# TECHNOLOGIE A ZAŘÍZENÍ PRO ENERGETICKÉ VYUŽITÍ ODPADŮ

♦

# OD KONCEPČNÍCH ŘEŠENÍ K ŘEŠENÍM ŠITÝM NA MÍRU

**Petr Stehlík**

Vysoké učení technické v Brně

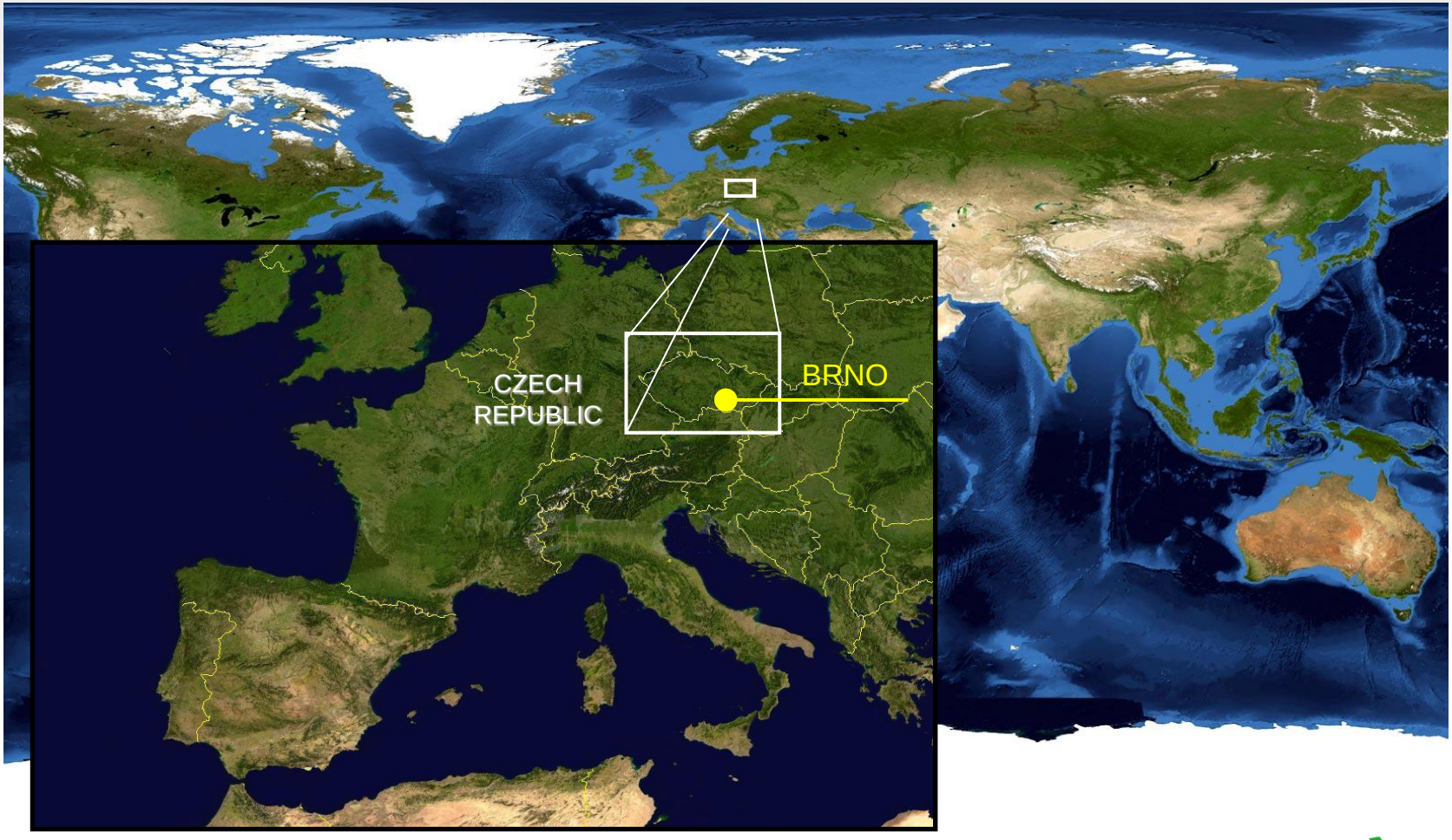
# Activities Performed within …

**Background:**

- **Strategic projects** (research, for ministries, commercial)
- **NETME Centre, Waste-to-Energy Competence Centre (WtE CC)**
- **Plenary/Keynote lectures worldwide** (e.g. below)
- **Systematic and long-term collaboration among partners of WtE CC consortium *„Academy of Science (fundamental research) – University (applied research) – Innovative company (full-scale application) – Feedback from industrial implementations“***
- **Monograph:**
  *Stehlik, P.: Up-to-Date Waste to Energy Approach. From Idea to Industrial Application, Springer International Publishing, Switzerland, Cham, 2016*


NETME Centre

# Brno, Czech Republic




NETME Centre

# *University, NETME Centre & WtE Competence Centre*

BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING

NETME Centre

# *Motivation*

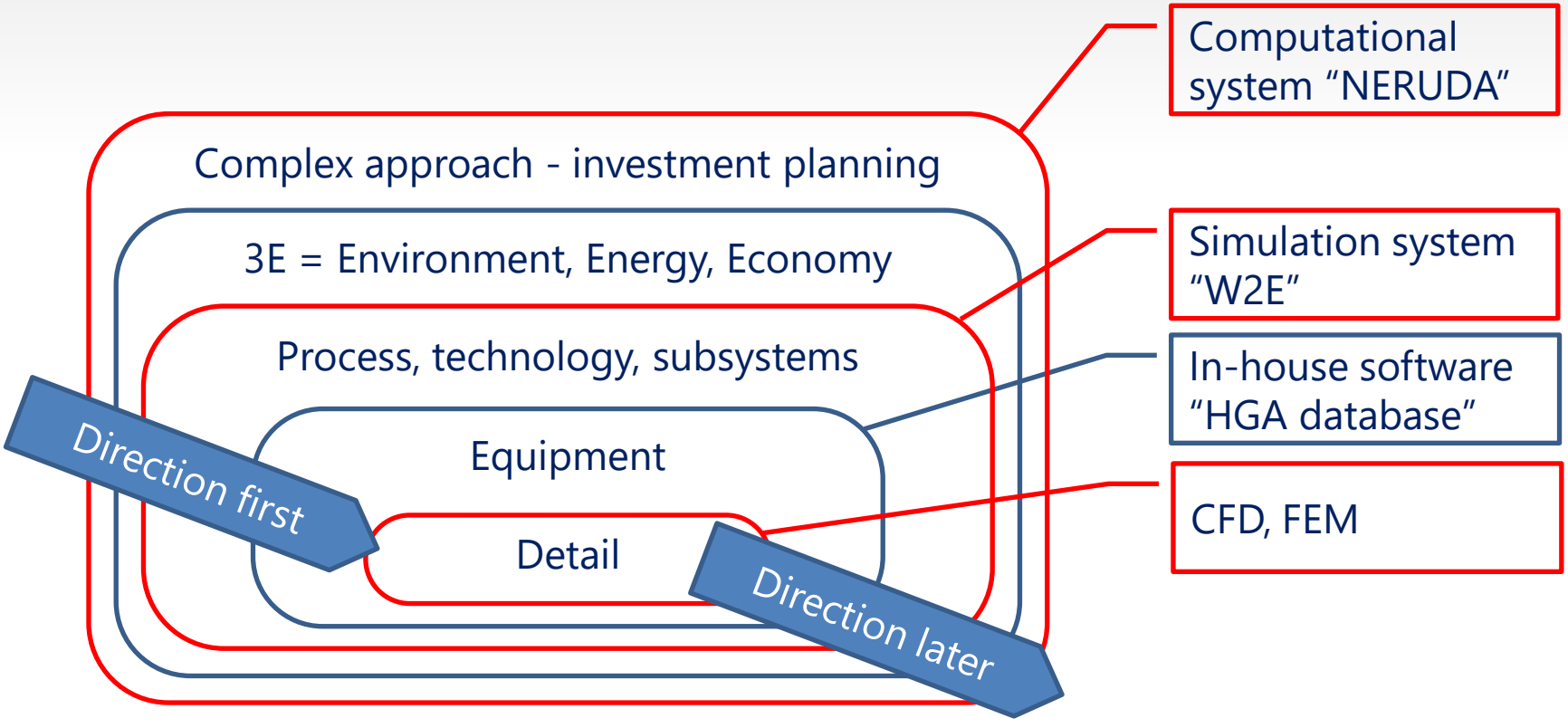
- Energy from MSW can cover up to 4.5 % of global primary energy sources (PES)
- Sludge processing (both sewage and industrial)
- Hazardous waste
- Waste gases
- Many years' systematic activities in the field of WtE *„from A to Z"*
- Possibility to penetrate international market in this area with unique and original approach

Public opinion

Research and development

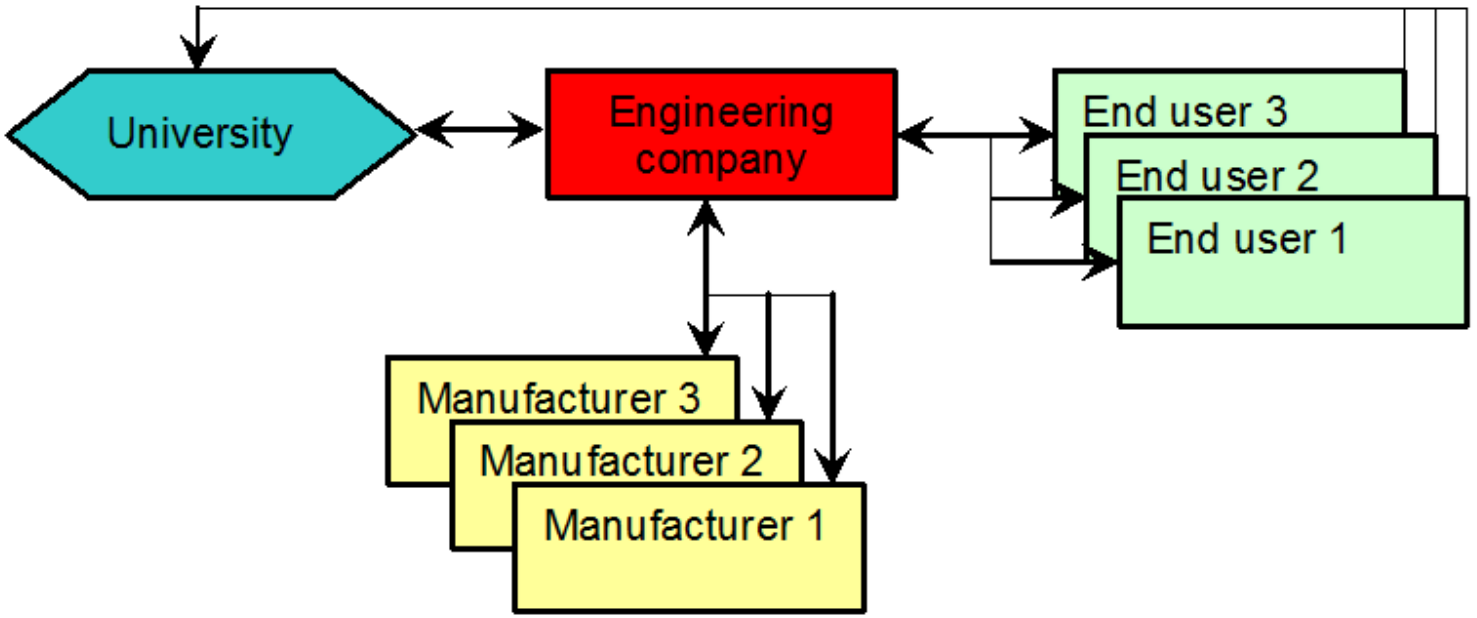

Subsidies

# *From idea to industrial application and/or from „A“ to „Z“*

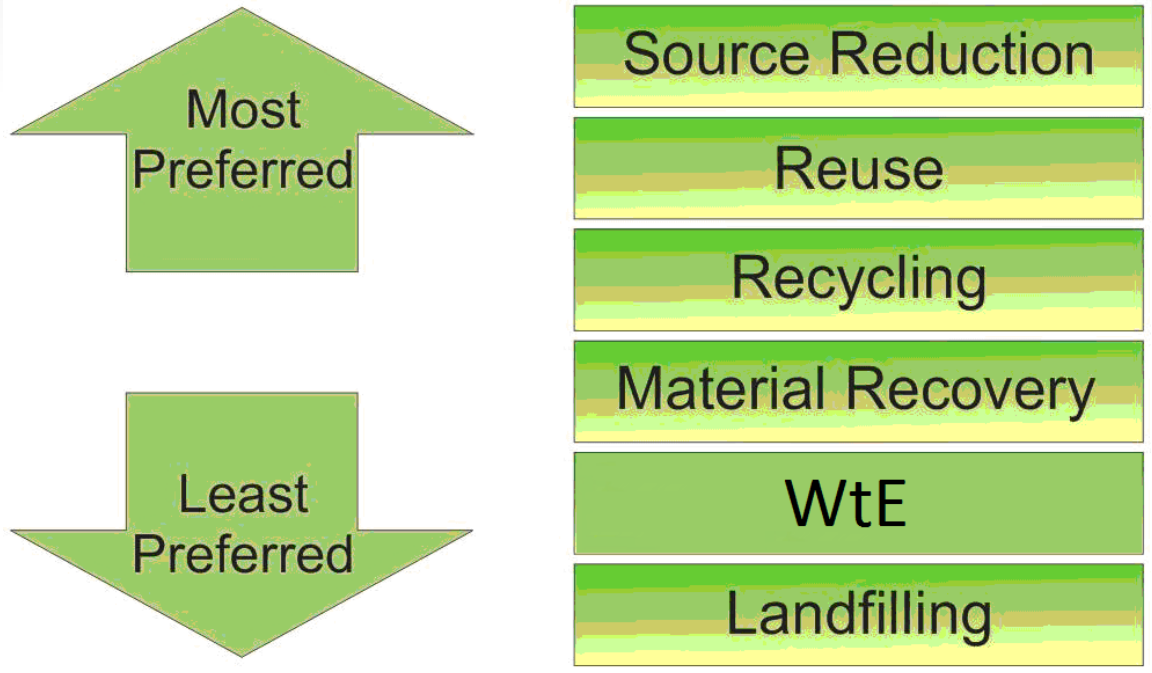


# *From idea to industrial application and/or from „A“ to „Z“*

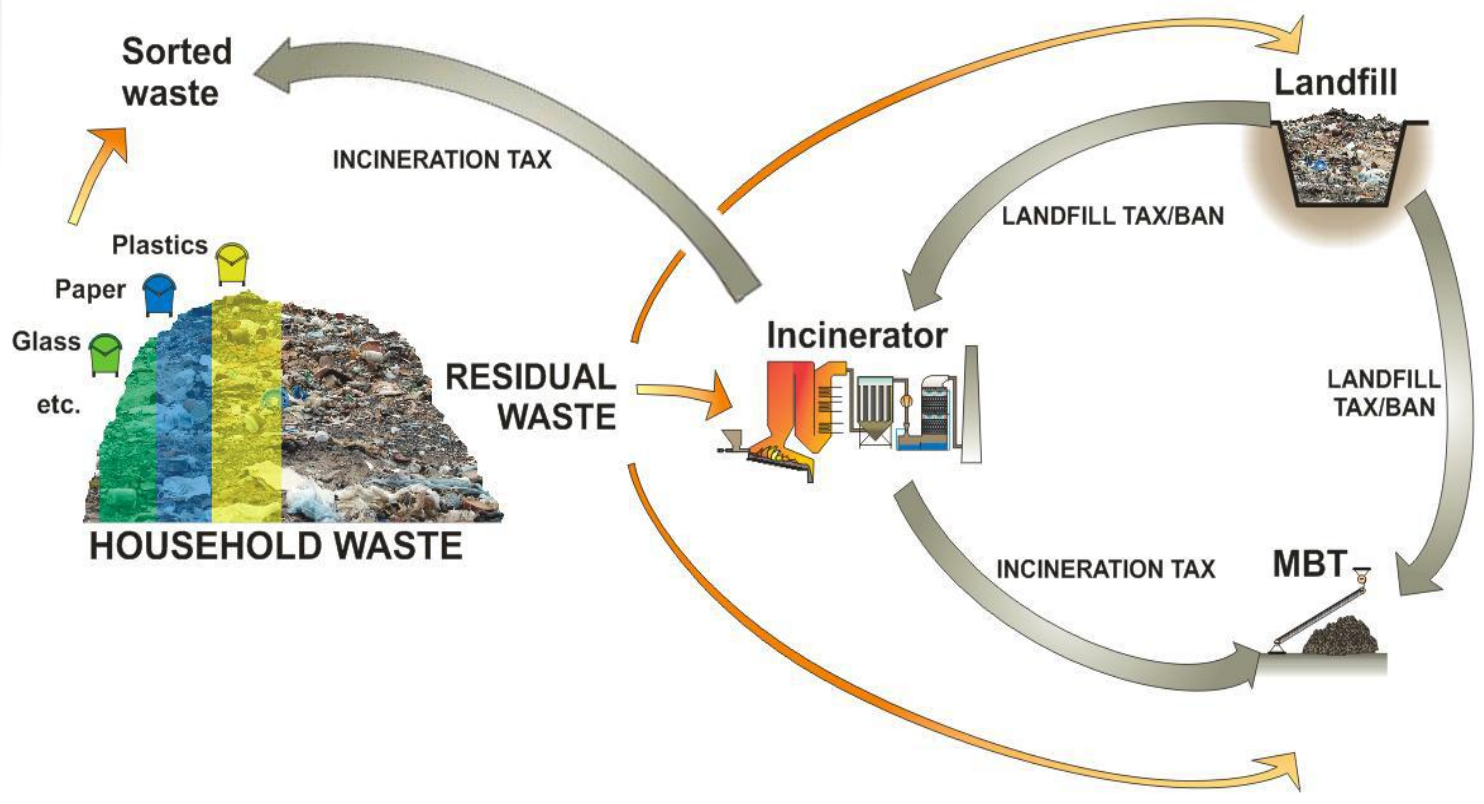
- Efficient combining know-how, experience and sophisticated approach
- Successful approach combines industrial practice and research ⇒ mutual benefit



# *Waste treatment hierarchy according 2008/98/EC Directive*

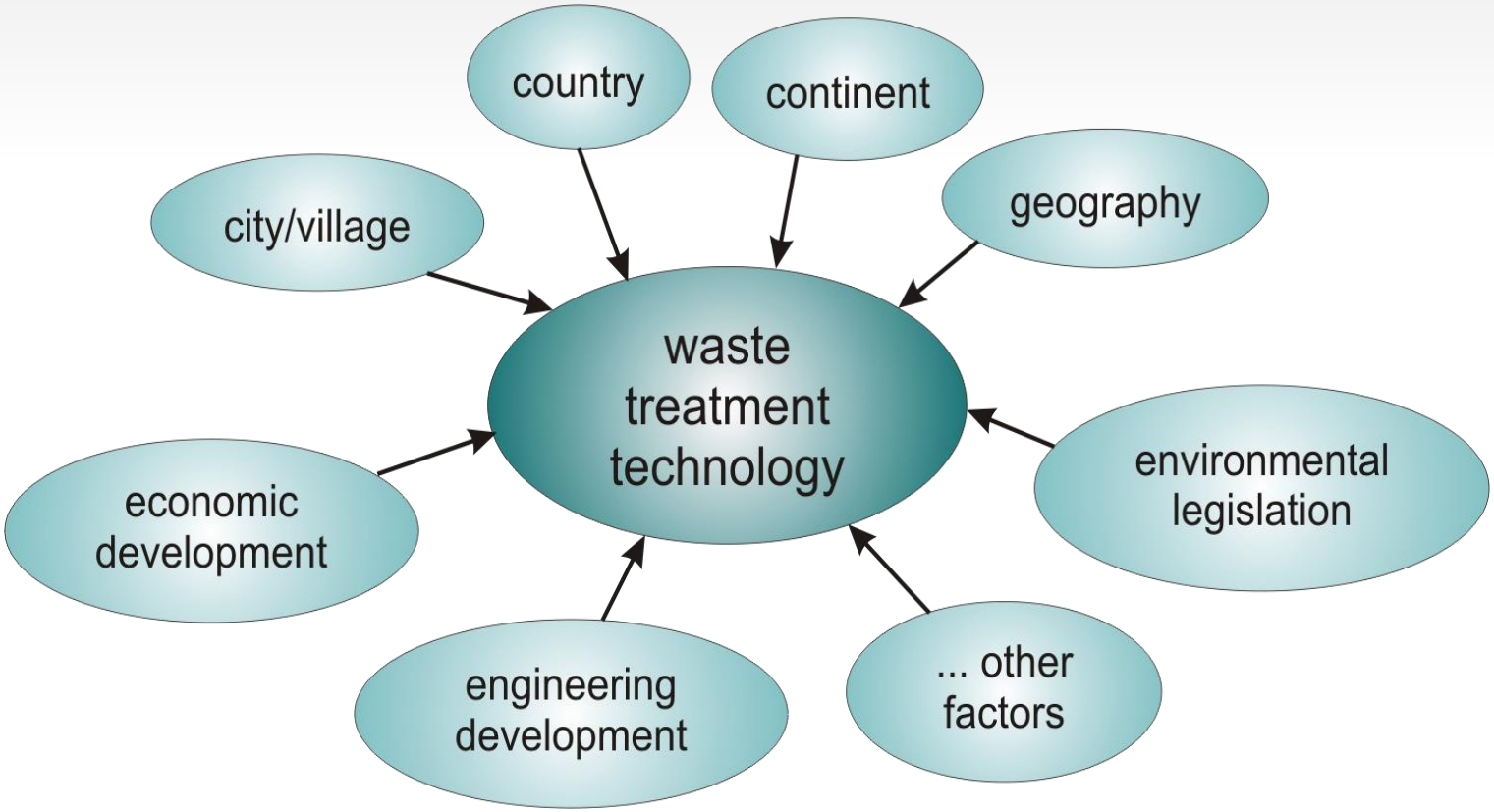


# *Economic drivers (taxes, bans) influencing waste flows and waste treatment*

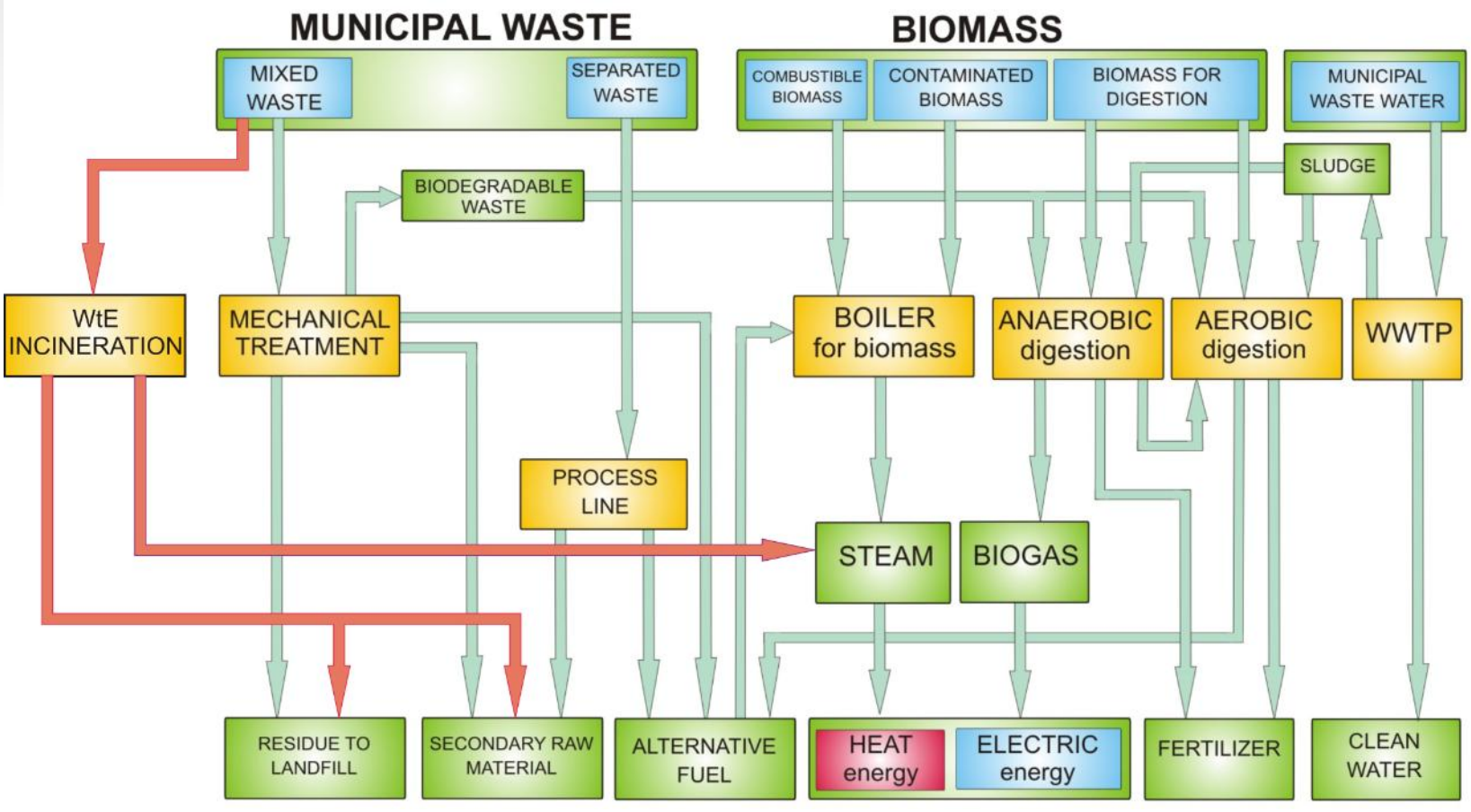



**MBT** = mechanical-biological treatment

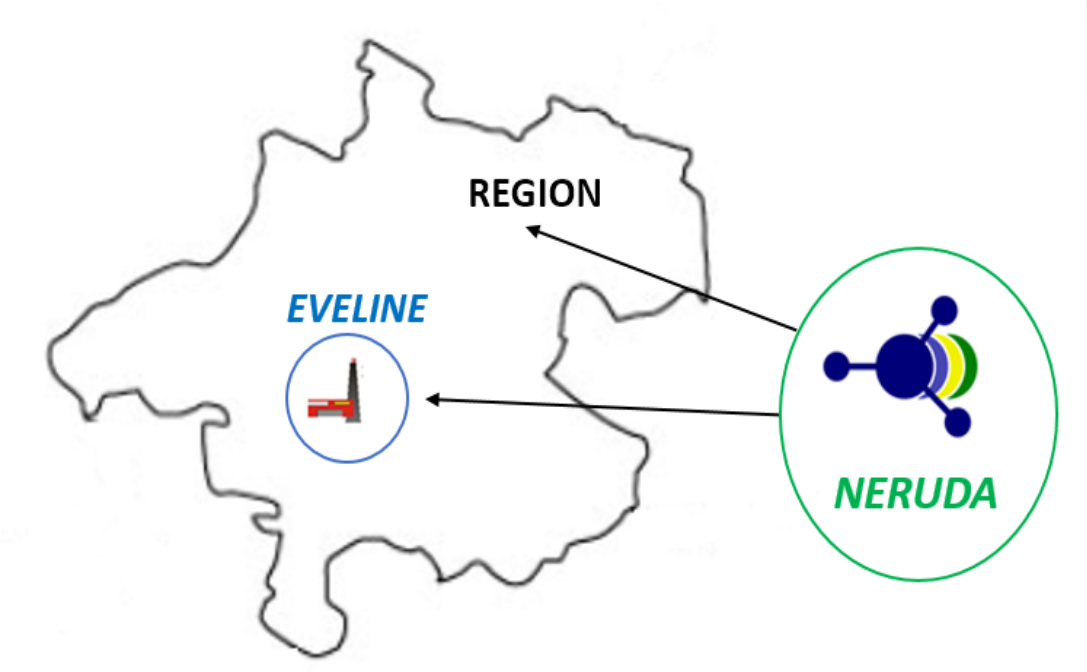
# *Factors influencing waste processing*



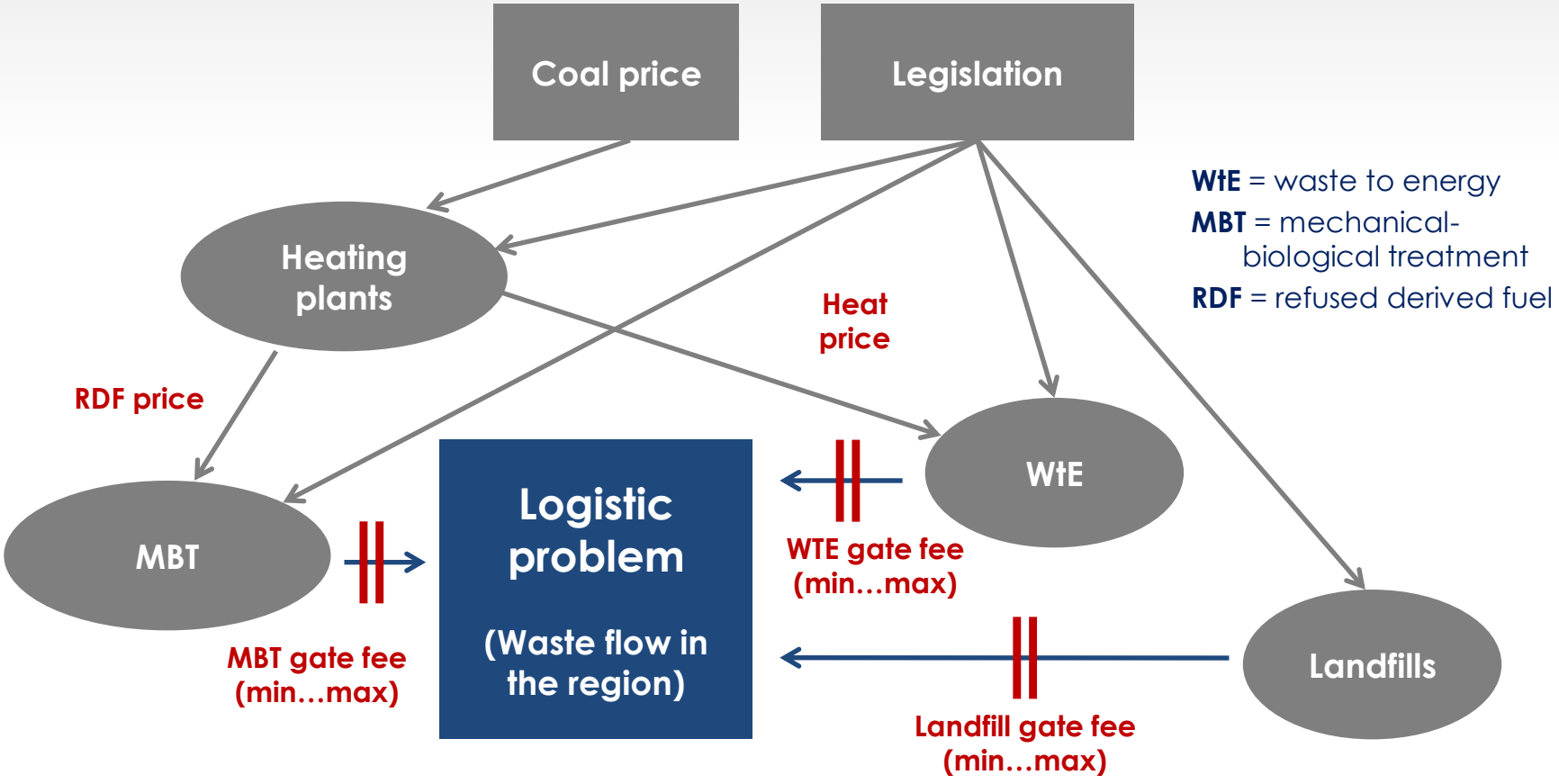
# Complex integrated system for regions



# *Complex integrated system for regions*



# *Logistic optimization problem – relations in complex system*



# *Necessary conditions for WtE*

| referential content of $O_2$ [% vol] | emission limits [mg/m³] | | | | | | | PCDD/F limit [ng TEQ/m³] |
|---|---|---|---|---|---|---|---|---|
| | $SO_2$ | $NO_x$ as $NO_2$ | CO | HCl | HF | dust | organic substances | |
| **11** | 50 | 200 (400*) | 50 | 10 | 1 | 10 | 10 | 0.1 |

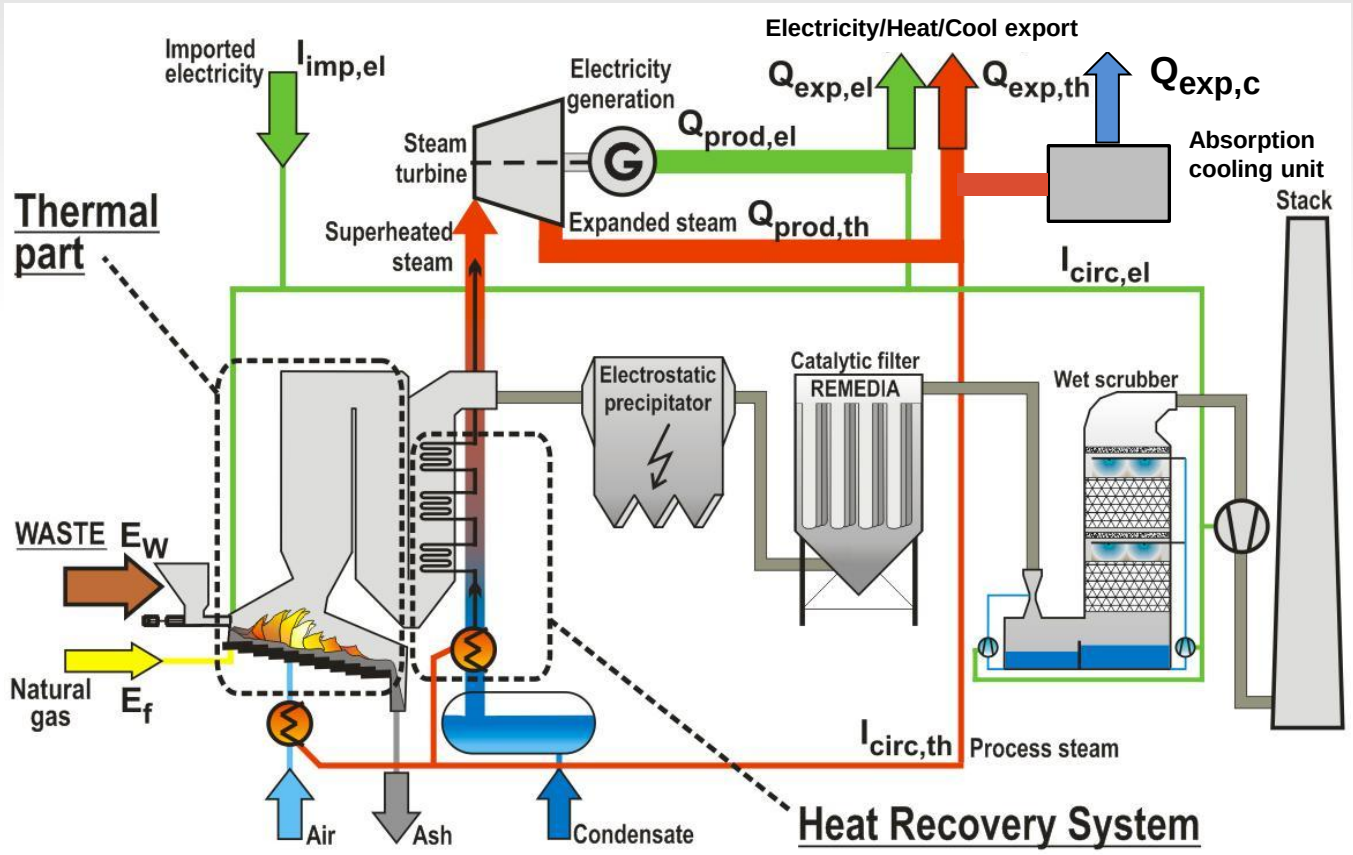
Average daily values of **emission limits** for waste incineration according to 2010/75/EU

*Note: * 400 mg/m3 is value for plants with a nominal capacity of 6 t/h or less*

# *Up-to-date MSW incinerator with capacity of 100,000 t/y*

# Up-to-date MSW incinerator

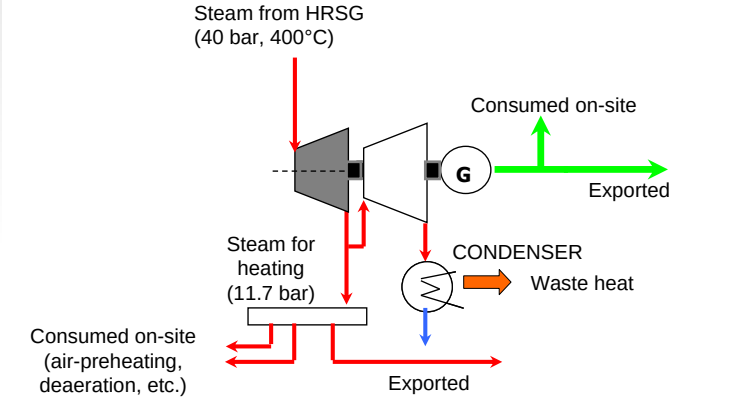
Energy efficiency assessment

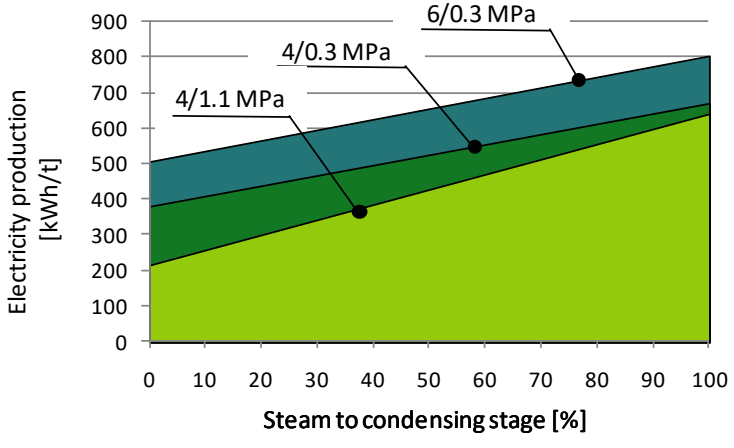


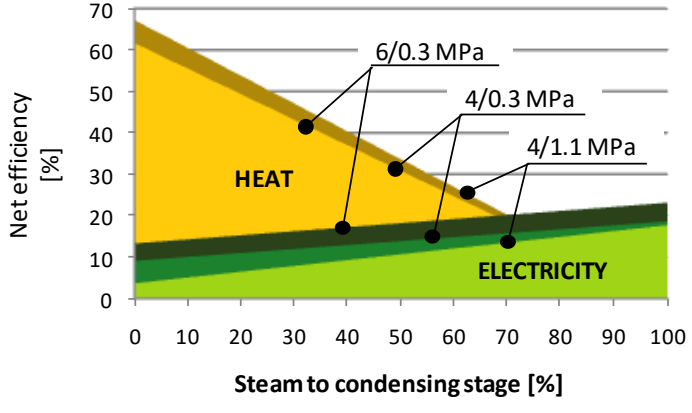

| Proposed by | Criterion | Equation | Waste-to-Energy |
|---|---|---|---|
| EU Directive on waste | Energy efficiency | $\eta_e = \frac{Q_{prod} - (E_f + I_{imp})}{f_B \cdot (E_w + E_f)}$ | $\eta_e > 0.6$<br>$\eta_e > 0.65^*$ |

# Expected energy production

- Net efficiency of power production in condensation regime does not exceed 20 %.
- Further efficiency increase is problematic and requires application of expensive materials and measures

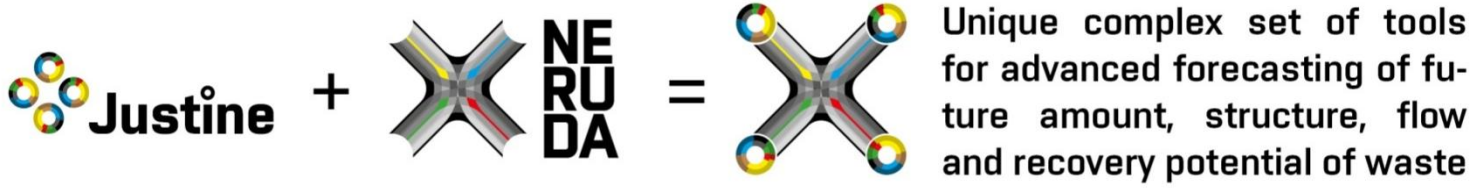


# *Sophisticated approach in investment planning*

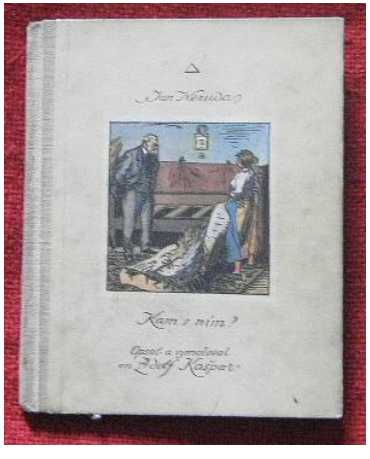
- Advanced computational tools to support decision-making in waste management developed at BUT

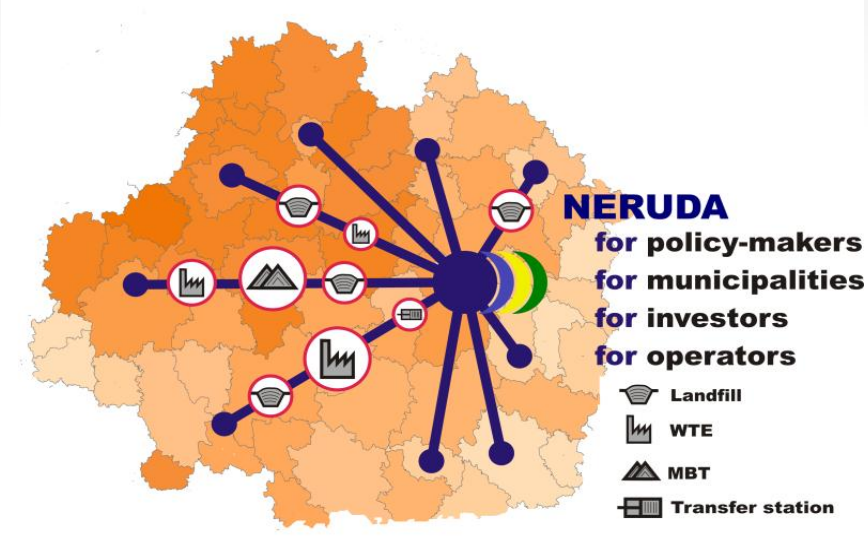


# *NERUDA – Software solution*

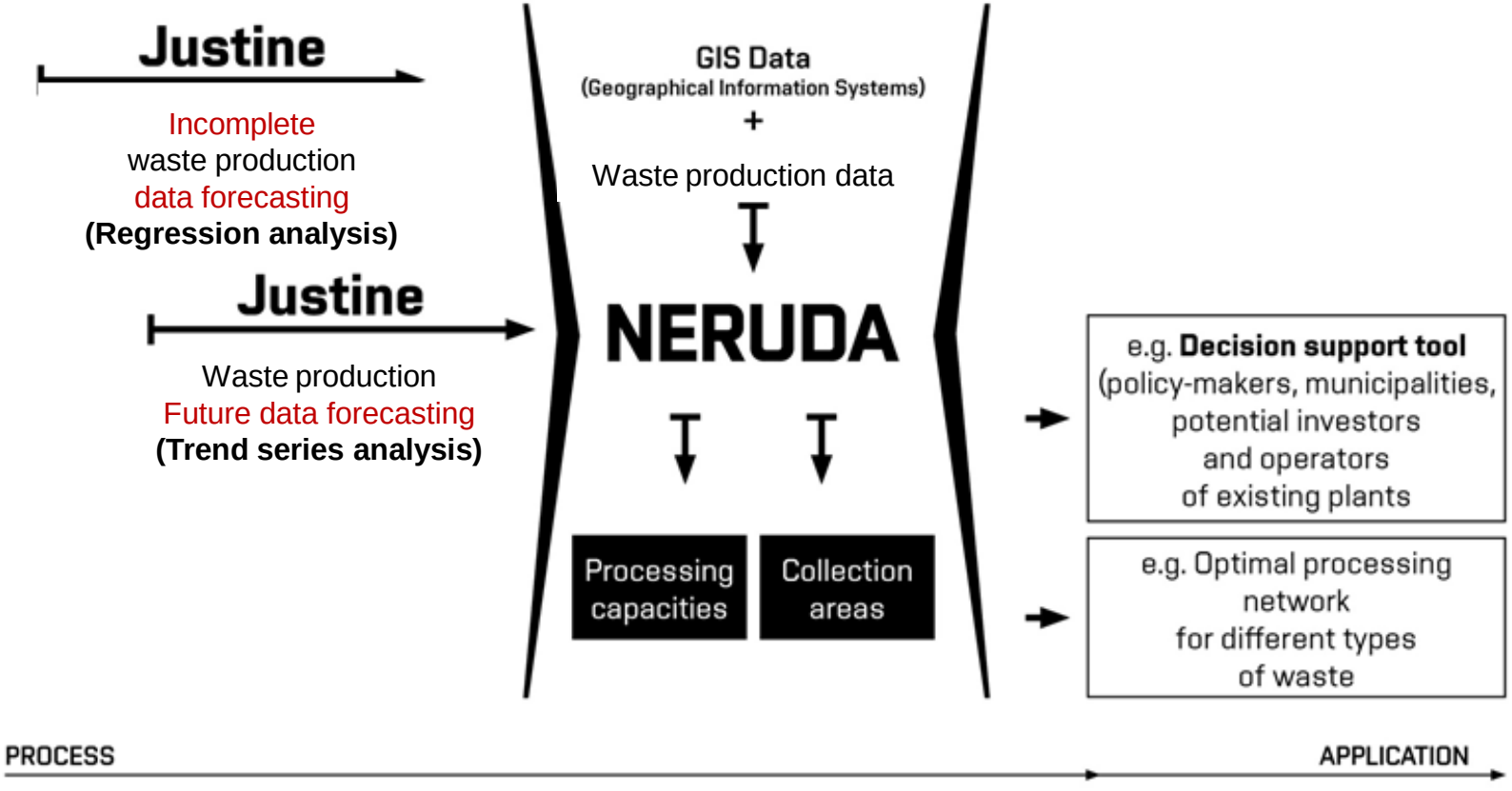
**A tool supporting decision-making in waste management**

NERUDA



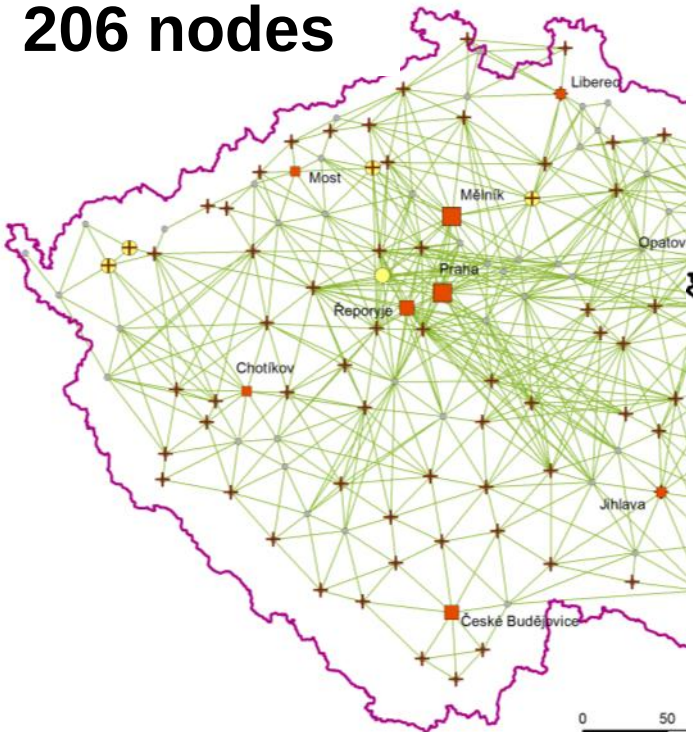


# *Complex approach*

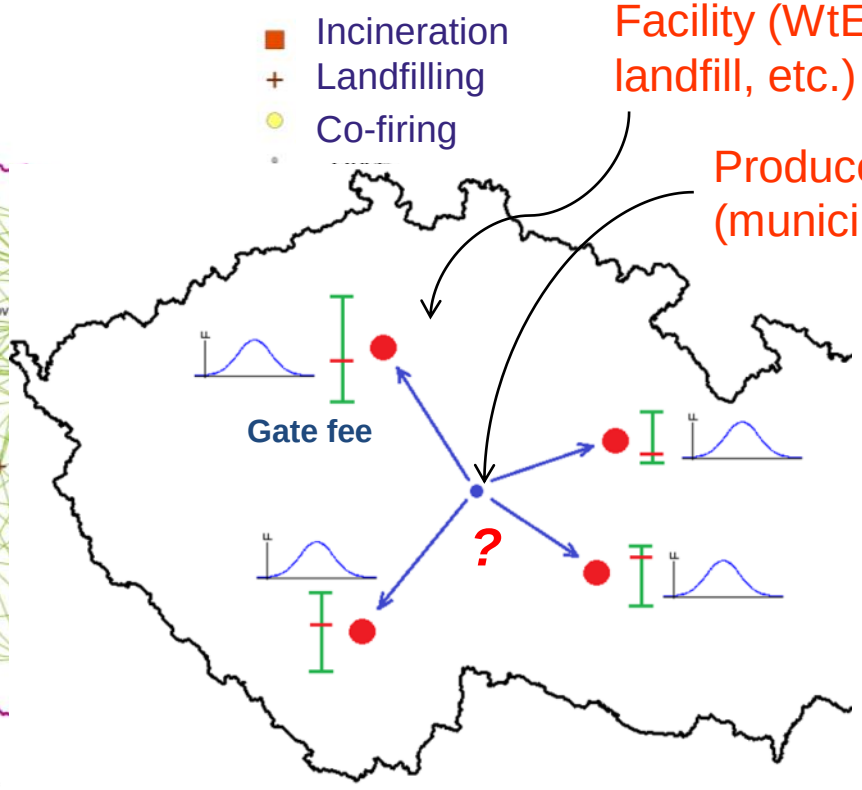


# NERUDA - Basic principle

**206 nodes**




Geographical data and statistics behind




Optimization in a transportation problem

$$\min \sum_j dv_j x_j + \sum_i \sum_j a_{ij} x_j p_i^{WTE} ,$$

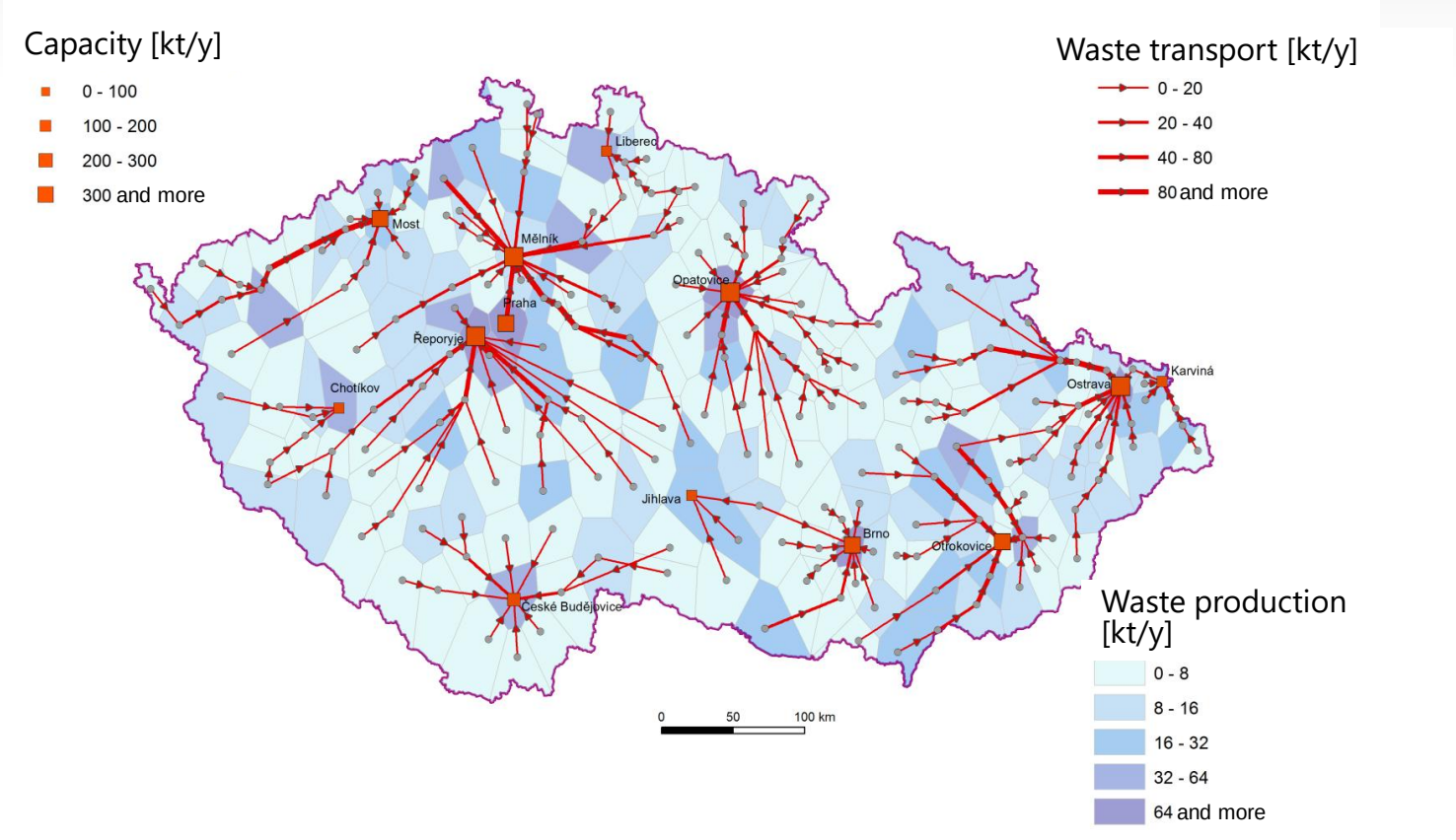
Transportation cost  Processing cost

Simplified version – WtE facilities only

# *Visualization of result (simplified)*

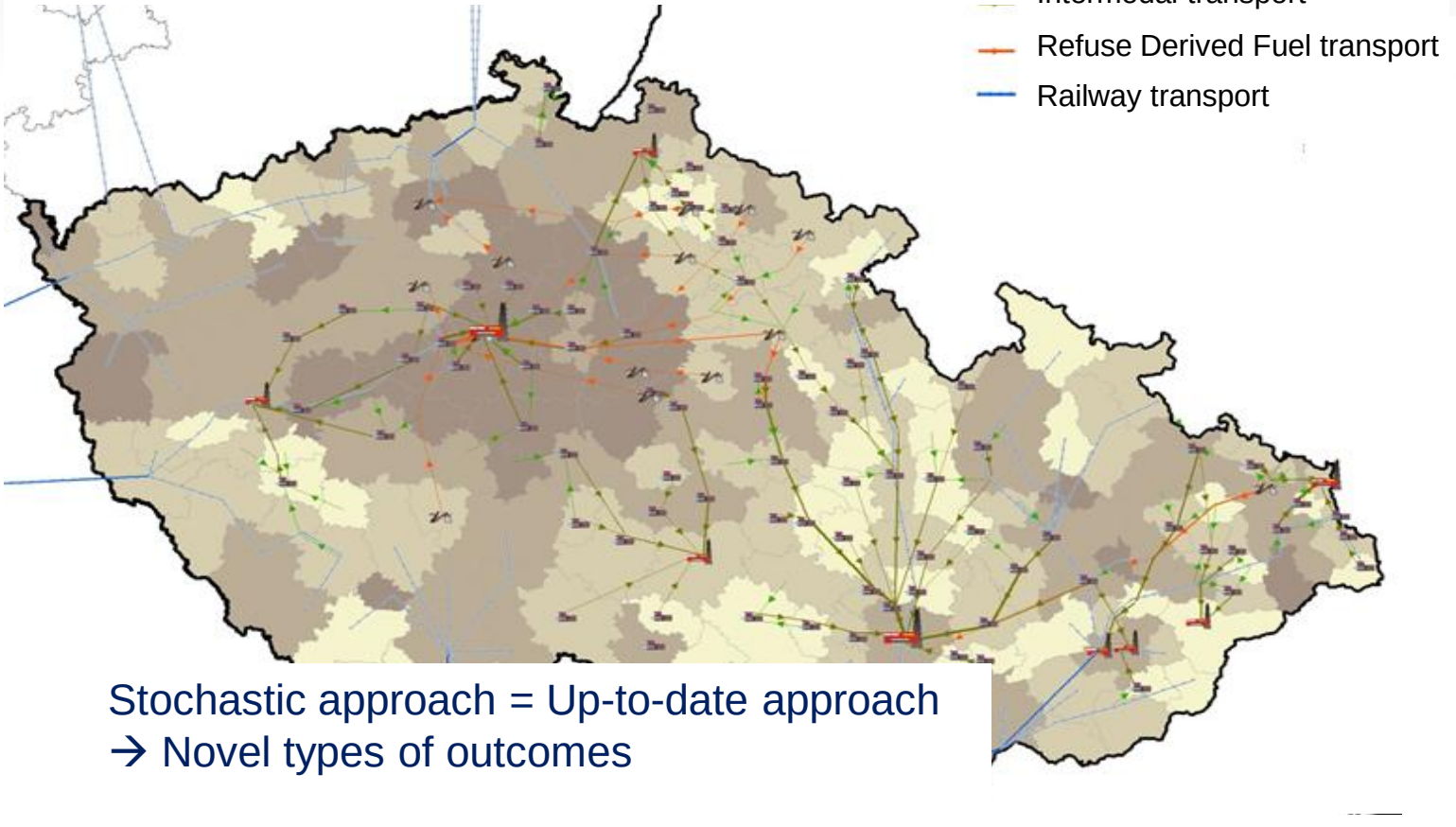
NERUDA
Short-distance transport

- One particular scenario (one simulation run)



# *Visualization of result (complex)*

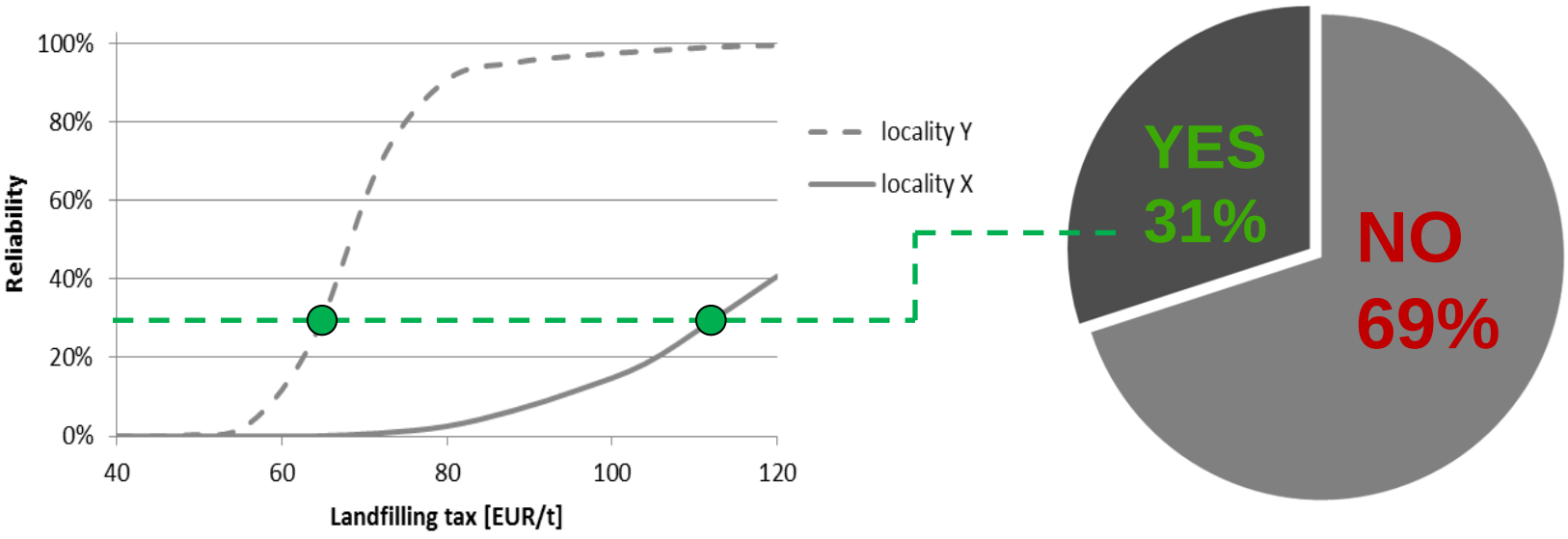
One particular scenario (another simulation run)




Stochastic approach = Up-to-date approach
→ Novel types of outcomes

# *Survival function*

Economic sustainability of two WtE projects intended in two different localities




ŠOMPLÁK et al. **Logistic model-based tool for policy-making towards sustainable waste management**. Clean Technologies and Environmental Policy. 2014. 16

# *Recent applications / References*

Municipal solid waste (MSW)

- Country level analysis
  - Ministry of Industry and Trade of the Czech Republic (2013)
  - Ministry of Environment of the Czech Republic (2015)
- Regional level analysis
  - Analysis within Waste Management Plan creation processes (2015, 2x)
- Microregions
  - Development of strategies for residual waste treatment (2015, 2x)

- Investors and future operators
  - Pre- feasibility studies for large WtE plant (2012, 2013)

**NERUDA** = open tool ready for real applications worldwide

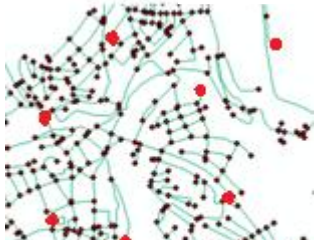
# *NERUDA Street*

Justine + NERUDA Street = 

**Powerful set of tools for optimization of collection of household waste and its fractions**

Tool applied for Forecasting in Waste Management

Advanced solution for routing problems (VRP, ARP)



VRP
Vehicle routing problem

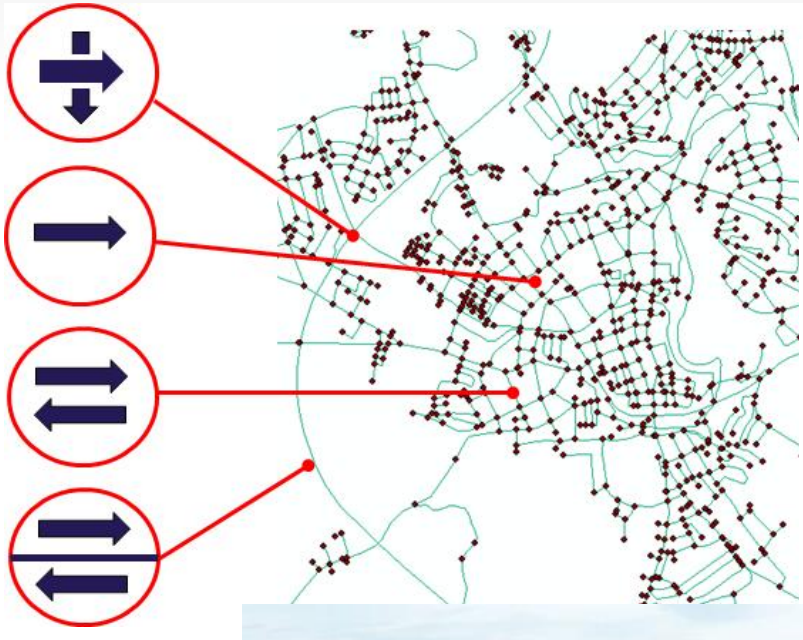
ARP
Arc routing problem

- Smart-City infrastructure optimization
- Separation vs material recovery
- High separation targets vs cost

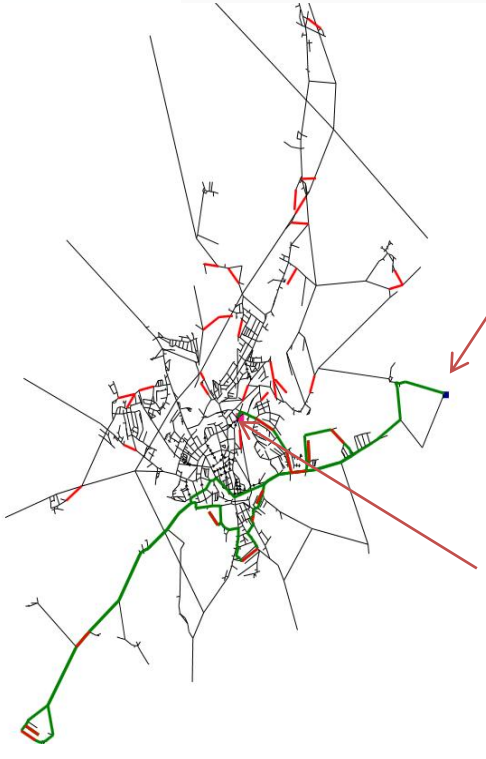

?

# *NERUDA Street*

GIS-based model



Result



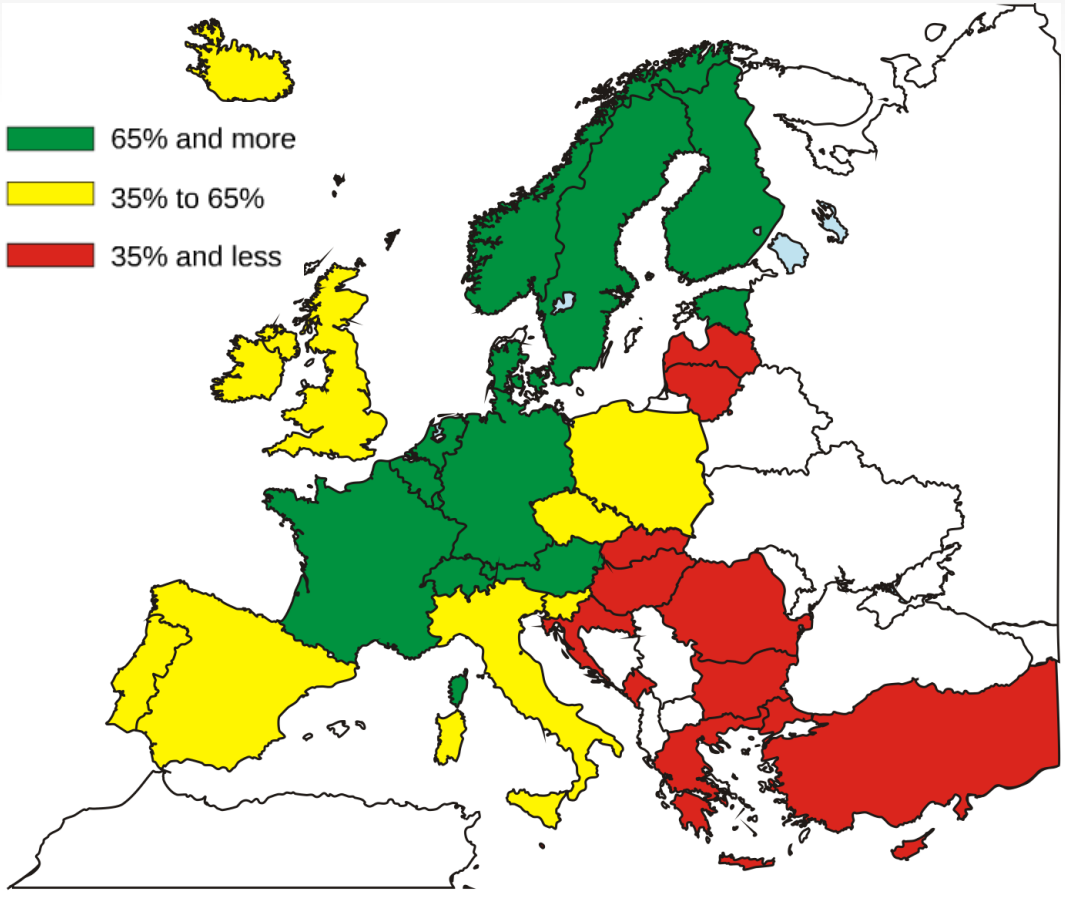
# *NERUDA Street*

To avoid …


# *NERUDA* EU

for CZECH REPUBLIC

Recovery shares of municipal solid waste (MSW) in EU27 in 2014 (**material + energy**)




Source: Eurostat (http://epp.eurostat.ec.europa.eu)

/ / year

Waste amount / person / year/

**506 kg**

**47%** recovery

**35%** Material recovery

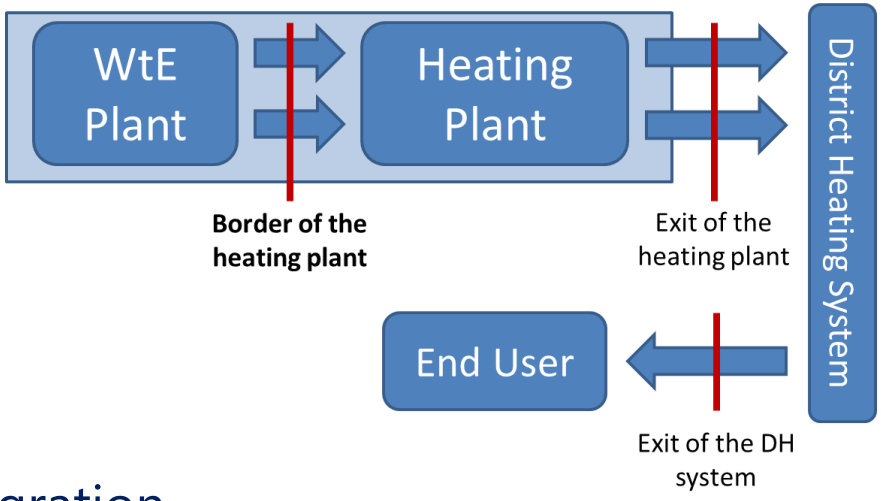
**12%** incineration

**48%** landfilling

**5%** other

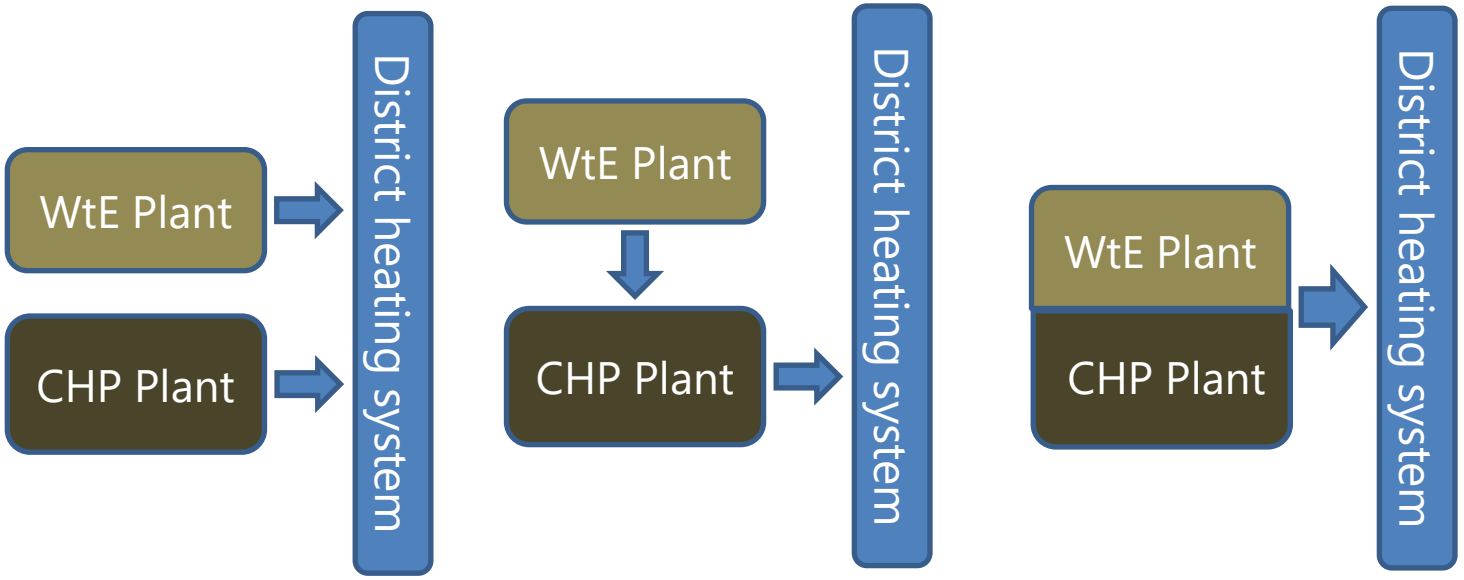
# *Integration of WtE plant (Wte) and Heat & Power plant (CHP)*

- Acceptable heat price from WtE plant is usually much lower than costs of heat production in CHP plant
- Factors to be considered:
  - Structure of heat demand
  - Technological impact on the existing technology
  - Economic gactors (variable and fixed costs of heat production)
  - Possibilities of WtE plant integration (e.g. common employees, use of existing facilities)



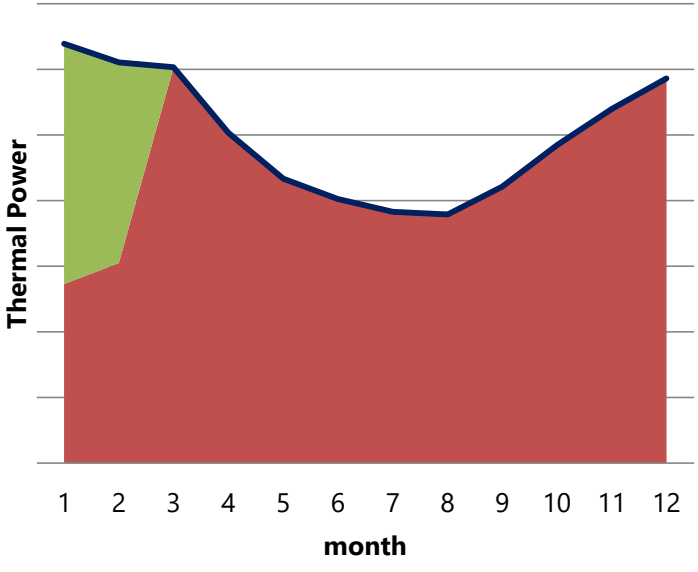
# *Integration of WtE plant (Wte) and Heat & Power plant (CHP)*

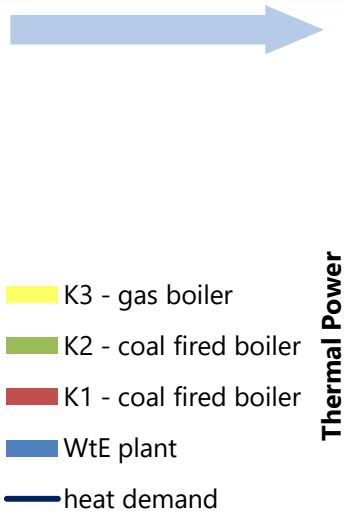
- It is necessary to create a technoeconomic model of WtE plant and CHP plant cooperation which considers both technical and economical aspects
- Ownership structure plays an important role



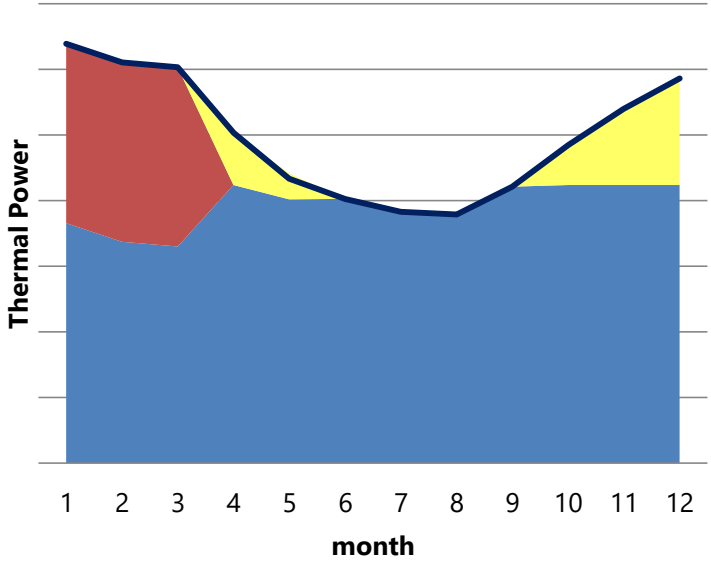
# *Impact of WtE plant integration*

Existing CHP plant

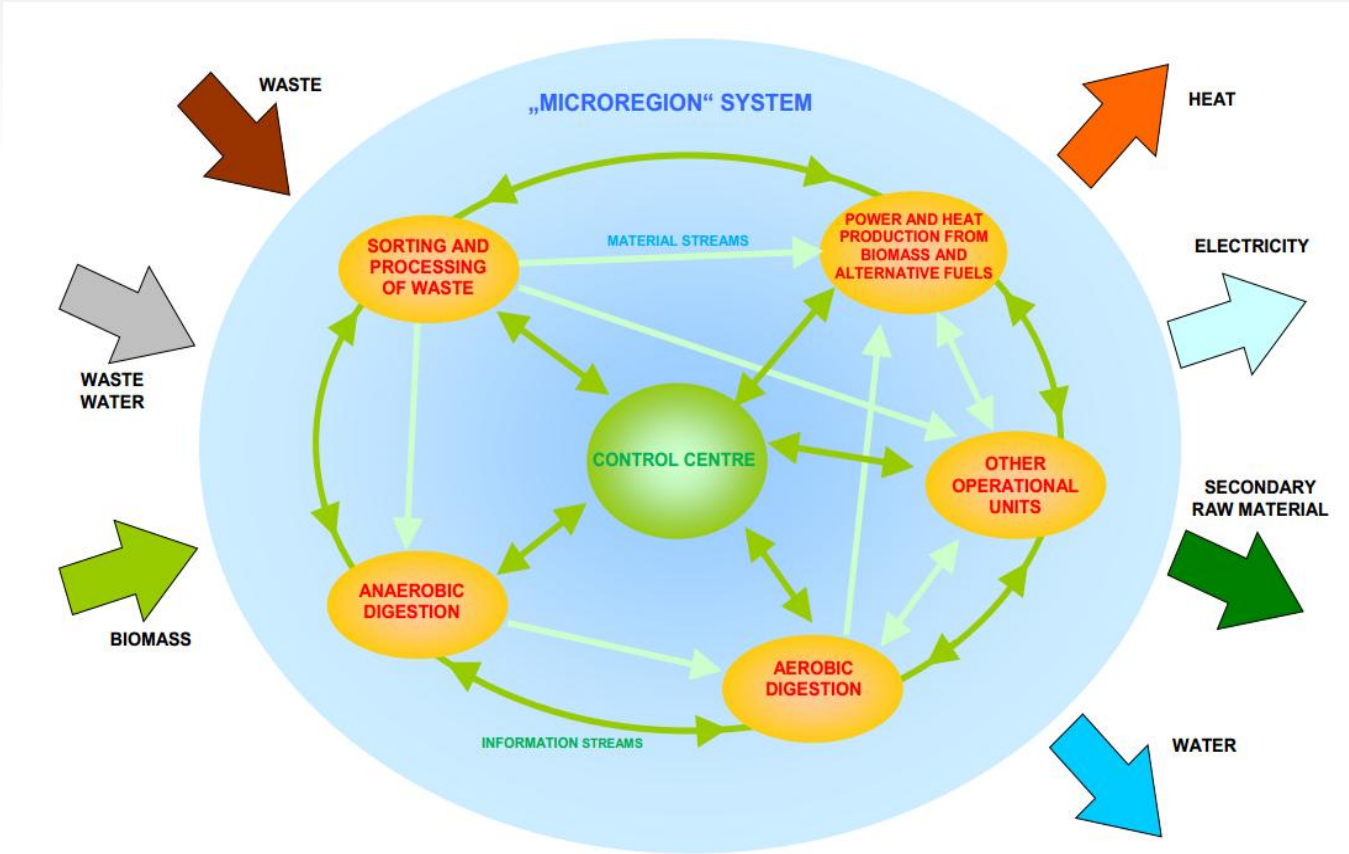


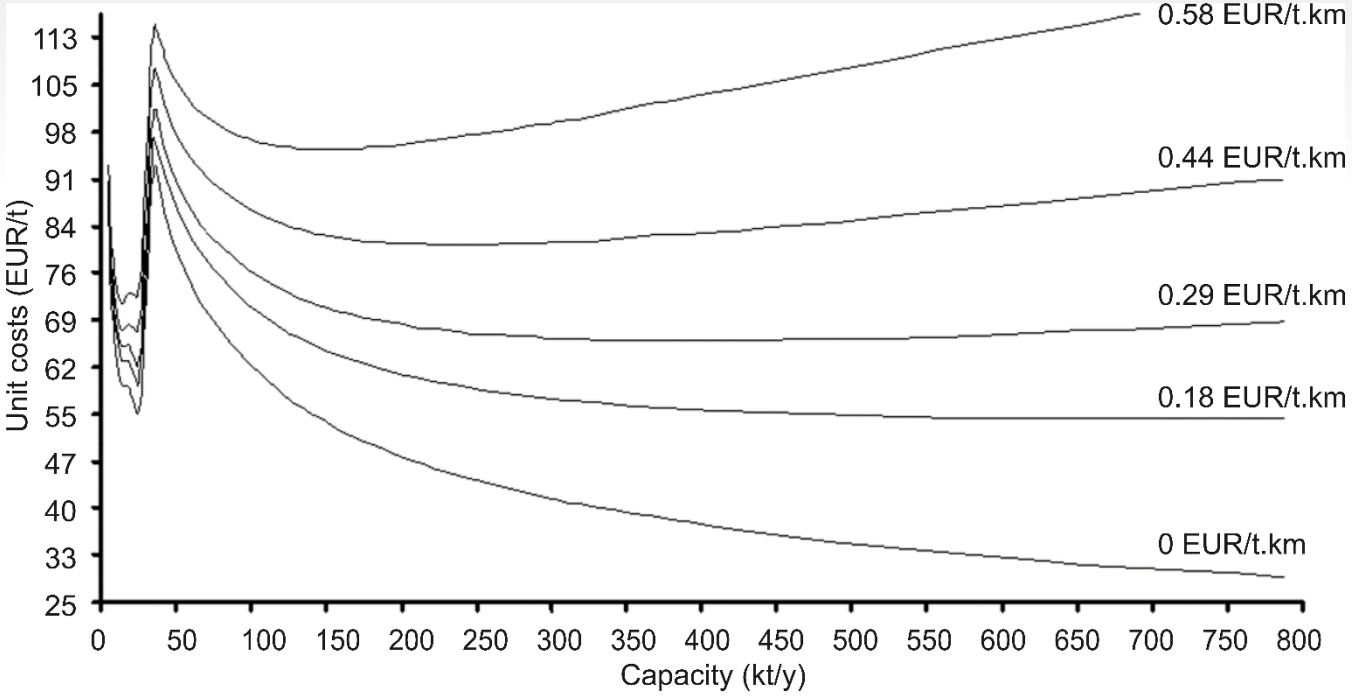

(CHP + WtE) plant



# *Management system „REGION/Micro-Region“*
# *„Fuel and Waste Smart Grid“*



# *Units of lower or higher capacities?*



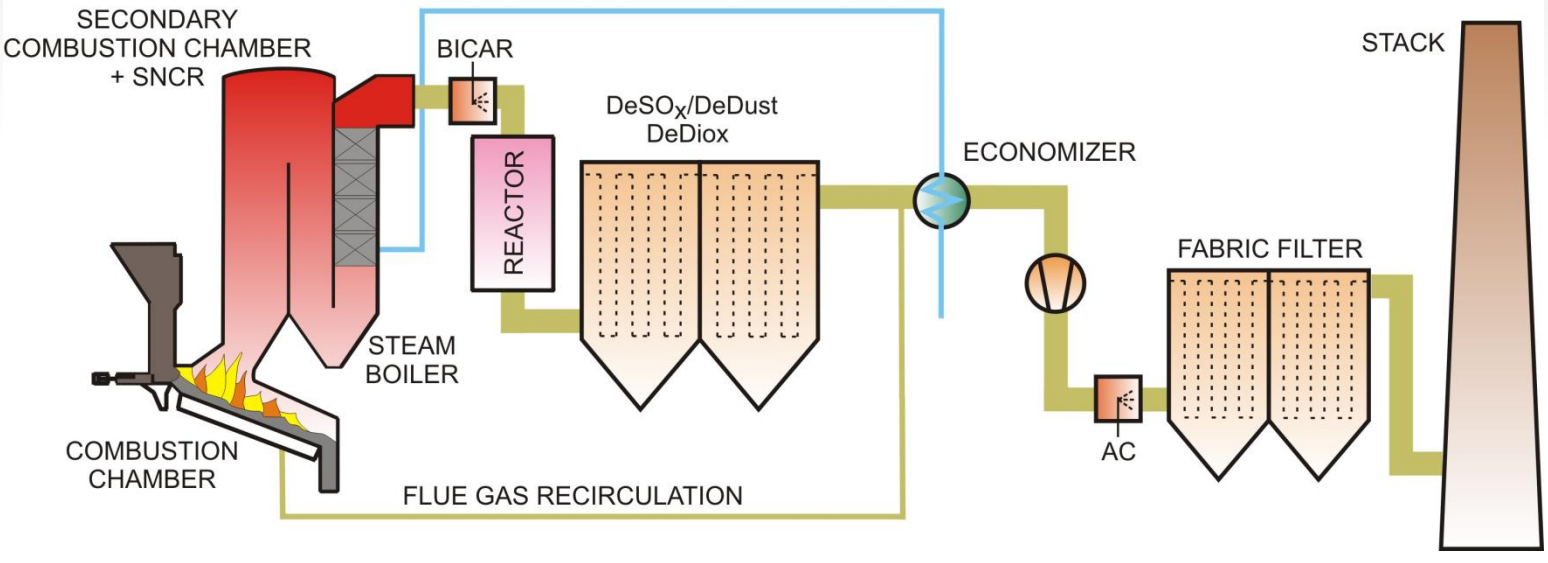

Based on a thorough analysis performed, even units of lower capacity are feasible in terms of unit costs!

Cost for transport must be considered!!!

# *Lower capacity units – economics*

- The small capacity technology is designed to produce heat!
- Therefore the only question is as follows:
  Is there a possibility to sell at least 70% of annual heat energy production at fair price (e.g. 10 EUR/GJ) in the Czech Republic?

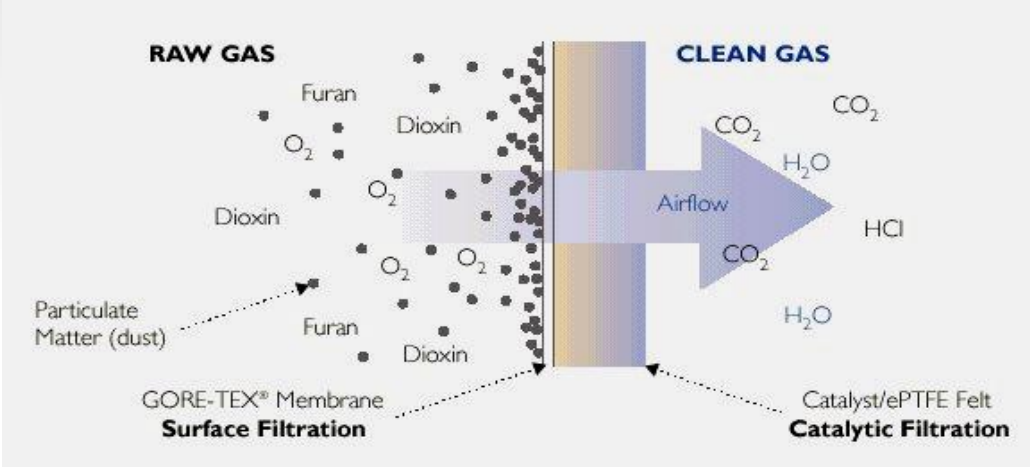
# *Lower capacity units – technological concept EVELINE*




Completely dry process

Ready for $NO_x$ Selective Catalytic Reduction if needed

# *Lower capacity units*




**4D Filtration:**

1D – **De Dusting**
solid particles filtration

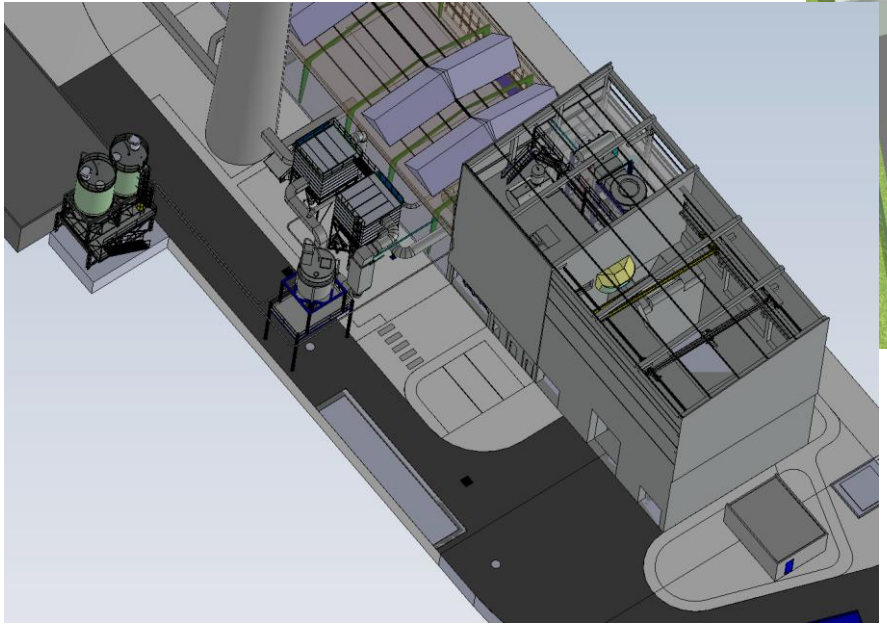
2D – **Dry Sorption**
neutralization of acidic compounds (SO2, HCl, HF, partially NOx)

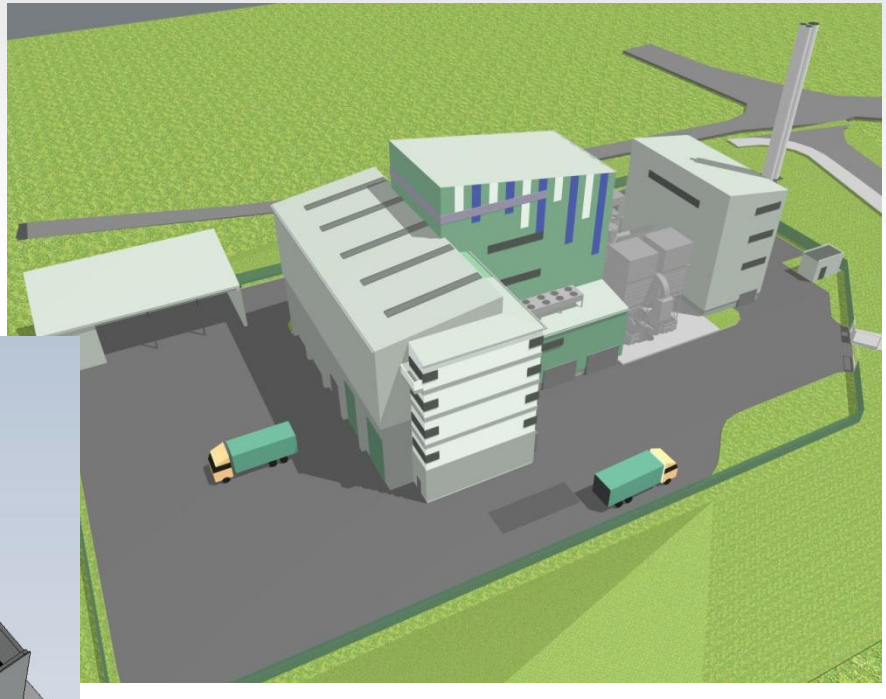
3D – **De Diox**
catalytic reduction of PCDD/F

4D – **De NOx**
SCR NOx

# *Lower capacity units – visualization*

Brown-field design



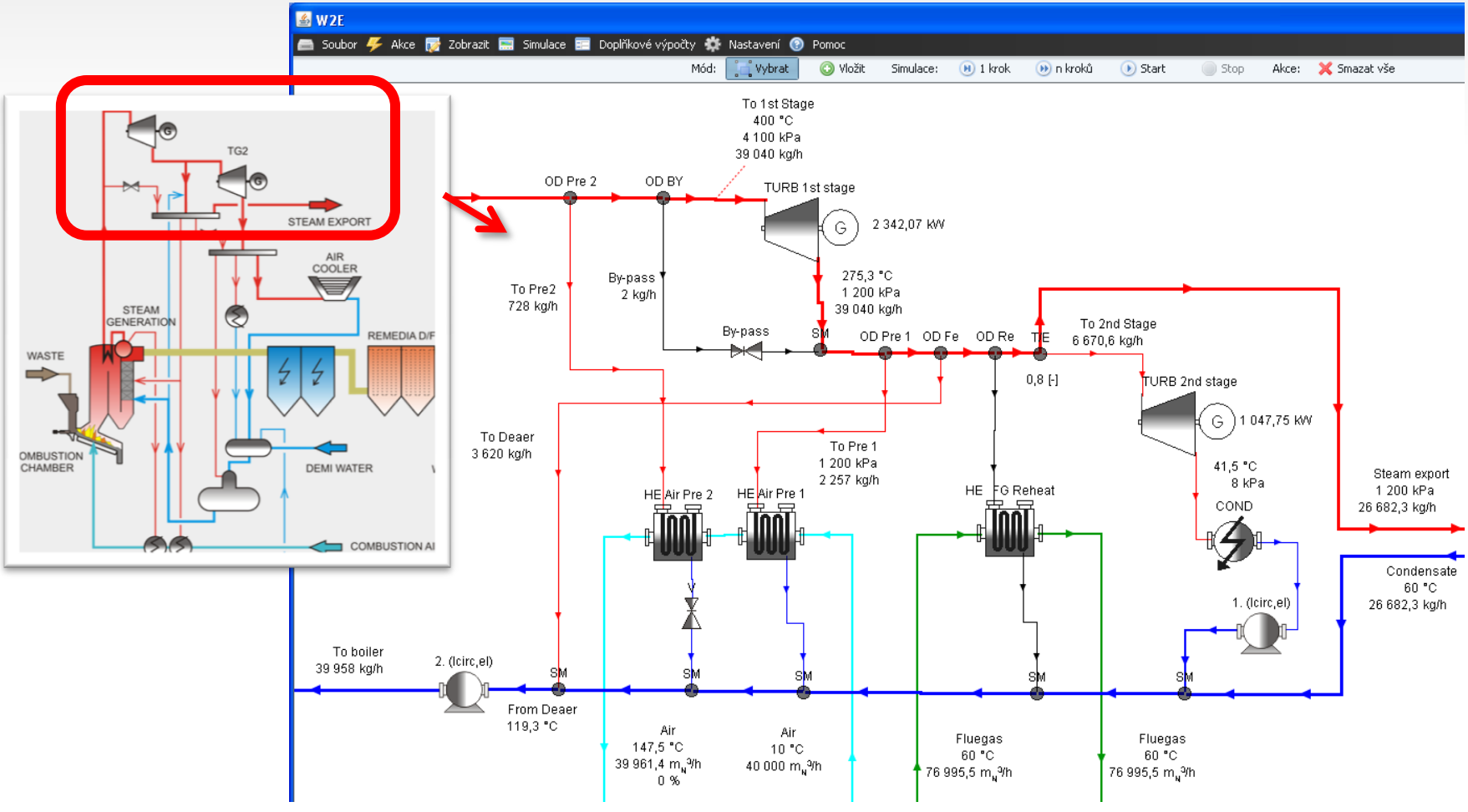


Grass-root design

# *Lower capacity units – visualization*

… and where an acceptable architectural design is needed …

# Computational support
# Simulation software W2E



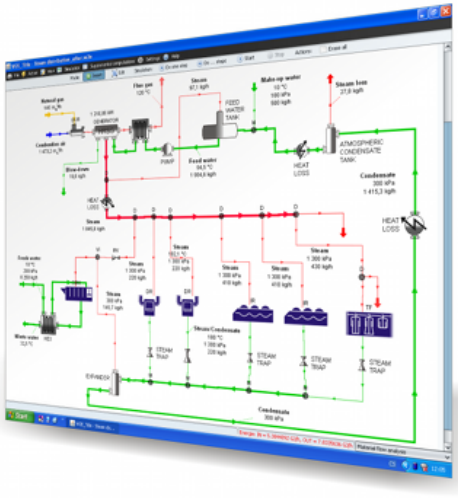
# *Simulation software W2E*

upei.fme.vutbr.cz/w2e/english

## Waste to Energy (W2E) Software

CZECH VERSION

### What is W2E?



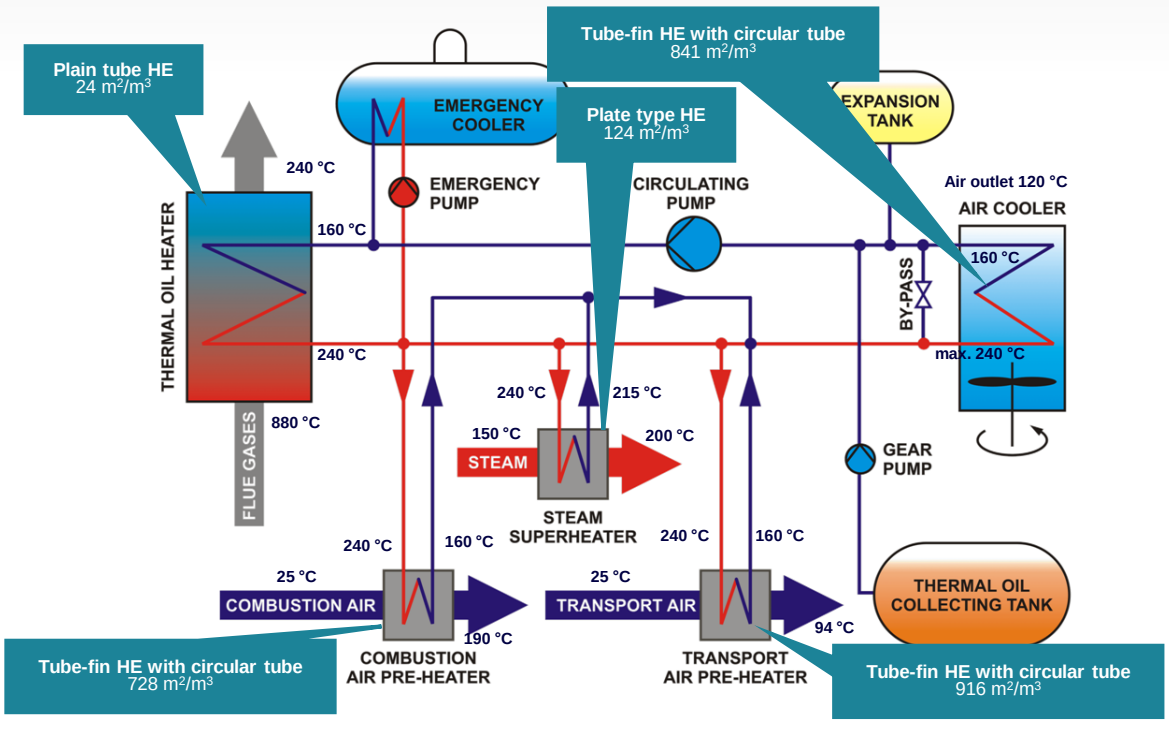
Waste to Energy (W2E) software represents a sequential modular simulation tool denoted for heat and mass balance calculation of units in the field of waste and biomass utilization for energy production. It can be characterized as opened system, i.e. it can be easily improved in terms of new model addition in the future. It is mainly created for rapid engineering calculations providing technological and basic construction data. It can be effectively utilized as a supportive tool for research and development in this field as well as dissemination tool making the results of research accessible for industrial practice. The software is characterized by user-friendly interface composed of drawing canvas and interactive editor used for model creation and calculation boundary condition setting, respectively.

# *Technology & Equipment*
# *Industrial case*

**Incinerator for treatment of sludge from refinery** with capacity of 2 × 6.1 t/h (4.1 t/h of sludge and 2.0 t/h of oil slurry)

# Energy recovery - industrial case

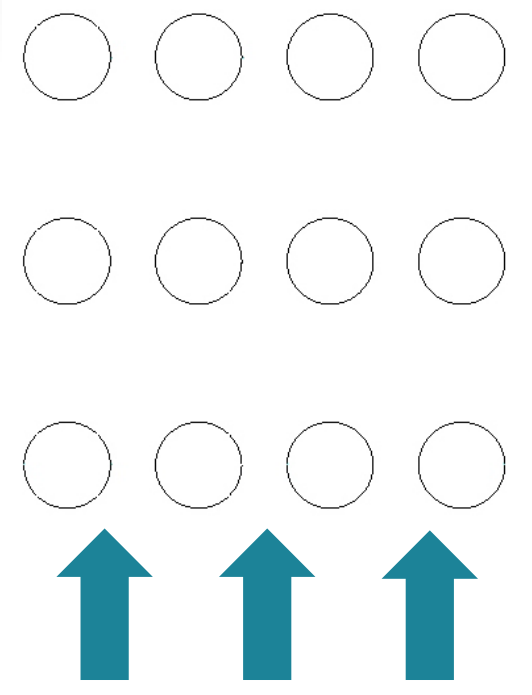
4 MW cross-flow recuperative HE (two 2 MW tube banks) with thermal oil being used as a heat carrier:




# *Extremely heavy fouling*

Heavy fouling in the “flue gas – thermal oil” heat exchanger:

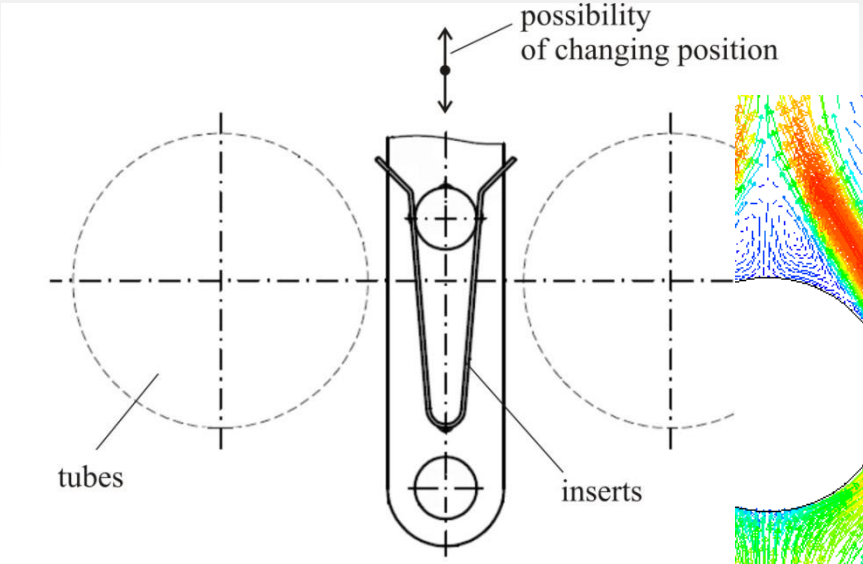
In-line tube bank:



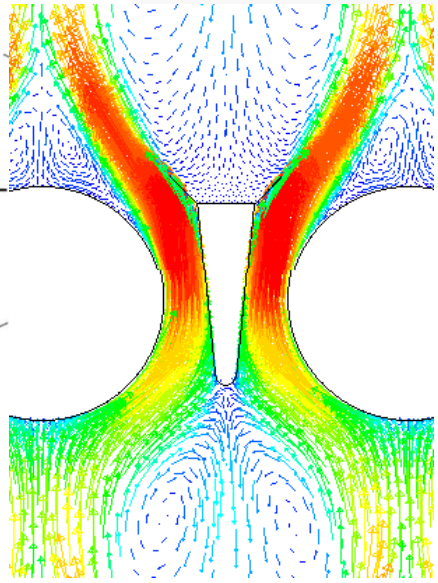
Flue gas flow

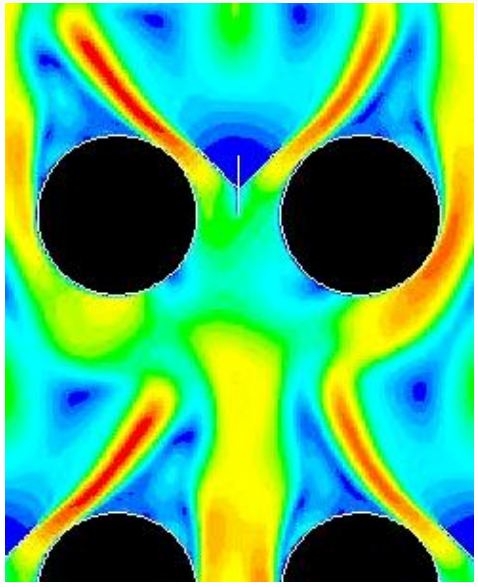
# *Preventive solution*

Inserts for improved auto-cleaning capability




Inserts + CFD = favourite economic evaluation

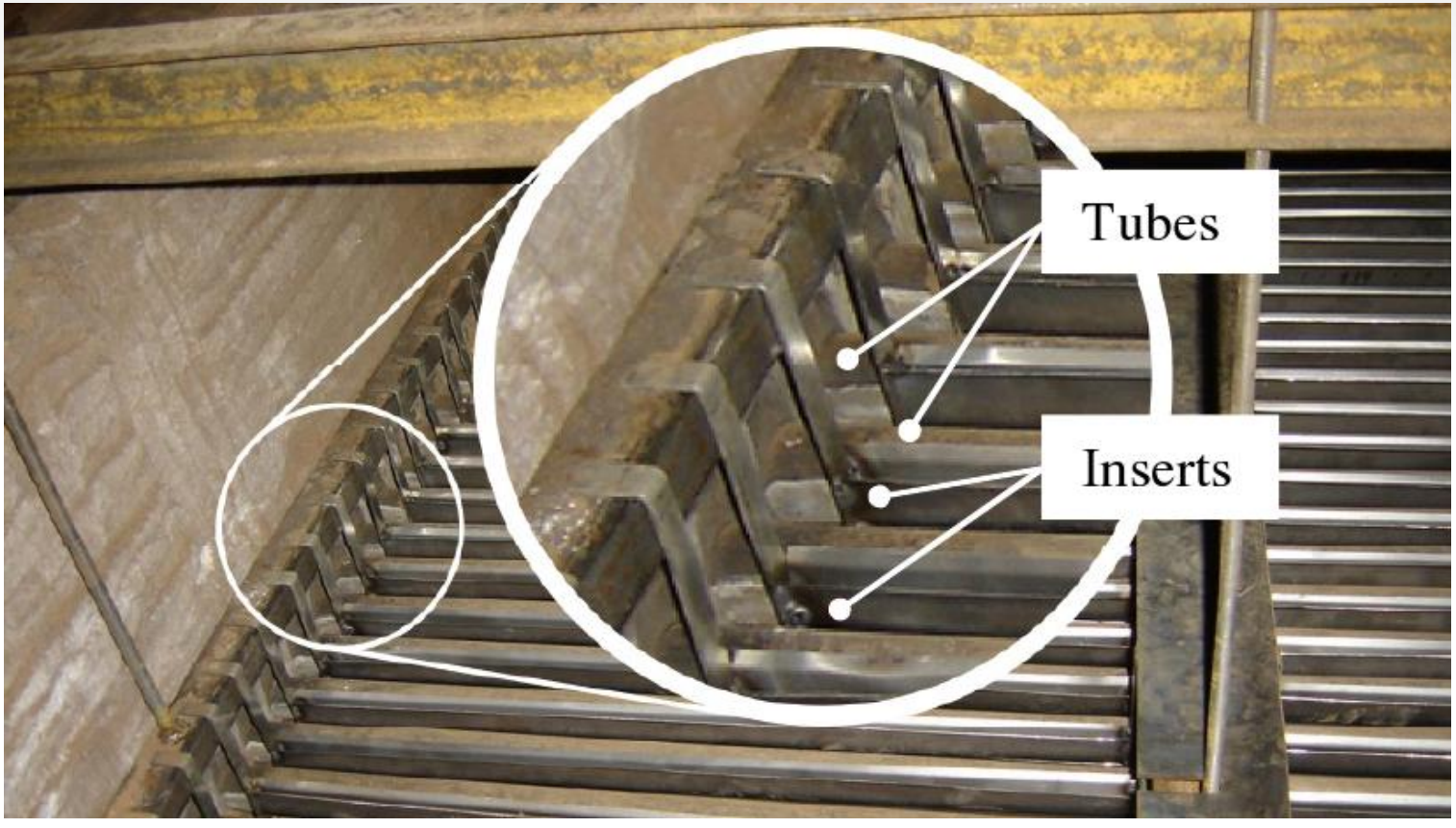




Example of passive enhancement approach for improved auto-cleaning capability in applications with highly fouling flue gas containing high amounts of ash particles (Courtesy of EVECO Brno Ltd)

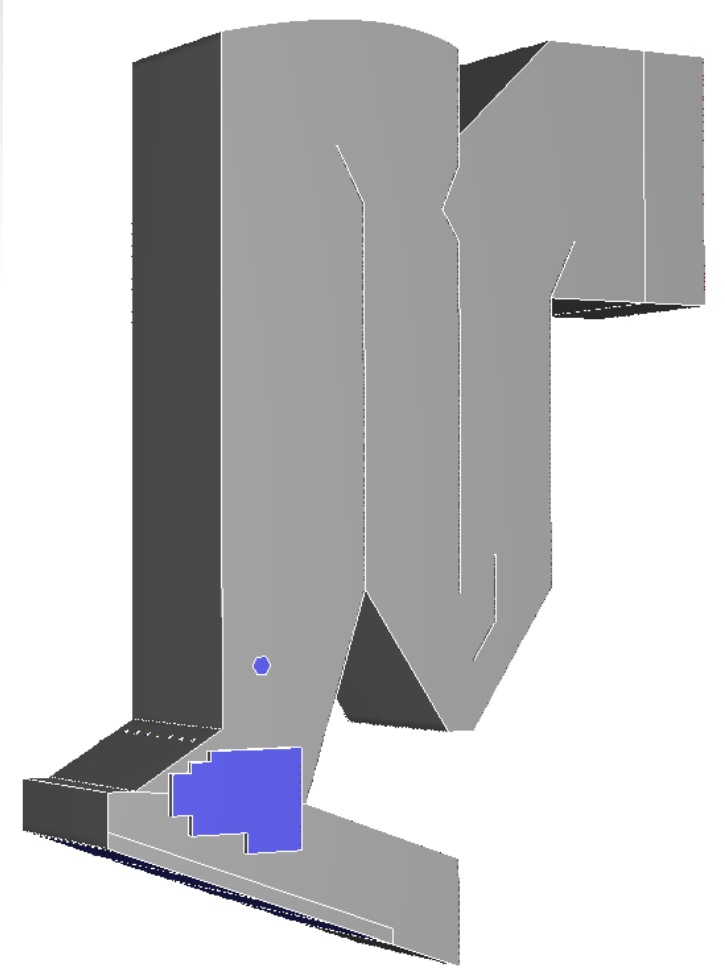
# *Preventive solution*

Tube bank inserts as a customized solution:



# *Emissions reduction: Boiler of a MSW incinerator (DeNOx)*

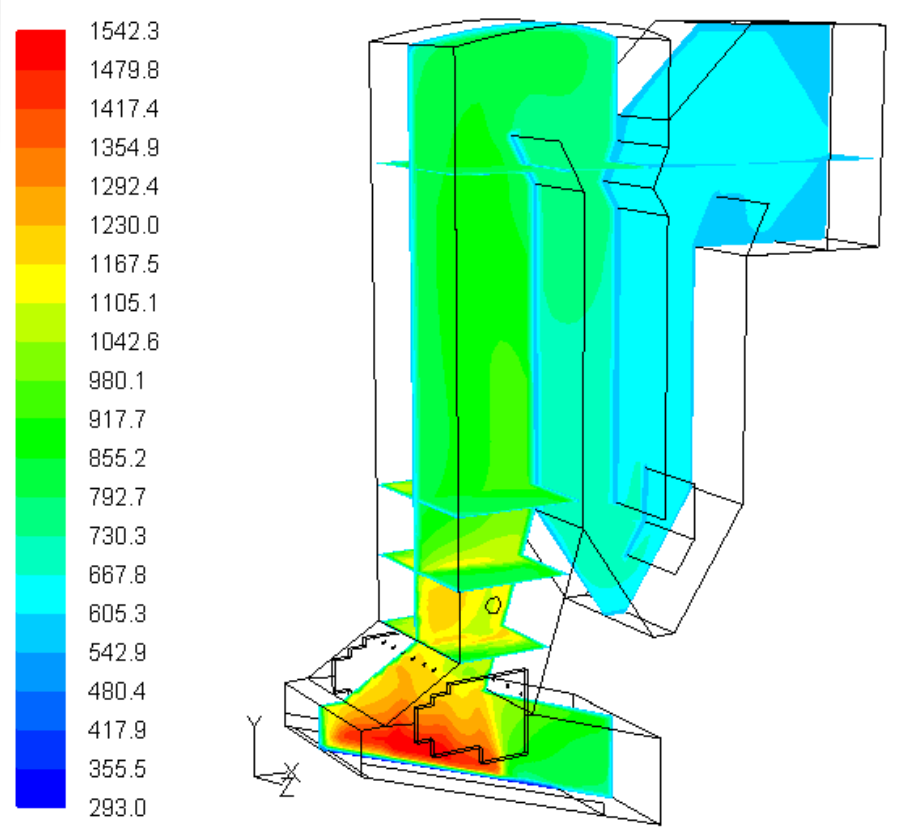
Outline of MSWI boiler – side view:

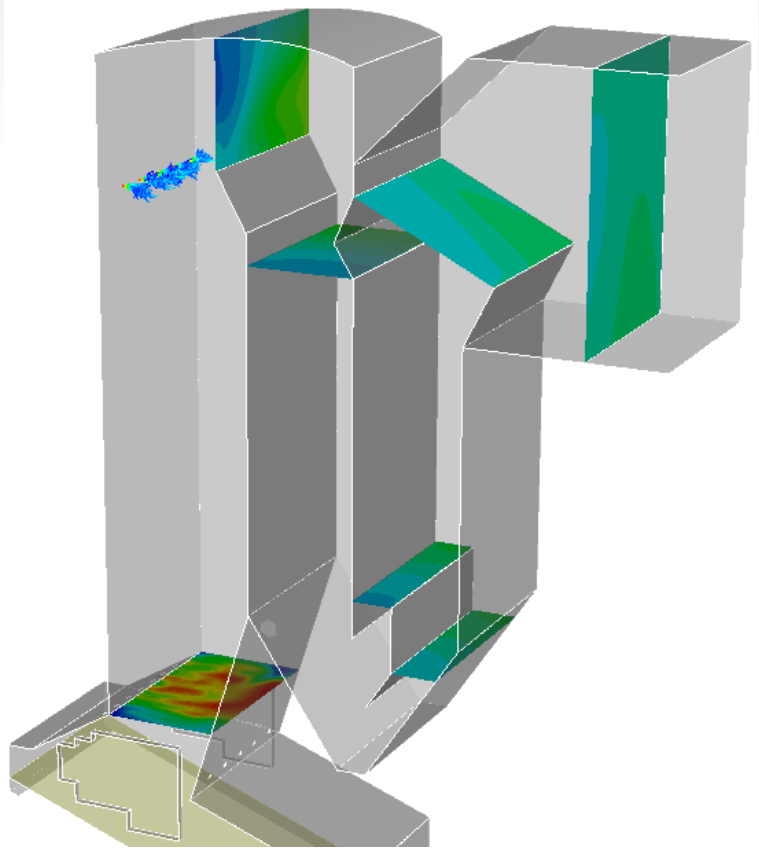


MSWI plant – photo:

# *CFD-supported design of SNCR system*

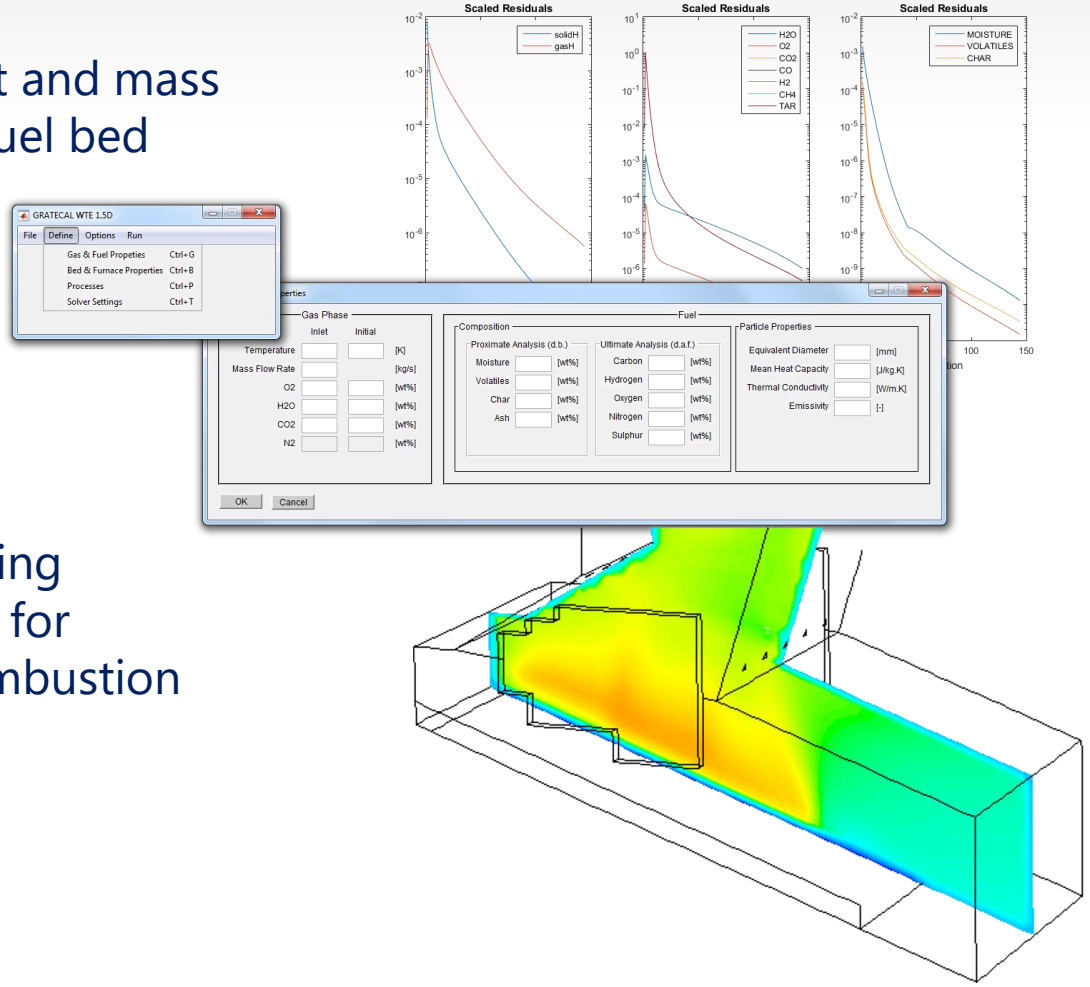
CFD prediction of SNCR system performance



# *Grate design: GRATECAL WTE 1.5D*

- Numerical tool for simulation of solid fuel combustion in grate-fired furnaces
- Numerically solves heat and mass transfer within a solid fuel bed
- Analyses thermal conversion of solid fuel bed including evaporation, pyrolysis, char oxidation and homogenous reactions
- Enables two-way coupling with external CFD code for iterative solution of combustion in a grate-fired furnace



# HGA (Hot Gas Applications) database ZJ

## HGA DATABASE

### Conventional types

- Segmental baffles
- Helical baffles
- Rod baffles
- Orifice baffles
- Twisted tubes

- Shell-and-Tube
- Double-Pipe
- Plate-Type
- Heat-Pipe

| | | |
|---|---|---|
| Process fluid | Hot | flue gas |
| | Cold | air |
| Inlet temperature | Hot | greater than 850 °C |
| | Cold | less than 200 °C |
| Inlet pressure | Hot | atmospheric pressure |
| | Cold | atmospheric pressure |
| Fouling | Hot | dust |
| | Cold | none |
| Temperature fluctuation | Hot | high fluctuation |
| | Cold | minimum fluctuation |

### Special types

- Coaxial heat exchanger
  - Simple
  - W. regenerative layer
- Double U-tubes
- Sludge aplications
  - Water – Sludge
  - Flue gas - Sludge
- Radiation recuperator

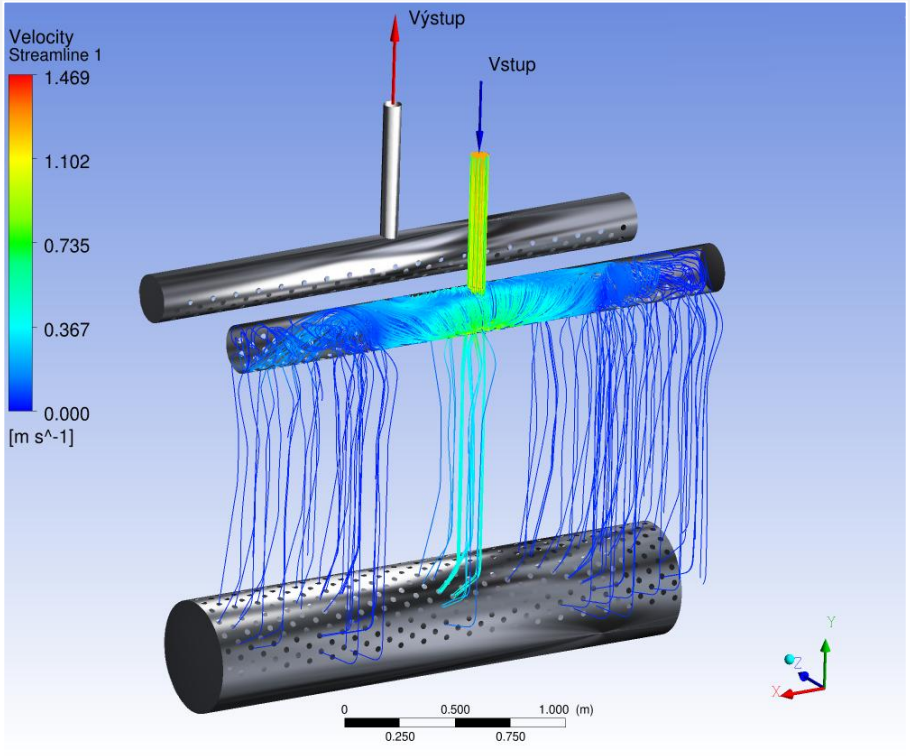
# *Troubleshooting and retrofit of a HRSG evaporator section*

Damage to tubes of the economizer

Deformation of economizer tubes

Locations of damage - cracks

# *Troubleshooting and retrofit of a HRSG evaporator section*




Path-lines corresponding to flow in the "correct" direction

Discovered facts:

- **Inappropriate routine over-design** of the economizer, low flow velocity
- CFD simulation pointed to incorrect functioning of the inlet distributor and outlet collector
- **Largely uneven flow distribution (even flow reversal)** caused significantly different dilatations of groups of tubes in the bundle

# *Industrial burners – design and simulations*

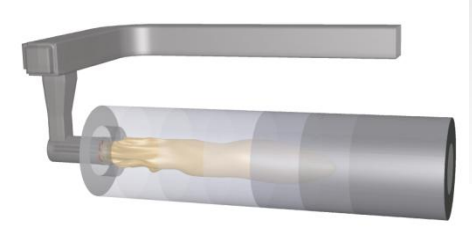
**Burner design:**

- Gas and oil burners
- Ultra Low $NO_x$
- For combustion of low-calorific gaseous and liquid fuels including waste products

**Simulations:**

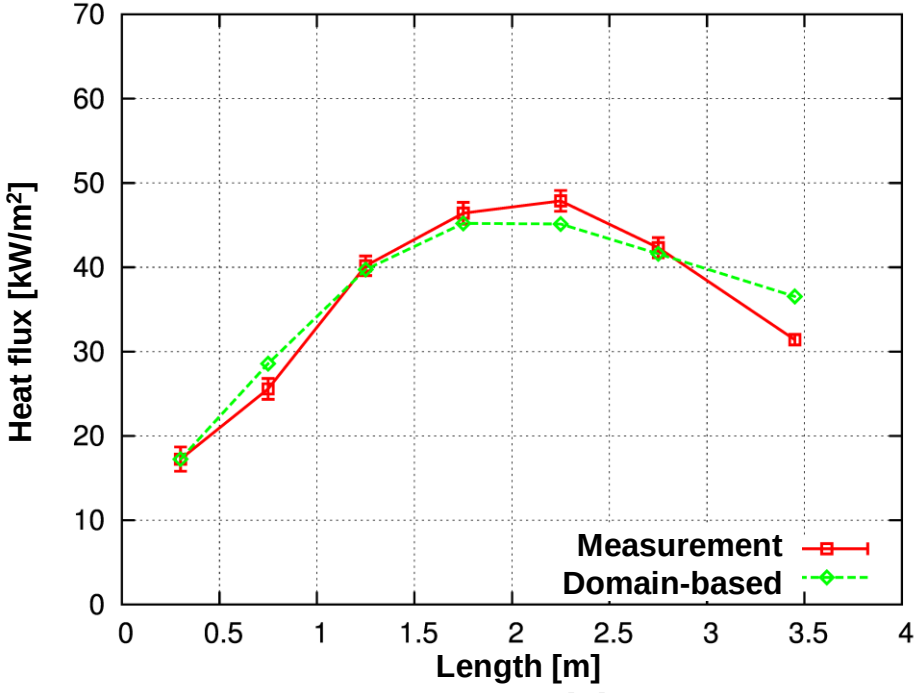
- Mathematical models for $NO_x$ prediction
- Swirl combustion
- Virtual prototype testing

# *Simulation of industrial gas-staged burner - Validation of an appropriate model*



Unsteady model (U-RANS), turbulence k-ω, EDM, DO, WSGGM (modified) domain-based

- Convergence in each time step
- Good agreement of prediction with measurement (total and local heat fluxes)



# *Troubleshooting of liquid fuel atomization*

**Original nozzle**

- Angle of atomized liquid: 5°
- Break up into droplets: 130 cm

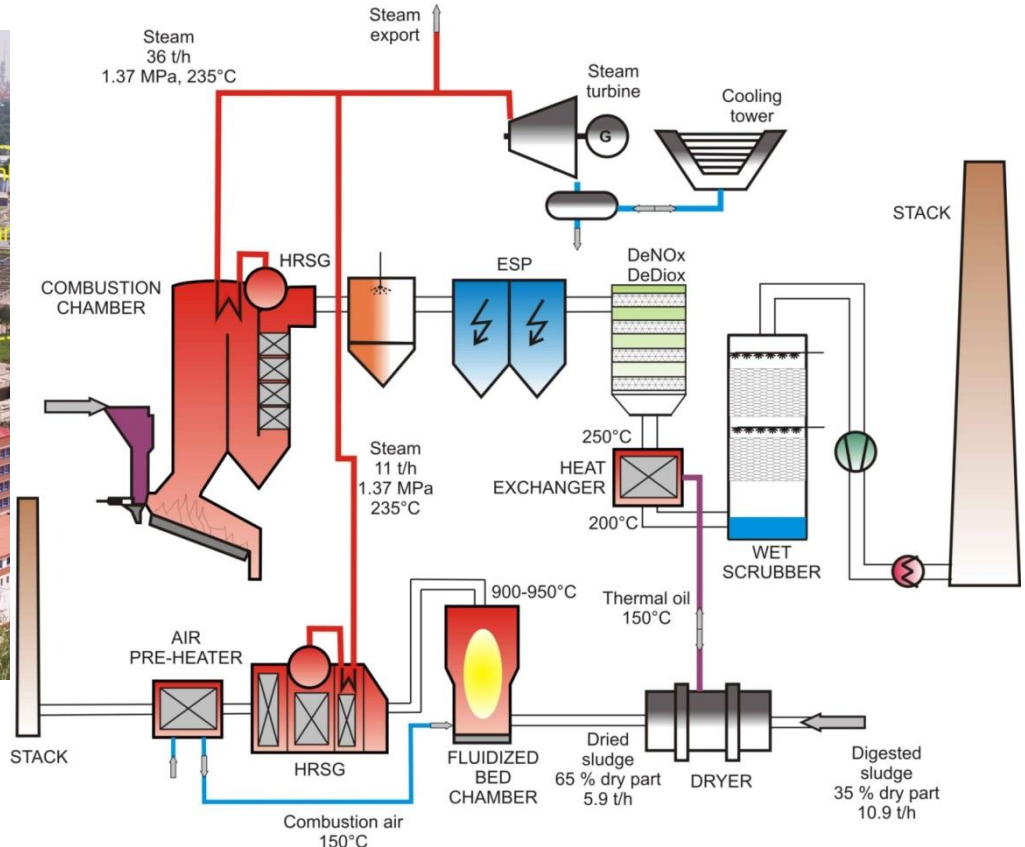
**Newly designed nozzle (effervescent)**

- Angle of atomized liquid: 25°
- Break up into droplets: immediately

# *Last but not least:* ***Sewage sludge treatment***

## Study on conceptual development of sludge treatment from WWTP Prague

- Thermal treatment of digested sludge within the area of WWTP ( 2004)
- Integration with existing WtE Plant technology (300 kt/y) (synergic effects – waste heat from WtE is utilized for sludge drying; common steam utilization within cogeneration system; transport issues, 2008)
- Analyzing sludge utilization alternatives in remote area (2009)

# *Conclusions*

- **Effective utilization of results of research and development** based on using
  up-to-date computational tools, experimental approach, feedback from industrial and municipal spheres
- **Complex approach**
  - Conceptual + detailed design
  - From idea to industrial application
  - Industrial experience and “know-how”
  - Sophisticated approach
- **References**
- **Tailor-made solutions**