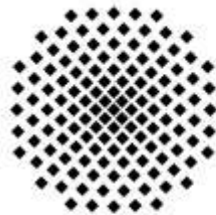

Exergy-Efficiency as Enhancement of Energy-Efficiency – an LCA Perspective

Fraunhofer



Institut
Bauphysik



University of Stuttgart

Chair of Building Physics (LBP)
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Exergy-Efficiency as Enhancement of Energy-Efficiency – an LCA Perspective

LCA8, Seattle

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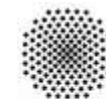
Michael Faltenbacher
PE INTERNATIONAL GmbH



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- ▶ Energy
- ▶ Exergy
- ▶ Energy and Exergy Efficiency
- ▶ LCA Perspective
- ▶ Conclusions

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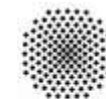


Energy

Types of energy

- ▶ Chemical energy
- ▶ Thermal energy
- ▶ Potential energy
- ▶ Kinetic energy
- ▶ Radiation energy
- ▶ Nuclear energy
- ▶ ...

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Exergy

What is exergy? – Definition

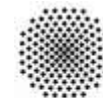
- ▶ The exergy of a system with respect to a reservoir is the maximum work done by the system during a transformation which brings it into equilibrium with the surrounding.

$$\text{Energy} = \text{Exergy} + \text{Anergy} \text{ [Gibbs]}$$

Note: Anergy is the complementary part of the energy that can not be converted into work.

- ▶ Exergy is defined as a measure of the actual potential of a system to do work.
- ▶ Energy that has a high convertibility potential is said to contain a high share of exergy.
- ▶ Electricity and mechanical work are perfectly convertible and for these forms exergy contents equals the energy content.
- ▶ For nuclear and fossil fuels theoretical conversion potential is close to perfect, but severely limited by available technical processes.
- ▶ Reversely, heat at temperature close to the reservoir has low convertibility potential, the exergy content of such heat is much lower than its energy content.

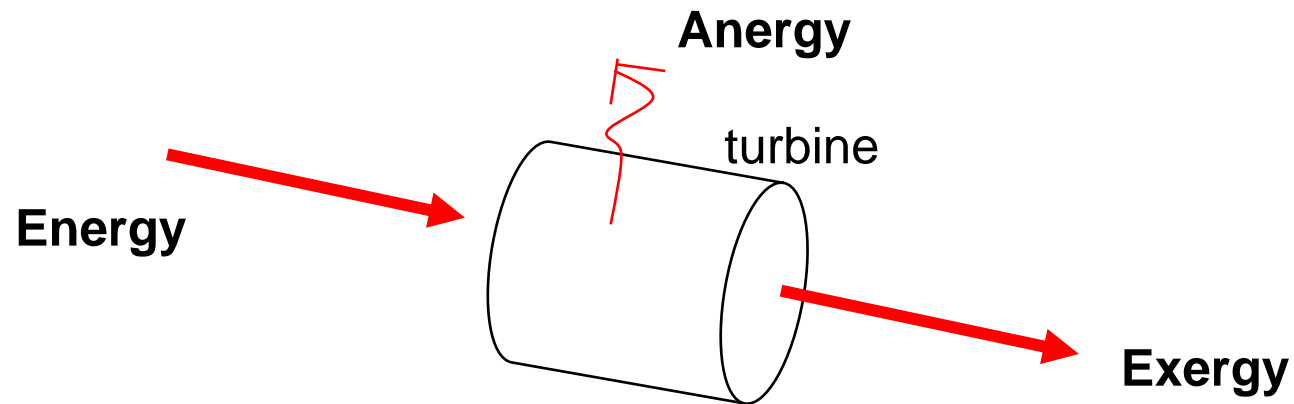
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Exergy

What is exergy? – Usage

- ▶ Describing technical processes such as cogeneration and heat pumps.
- ▶ In cogeneration, part of the energy is converted to work or electricity with high exergy content, and the remaining heat is used for purposes where moderate temperature (lower exergy content) is useful, such as food processing, drying and space heating
- ▶ Example: Heat transfer



- ▶ Note:
 - Energy balance is closed: Input = Output
 - But you can only use part of it (what is called in common parlance energy lost is in reality anergy)

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Exergy

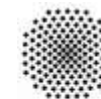
What is exergy? – Conclusion

- ▶ **Exergy** is a measure that indicates to what degree energy is convertible to other forms of energy
- ▶ It is a measure of the **quality** level of the energy

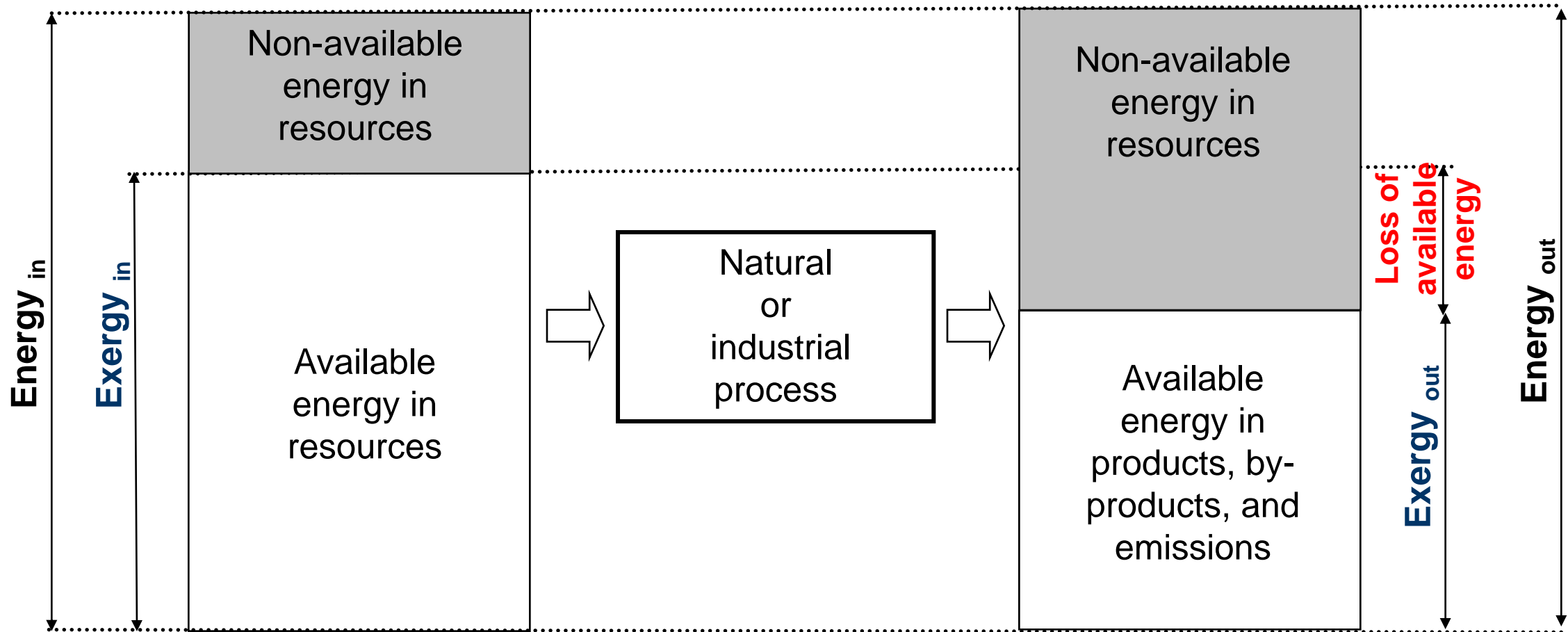
- ▶ **First law** of thermodynamics:
 - Energy in = Energy out → Energy can neither disappear or be generated

- ▶ **Second law** of thermodynamics:
 - Exergy in > Exergy out → Real processes result in a loss of energy (to be transformed into work) due to the generation of entropy.

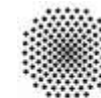
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Energy – Exergy



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Efficiency

What is efficiency?

In general: Efficiency can be defined as the ratio of output to input for any given system

- ▶ Investigating thermal processes, this ratio is called “Carnot efficiency”: $\eta_c = 1 - \frac{T_0}{T_s}$

The Carnot efficiency (ideal efficiency) is a measure of the quality of the conversion of heat into work between temperature levels.

- ▶ The exergetic efficiency (η_{ex}) is:

$$\eta_{Ex} = \frac{\sum (QF \cdot En_{useful\ output})}{\sum (QF \cdot En_{input})}$$

With: QF = Quality factor = Exergy / energy ratio = η_c for heat

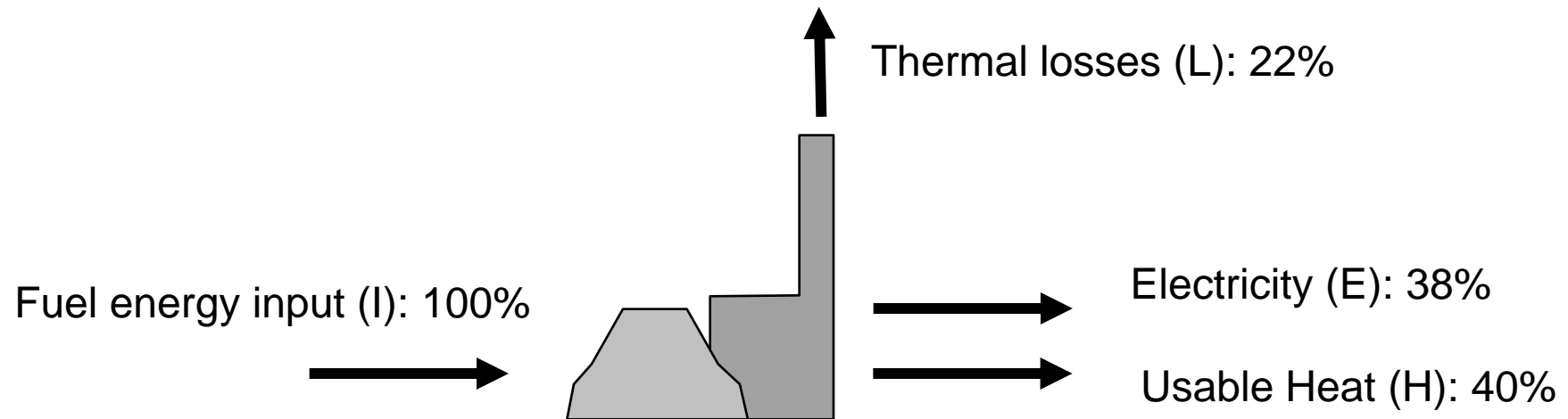
- Since, all Electricity is convertible into heat: $QF_E = 1$
 - For heat, the carnot factor is the QF $QF_H < 1$ (= 0 at ambient temperature)
- ▶ Applying this methodology, comparisons of the energetic and exergetic efficiencies can be made.

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Energy and Exergy Efficiency

Example – Combined heat and power plant (CHP)*



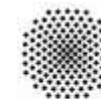
▶ Fuel efficiency = $E + H = 0,78$

▶ Exergetic efficiency $\eta_{Ex} = \frac{\sum (QF \cdot En_{useful\ output})}{\sum (QF \cdot En_{input})} = \frac{QF_E \cdot E + QF_H \cdot H}{QF_F \cdot En_{input}} = \frac{1 \cdot 0,38 + 0,42 \cdot 0,4}{1} = 0,55$

with $QF_H = \eta_C = 1 - \frac{T_0}{T_S}$ $T_0 = 0^\circ\text{C} (=273\text{K}), T_S = 200^\circ\text{C} (=473\text{K})$

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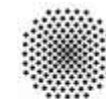
*Gas turbine with steam recovery boiler



First Conclusions

- ▶ The consideration of energy quality leads to the concept of exergy
- ▶ Energy efficiency does not include the usability of the converted energy
- ▶ Exergy efficiency includes the quality level of the converted energy
- ▶ as LCA is related to a functional unit (considering usability and quantified performance), the quality level of the energy output is of interest
- ▶ LCA studies should include the relation to exergy output

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LCA Perspective – Example

Example: Environmental assessment of different natural gas fired combustion plants related to energy and exergy output

Plant Parameters: fuel energy supplied (= 100%)

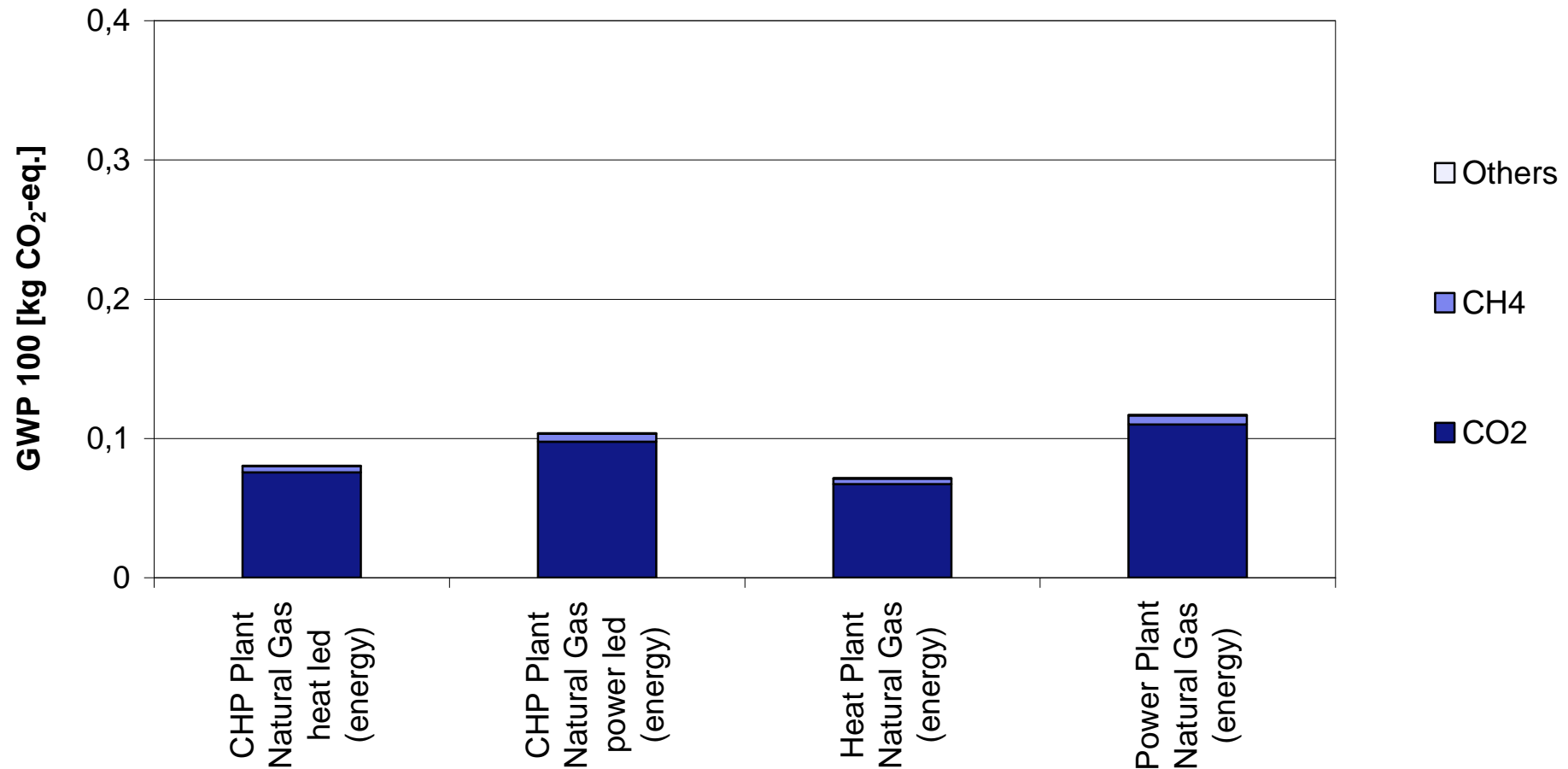
Technology	Electricity output [%]	Heat output [%]	Heat output temperature [K]	Energetic efficiency η_{fuel}	Exergetic efficiency η_{exergy}
Heat Plant	0	90	343	0.90	0.18
Power Plant	55	0	-	0.55	0.55
CHP (heat led)	20	60	473	0.80	0.45
CHP (power led)	50	12	473	0.62	0.55

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LCA Perspective – GWP related to Energy

Energy: Global Warming Potential related to 1MJ of Output

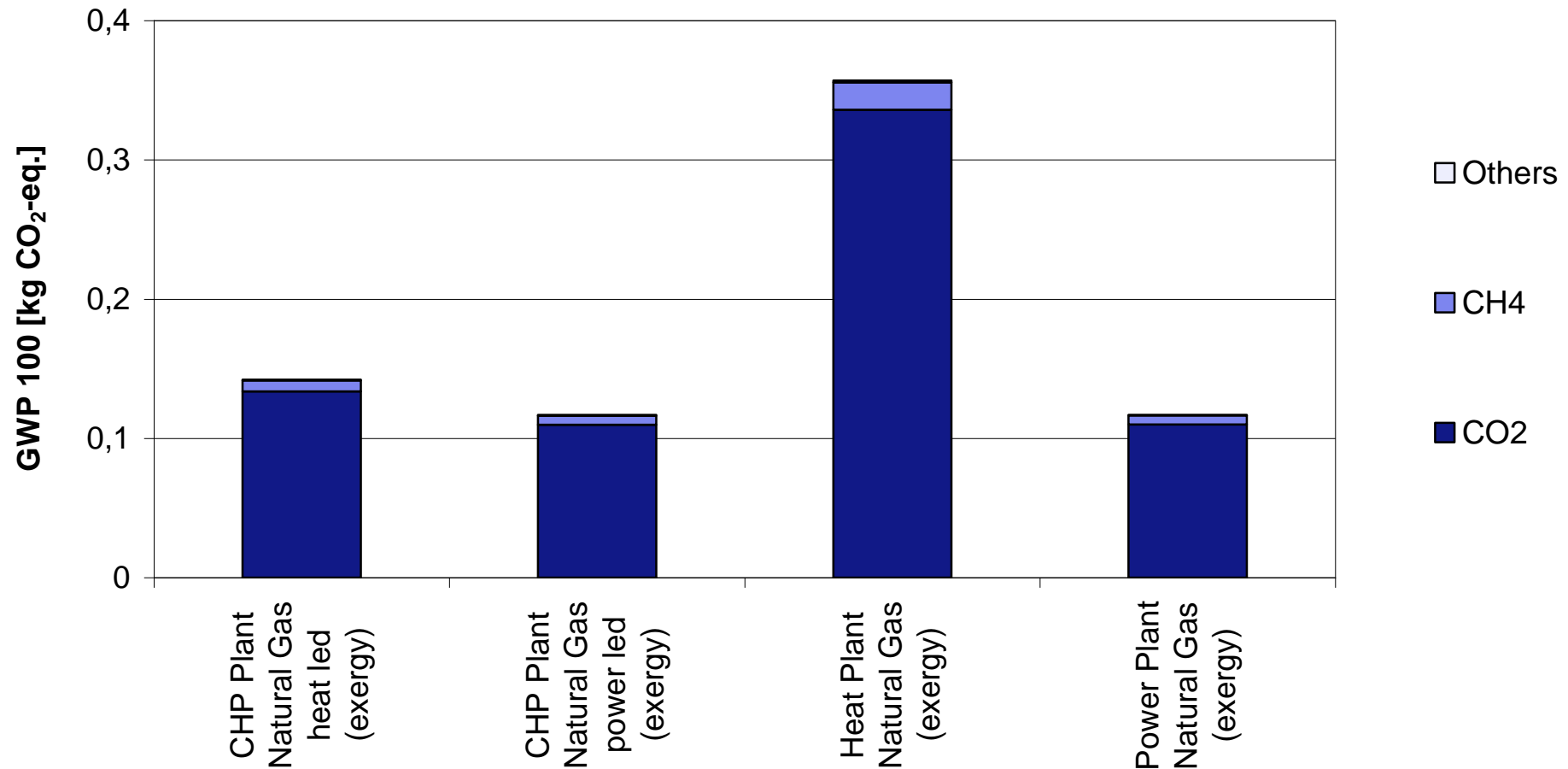


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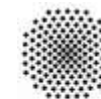


LCA Perspective – GWP related to Exergy

Exergy: Global Warming Potential related to 1MJ of Output

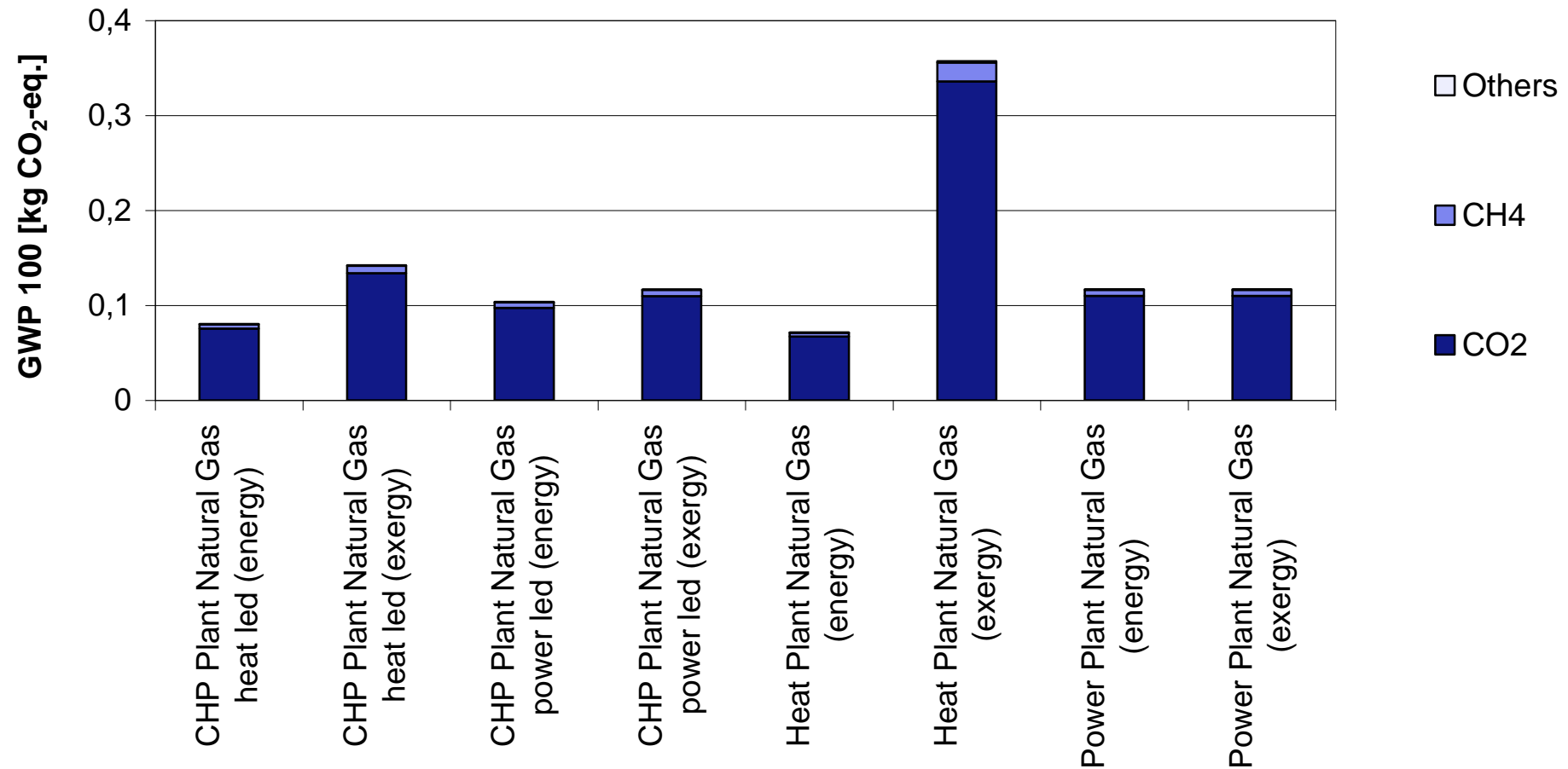


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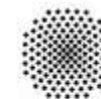


LCA Perspective – GWP Energy and Exergy relation overview

Energy and Exergy: Global Warming Potential related to 1MJ of Output

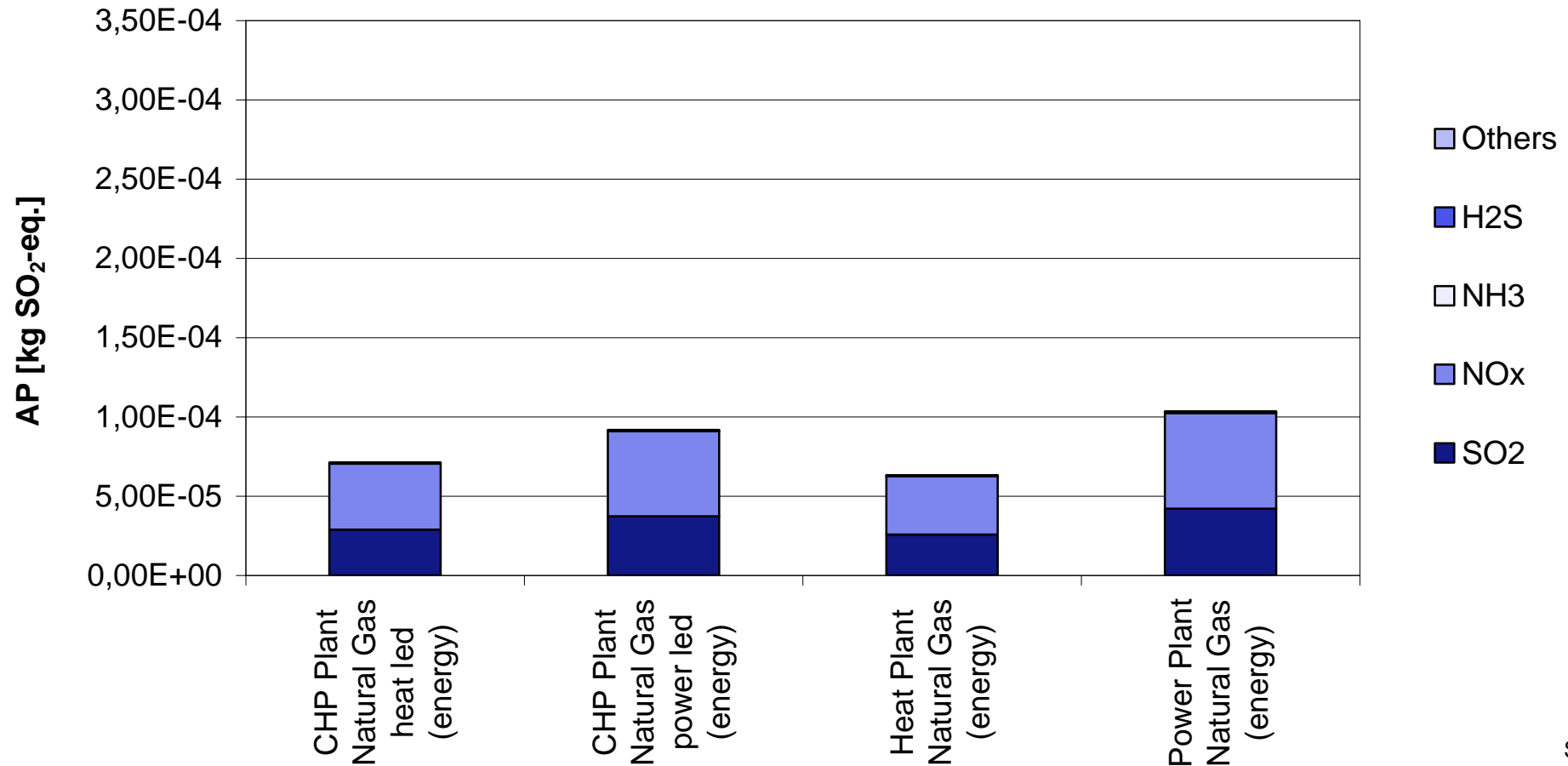


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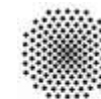


LCA Perspective – AP related to Energy

Energy: Acidification Potential related to 1MJ of Output

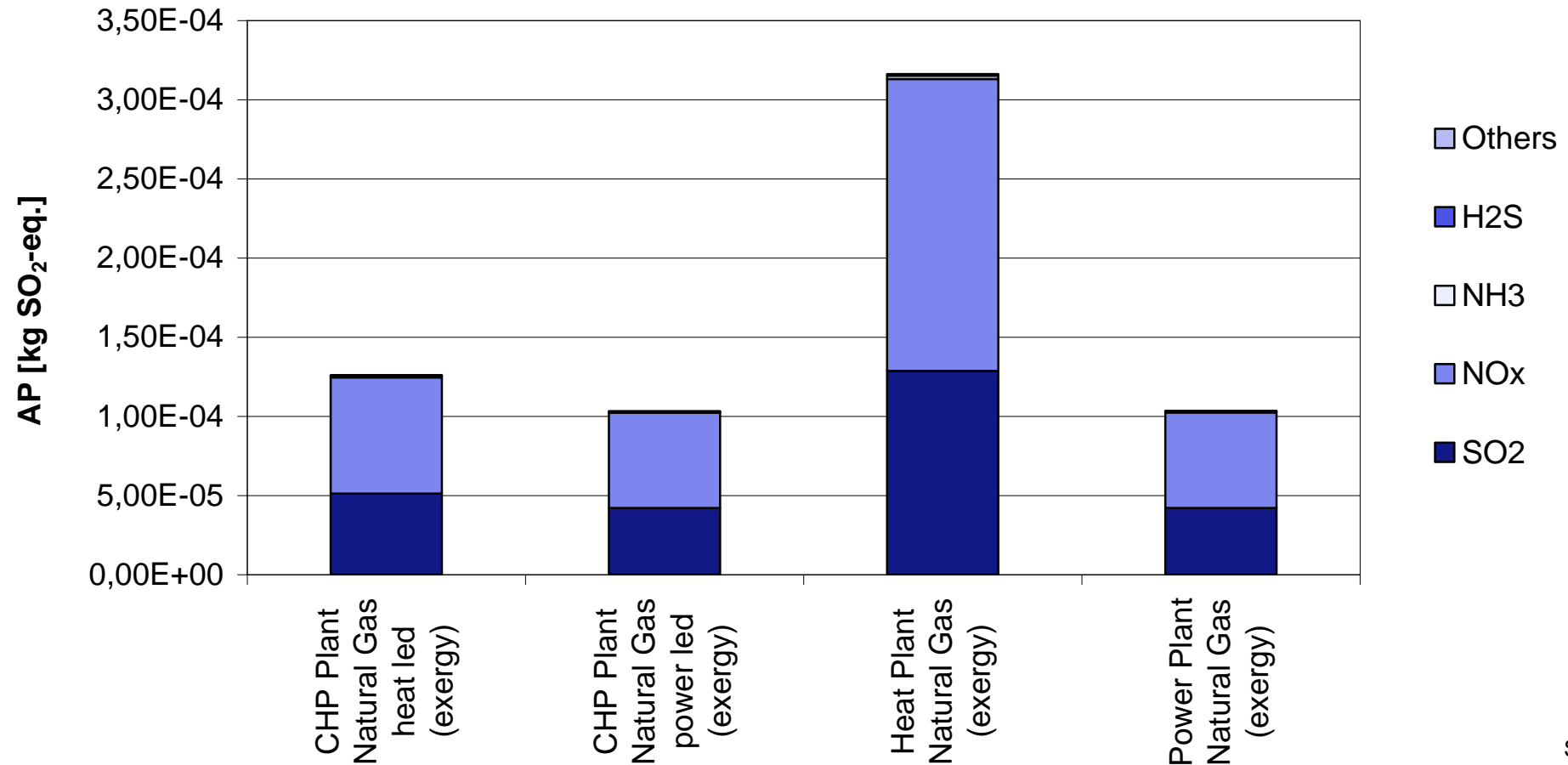


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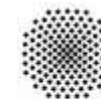


LCA Perspective – AP related to Exergy

Exergy: Acidification Potential related to 1MJ of Output

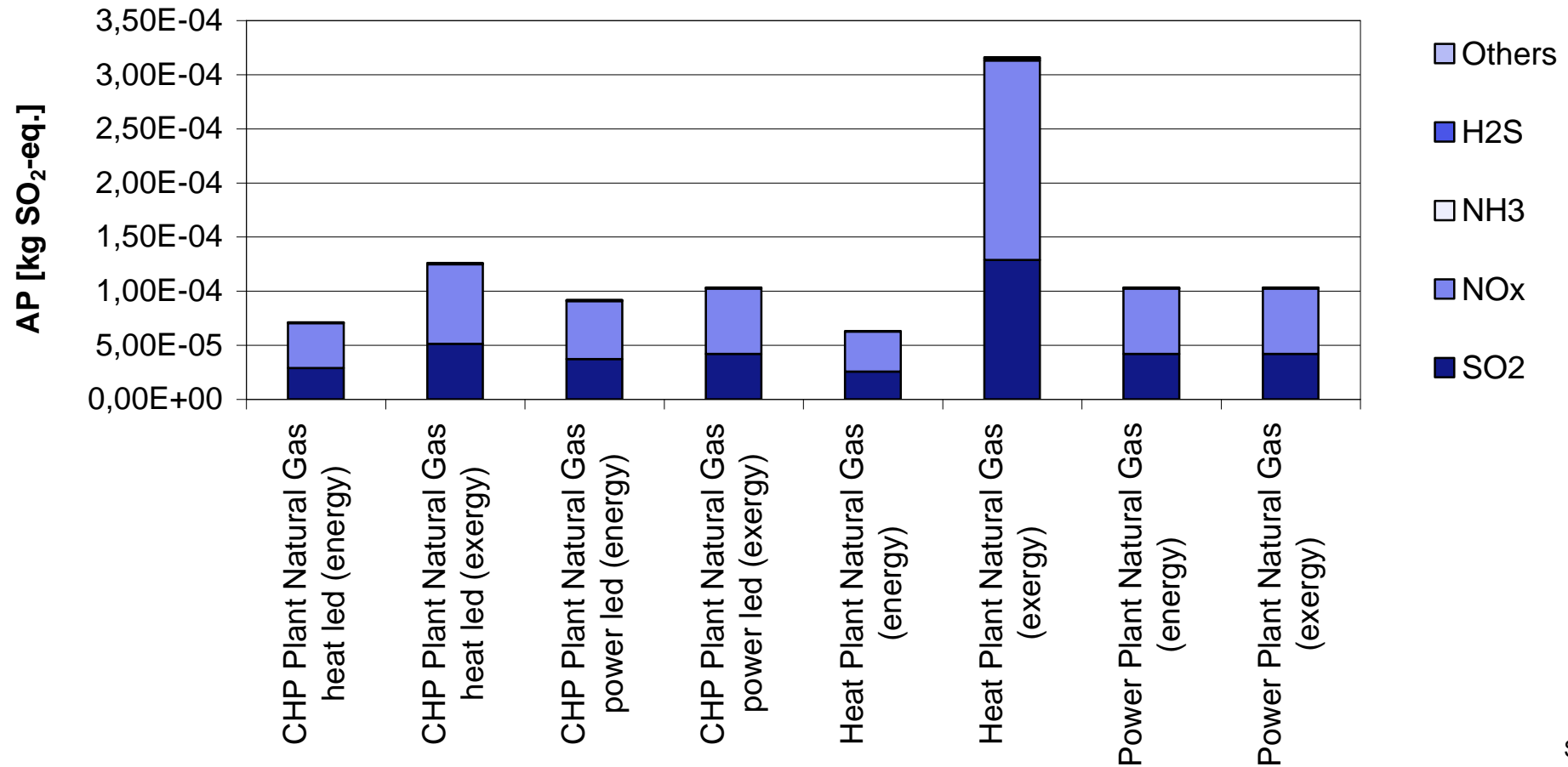


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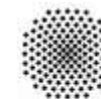


LCA Perspective – AP Energy and Exergy relation overview

Energy and Exergy: Acidification Potential related to 1MJ of Output



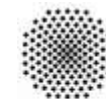
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LCA Perspective – Conclusions

- ▶ environmental profiles are different in relation to energy output and exergy output
- ▶ the difference of the environmental profile between energy and exergy analysis is as much more higher the more heat is produced
- ▶ from that the following fundamental conclusions can be derived:
 - the quality level of energy outputs influence the possible usability and therewith the quantified performance of the system
 - the quantified performance is the key element of the functional unit in LCA
 - so in LCA the quality of energy should be considered
 - exergy analysis is appropriate to be included in LCA
- ▶ LCA of energy production systems should be analyzed under consideration of the generated exergy output

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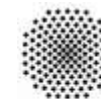


Conclusions for Heat and Power Generation

From an LCA perspective: which heat and power generation technologies are most suitable?

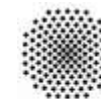
- ▶ the exergy output should be maximized
- ▶ heat losses should be minimized by using CHP technologies and waste heat utilization
- ▶ high exergetic energy carriers (e.g. natural gas) should not be used to produce low exergetic heat
- ▶ the quality of the requested energy should correspond to the quality of the used energy (if only low temperature heat, e.g. for space heating is requested, the energy supply should be appropriate)

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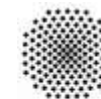
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