mathrm{Ew}+ \mathrm{Ef})}$

- $R1 = \frac{(\text{Energy produced} - \text{Energy from fuels – Other energy imported})}{0.97 * (\text{Energy of waste input} + \text{Energy from fuels})}$

# Utilization of the R1 formula

- The parameters for each waste-to-energy facility are inserted to the R1 formula and the ones who have values over 0.65 (or 0.6 for older plants) achieve the R1 status.
- It should be denoted that the R1 formula played an important role in assisting the waste-to-energy plants to receive a legal status, especially during a period that the specifics of the waste-to-energy technologies where not fully understood by the lawmakers.
- Therefore, the significance of the R1 formula for the waste-to-energy sector should be stated.
- It must be pointed out that the R1 formula does not claim to be a pure energy efficiency formula but a “utilization efficiency” formula.

In 1 ton of bottom ash:

M. Castaldi & N. Themelis (2010). The Case for Increasing the Global Capacity for Waste to Energy (WTE). Waste and Biomass Valor 1:91–105.

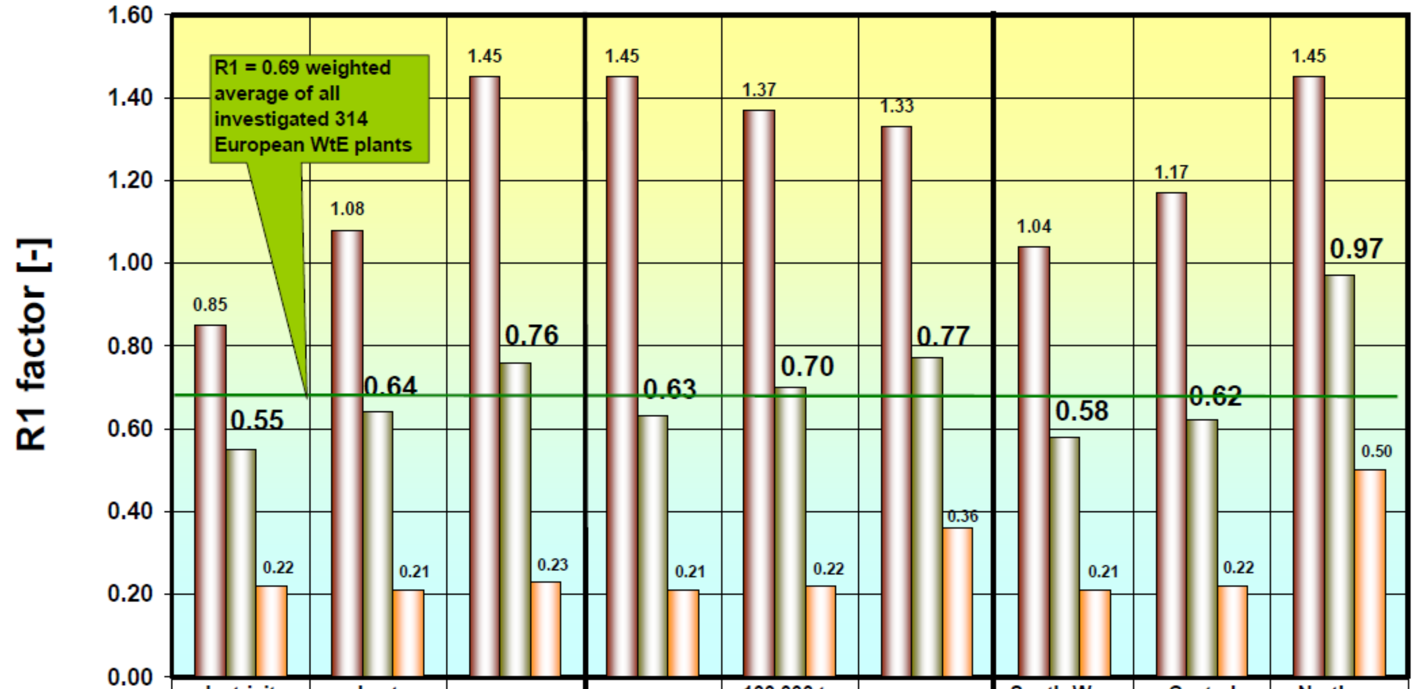
- The quality of secondary aluminium is affected by its oxidation level (Astrup & Grosso, 2016)

- Waste-to-energy plants are not only energy production units but also metal recovery facilities.

# Weighted significance of CHP

$$R1 = \frac{(Ep - (Ef + Ei))}{0.97 * (Ew + Ef)}$$

2.6 for electricity
1.1 for heat
1 for other fuels




| | electricity production only | heat production only | CHP production | < 100,000 Mg/year | 100,000 to 250,000 Mg/year | > 250,000 Mg/year | South-Western Europe HDD* < 2150 | Central Europe HDD* 2150 - 3350 | Northern Europe HDD* > 3350 |
|---|---|---|---|---|---|---|---|---|---|
| R1 max [-] | 0.85 | 1.08 | 1.45 | 1.45 | 1.37 | 1.33 | 1.04 | 1.17 | 1.45 |
| R1 weight. average [-] | 0.55 | 0.64 | 0.76 | 0.63 | 0.70 | 0.77 | 0.58 | 0.62 | 0.97 |
| R1 min [-] | 0.22 | 0.21 | 0.23 | 0.21 | 0.22 | 0.36 | 0.21 | 0.22 | 0.50 |

* HDD = Hearing Degree Day

Reimann 2012

Is there a possible alternative?

Which parameters do we need?

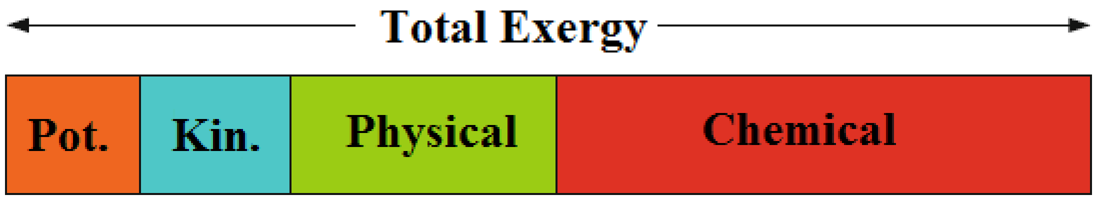
# Combined Heat and Power efficiency

- CHP efficiency is the first basic parameter that we should take tinto consideration
- The case of heat vs electricity
  - Physical exergy instead of R1 factors ( 2.6 & 1.1)
- Chemical exergy of gaseous fuels, bio-oil etc.
- Chemical exergy of metals

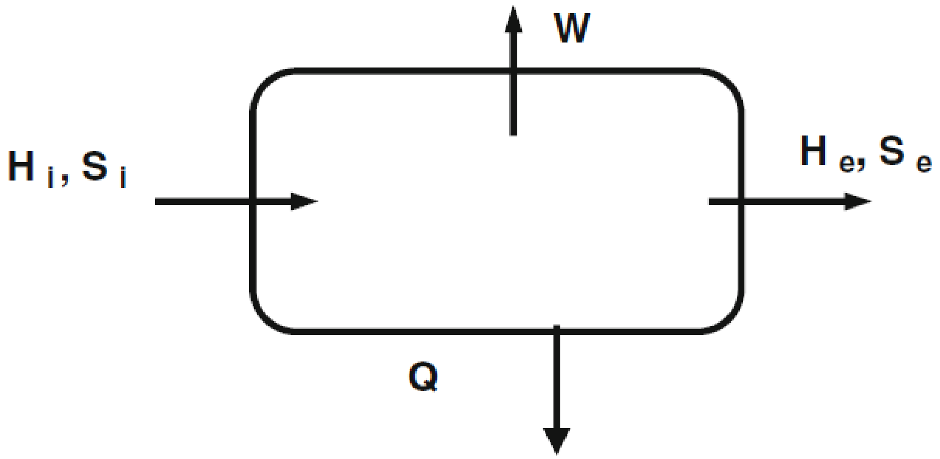
# The concept of exergy

Measure of the maximum amount of work that can theoretically be obtained by bringing a resource into equilibrium with its surroundings through a reversible process.

$[B = h - ho - To ( s - so)]$




- A linear combination of the entropy and energy balances
- Reflects the 'quality' of energy



# Exergy of different streams

| Physical Exergy | Chemical Exergy | |
|---|---|---|
| CHP | Products (e.g. Gaseous fuels) | Residue metals |

**CHP**

- Conversion of electricity into work on a 1:1 basis

Exergy of heat depends on temperature and pressure

e.g. Steam with 100 MJ
(P: 1 atm, T: 450 K) → 33.3 MJ
(P: 1 atm, T: 550 K) → 45.5 MJ
(P: 1 atm, T: 650 K) → 63.9 MJ

**Products (e.g. Gaseous fuels)**

| Sustance | Chemical exergy |
|---|---|
| Carbon Monoxide | 275 kJ/mol |
| Hydrogen | 236 kJ/mol |
| Methane | 831 kJ/mol |
| Carbon (graphite) | 410 kJ/mol |
| Carbon Dioxide | 20 kJ/mol |

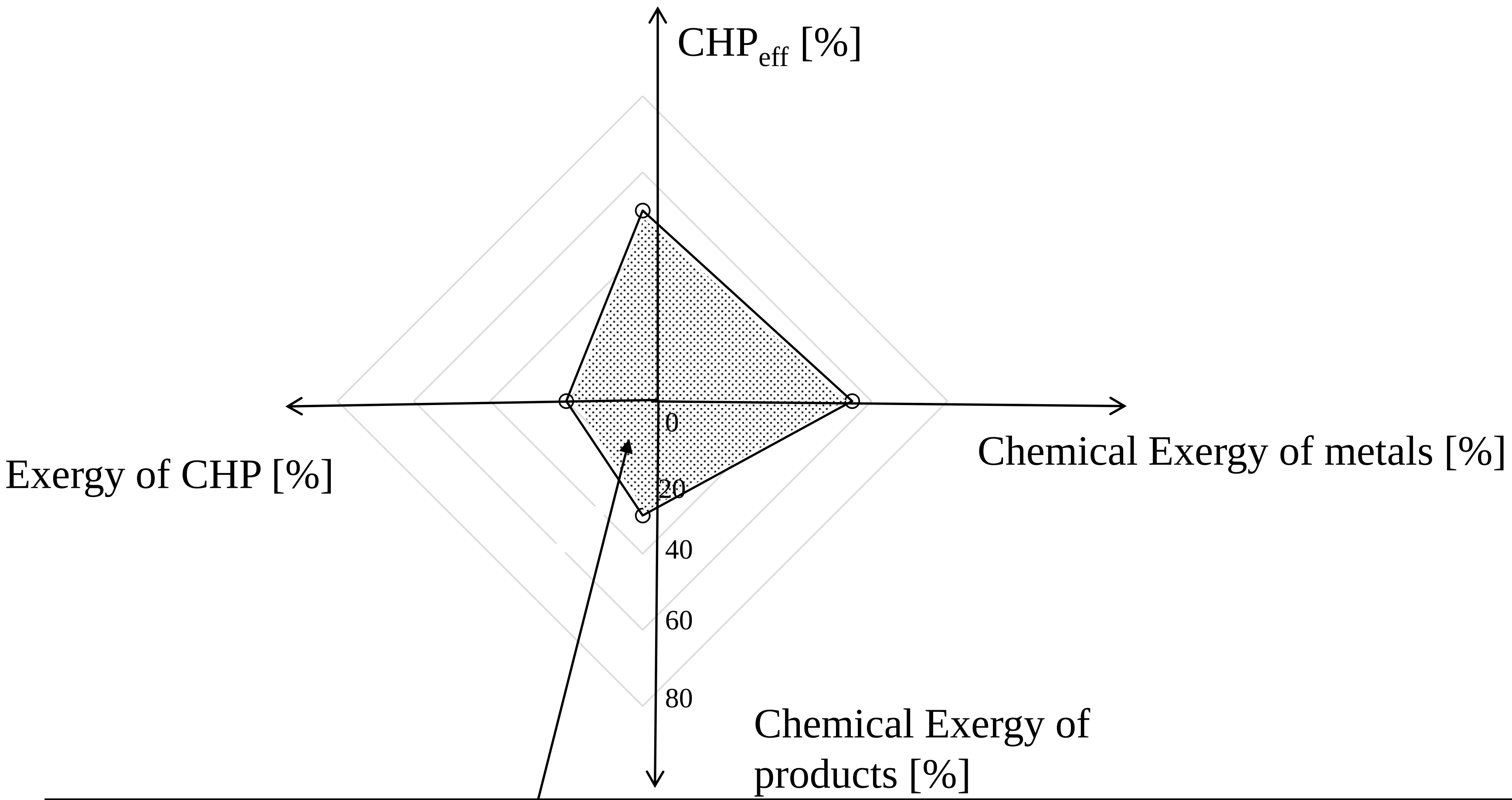
**Residue metals**

| Substance | Chemical Exergy |
|---|---|
| Ni (II) | 232.7 (kJ $mol^{-1}$) |
| Zn (II) | 339.2 (kJ $mol^{-1}$) |
| Cu (II) | 134.2 (kJ $mol^{-1}$) |
| Pb (II) | 232.8 (kJ $mol^{-1}$) |

# Selected parameters

- CHP
- Exergy of CHP
- Exergy of Products
- Exergy of Metals

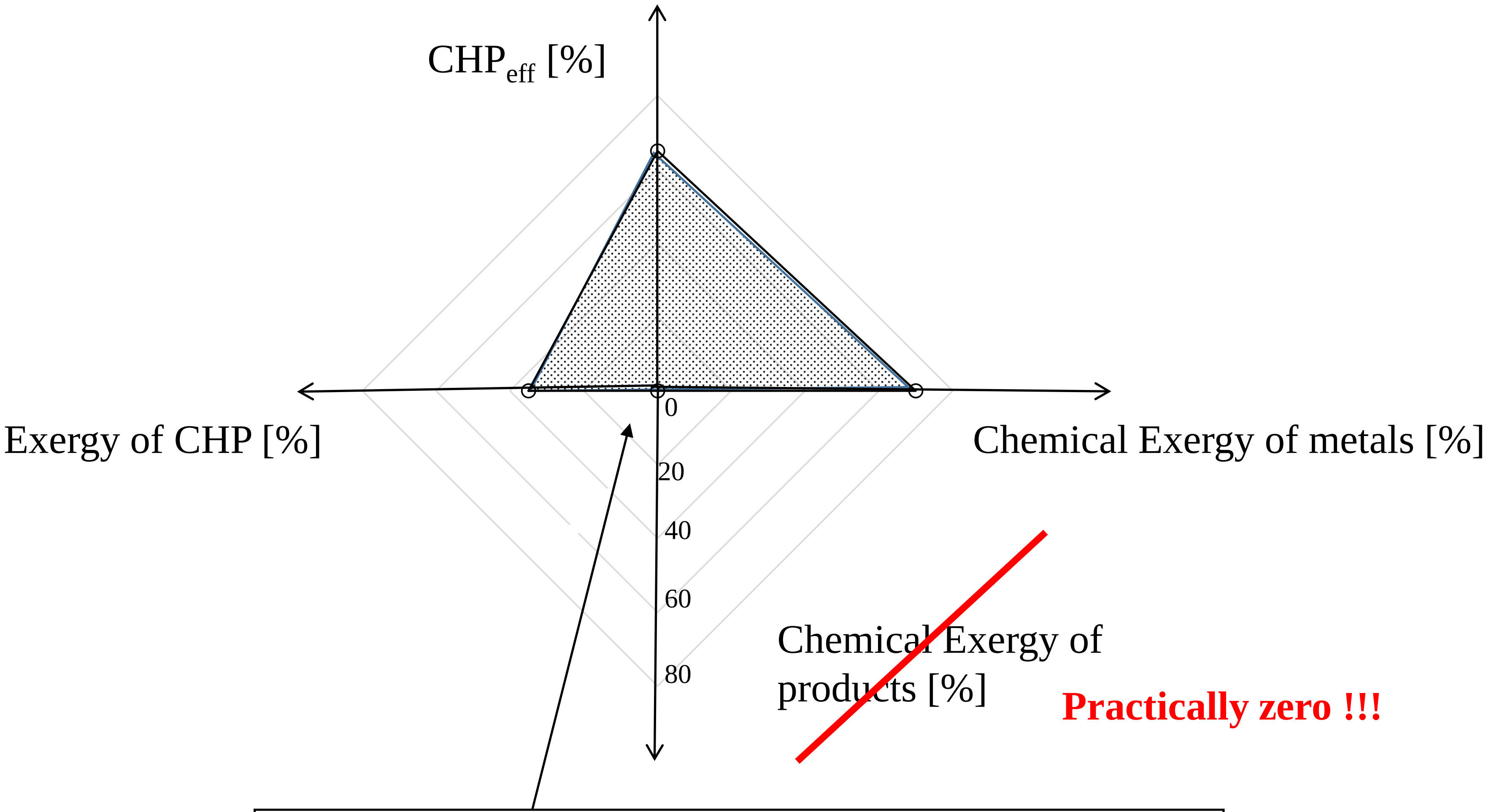
# Introducing the 3T Method




**<u>Integrated efficiency index - General solution for all thermal treatments</u>**

$$\sin\left(\frac{\pi}{2}\right) / 2*[(Prod\text{-}\ Bch_{eff} * Bph_{eff}) + (Bph_{eff} * CHP_{eff}) + (CHP_{eff} * Bch_{eff}\ \{m\}) + (Prod\text{-}\ Bch_{eff} * Bch_{eff}\ \{m\})]$$

# Speciacialized 3T Solution for incineration

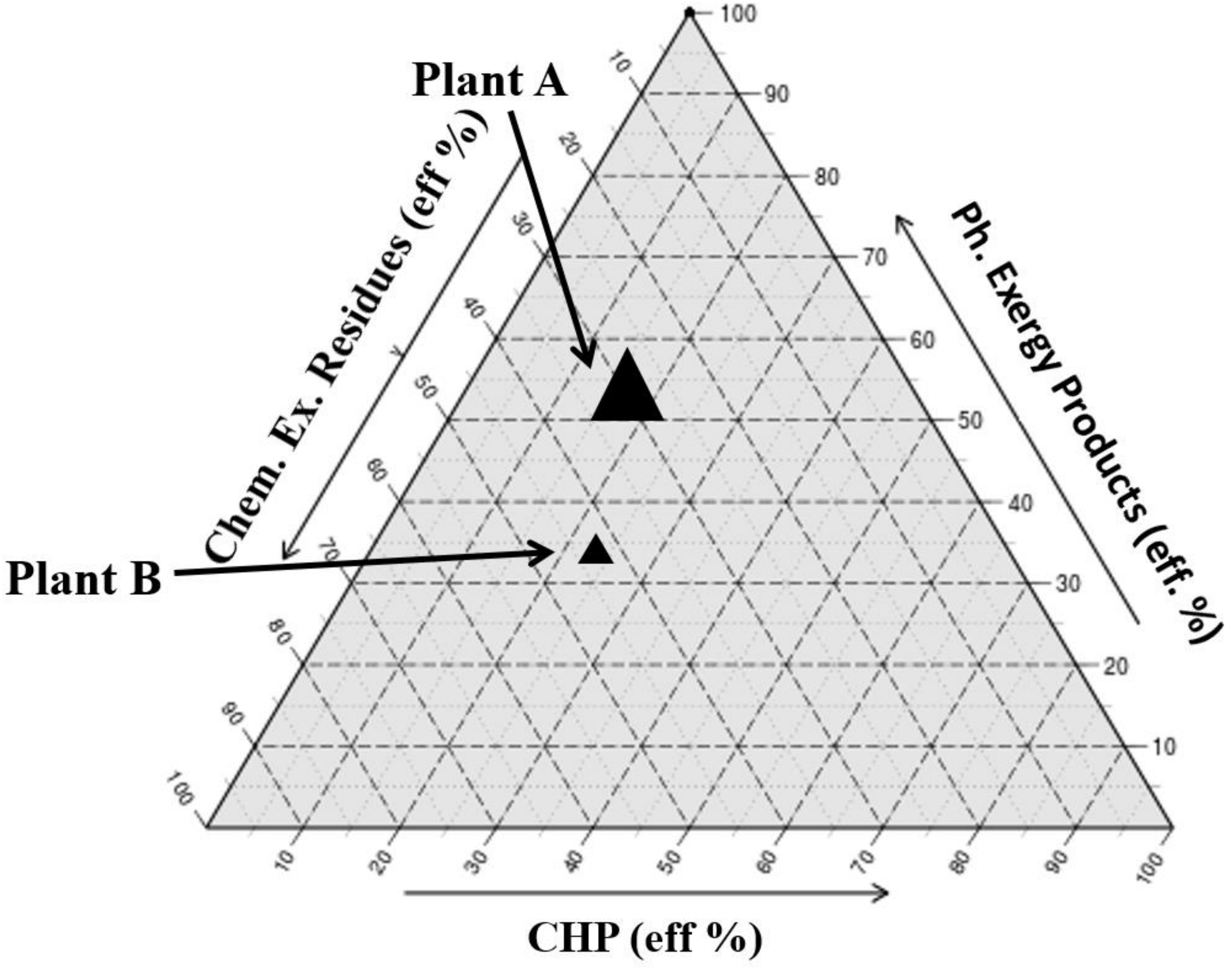



**<u>Integrated efficiency index - Specialized solution for combustion</u>**

$[(Bph_{eff} + Bch_{eff}\{m\}) * CHP_{eff})] / 2$

One more thing !

# Mapping of waste-to-energy plants




- The individual efficiencies of each plant are normalized in order to add to 100.
- Placing each plant into a ternary diagram acts as visual mapping.
- The size of each plant's triangle corresponds to the overall value of the T3 value.

# Conclusions

- R1 formula has been a great first tool for assessing waste-to-energy plants.
- But the assessment of novel waste-to- energy technologies requires the development of new tools that will be more compatible.
- This work proposes the 3T method where thermodynamic parameters are combined in a radar graph and the overall efficiency is calculated from the area of the trapezoid.
  - The comparison of different technologies becomes possible.
  - The specialized solution allows the data mapping of incineration WtE plants.
- The method includes also the recovery of metals and is in good agreement with the concept of “circular economy”.

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# THANK YOU FOR YOUR ATTENTION

**email: stergios.vakalis@outlook.com**

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