TECHNISCHE UNIVERSITÄT DRESDEN

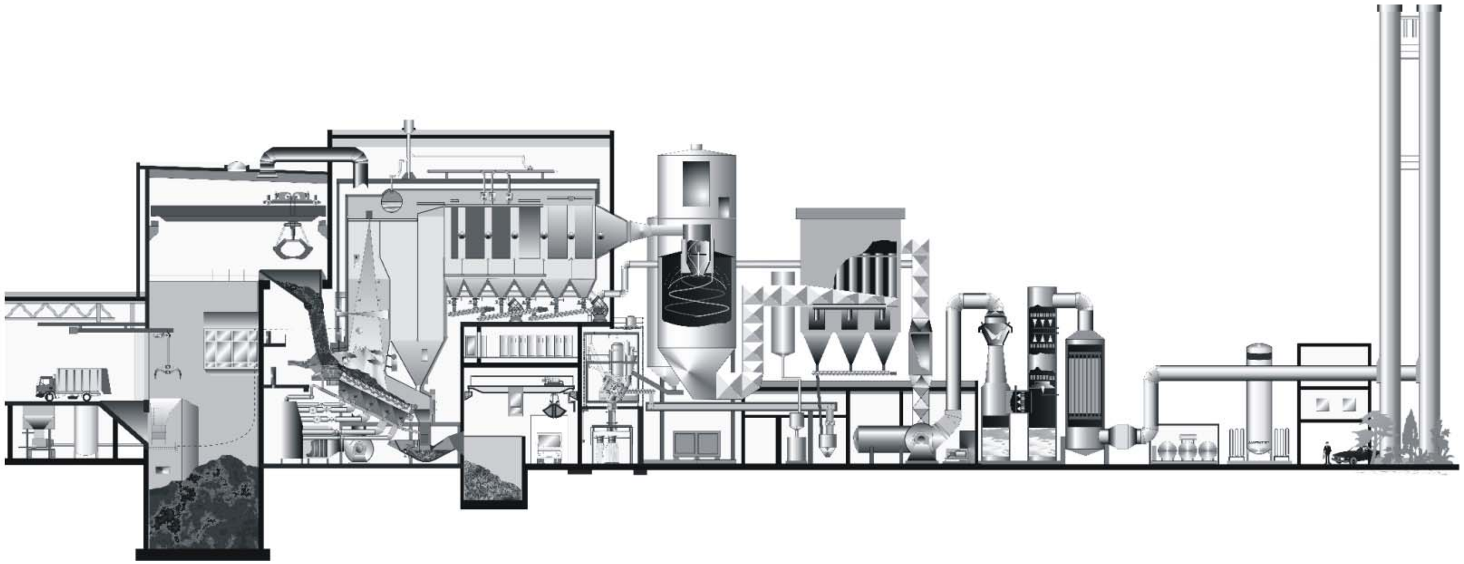
Institut für Energietechnik

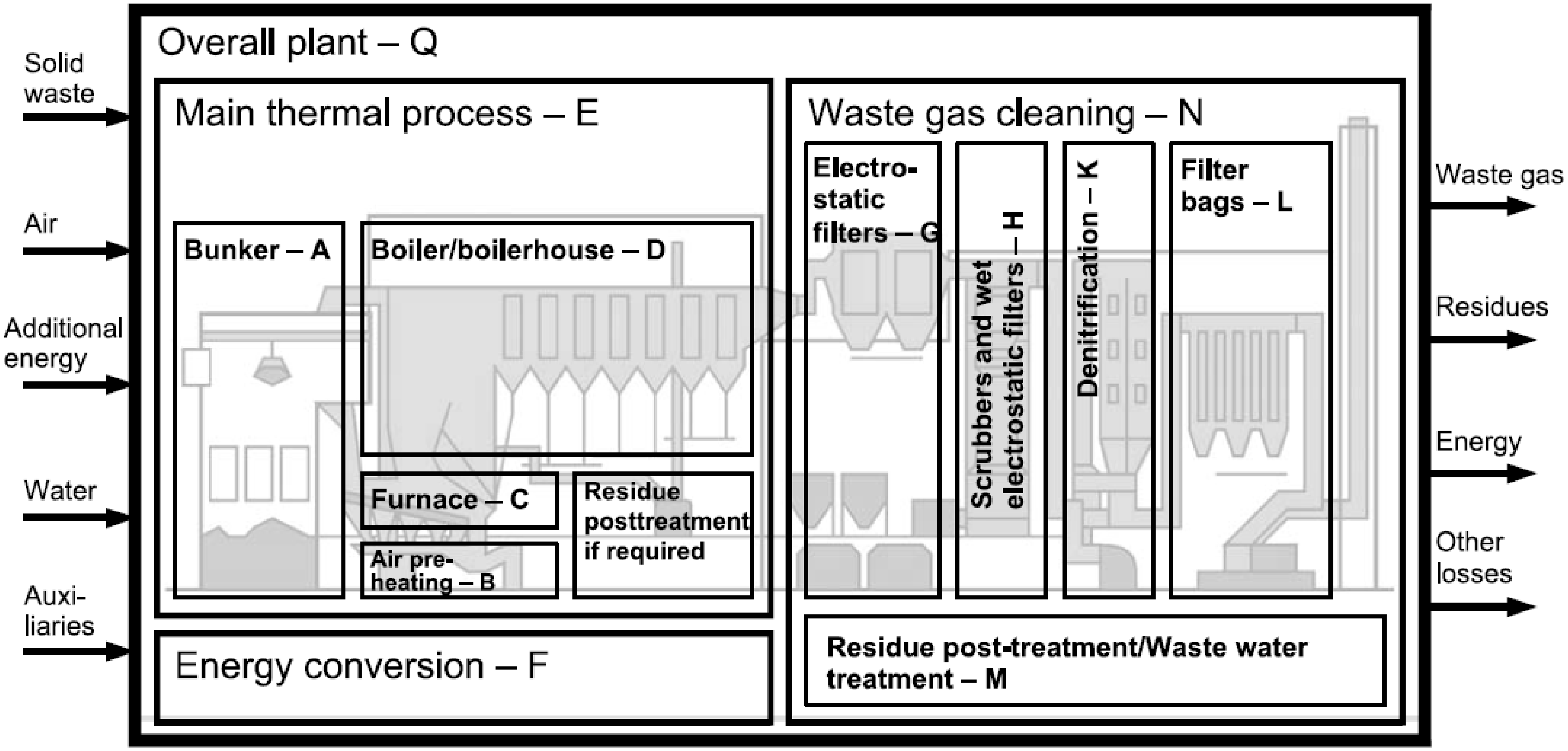
Fakultät Maschinenwesen Institut für Energietechnik, Professur Verbrennung, Wärme- und Stoffübertragung

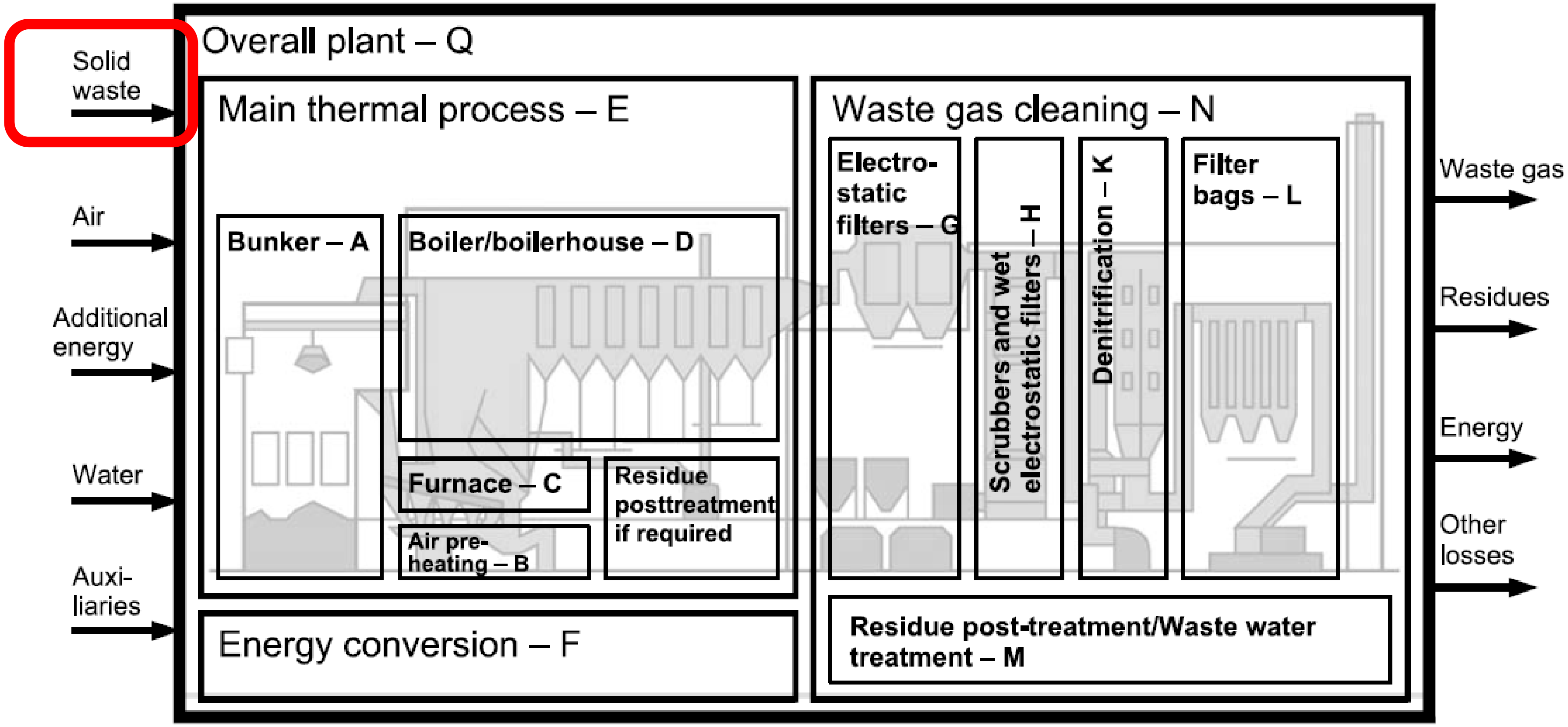
Determination of the energy efficiency by balancing of the WtE-plant

Michael Beckmann

10. March 2014; Karlsruhe




Solid waste
Air
Additional energy
Water
Auxi-liaries
Overall plant – Q
Main thermal process – E
Bunker – A
Boiler/boilerhouse – D
Furnace – C
Air pre-heating – B
Residue posttreatment if required
Energy conversion – F
Waste gas cleaning – N
Electro-static filters – G
Scrubbers and wet electrostatic filters – H
Denitrification – K
Filter bags – L
Residue post-treatment/Waste water treatment – M
Waste gas
Residues
Energy
Other losses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Overall plant – Q
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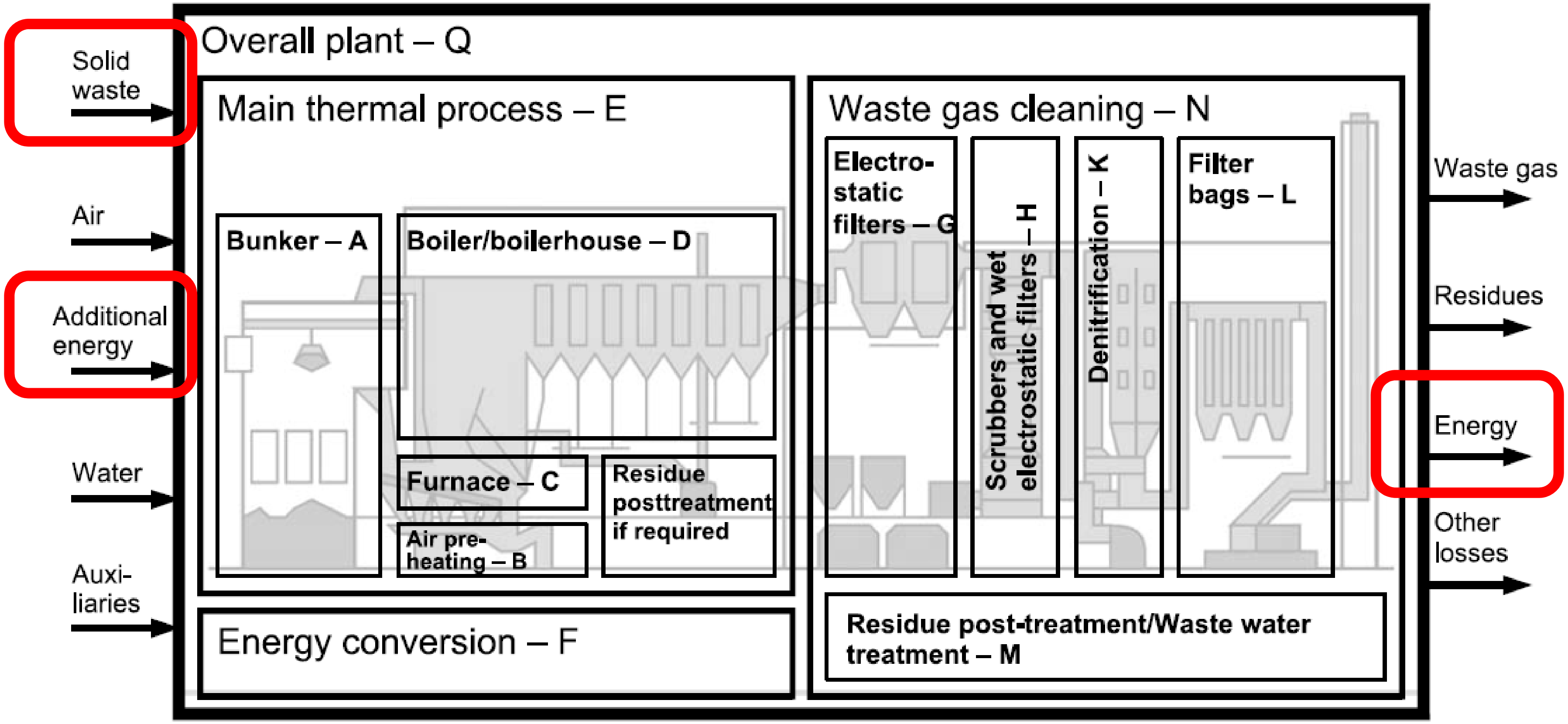
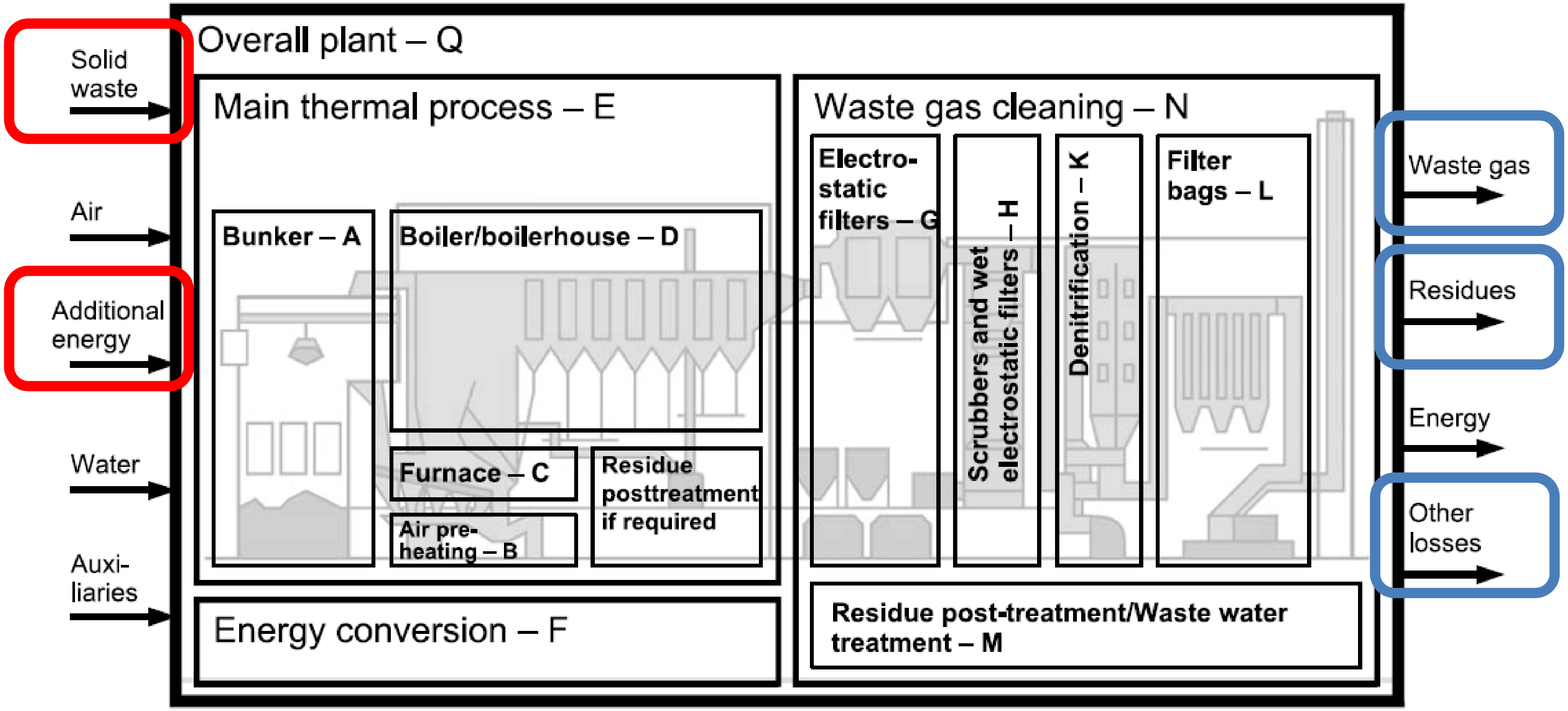
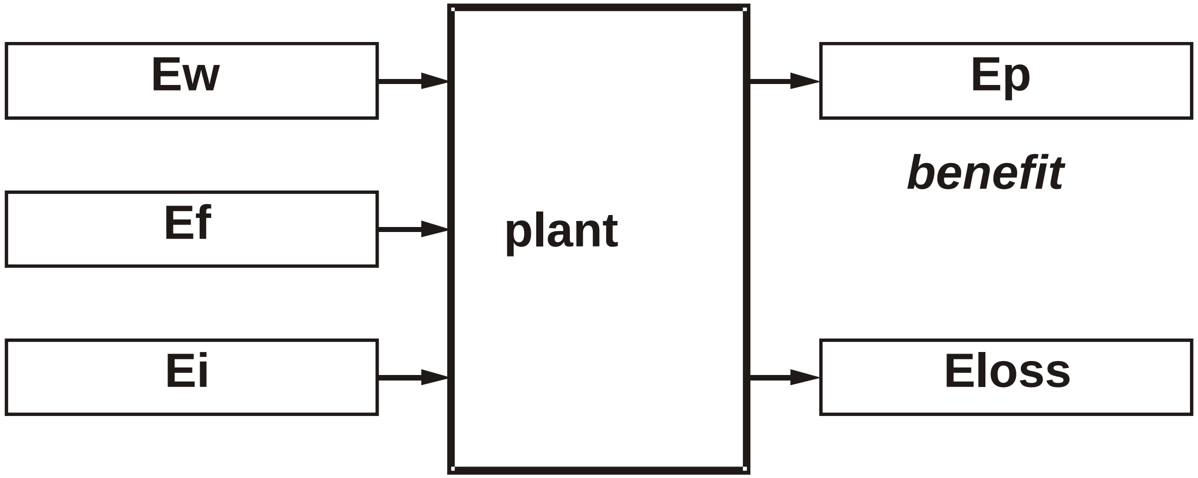
Waste gas
Residues
Energy
Other
losses



$$\eta_P = \frac{benefit(output)}{demand(input)} = \frac{\text{energy}}{\text{waste and additioinal energy}}$$



$$\eta_P = \frac{benefit(output)}{demand(input)} = \frac{demand - losses}{demand} = 1 - \frac{losses}{demand}$$



Ew **w**aste
Ef **add. f**uel
Ei **i**mported
Ep **p**roduced
Eloss **losses**

Σ	Ew + Ef + Ei	=	Σ	Ep + Eloss

demand ***equal*** ***benefit + losses***

balancing circle 1 ⇒ plant efficiency

$$\eta_P = \frac{benefit(output)}{demand(input)} = \frac{Ep}{Ew + (Ef + Ei)}$$

balancing circle 1 ⇒ plant efficiency

$$\eta_P = \frac{benefit(output)}{demand(input)} = \frac{Ep}{Ew + (Ef + Ei)}$$

R1

$$R1 = \frac{Ep - (Ef + Ei)}{0,97 * (Ew + Ef)}$$

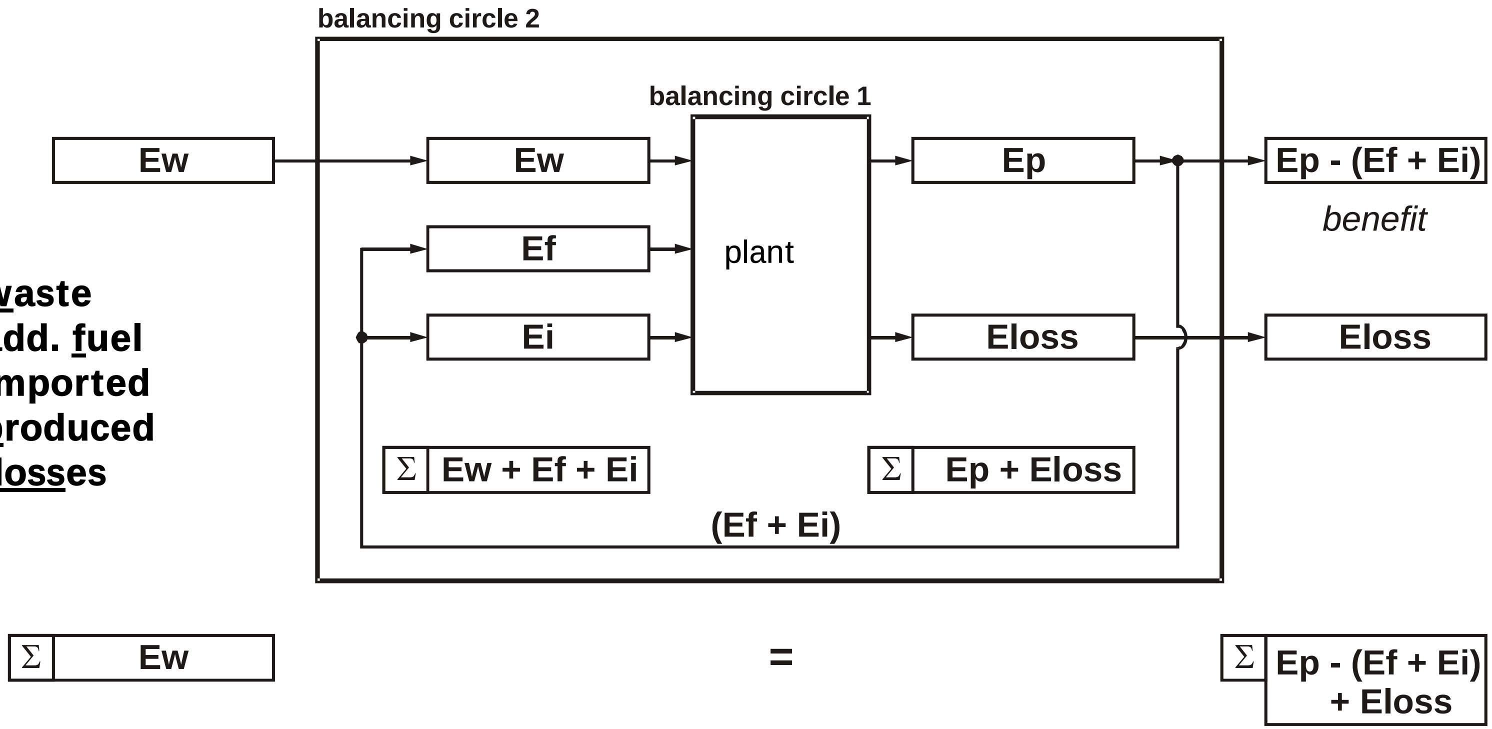
balancing circle 1 ⇒ plant efficiency

$$\eta_P = \frac{benefit(output)}{demand(input)} = \frac{Ep}{Ew + (Ef + Ei)}$$

R1

$$R1 = \frac{Ep - (Ef + Ei)}{0{,}97 * (Ew + Ef)}$$

Ew waste
Ef add. fuel
Ei imported
Ep produced
Eloss losses



demand *equal* *benefit + losses*

balancing circle 2 ⇒ net efficiency

$$\eta_{net} = \frac{benefit(output)}{demand(input)} = \frac{Ep - (Ef + Ei)}{Ew}$$

balancing circle 2 $\Rightarrow$ net efficiency

$$\eta_{net} = \frac{benefit(output)}{demand(input)} = \frac{Ep - (Ef + Ei)}{Ew}$$

R1

$$R1 = \frac{Ep - (Ef + Ei)}{0,97 * (Ew + Ef)}$$

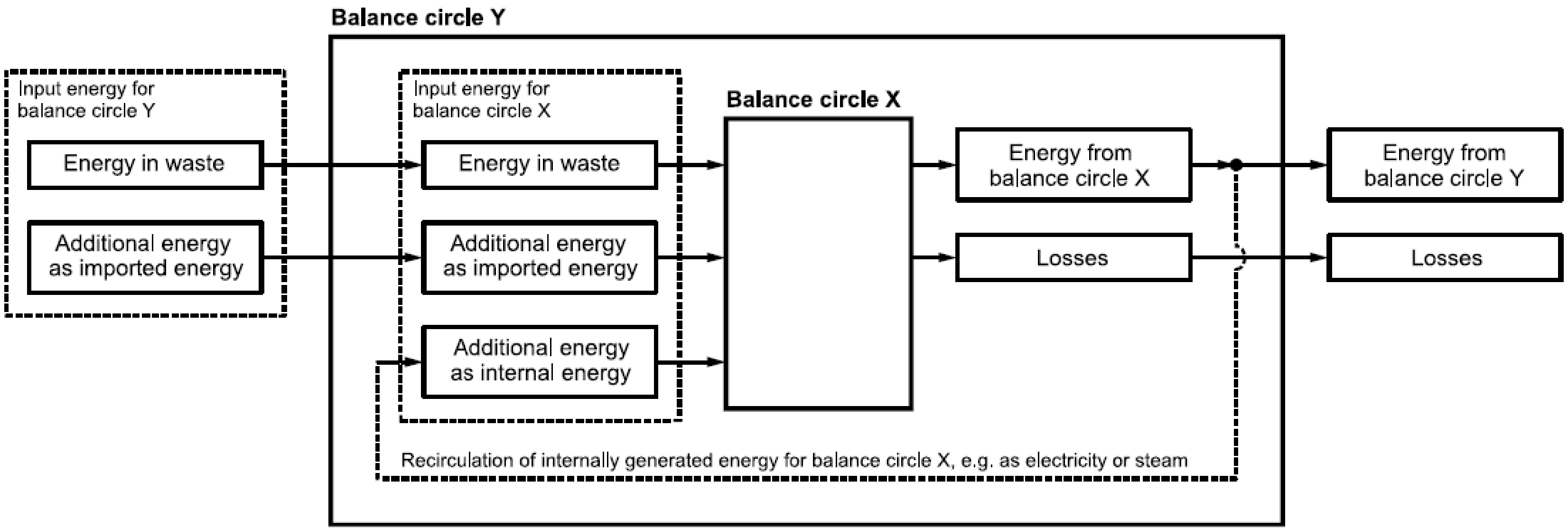
balancing circle 2 $\Rightarrow$ net efficiency

$$\eta_{net} = \frac{benefit(output)}{demand(input)} = \frac{Ep-(Ef+Ei)}{Ew}$$

R1

$$R1 = \frac{Ep-(Ef+Ei)}{0{,}97*(Ew+Ef)}$$

Definition of input energy, additional and internally circulated energy – diagram illustrating the principle



According to VDI 3460 (2)

Classification of Waste-to-energy Plants in Terms of Energy Recovery

VGB PowerTech 10/2007 P 76 – 81.

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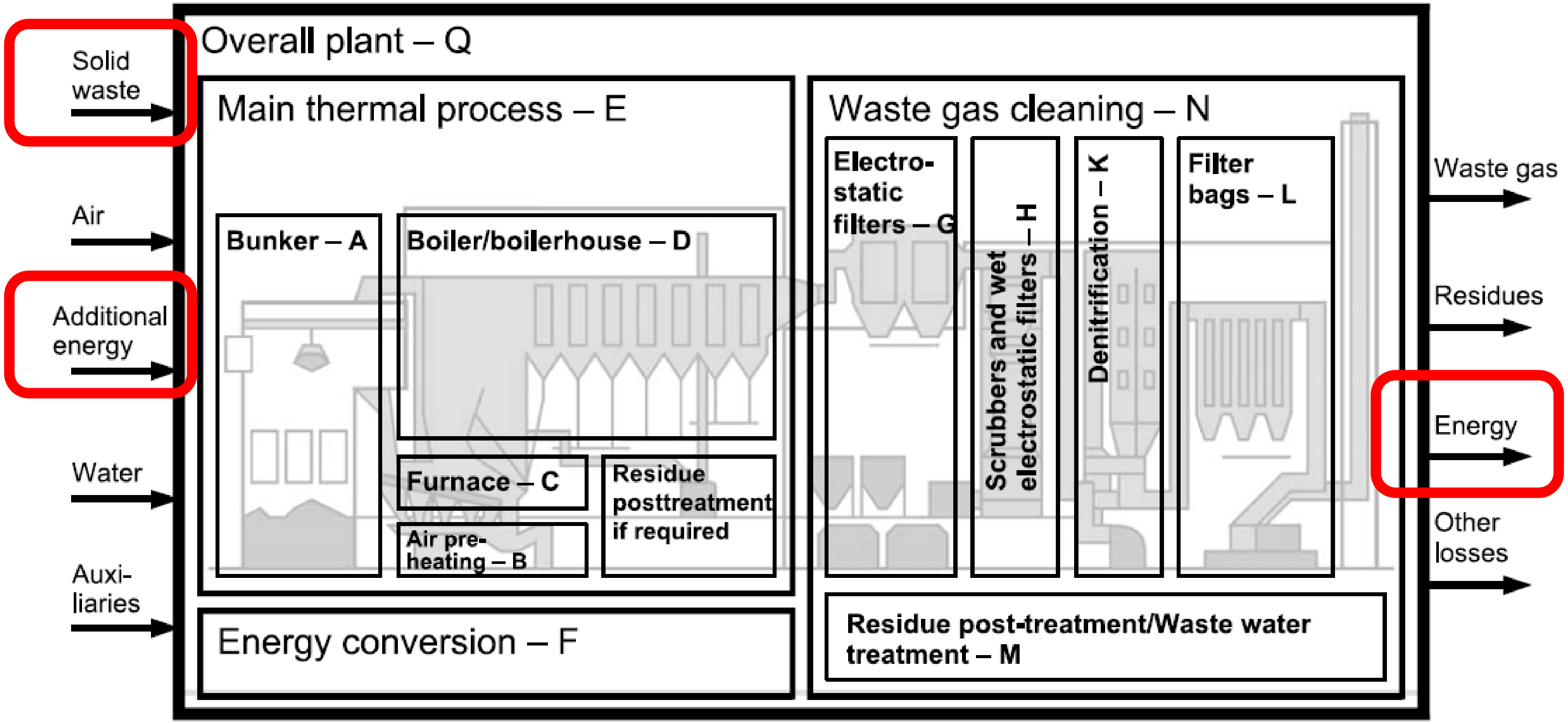
Resumé

1. The VDI guideline 3460 [2] is based on known and proven engineering knowledge and forms the basis for assessing the energy efficiency of waste-to-energy plants with particular reference to optimisation.
2. The R1 formula [3] has a politically regulatory function for differentiating between R1 and D10 (R1 as the technical term).
3. When differentiating between the two approaches mentioned above, 1 and 2, it is unnecessary to refer to R1 in VDI guideline 3460.



$$\eta_P = \frac{benefit(output)}{demand(input)} = \frac{\text{energy}}{\text{waste and additioinal energy}}$$

Input flows (Demand (input))

No.		Mass $\dot{m}_{Q,k}$ in Mg/a	Energy $\dot{E}_{Q,k}$ in MWh/a	Carbon $\dot{m}_{C,Q,k}$ in Mg_C/a
Q1	Solid waste	201.104	559.708	40.221
Q2	Air for solid waste	1.323.187	0	–
Q3	Additional fuel	575	20.087	486
Q4	Air for additional fuel	9.537	0	–
Q5	Additional electrical energy	–	394	–
Q6	Additional thermal energy	104.300	7.278	–
Q7	Auxiliaries	159.068	0	40
	Total – Demand (input)	1.797.772	587.467	40.747

Balance circle Q – target energy

Main thermal process

Furnace,
Firing of hospital waste,
boiler air preheating,
slag treatment

Waste gas cleaning

including concentration unit

Energy conversion

Balance circle Q – AVA includes all internal recirculation; released energy = plant's target energy

Output flows

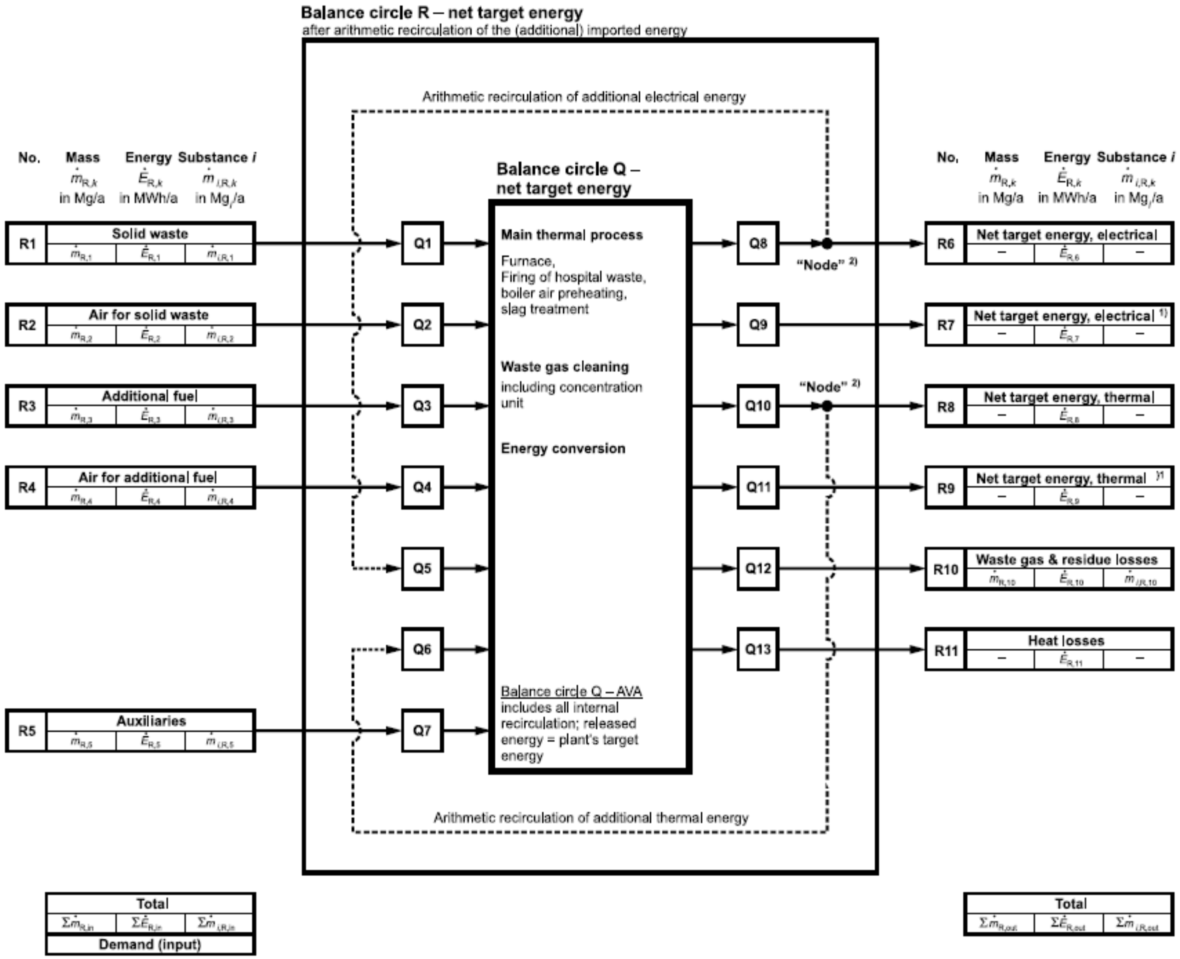
No.		Mass $\dot{m}_{Q,k}$ in Mg/a	Energy $\dot{E}_{Q,k}$ in MWh/a	Carbon $\dot{m}_{C,Q,k}$ in Mg_C/a
Q8	Target energy, electrical	–	65.842	–
Q9	Target energy, electrical [1)]	–	7.893	–
Q10	Target energy, thermal	104.300	71.782	–
Q11	Target energy, thermal [1)]	–	3.351	–
Q12	Waste gas and residue losses	1.693.472	64.139	40.747
Q13	Heat losses	–	374.460	–
	Total	1.797.772	587.467	40.747

Plant efficiencies

$\eta_{P,Q,el}$	0,126
$\eta_{P,Q,th}$	0,128
$\eta_{A,Q,total}$	0,253

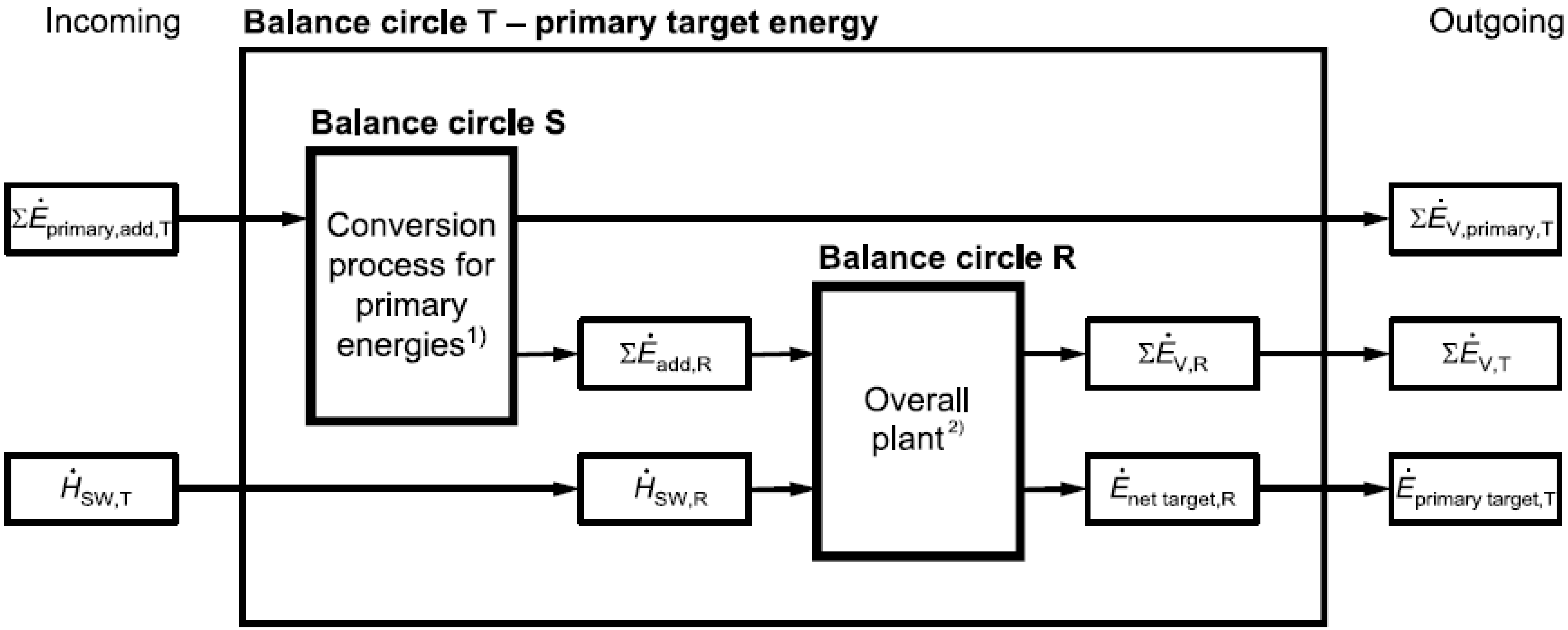
[1)] Target energy broken down here in accordance with operator's information into target energy supplied to public services company (Q8 and Q10) and target energy to neighbouring customers on site (for composting, sorting, etc., Q9 and Q11)

According to VDI 3460 (2)



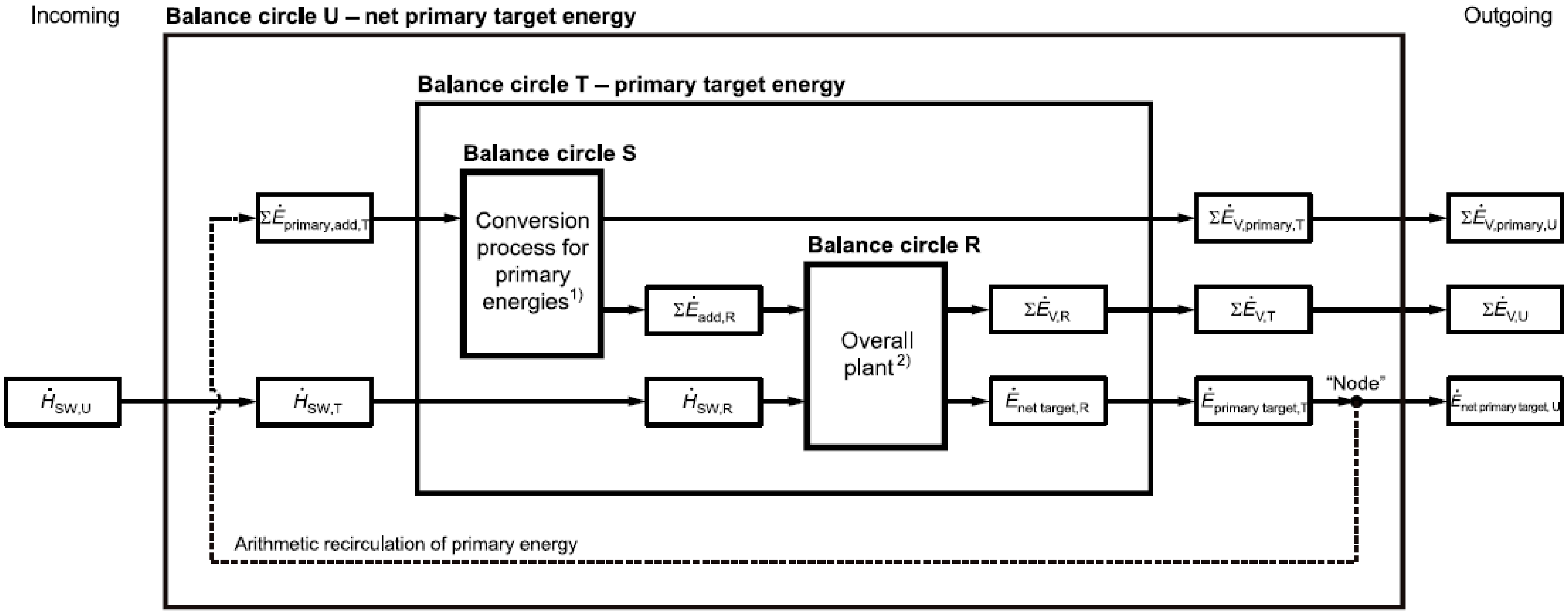
[1] Target energy broken down here in accordance with operator's information into target energy supplied to public services company (Q8 and Q10) and target energy to neighbouring customers on site (for composting, sorting, etc., Q9 and Q11)

[2] Public services company, district heat transfer station, etc.



[1] e.g. generation of electricity, oxygen, etc.
[2] including recirculation of thermal and electrical energy

$$\left(\eta_{primary} = \frac{\dot{E}_{primary\ target}}{\dot{H}_{SW} + \sum \dot{E}_{primary\ add}} \right)_T$$

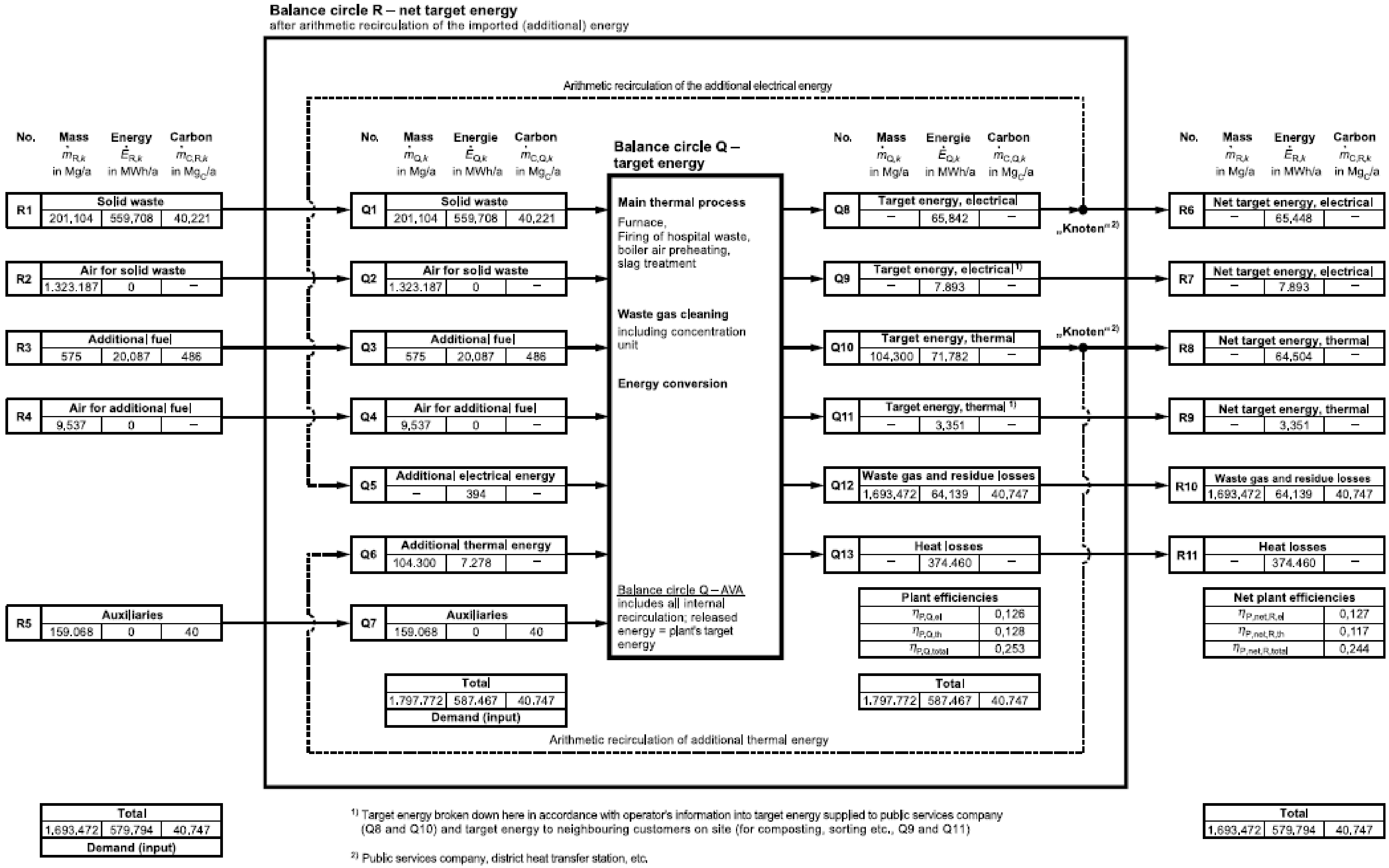


[1] e.g. generation of electricity, oxygen, etc.
[2] including recirculation of thermal and electrical energy

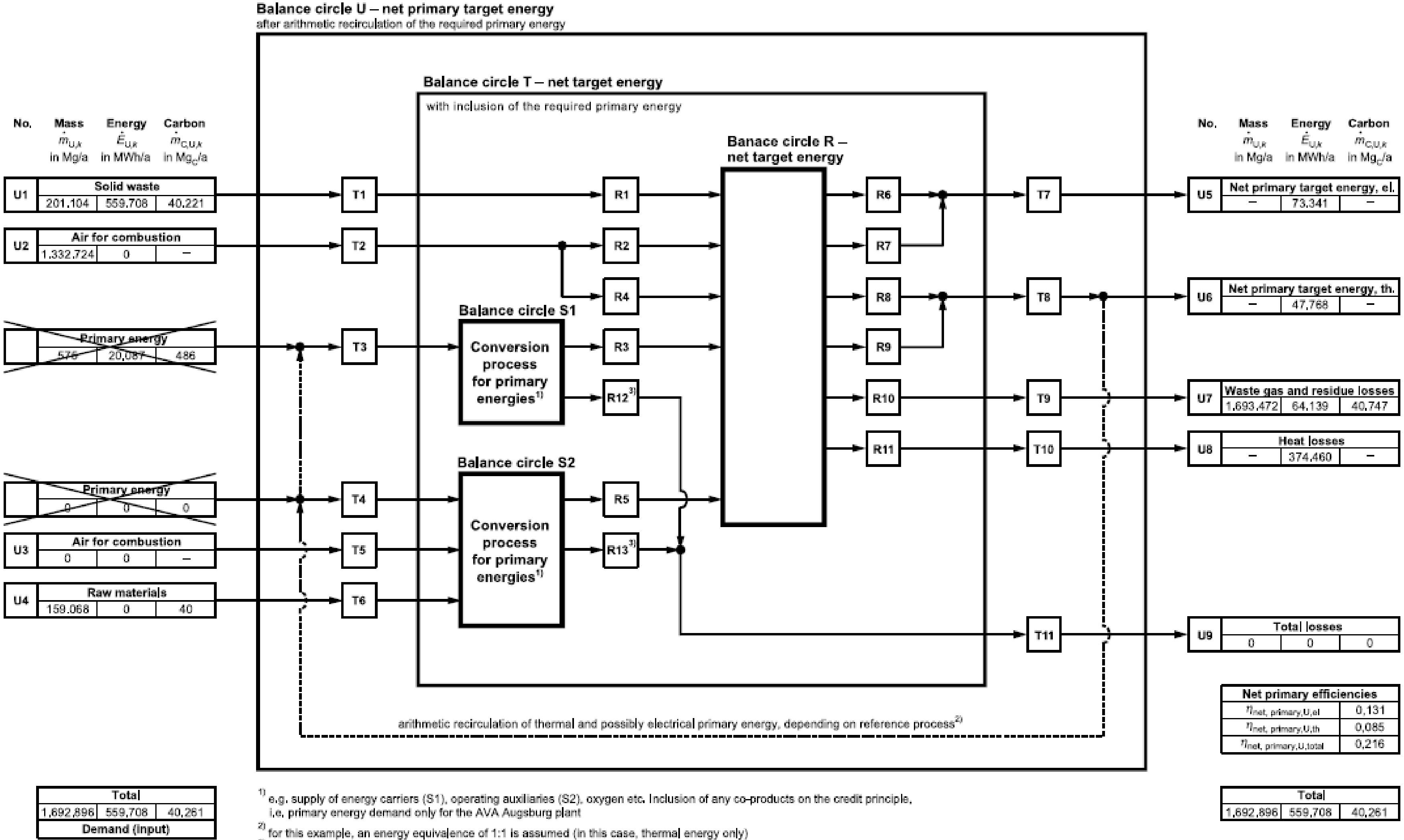
$$\left(\eta_{\text{net primary}} = \frac{\dot{E}_{\text{net primary target}}}{\dot{H}_{\text{SW}}}\right)_{\text{U}}$$

$$(\dot{E}_{\text{net primary target}})_{\text{U}} = (\dot{E}_{\text{primary target}} - \sum \dot{E}_{\text{primary,add}})_{\text{T}}$$

$$\text{for } (\dot{E}_{\text{net primary target}})_{\text{U}} > 0$$



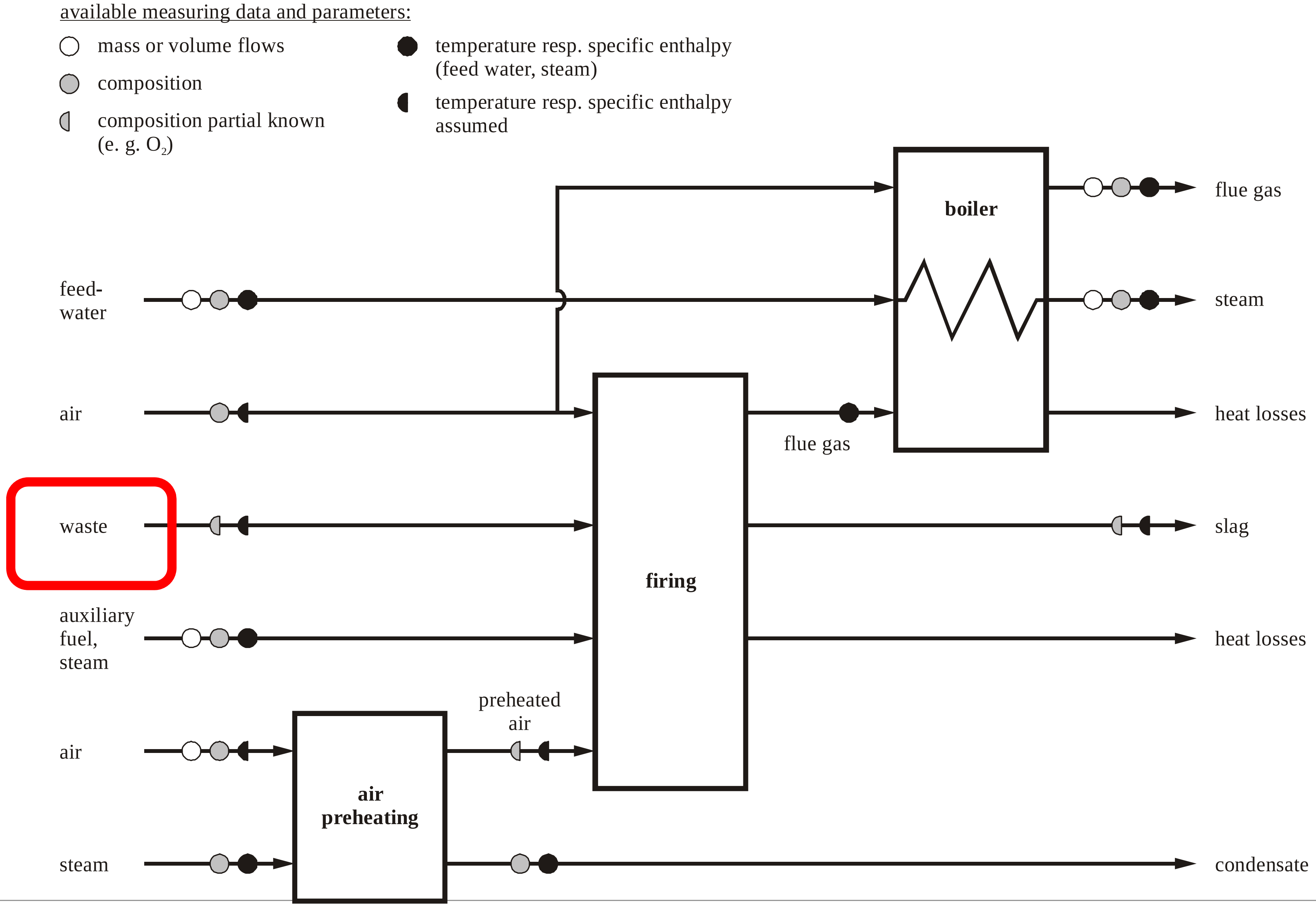
Balance circle R – net target energy
after arithmetic recirculation of the imported (additional) energy
Arithmetic recirculation of the additional electrical energy
No. Mass $\dot{m}_{R,k}$ in Mg/a Energy $\dot{E}_{R,k}$ in MWh/a Carbon $\dot{m}_{C,R,k}$ in Mg_C/a
R1 Solid waste 201,104 559,708 40,221
R2 Air for solid waste 1.323.187 0 –
R3 Additional fuel 575 20,087 486
R4 Air for additional fuel 9,537 0 –
R5 Auxiliaries 159.068 0 40
Total 1,693,472 579,794 40,747 Demand (input)
No. Mass $\dot{m}_{Q,k}$ in Mg/a Energie $\dot{E}_{Q,k}$ in MWh/a Carbon $\dot{m}_{C,Q,k}$ in Mg_C/a
Q1 Solid waste 201,104 559,708 40,221
Q2 Air for solid waste 1.323.187 0 –
Q3 Additional fuel 575 20,087 486
Q4 Air for additional fuel 9,537 0 –
Q5 Additional electrical energy – 394 –
Q6 Additional thermal energy 104.300 7.278 –
Q7 Auxiliaries 159.068 0 40
Total 1.797.772 587.467 40.747 Demand (input)
Balance circle Q – target energy
Main thermal process
Furnace, Firing of hospital waste, boiler air preheating, slag treatment
Waste gas cleaning
including concentration unit
Energy conversion
Balance circle Q – AVA includes all internal recirculation; released energy = plant's target energy
No. Mass $\dot{m}_{Q,k}$ in Mg/a Energie $\dot{E}_{Q,k}$ in MWh/a Carbon $\dot{m}_{C,Q,k}$ in Mg_C/a
Q8 Target energy, electrical – 65,842 –
Q9 Target energy, electrical 1) – 7.893 –
Q10 Target energy, thermal 104,300 71,782 –
Q11 Target energy, thermal 1) – 3,351 –
Q12 Waste gas and residue losses 1,693,472 64,139 40,747
Q13 Heat losses – 374.460 –
Plant efficiencies
$\eta_{P,Q,el}$ 0,126
$\eta_{P,Q,th}$ 0,128
$\eta_{P,Q,total}$ 0,253
Total 1.797.772 587.467 40.747
„Knoten" 2)
No. Mass $\dot{m}_{R,k}$ in Mg/a Energy $\dot{E}_{R,k}$ in MWh/a Carbon $\dot{m}_{C,R,k}$ in Mg_C/a
R6 Net target energy, electrical – 65,448 –
R7 Net target energy, electrical – 7.893 –
R8 Net target energy, thermal – 64,504 –
R9 Net target energy, thermal – 3,351 –
R10 Waste gas and residue losses 1,693,472 64,139 40,747
R11 Heat losses – 374.460 –
Net plant efficiencies
$\eta_{P,net,R,el}$ 0,127
$\eta_{P,net,R,th}$ 0,117
$\eta_{P,net,R,total}$ 0,244
Total 1,693,472 579,794 40,747
Arithmetic recirculation of additional thermal energy
1) Target energy broken down here in accordance with operator's information into target energy supplied to public services company (Q8 and Q10) and target energy to neighbouring customers on site (for composting, sorting etc., Q9 and Q11)
2) Public services company, district heat transfer station, etc.

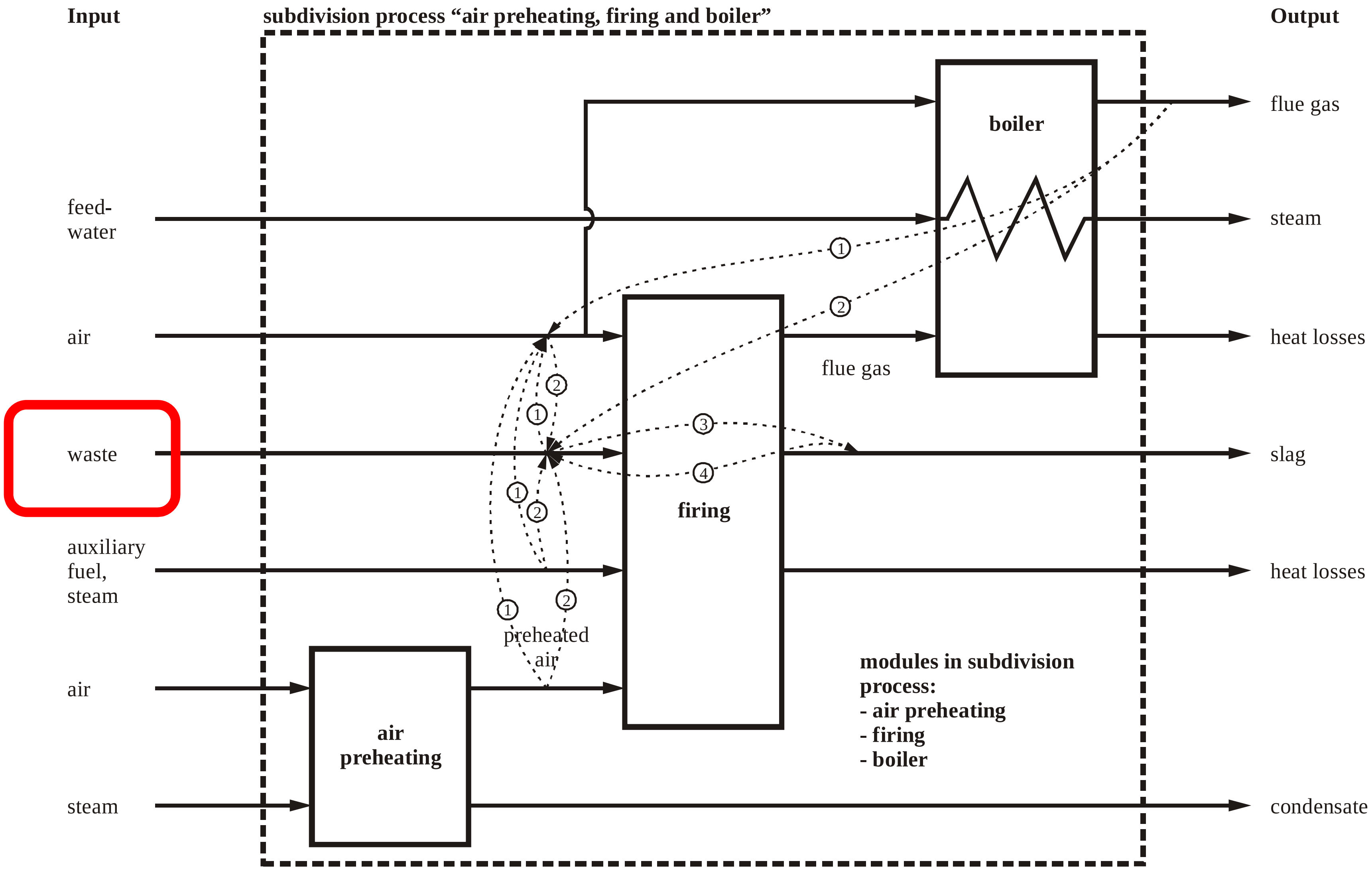


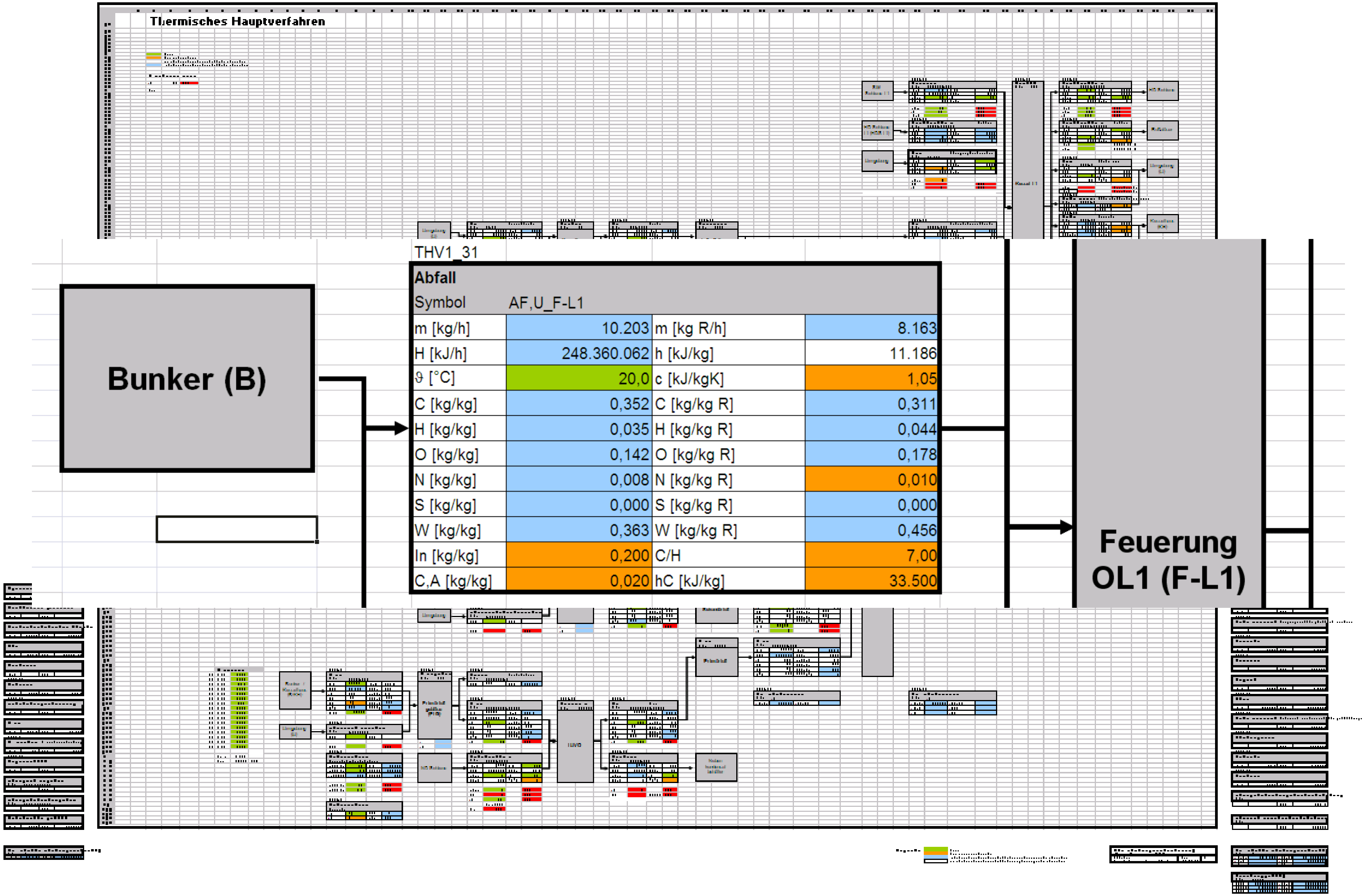
1) e.g. supply of energy carriers (S1), operating auxiliaries (S2), oxygen etc. Inclusion of any co-products on the credit principle, i.e. primary energy demand only for the AVA Augsburg plant

2) for this example, an energy equivalence of 1:1 is assumed (in this case, thermal energy only)

3) further numbering continues the existing sequence


available measuring data and parameters:
mass or volume flows
composition
composition partial known (e. g. O2)
temperature resp. specific enthalpy (feed water, steam)
temperature resp. specific enthalpy assumed
boiler
flue gas
steam
heat losses
feed-water
air
firing
flue gas
waste
slag
auxiliary fuel, steam
heat losses
preheated air
air
air preheating
steam
condensate

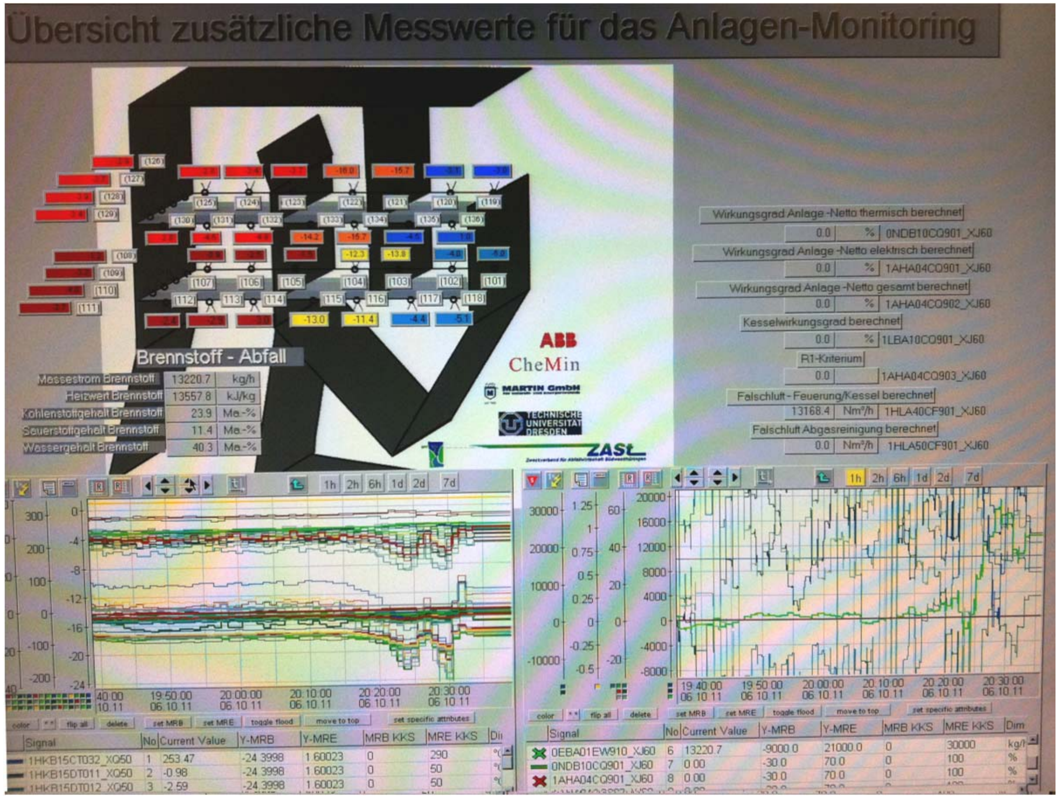

Input
subdivision process "air preheating, firing and boiler"
Output
feed-
water
air
waste
auxiliary
fuel,
steam
air
steam
boiler
firing
air
preheating
flue gas
preheated
air
1
2
3
4
modules in subdivision
process:
- air preheating
- firing
- boiler
flue gas
steam
heat losses
slag
heat losses
condensate

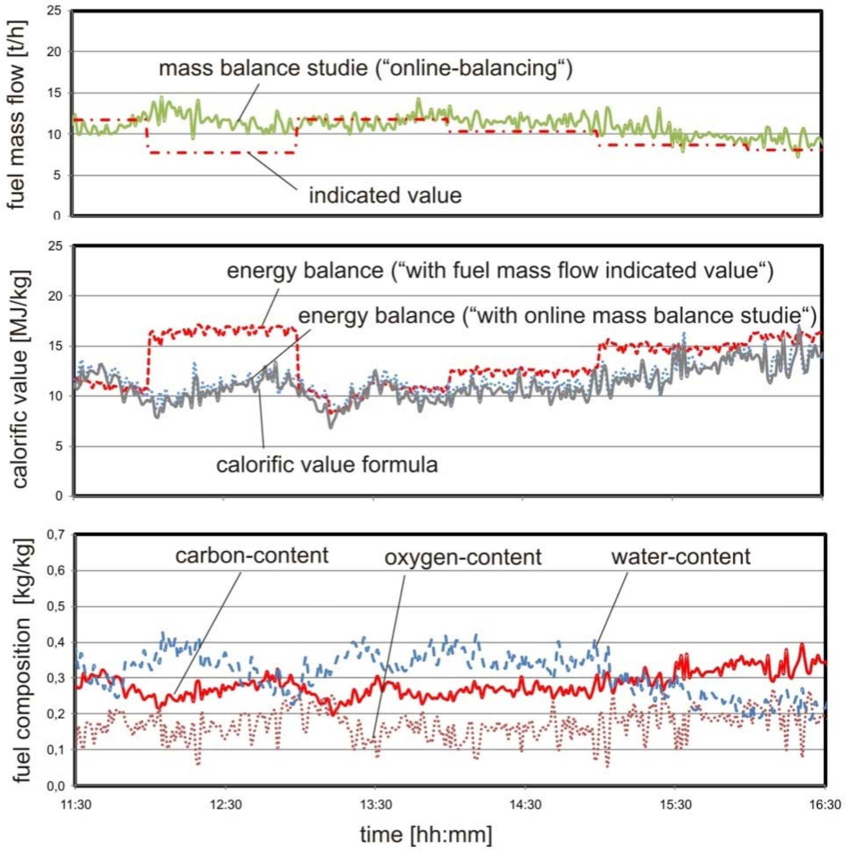


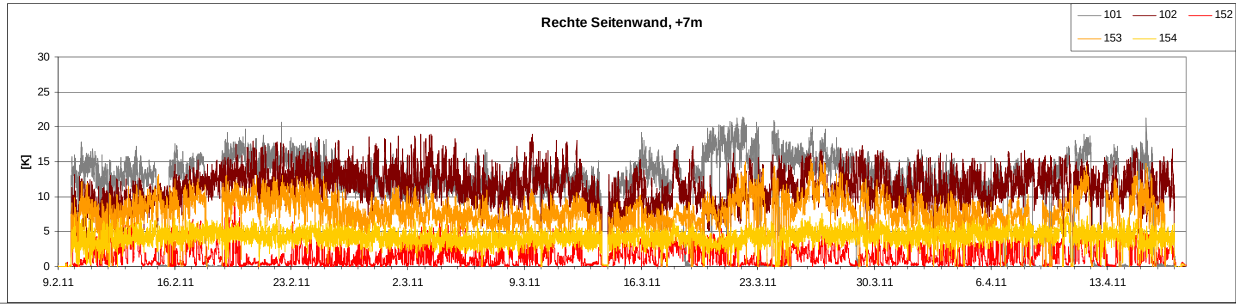
Abfall			
Symbol	AF,U_F-L1		
m [kg/h]	10.203	m [kg R/h]	8.163
H [kJ/h]	248.360.062	h [kJ/kg]	11.186
ϑ [°C]	20,0	c [kJ/kgK]	1,05
C [kg/kg]	0,352	C [kg/kg R]	0,311
H [kg/kg]	0,035	H [kg/kg R]	0,044
O [kg/kg]	0,142	O [kg/kg R]	0,178
N [kg/kg]	0,008	N [kg/kg R]	0,010
S [kg/kg]	0,000	S [kg/kg R]	0,000
W [kg/kg]	0,363	W [kg/kg R]	0,456
In [kg/kg]	0,200	C/H	7,00
C,A [kg/kg]	0,020	hC [kJ/kg]	33.500

- **285 measuring values for balancing**

- **Reading / recording the measured data signals via the OPC-Server connection**
- **Converting the measured signal corresponding to the calibration of measuring device if necessary**
- **Checking the measured value if the value is within an individually defined ratio (upper and lower limit) and**
- **Checking the measured value - if the value is defined as indicator parameter - to see if it can be allocated to a practically stationary state**


Übersicht zusätzliche Messwerte für das Anlagen-Monitoring
Brennstoff - Abfall
Wirkungsgrad Anlage -Netto thermisch berechnet
Wirkungsgrad Anlage -Netto elektrisch berechnet
Wirkungsgrad Anlage -Netto gesamt berechnet
Kesselwirkungsgrad berechnet
R1-Kriterium
Falschluft - Feuerung/Kessel berechnet
Falschluft Abgasreinigung berechnet
ABB
CheMin
MARTIN GmbH
ZASt


fuel mass flow [t/h]
mass balance studie (“online-balancing“)
indicated value
calorific value [MJ/kg]
energy balance (“with fuel mass flow indicated value“)
energy balance (“with online mass balance studie“)
calorific value formula
fuel composition [kg/kg]
carbon-content
oxygen-content
water-content
11:30
12:30
13:30
14:30
15:30
16:30
time [hh:mm]


Rechte Seitenwand, +7m
101
102
152
153
154
[K]
9.2.11
16.2.11
23.2.11
2.3.11
9.3.11
16.3.11
23.3.11
30.3.11
6.4.11
13.4.11

We would like to thank the operators and manufactures of MSWI plants who have supported us in the development and testing of the ***online balancing methode***.

»Wissen schafft Brücken.«