TECHNOLOGY-SPECIFIC LIFE CYCLE ASSESSMENT CONTIBUTING TO AN ENERGY STRATEGY

51th LCA Discussion Forum

THE ROLE OF ENVIRONMENTAL LIFE CYCLE THINKING IN LONG-TERM (ENERGY) STRATEGIES

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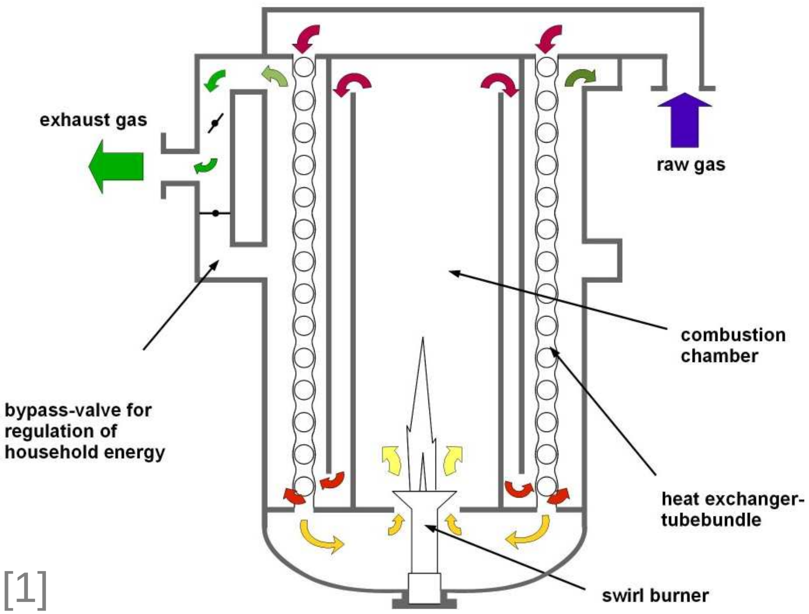
AGENDA

1. Technological Development
2. Fire Tube Boiler
3. Functional Unit
4. Bottom up-Top down-Approach
5. Inventarisation
6. Impact Assessment
7. Evaluation
8. Discussion and Outlook
9. References

1. Technological Development

2013	LCA of an improved fire tube boiler	HTW Berlin
2013-2016	Micro-profiled Plate Heat Exchanger	TTZ GmbH
2009-2012	Thermochemical Storage Unit	TH Wildau
2009-2011	Integrated Algae Reactor System	TH Wildau
2008-2011	High-end Product Gas Cooler	TU Berlin/UNott
2006-2008	High-performance Forming Machine	Omega/Contec



[1]
V-Thermal Afterburning Unit, ip tube® bundle

Construction Methodology: Concept Functionalisation of Assembly Units

Assembly Surfaces ⇨ Actice Functional Elements

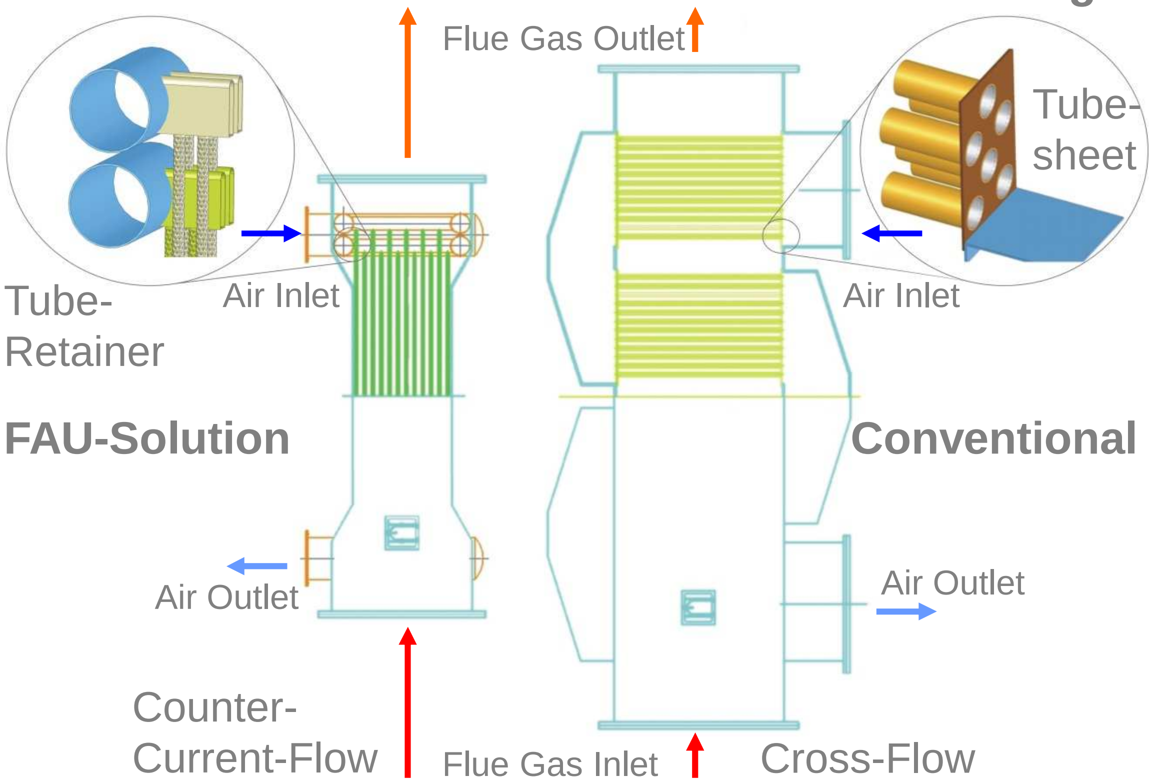
FAU-Concept ⇨ Functionalisation + New Constructional Design

Hydraulic Forming Machine
industrial power tube
(ip tube®)

Functional Elements

⇩

Specific Surface Structure Technology



Air Preheating Unit[2,3]

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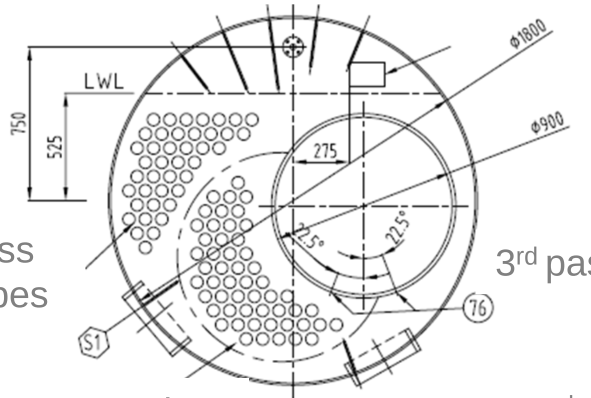
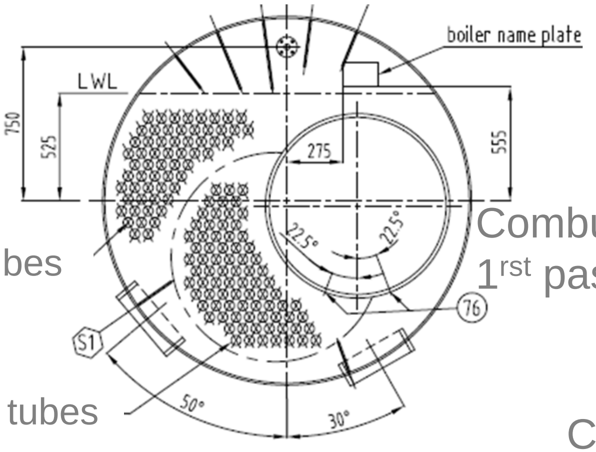
2. Fire Tube Boiler





3rd pass 41 tubes

3rd pass 60 tubes

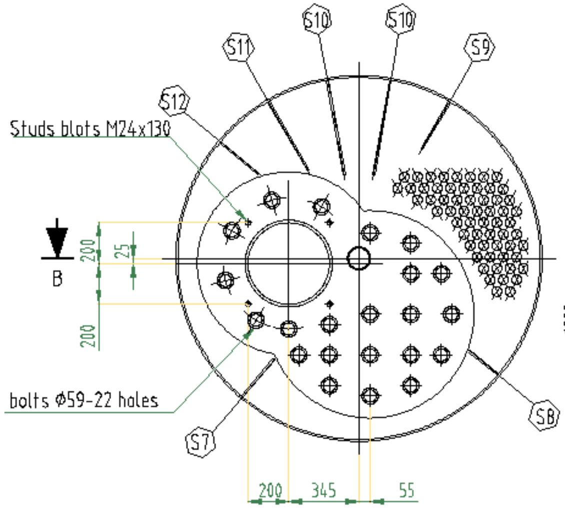
Combustion Chamber: 1^{rst} pass

2nd pass 53 tubes

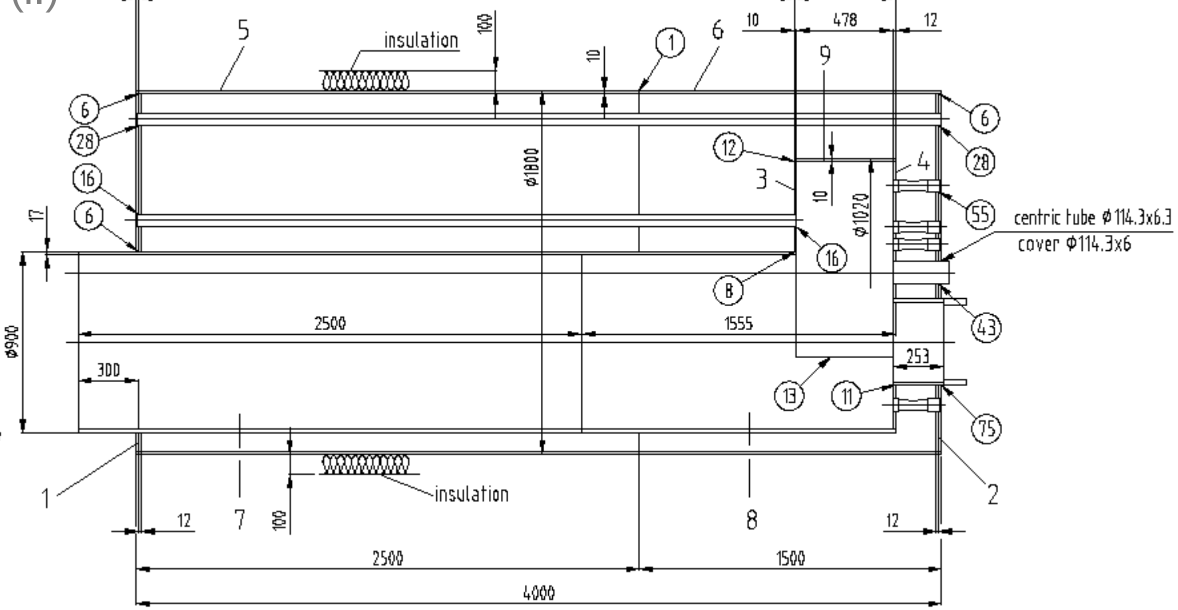
2nd pass 80 tubes

Latitudinal Section: modified (l.)

Conventional (r.)



End Plate



Longitudinal Section

3. Functional Unit

Specific Data

Quantity	Value	Unit
Steam Mass Flow	3500	$kg_S \cdot h^{-1}$
Steam Pressure	11	bar
Steam Temperature	184	°C
Natural Gas LL*	33.400	$MJ \cdot m^{-3}$
Gas Flow (3 bar g)	260	$m_N^3 \cdot h^{-1}$
Air Flow	2573	$m_N^3 \cdot h^{-1}$
Flue Gas Flow	2835	$m_N^3 \cdot h^{-1}$
Feed Water Flow (105°C)	3600	$kg \cdot h^{-1}$
Thermal Capacity	2281	kW
Thermal Efficiency	0.9465	-
Lifetime*	15	a
Boiler Mass (Tube)*	3288.24	kg

* Shortfall Fuel Mazut (HFO), 30 a/45 a, 1-3 major + 6-18 small revisions
+ Shell, Eco, Δm = 756.24 kg (-23%), m_i = 2532, $\Delta\eta$ = 1.65 %, η_0 = 93 %.

Variants

Process Steam

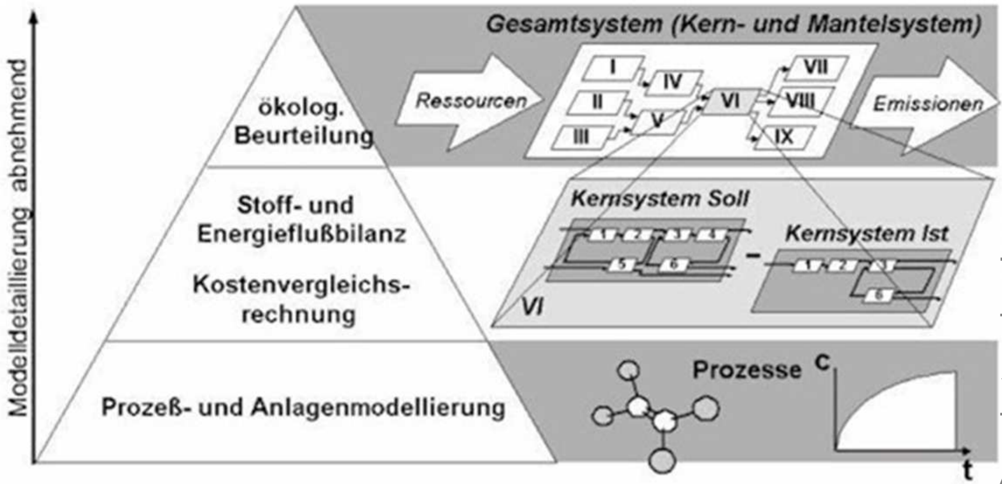
Process Heat

Electricity 350 kW *

* η_G = 15 %,
Steam Turbine-
(Siemens AG Görlitz)
Steam Motor-
Gen Set-Condenser
(Spilling Energie Systeme GmbH Hamburg)

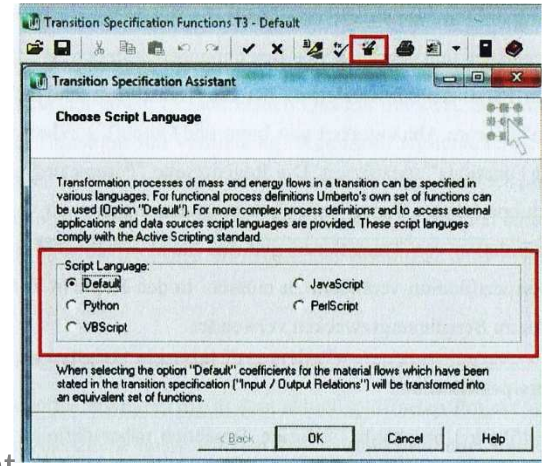
Specific Data corresponding to The Funtional Unit 3.5 t_S/h (11 bar,184 °C) [4,5]

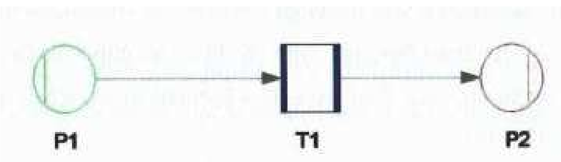
4. Bottom up-Top down-Approach



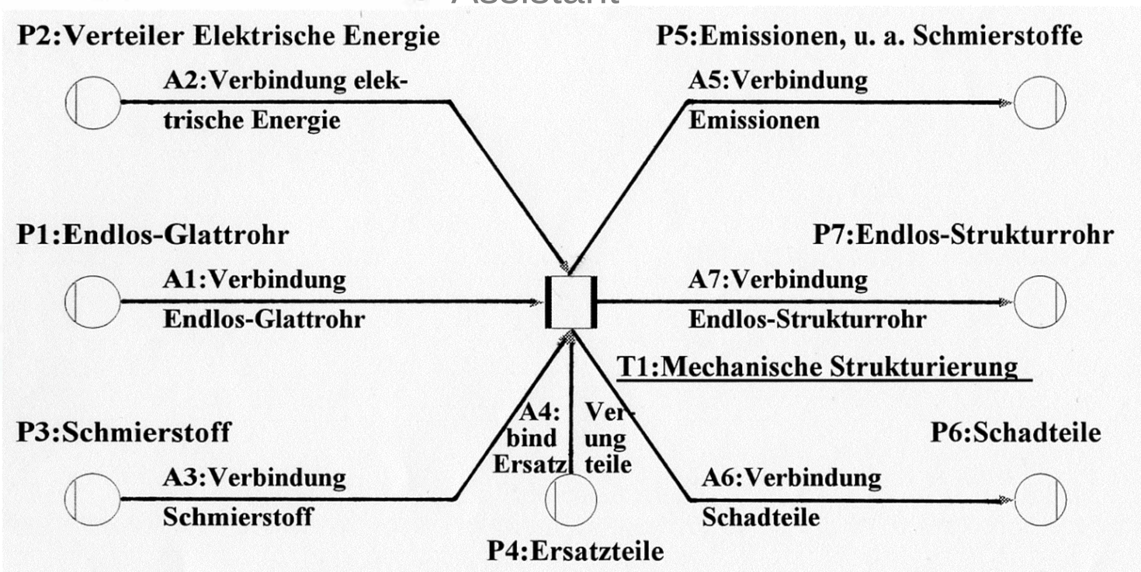
Core-System Bottom up
Shell-System Top down

Transi-tion Speci-fication Assistant





Boiler under Construction



[6,7,8] Specific module of the forming process generated under UMBERTO

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5. Inventarisation

CH_4	C_2H_6	$i\text{-}C_4H_{10}$	$N\text{-}C_5H_{12}$	C_6H_{14}	N_2	CO_2
Mol-%						
81.6	3.1	0.4	0.002	0.001	1.9	13

Natural Gas LL

$$\Phi_{\Lambda,spec.} = \sum^{j,o,\pi} K_{j,o} + \left(\frac{K_\pi}{\Delta t}\right)_m \cdot \int_0^{na-1} K_\pi(t)\cdot\left(\frac{1+I(t)}{1+Z(t)-I(t)}\right)^t dt$$

$$\Phi_{X,spec.} = \sum_1^{i,j,l,m} \Theta_{i,j,l,m}$$

i – Item of the balance
j – Life Cycle Phase
l – Type of Term
m – Number of Term
o – Type of Cost
π – Cost Value

Mass-, Energy and Cost Balance

Gas	Compound	Vol.-%
Nitrogen	N_2	78.08
Oxygen	O_2	20.95
*Water	H_2O	< 4
Argon	Ar	0.93
*Carbon Dioxide	CO_2	0.036
Neon	Ne	0.0018
Helium	He	0.0005
*Methane	CH_4	0.00017
Hydrogen	H_2	0.00005
*Nitrous Oxide	N_2O	0.00003
*Ozone	O_3	0.000004
earthnear, * variable		

Combustion Air

Flue Gas	Vol.-%
CO_2	8.71
H_2O	18.27
N_2	71.32
O_2	1.7

Flue Gas [9,10]

6. Impact Assessment

$$\Phi_{K,spec.} = \sum^{i,j} m_i \cdot f_{\Phi K,i} \cdot f_{AK,i} \cdot P_{j,spec.}$$

Environmental Impact Potential

m_i = Mass Freight of a Substance,
$f\Phi_{K,i}$ = Specific Characterisation Factor of the Category $_K$,
$fA_{K,i}$ = Specific Allocation Factor of the Category $_K$,
$P_{j,spez}$ = Specific Mass and Energy Turnover of Process Chains,
I = Index of Substances of the Category $_K$,
j = Index of Life Cycle Phases of the Object.

Federal Environmental Agency Potential Method

Mid Point-orientated Potential: neither Inventory nor Damage

$$\Phi_{GW,100,CO_2,i} = \frac{\int_0^{T_H} a_i(t) \cdot \lambda_i(t)\, dt}{\int_0^{T_H} a_{Ref.}(t) \cdot \lambda_{Ref.}(t)\, dt}$$

a = Radiation Impact, $[a] = W \cdot m^{-2} \cdot kg^{-1}$,
λ = Decay Constant,
t = Time Coordinate,
T_H = Time Horizon.

Example: Model of Global Warming Potential

$$\Phi_{K,N,spec.} = \frac{\Phi_{K,spec.}}{\Phi_{K,all}}$$

Normalisation to Reference Frame

7. Evaluation

$$\iota_K = \frac{\Phi_{K,all} - \Phi_{K,G}}{\Phi_{K,G}}$$

I_K = Grade of Goal Getting
$\Phi_{K,all}$ = Actual Value
$\Phi_{K,G}$ = Goal Value

Objective Goals in Germany until 2020:

- **Increased Energy Efficiency by 20 %**
- **Increased Resource Efficiency by 37.5 %**
- **Decreased Global Warming Potential by 40 %**

$$G_K = \frac{\iota_K}{\sum^{K} \iota_K}$$

Weighting Coefficient

$\Longrightarrow$

$$\Xi_{K,\iota} = G_K \cdot \Phi_{K,N,spec.}$$

Index of Overall Effect

$\Delta\eta/\eta_0$ = 1.8 %
$\Phi_{E,N,spec.}$ = $9.7 \cdot 10^{-8}$
$\Delta m/m_0$ = 0.76 %
$\Phi_{R,N,spec.}$ = $1.3 \cdot 10^{-9}$
$\Delta V/V_0$ = 0.16 %
$\Phi_{GWP,N,spec.}$ = $6.4 \cdot 10^{-8}$
$\Longrightarrow$ G_E = 0.15
G_R = 0.37
G_{GWP} = 0.48

$$\Xi_{K,\iota} = \Xi_{E,\iota} + \Xi_{R,\iota} + \Xi_{GWP,\iota} = 1.5 \cdot 10^{-8} + 5 \cdot 10^{-10} + 3.1 \cdot 10^{-8} = 4.6 \cdot 10^{-8}$$

Improved Boiler contributes 33% Energy Efficiency and 67 % GWP to Objective Goal

8. Discussion and Outlook

- **Best Available Technology**
  - Successful Re-design of the Boiler and Use of ip tube® Bundles
  - Increased Efficiency $\Delta\eta/\eta_0$ = 1.8 %
  - Decreased Boiler Fuel Demand and CO_2-Emission $\Delta V/V_0$= 0.16 %
  - Decreased Boiler Mass $\Delta m/m_0$ = 0.76 %
- **Life Cycle Assessment**
  - Federal Environmental Agency Potential Method
  - Mid Point-Orientation and Normalisation to Reference Frame
  - Integration of Objective Goals by Grade of Goal Getting
- **Modelling, Calculation**
  - Software-Tool UMBERTO
  - Weighted Index of Overall Effect
- **Significant Conclusions**
  - Global Warming Potential Reduction by 67 %
  - Improvement of Energy and Resource Efficiency by 33 % and 1 %

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