第八次生活垃圾焚烧处理技术与设备研讨会

中国城市生活垃圾焚烧与低碳发展论坛

2019年9月27日 | 西安

主题报告 | 赵岩副教授，北京师范大学环境学院

生命周期环境影响视角下的生活垃圾焚烧系统评估

China Integrated Waste Management NAMA

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

中国城市环境卫生协会
China Association of Urban Environmental Sanitation

NAMA Facility

Incineration system of municipal solid waste from a life cycle assessment perspective

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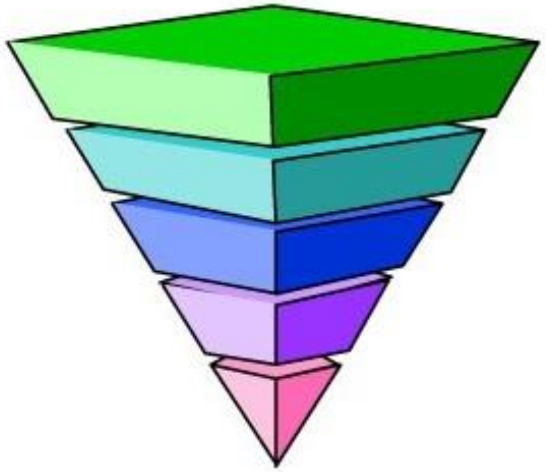
Outlines

- Life cycle and environmental impact assessment of solid waste systems
- Energy issues in solid waste systems
- Incineration system of MSW from an LCA perspective

1 LCA of waste systems

Waste hierarchy

- Waste management has in the last decades in many countries been governed by the WASTE HIERARCHY

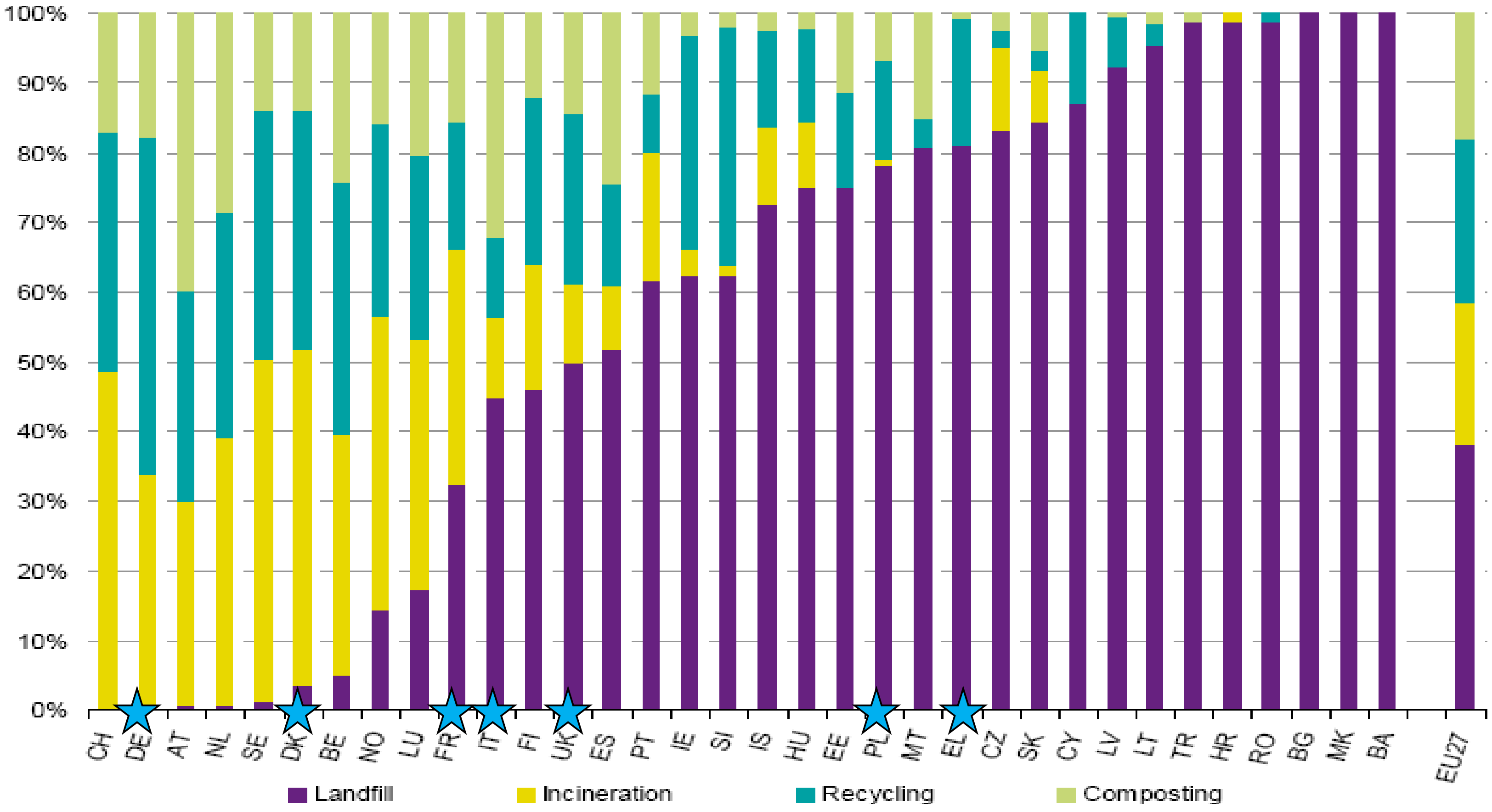


- Prevention, avoidance
- Material recycling
- Utilization
- Landfilling

- Environmental impact from waste management is an important indicator for technology and system evaluation

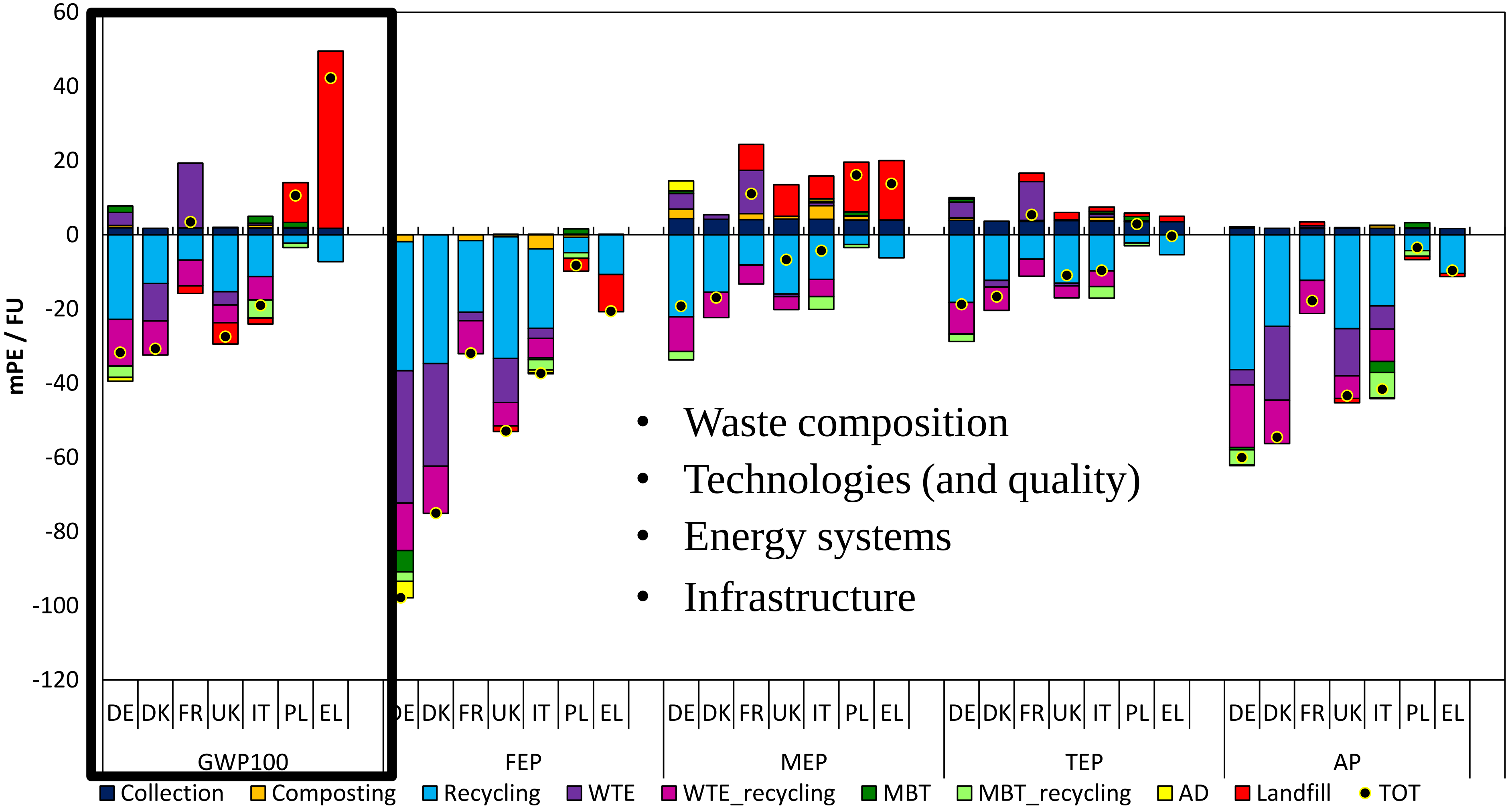
1 LCA of waste systems

Waste Management Strategy in Europe



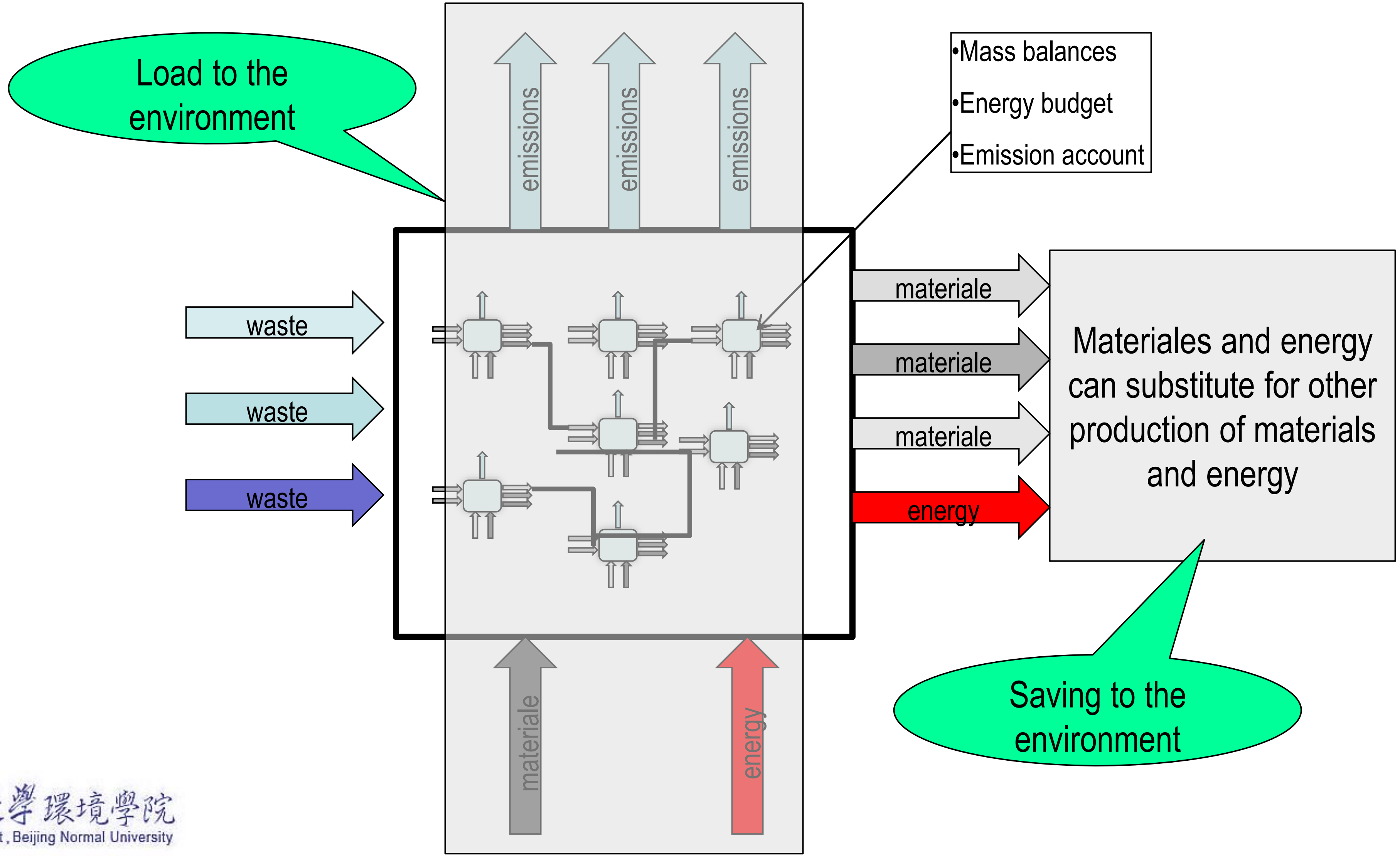
1 LCA of waste systems

Waste Management Strategy in Europe



- Waste composition
- Technologies (and quality)
- Energy systems
- Infrastructure

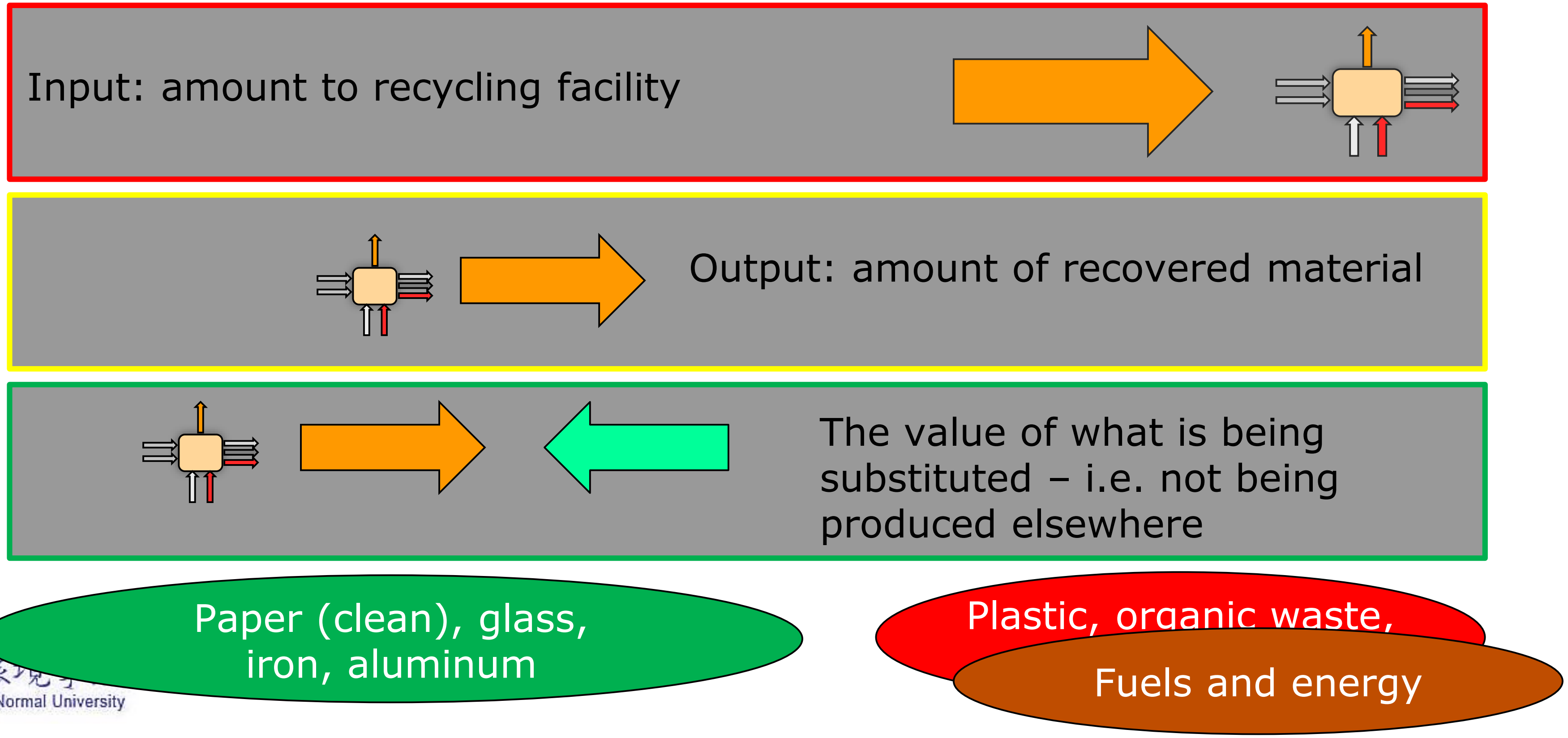
1 LCA of waste systems



1 LCA of waste systems

How is recycling addressed

- According to the Hierarchy, a high recycling percentage is good
- In a life-cycle context the achievements are differently defined

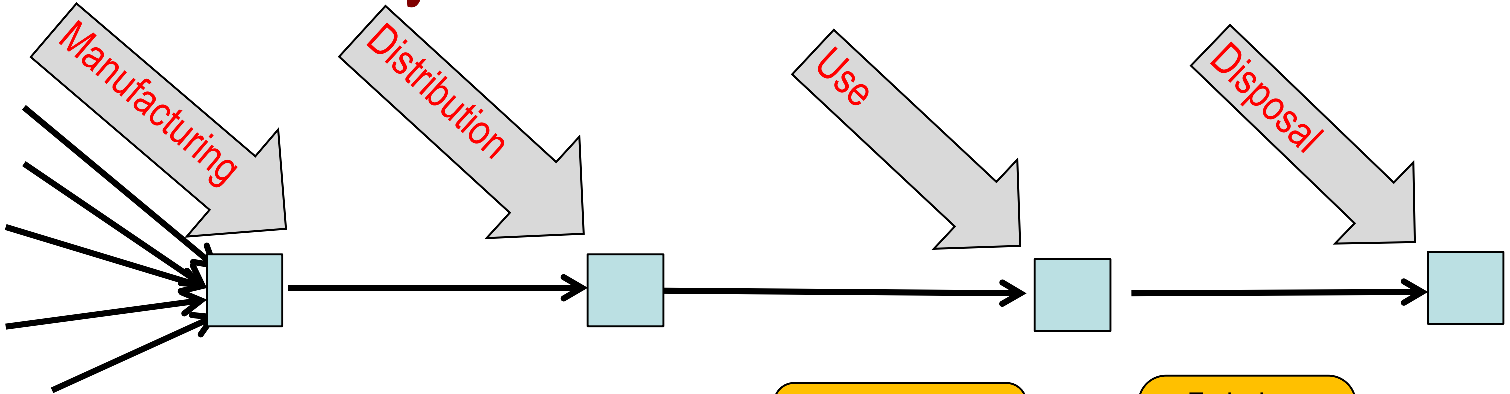


1 LCA of waste systems

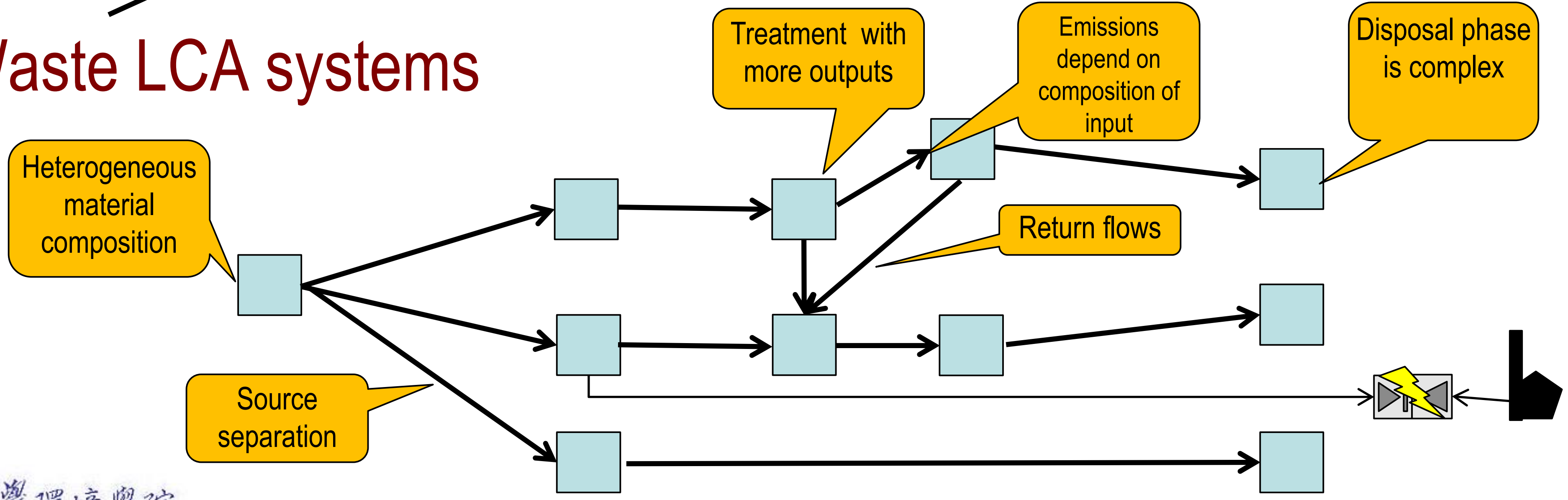
- Life cycle assessment (LCA)
  - In 1980's LCA was introduced to address environmental issues of a product in all its life stages, "Cradle-to-grave"
  - Accounts for all resource uses and environmental emissions for the main system (operation), all upstream activities and all downstream activities
  - Aggregates all emissions into potential impact categories; global warming potential, etc.
  - Offers normalization to person-equivalents transferring complex issues into understandable units

1 LCA of waste systems

Traditional LCA systems



Waste LCA systems



1 LCA of waste systems

- LCA in waste management is real
  - EU has introduced life-cycle-thinking in their thematic strategies and in the Waste Directive
  - The WASTE HIERARCHY still rules but LCT can be used to address the balance between recycling and utilization
  - LCA reflects the environmental issues much better than the hierarchy and aggregates the complex information into communicable numbers and provides real insight into the system allowing for future improvements in system set up, choice of technology and for operation.

1 LCA of waste systems

- LCA in waste management
  - Used in many cases in EU, USA, Canada, Japan, China etc. (Only UK and USA have governmental LCA tools)
  - Industries (packaging), national government, local government, technology developers
  - A variety of boundaries, impacts and technological data. No consensus about approach
  - Still an approach in its youth although 15 years of age

1 LCA of waste systems

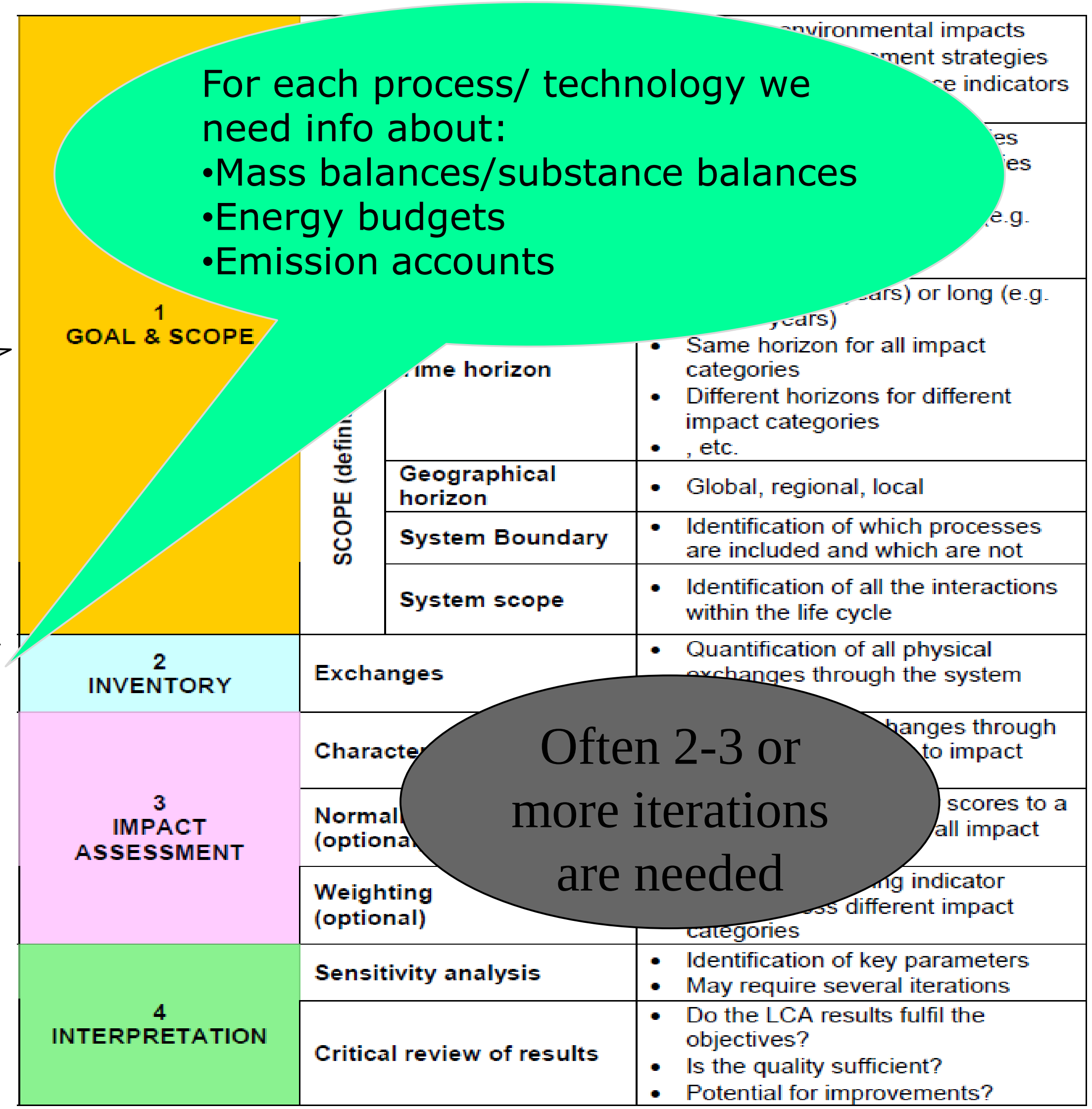
- An LCA consists of four steps

Defines the system so that it addresses the question and allows for comparison

Describes the technical systems, provides data and calculates the overall load from the system

Converts technical results into potential impacts and normalize the results

Interprets the results. Answers the question



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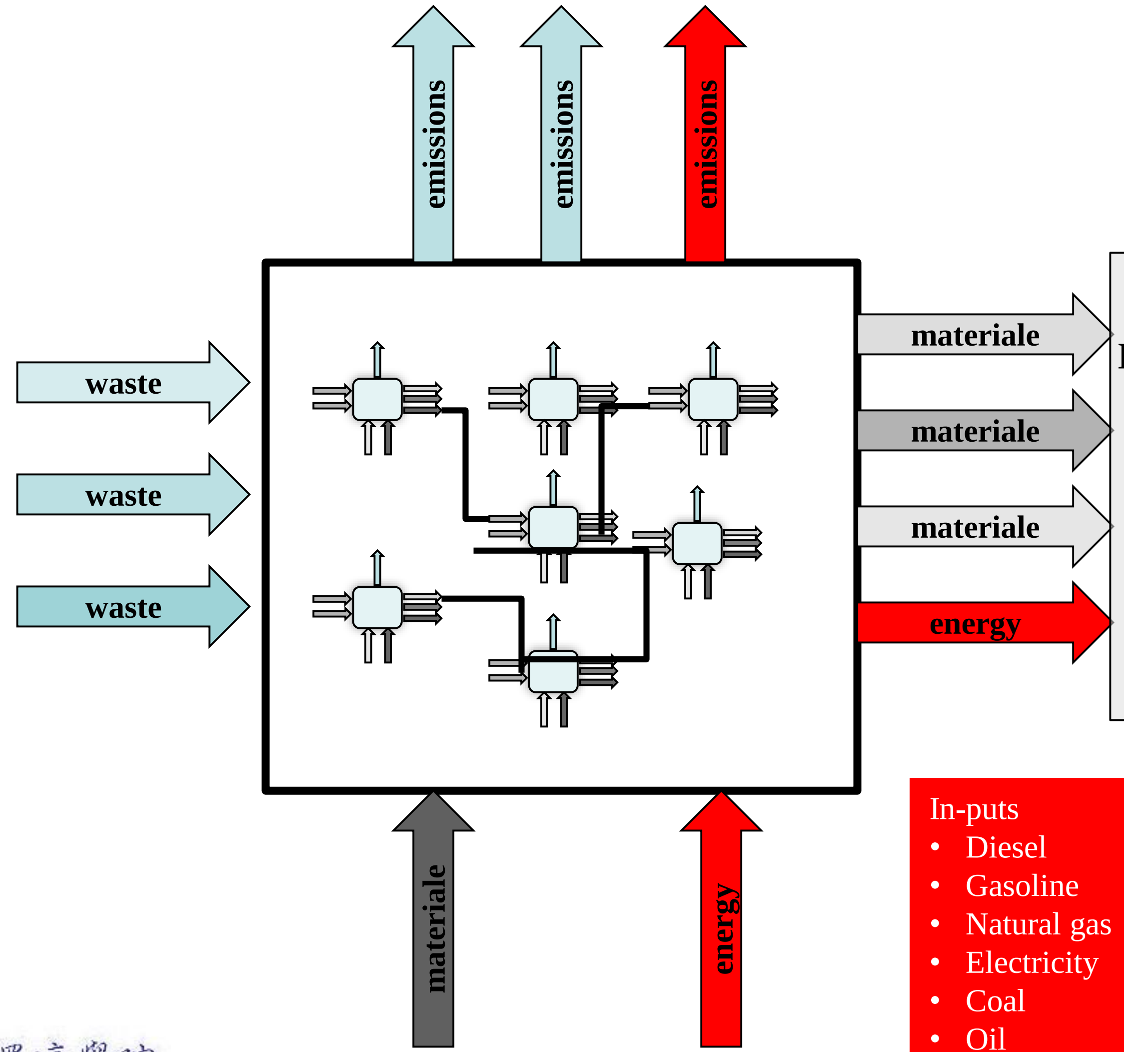
2 Energy issues in waste system



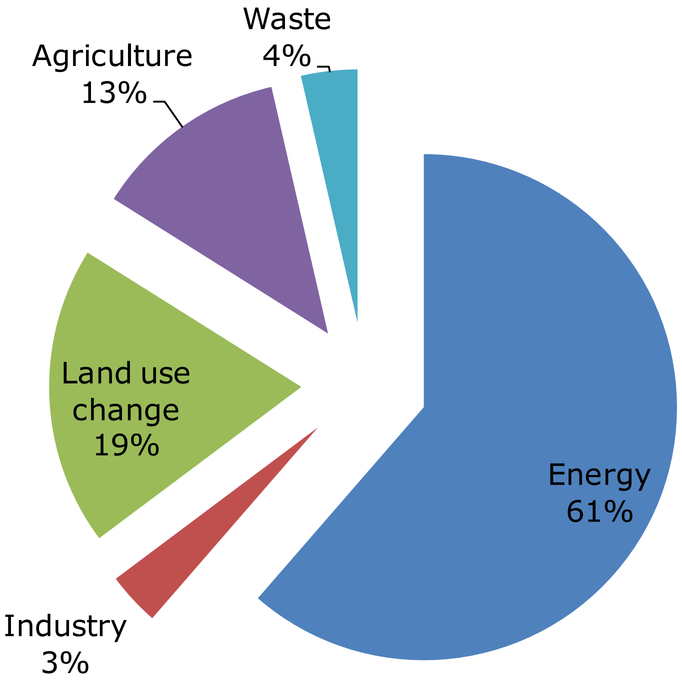
Materiales , nutrients and energy can substitute for other production of materials, nutrients and energy

Out-puts
- Biofuels
- Landfill gas
- Biogas (AD)
- Electricity
- RDF
- Heat

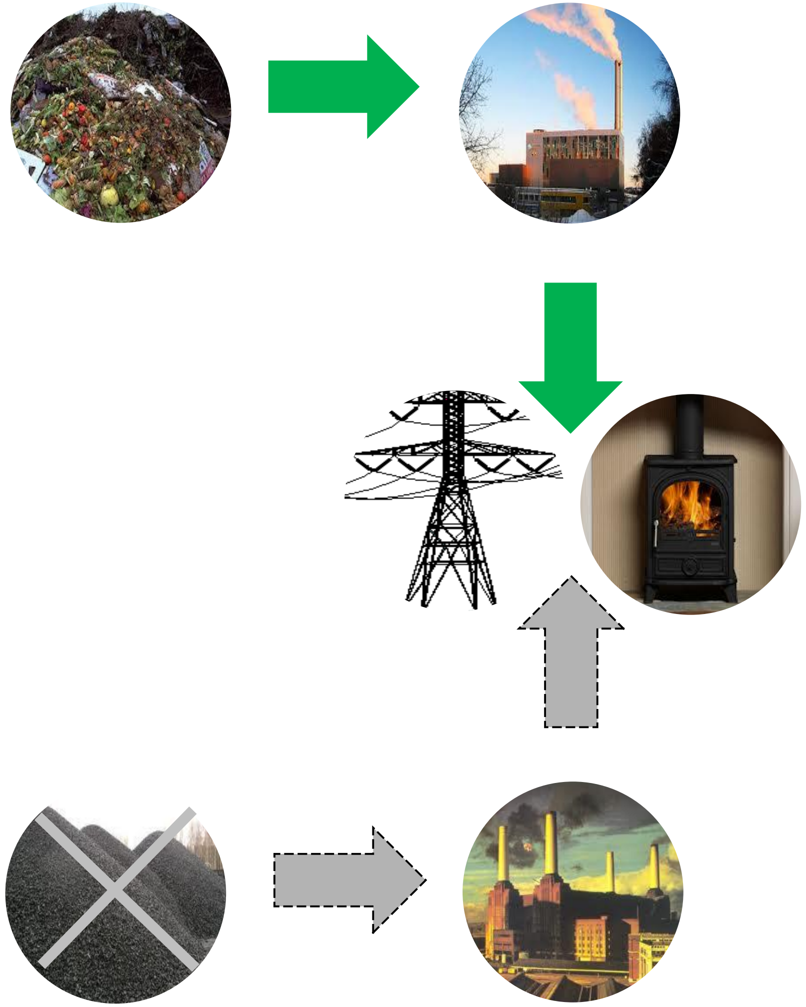
In-puts
- Diesel
- Gasoline
- Natural gas
- Electricity
- Coal
- Oil
- Heat

2 Energy issues in waste system

◻ Interactions Energy-Waste system: GHGs emissions



World Resource Institute 2008:World Greenhouse Gas Emissions: 2000.
Available at: http://www.wri.org/chart/world-greenhouse-gas-emissions-2000.



2 Energy issues in waste system

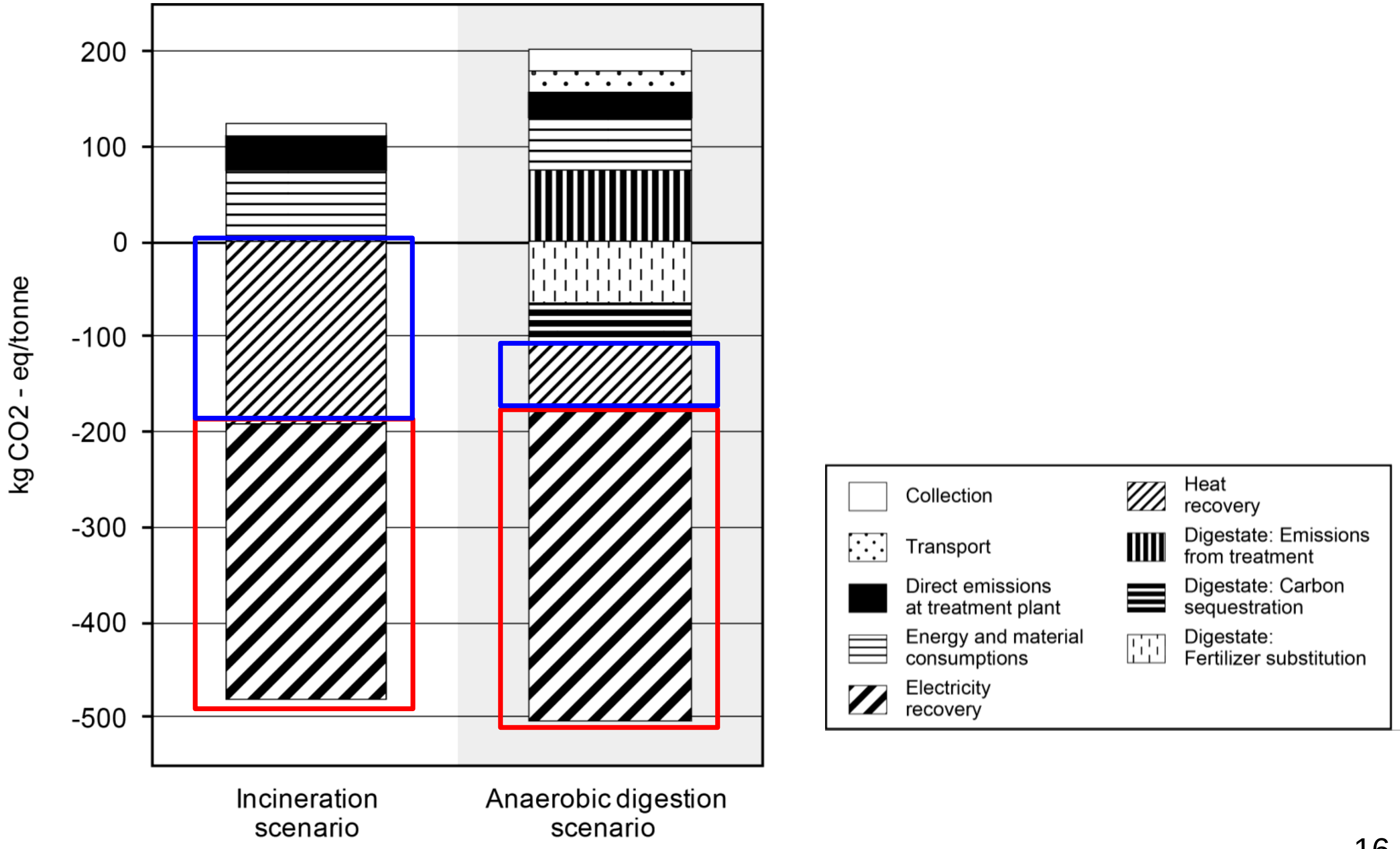
Energy savings are dominating wrt GWP

Example:

Organic waste

to incinerator or

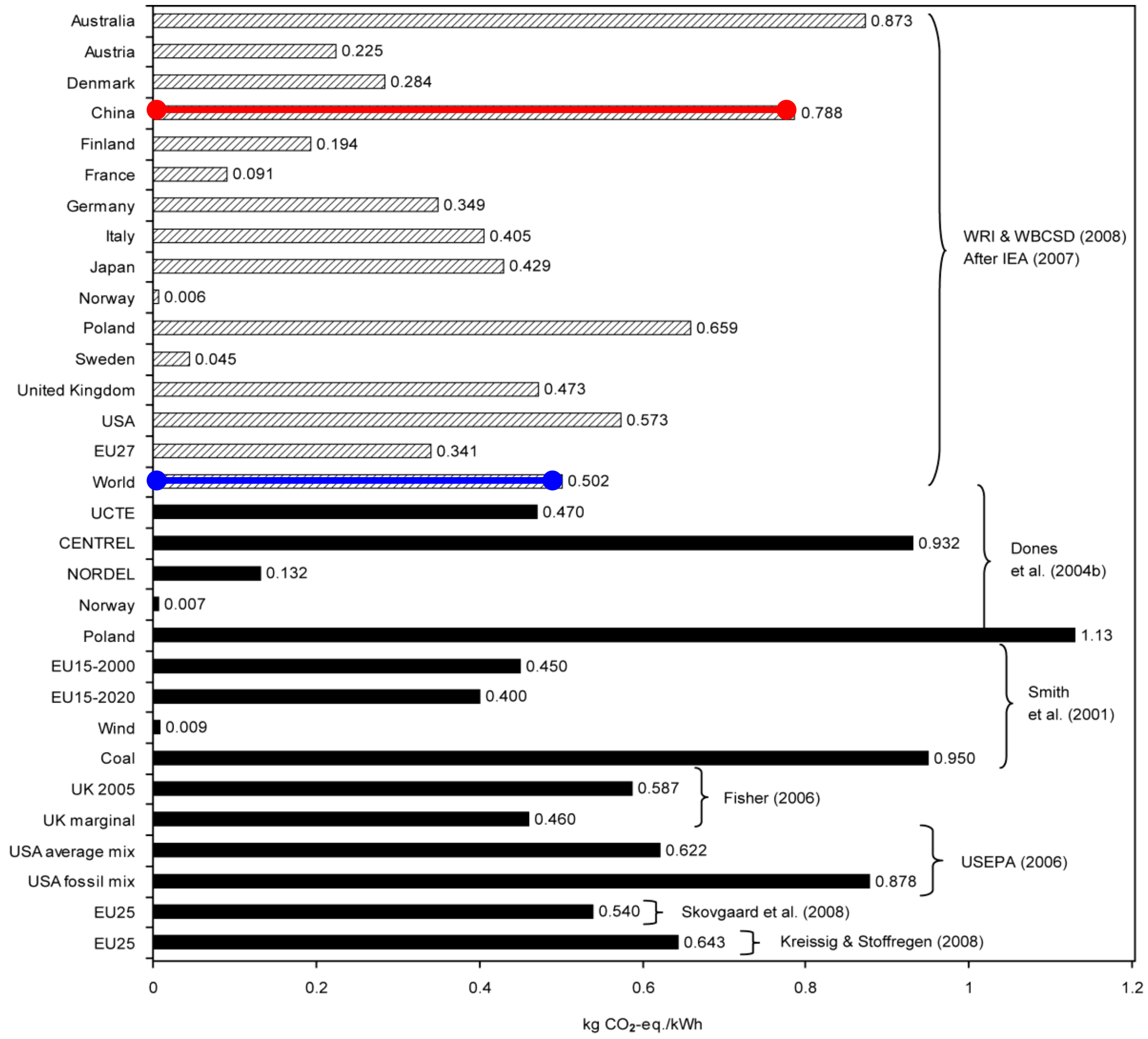
to anaerobic digestion



2 Energy issues in waste system

□ CO_2-emissions from electricity production

Room for improvement in reducing CO_2-emissions



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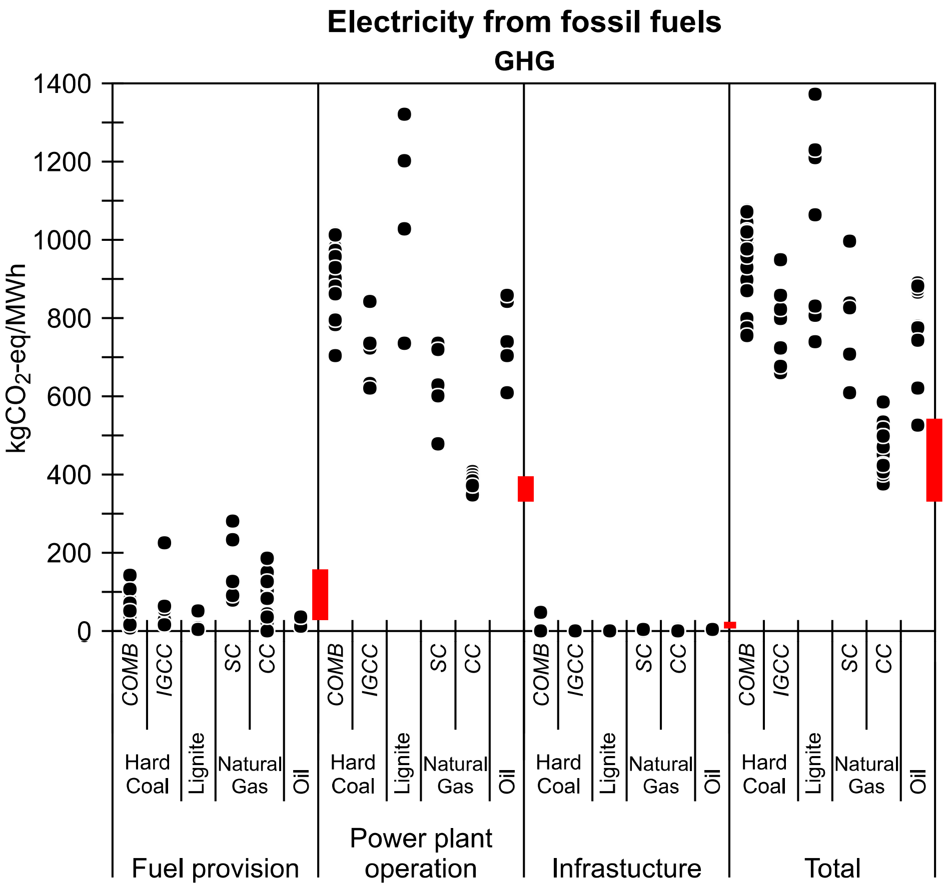
2 Energy issues in waste system

CO_2-emissions from electricity production

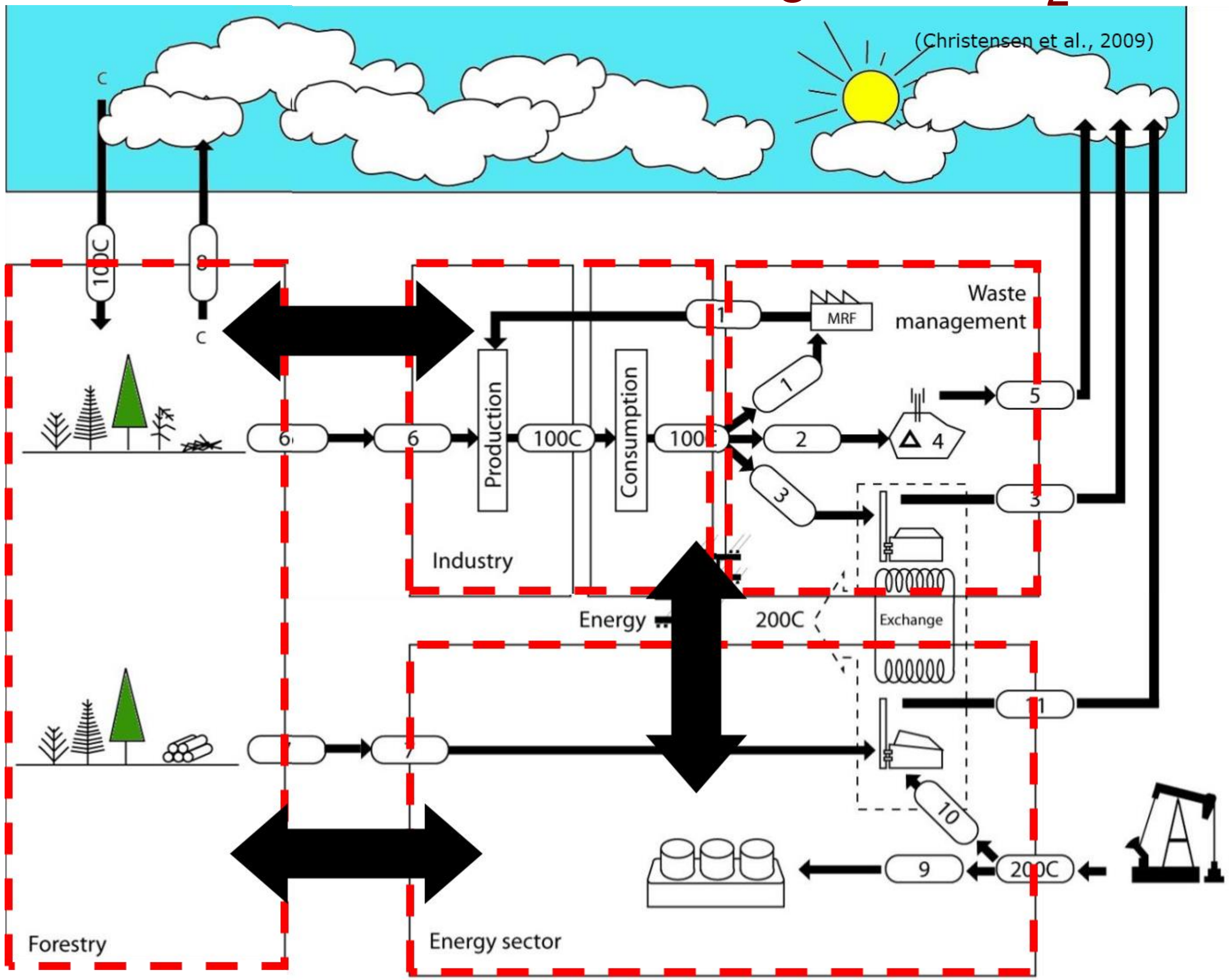


Energy from incineration is much cleaner than most fossil energy

Turconi, R., Boldrin, A., & Astrup, T. F. (2013). Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations. *Renewable and Sustainable Energy Reviews*, *28*, 555-565.

2 Energy issues in waste system

- Important issues in LCA – fossil or biogenic CO_2

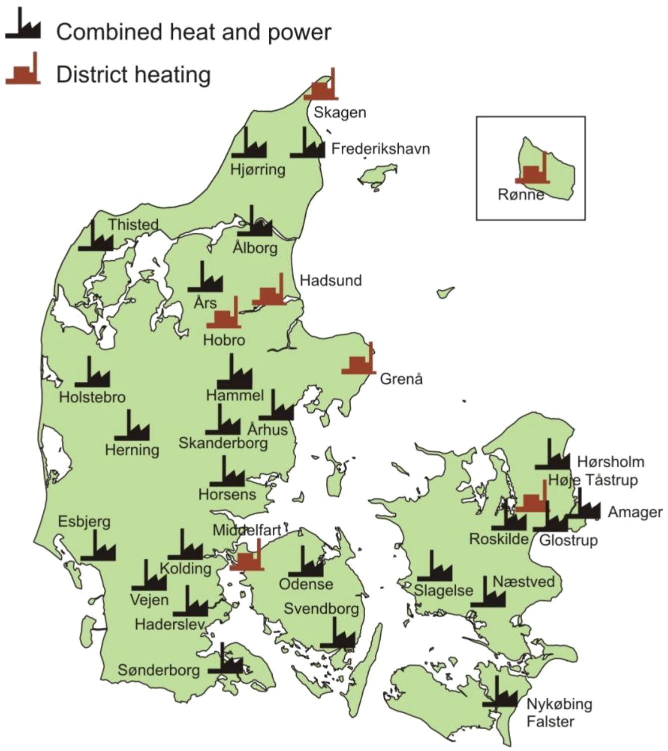


2 Energy issues in waste system

- Important issues in LCA – fossil or biogenic CO_2
  - Biogenic CO_2 is CO_2 neutral (taken up by e.g. forest trees, released again when the wood is incinerated, i.e. emissions equal each other out)
    - GWP = 0
  - Fossil CO_2 is not neutral → net contribution when released since captured millions of year ago
    - GWP = 1
  - C-biogenic bound: biogenic carbon that is bound in soil e.g. in landfill and is not supposed to release for years
    - GWP = - 3.67 kg CO_2-eqivalents/ kg C bound

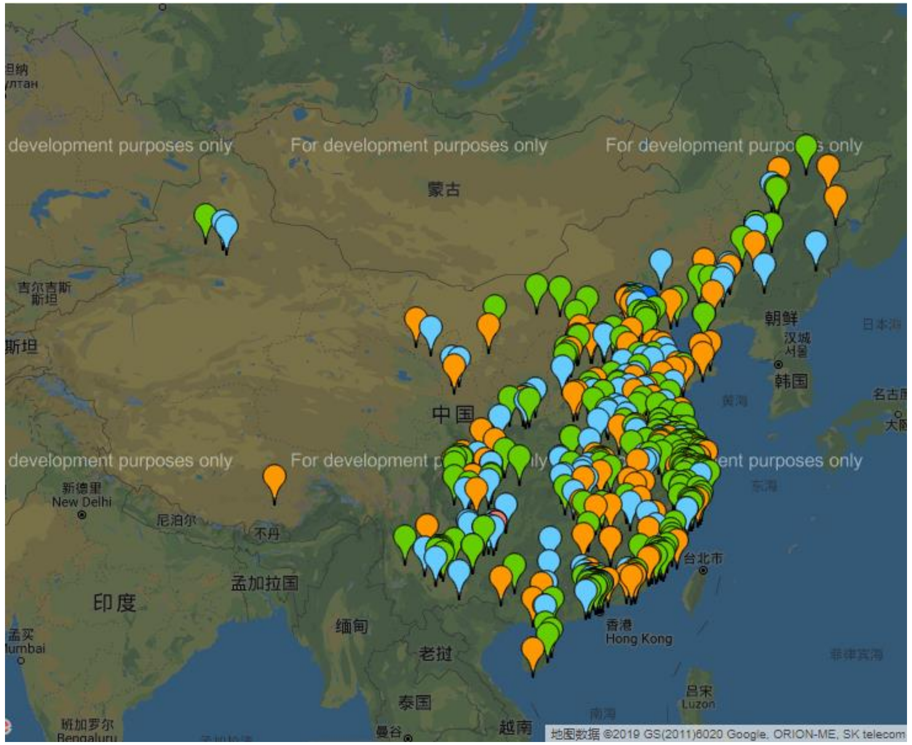
3 Incineration from a view of LCA

- "Incineration" to "Waste to Energy"



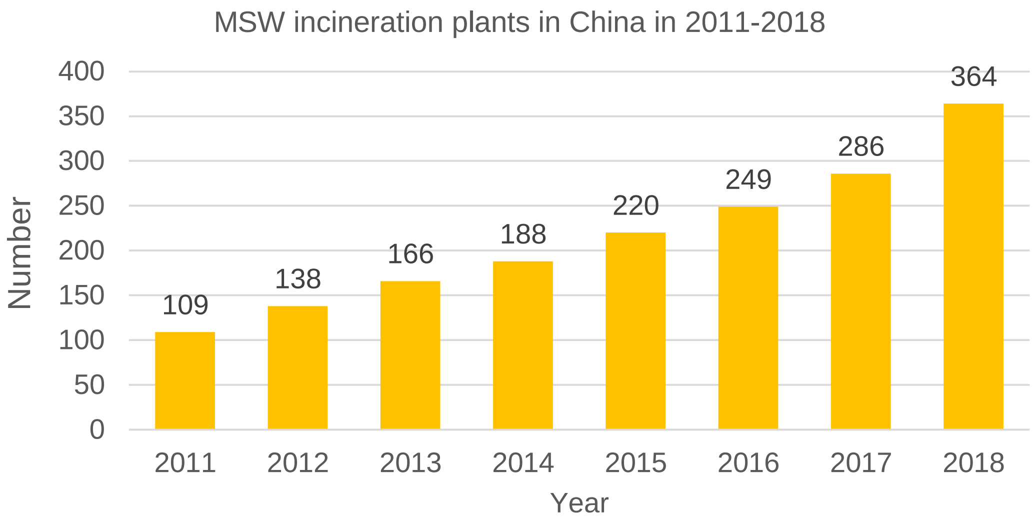
3 Incineration from a view of LCA

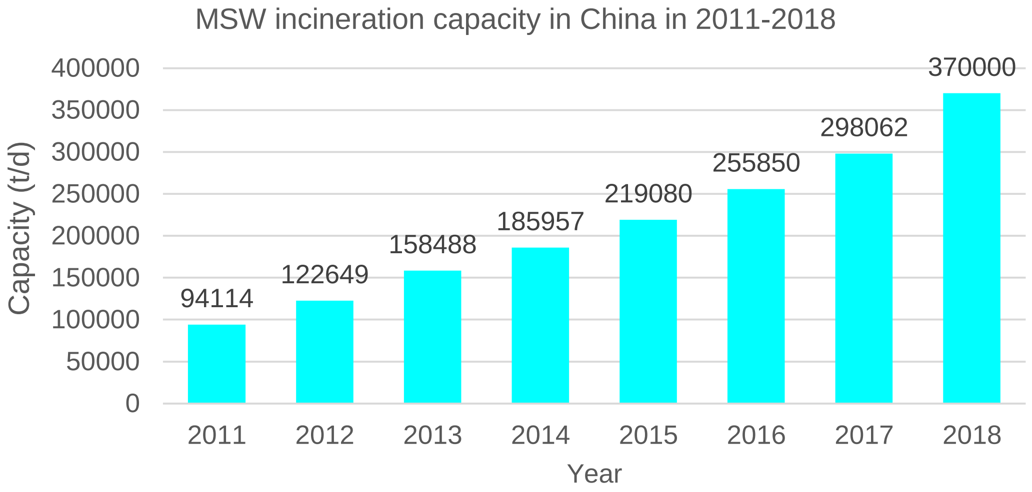
◻ Incineration in China



Running Under construction Proposed

http://www.waste-cwin.org/map/node





3 Incineration from a view of LCA

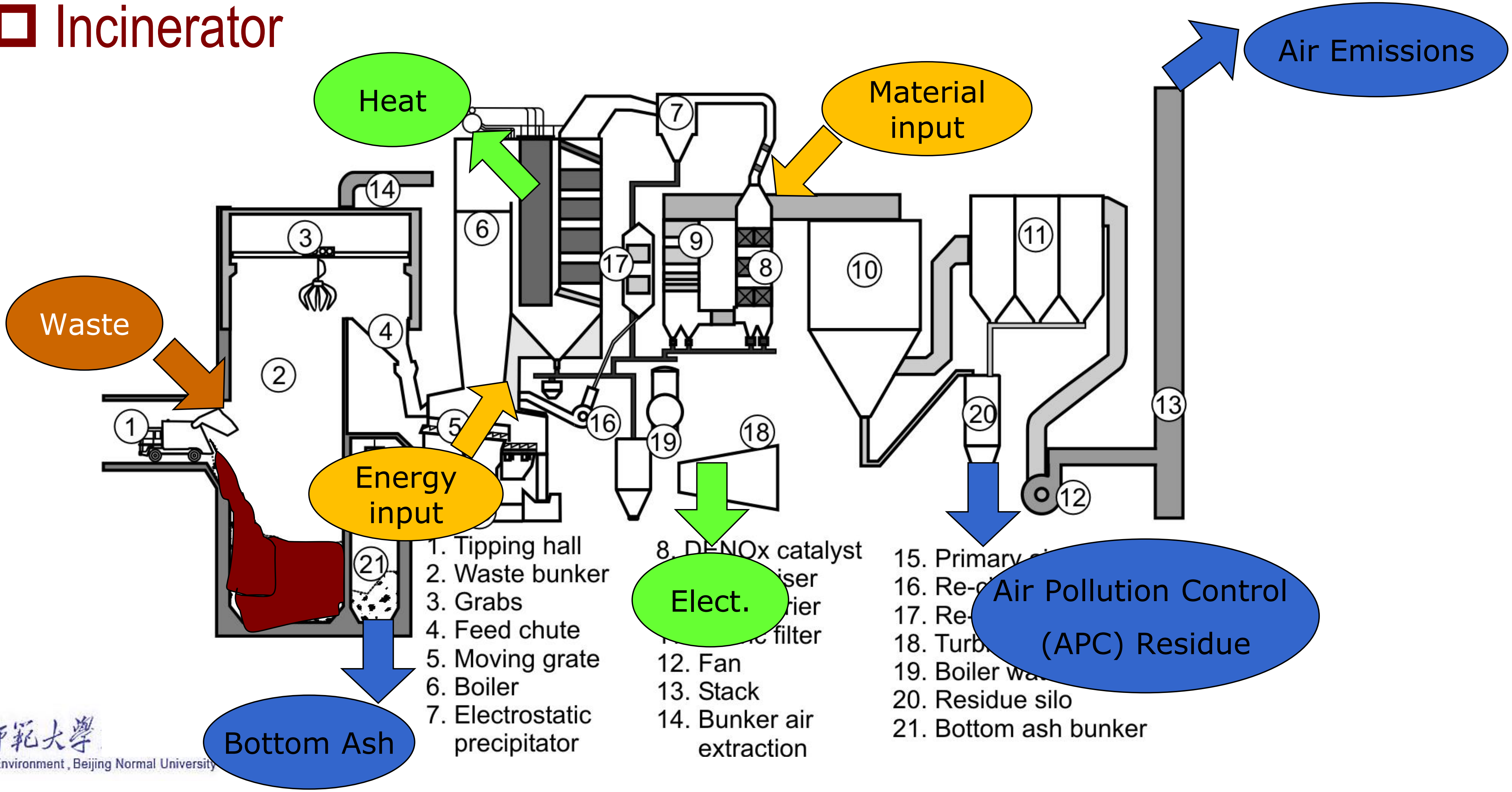
Municipal Solid Waste in Beijing

- Generation in 2015 – 7.90 Mt: Around 21,700 t/d
- Design Capacity of Facilities: 10,350 t/d in 2006 → 21,970 t/d in 2015

Appr. 70% is provided by incineration and biotreatment

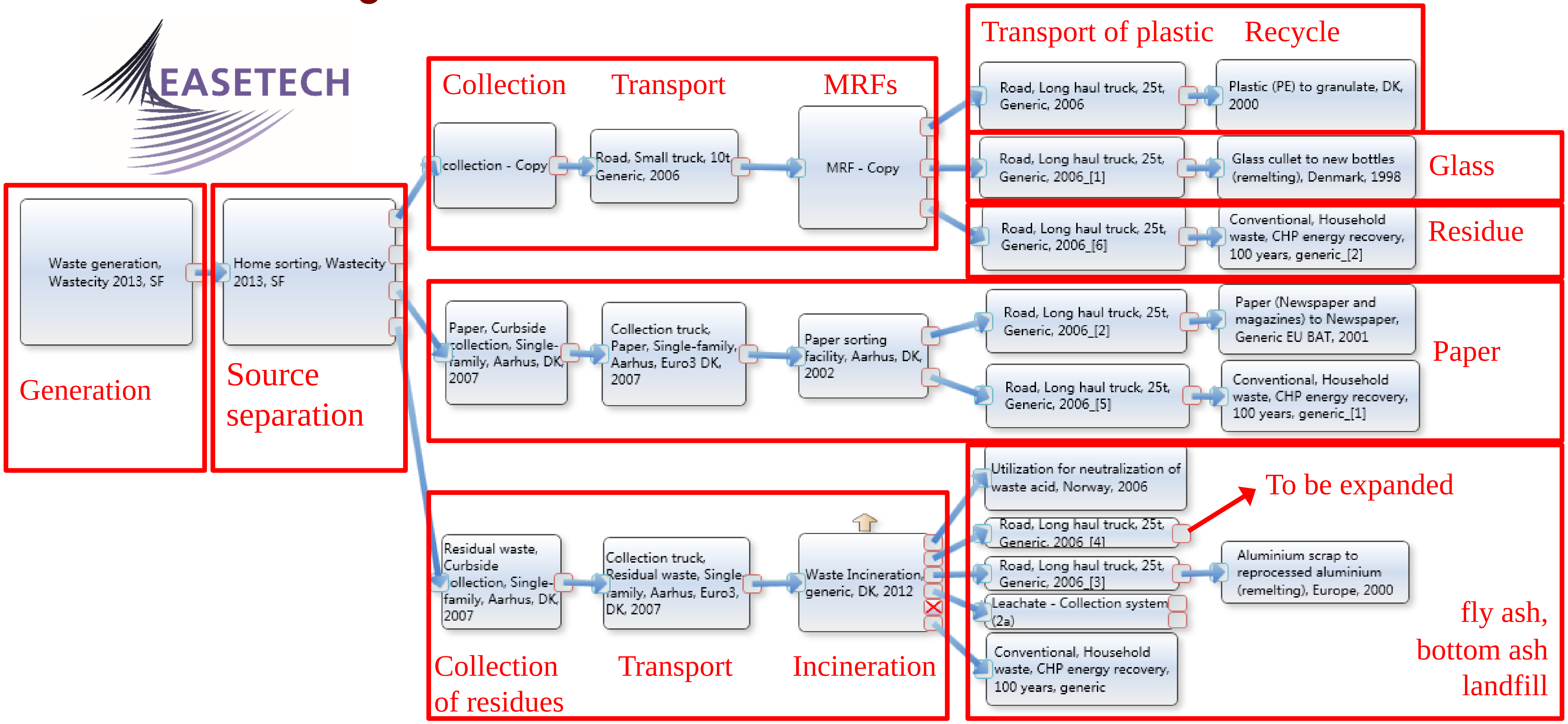
3 Incineration from a view of LCA

Incinerator



3 Incineration from a view of LCA

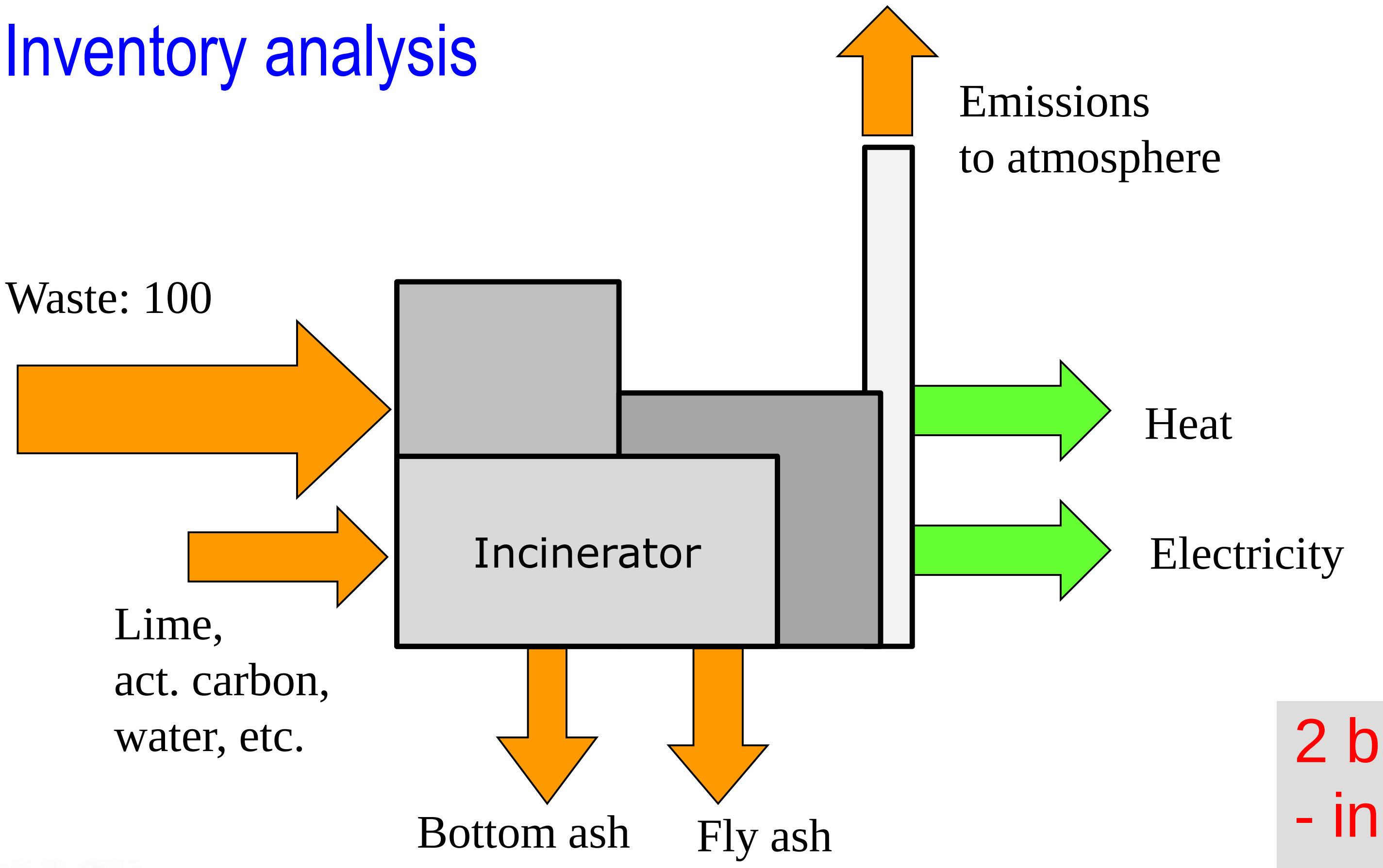
LCA modelling of incineration



3 Incineration from a view of LCA

LCA modelling of incineration

- Inventory analysis

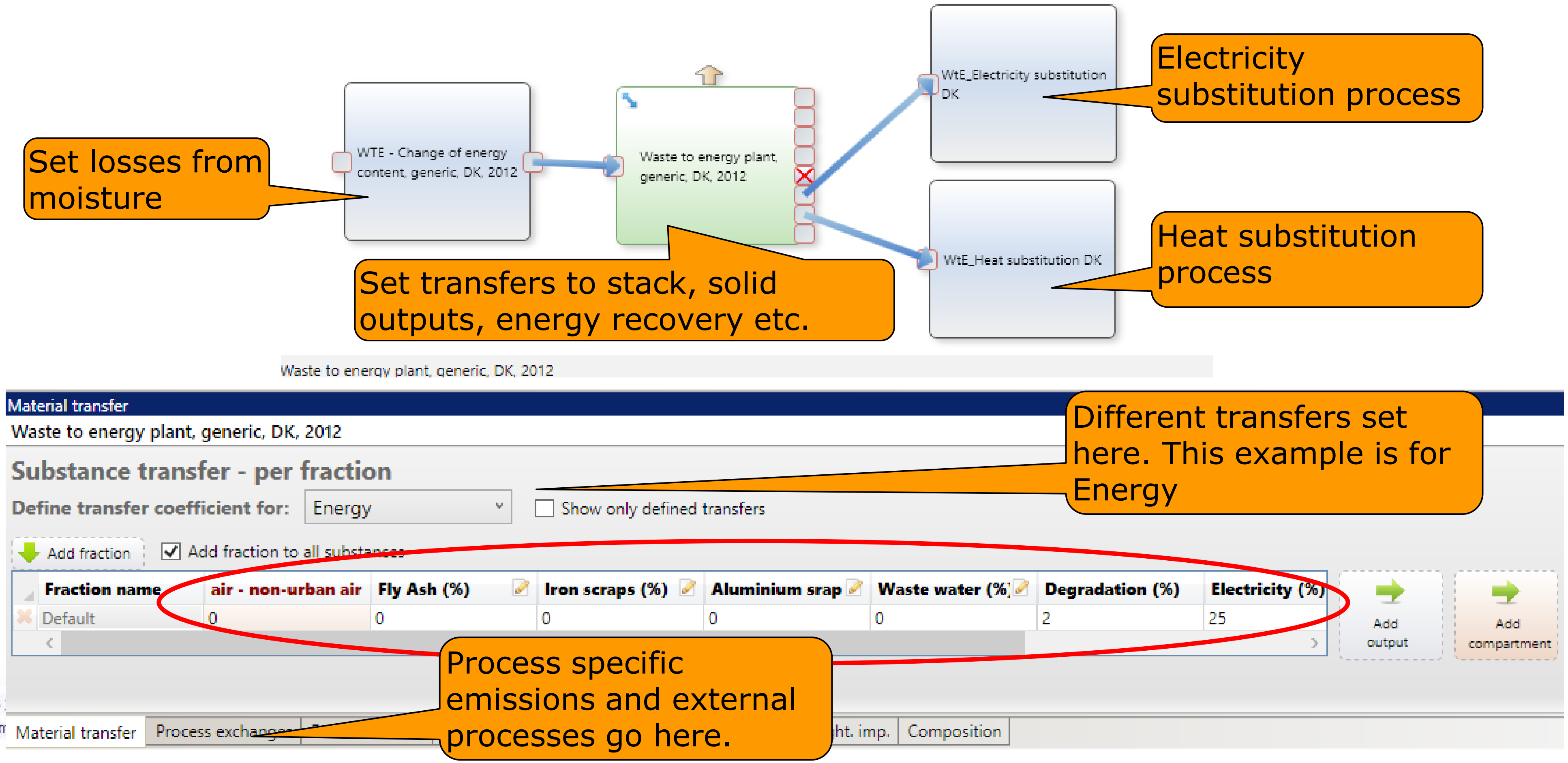


2 basic approaches:
- input related
- process related

3 Incineration from a view of LCA

LCA modelling of incineration

LCA modelling in EASETECH



3 Incineration from a view of LCA

Environmental impacts of incinerating MSW with auxiliary coal - A case of modelling incineration

Information of the City (2012):

Annual coal production: 0.61billion ton
Installed capacity of coal power: 4.6 million kW h
Population density: 9565 inhabitants/km^2
MSW generation: 280 t/d
MSW unit generation rate: 1.27 kg per person per day
The overall LHV: 4342 kJ/kg

Table 1
Composition of MSW in Shuozhou City (% by wet weight).

Fractions	Percentage (%)	Water content (%)	Total solid (%)	Volatile solid (%TS)	Element percentage (%TS)				
					C	H	O	N	S
Food waste	47.49	54.51	45.49	94.8	47.7	6.4	38.0	1.6	0.4
Plastics and rubbers	8.40	15.46	84.54	87.5	68.0	9.0	9.2	0.5	0.4
Paper and cardboard	6.22	25.92	74.08	86.6	41.1	5.6	39.2	0.2	0.2
Ash and dust	30.85	10.56	89.44	0.0	0.0	0.0	0.0	0.0	0.4
Textiles	3.13	6.48	93.52	96.4	52.1	6.0	31.1	3.2	0.4
Organic yard waste	0.58	29.93	70.07	76.0	43.0	5.2	25.3	1.5	0.2
Glass	1.45	1.67	98.33	0.0	0.0	0.0	0.0	0.0	0.08
Metals	1.88	1.38	98.62	0.0	0.0	0.0	0.0	0.0	0.05

3 Incineration from a view of LCA

A case of modelling incineration

Scenario	Source separation	Auxiliary coal	Heating value	Emission standard
A	N	Excessive (4:1)	7500 kJ/kg	Old
B	N	Moderate	5500 kJ/kg	Old
C	N	Excessive (4:1)	7500 kJ/kg	New
D	N	moderate	5500 kJ/kg	New
E	Y – Ash	Excessive (4:1)	7500 kJ/kg	Old
F	Y – Ash	moderate	5500 kJ/kg	New

Primary emission standards of air pollutants for power plants in China.

Standard	Item	Threshold limit value	Unit
GB13223-2003	SO_2	400	mg/m^3
	NO_x	450	mg/m^3
GB13223-2011	SO_2	100	mg/m^3
	NO_x	100	mg/m^3

3 Incineration from a view of LCA

A case of modelling incineration

Waste management system:

- All MSW is collected in mixed form into 6 m^3 containers by trucks
- 280 containers transported to facilities by 10 trucks

Incinerator information

- 17 km away from the downtown area
- Capacity: 700 tons/day
- Incineration technology: circulating fluidized bed with power generation
- Air pollution control technology: dry process + carbon adsorption + bag-type dust removal
- Fly ash: landfilled as hazardous waste
- Bottom ash: non-hazardous waste
- Power generation capacity: 1.63×10^8 kW h when incinerating 700 tons/day for 365 days, where 1.24×10^8 kW h is for external offering, and 0.39×10^8 kW h is for internal use.

3 Incineration from a view of LCA

A case of modelling incineration

Input and output inventory

- Materials
- Fuel
- Energy
- Emissions

Table 4
Input information on the material and energy in the incinerator.

Item	Amount	Unit	Output
Auxiliary coal	250	kg/ton waste	Bottom and fly ashes
Fuel oil	0.63	kg/ton waste	–
$Ca(OH)_2$	11.17	kg/ton waste	Air pollution control residues
Activated carbon	0.39	kg/ton waste	Air pollution control residues
Water	1037	kg/ton waste	Waste water

Table 6
Information on air and water emissions from the incineration

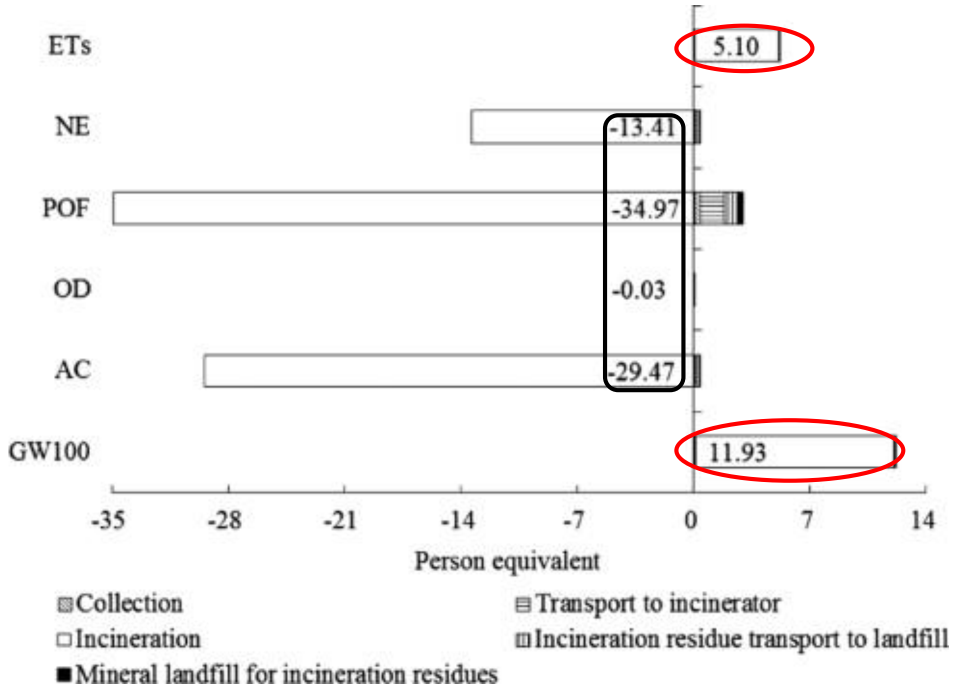
Category	Substance	Amount
Air emission	Cadmium (Cd)	9.0×10^{-4}
	Carbon monoxide (CO)	0.72
	Hydrogen chloride (HCl)	0.43
	Hydrogen fluoride (HF)	0.014
	Lead (Pb)	0.014
	Mercury (Hg)	0.0018
	Nitrogen oxides (NO_x)	0.36
	Dioxin (2,3,7,8-PCDF)	9.0×10^{-10}
	Sulfur dioxide (SO_2)	1.49
	Arsenic (As)	3.54×10^{-9}
	Chromium (Cr)	3.54×10^{-7}
	Hydrocarbons (HC)	0.27
Water emission	Ammonium–N (NH_4–N)	0.0004
	Biological Oxygen Demand (BOD)	0.004
	Chemical Oxygen Demand (COD)	0.02

3 Incineration from a view of LCA

A case of modelling incineration

- **Scenarios A and B**
  - The potential impacts from collection and transportation primarily contribute to global warming and photochemical ozone formation.
  - flue gas purification and recovery efficiency of electricity in incinerators are considered key parameters for environmental impacts and should be given considerable attention in MSW system management.

ETs: ecotoxicity in soil;
NE: nutrient enrichment
POF: photochemical ozone formation
OD: ozone depletion
AC: acidification
GW100: global warming (100 years).



3 Incineration from a view of LCA

A case of modelling incineration

- **Scenarios A and B**
  - In Scenario B, only 70 kg/t waste of auxiliary coal was needed, with an LHV of 5500 kJ/kg
  - The impacts on global warming are significantly improved with less auxiliary coal
  - Fewer emissions, such as NOx and SO_2, are avoided because of reduced power generation.

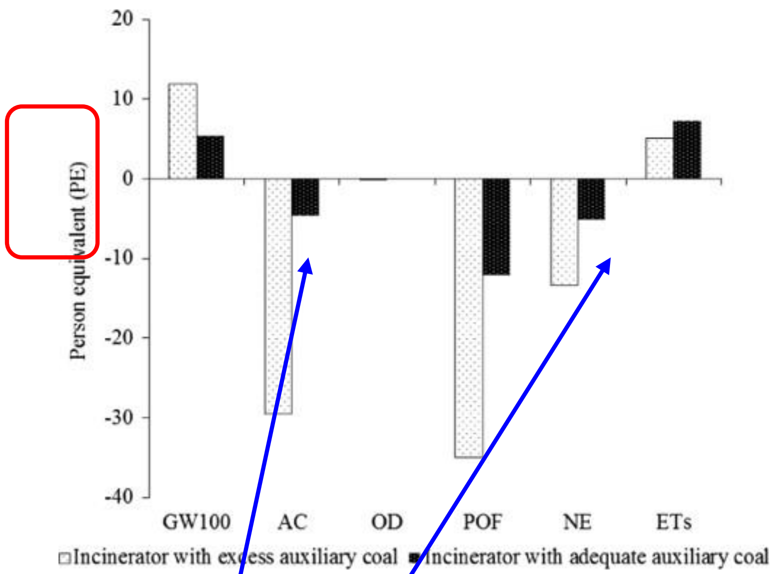


Table 7
Comparison of major air and water emissions from the incinerators in Scenarios A and B.

Substance	Category	Unit	Scenario A		Scenario B	
			Auxiliary coal	Electricity recovery	Auxiliary coal	Electricity recovery
Ammonia (NH_3)	Air emission	kg	5.39	−0.006	1.51	−0.003
Ammonium (NH_4^+)	Water emission	kg	0	−0.002	0	−0.001
Cadmium (Cd)	Air emission	kg	6.56×10^{-4}	−0.002	1.84×10^{-4}	-7.55×10^{-4}
Carbon dioxide (CO_2-fossil)	Air emission	kg	1.78×10^5	-1.45×10^5	4.99×10^4	-6.36×10^4
Chloride (Cl^-)	Water emission	kg	0	−143.79	0	−62.95
Chromium (Cr)	Air emission	kg	8.69×10^{-4}	-3.35×10^{-4}	2.43×10^{-4}	-1.47×10^{-4}
Dioxin (2,3,7,8-TCDD TEQ)	Air emission	kg	6.27×10^{-9}	-1.01×10^{-7}	1.75×10^{-9}	-4.42×10^{-8}
Hydrogen chloride (HCl)	Air emission	kg	9.13	−1.31	2.56	−0.57
Lead (Pb)	Air emission	kg	0.010	−0.24	0.003	−0.10
Mercury (Hg)	Air emission	kg	0.007	−0.01	0.002	−0.005
Methane (CH_4)	Air emission	kg	836.22	−352.98	234.14	−154.54
Nitrogen oxides (NO_x)	Air emission	kg	143.22	−877.01	40.10	−383.97
Sulfate (SO_4^{2-})	Water emission	kg	0	−9.10	0	−3.98
Sulfur dioxide (SO_2)	Air emission	kg	178.33	−1348.10	49.93	−590.21

3 Incineration from a view of LCA

A case of modelling incineration

- **Scenarios C and D**
  - After the new standard was implemented, waste incineration with excess auxiliary coal presented fewer advantages than before, and the impacts on acidification and nutrient enrichment turn into loads from savings.
  - Co-incineration of waste and a mass of coal is not recommended in MSW management. Further considering the low LHV of mixed waste and high percentage of ash and dust, direct incineration is probably unsuitable for MSW disposal in this city.

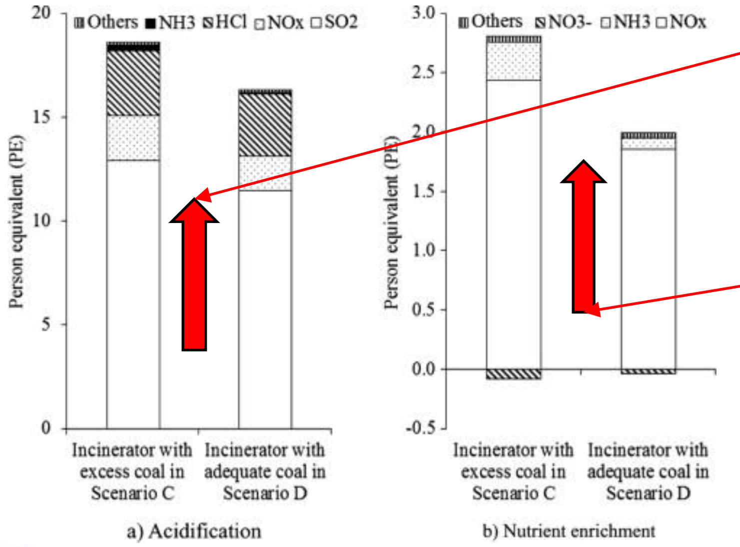


Fig. 3. Normalized potential impacts of the incinerators on acidification and nutrient enrichment in Scenarios C and D.

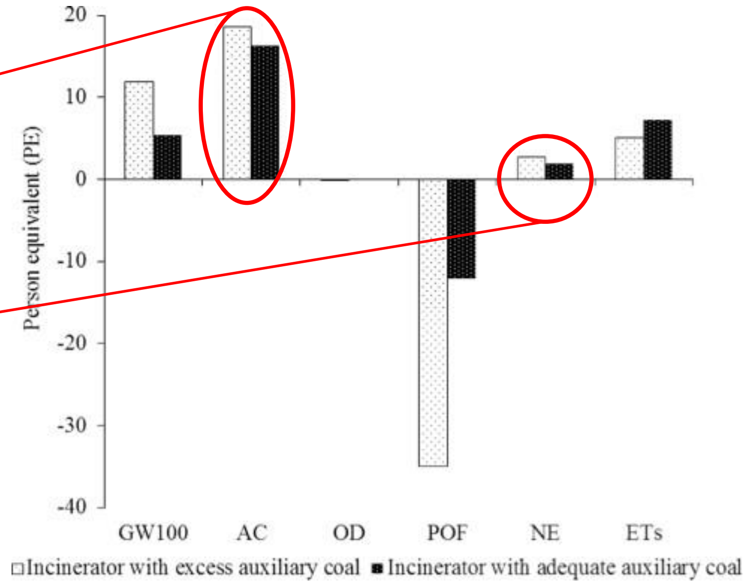


Fig. 4. Normalized potential impacts of the incinerators in Scenarios C and D.

ETs: ecotoxicity in soil;
NE: nutrient enrichment
POF: photochemical ozone formation
OD: ozone depletion
AC: acidification
GW100: global warming (100 years).

3 Incineration from a view of LCA

A case of modelling incineration

- **Scenario E and F**
  - When two-thirds of ash is source-separated and landfilled, the LHV of rest-waste is calculated as 5.5×10^{3} kJ/kg, which is sufficient for incineration without auxiliary coal.
  - Incineration in Scenario E presents impact savings on global warming. This finding is primarily attributed to the absence of auxiliary coal in Scenario E.
  - the impacts to global warming turn negative because of the counteraction between electricity substitution and waste specific emissions.

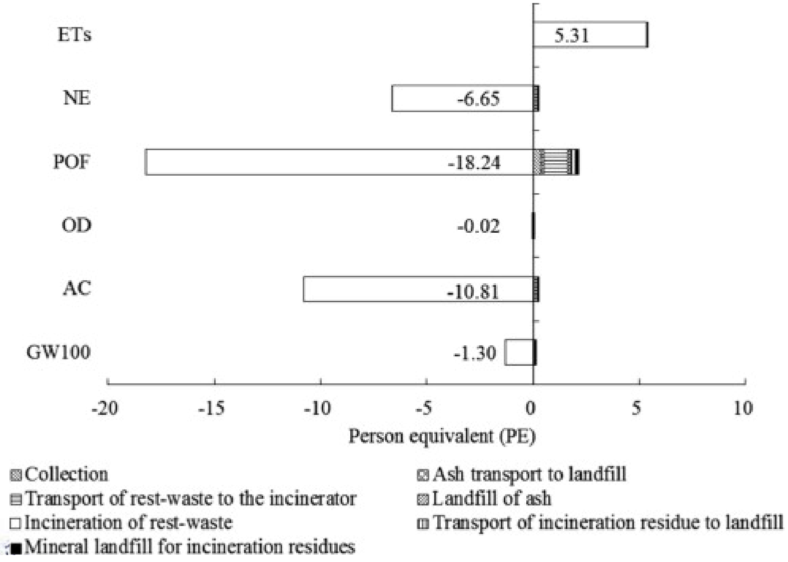


Fig. 5. Normalized potential impacts of the MSW system with ash separation

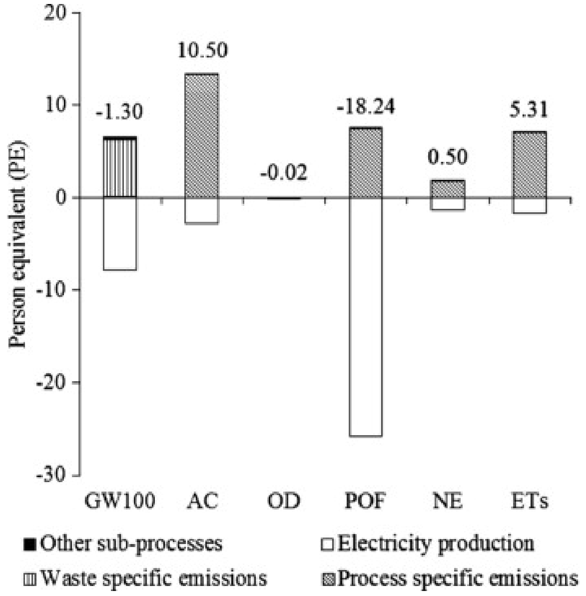


Fig. 6. Normalized potential impacts of the incinerator in Scenarios F.

3 Incineration from a view of LCA

Wrap-up

- The environmental impact potentials of incineration systems are balance between loads and savings
- The energy substitution is crucial to the performance
  - With marginal energy substitution, the dirtier the better
- Decision making on future waste management systems must take place on a system level – not on a single technology level
  - In the case above, ash separation of is probably more important than food waste
- LCA and modelling tools are useful and helpful in understanding the current and even future processes from a systematic perspective

Thanks for your attention

Further communication is welcome

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