SESSION 3: 09:00–09:30

ESTEP European Steel Technology Platform

ESTEP workshop

SecCarb4Steel

Preparation and use of biogenic and non-biogenic secondary carbon carriers (SCC) in processes for iron and steelmaking

Ecological evaluation of the utilization of secondary carbon sources in the steel industry through a Life Cycle Assessment approach

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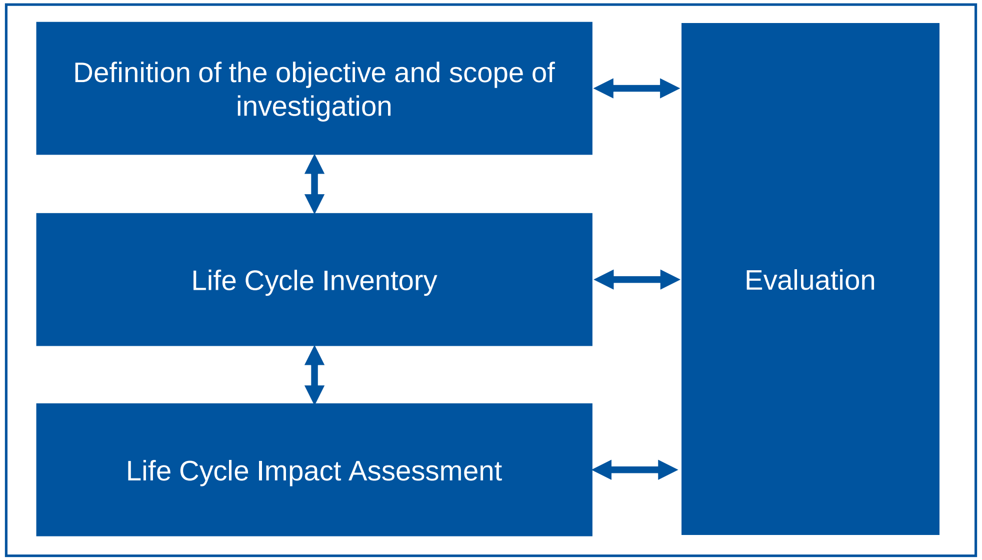
Basics about Life Cycle Assessments and Material Flow Analysis

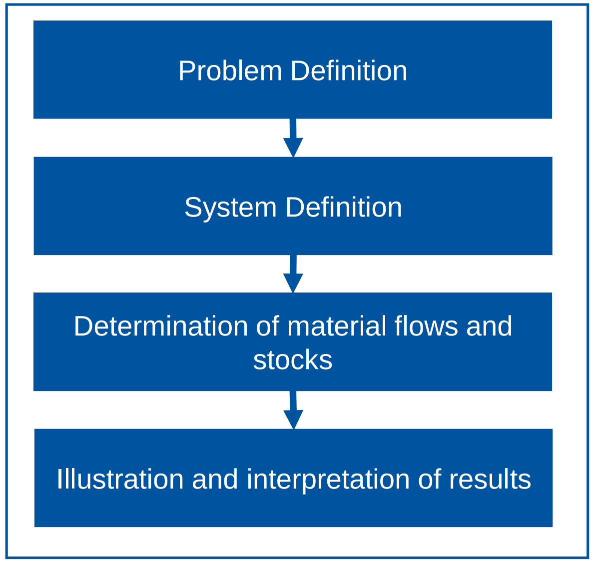
Foundations of Life Cycle Assessments (LCA) and Material Flow Analysis (MFA)

- LCA: Compilation and assessment of input and output flows and potential environmental impacts of a product system during its life cycle
- MFA: Systematic assessment of the state and changes of flows and stocks of materials within a system defined in space and time

Phases of a life cycle assessment [1]



Phases of a material flow analysis [2]

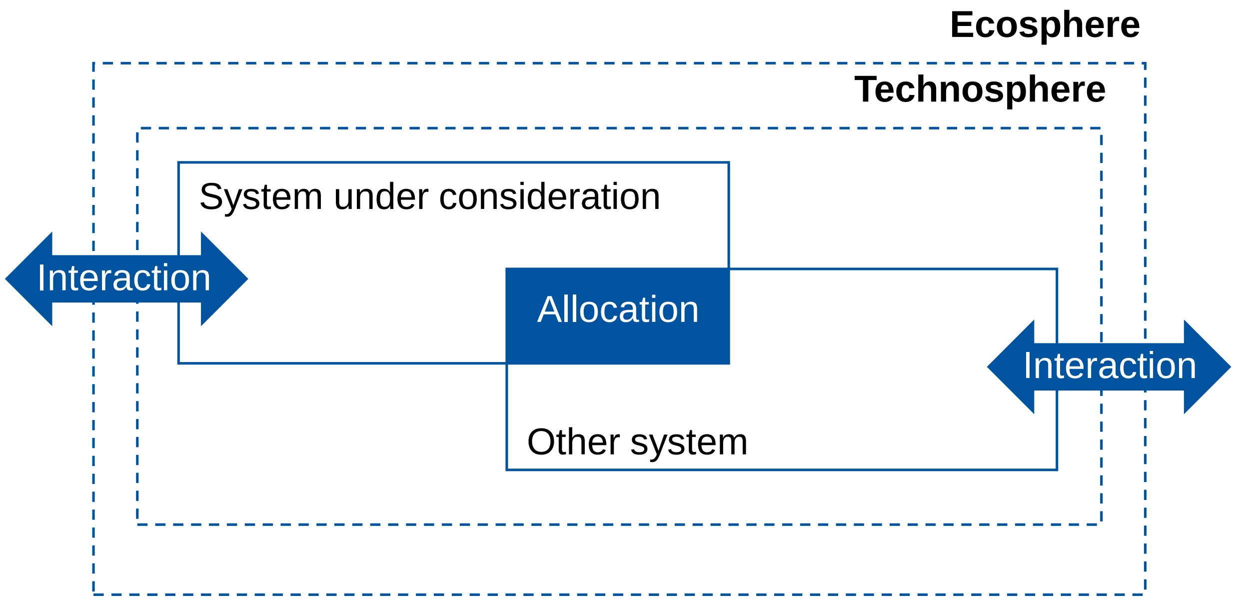


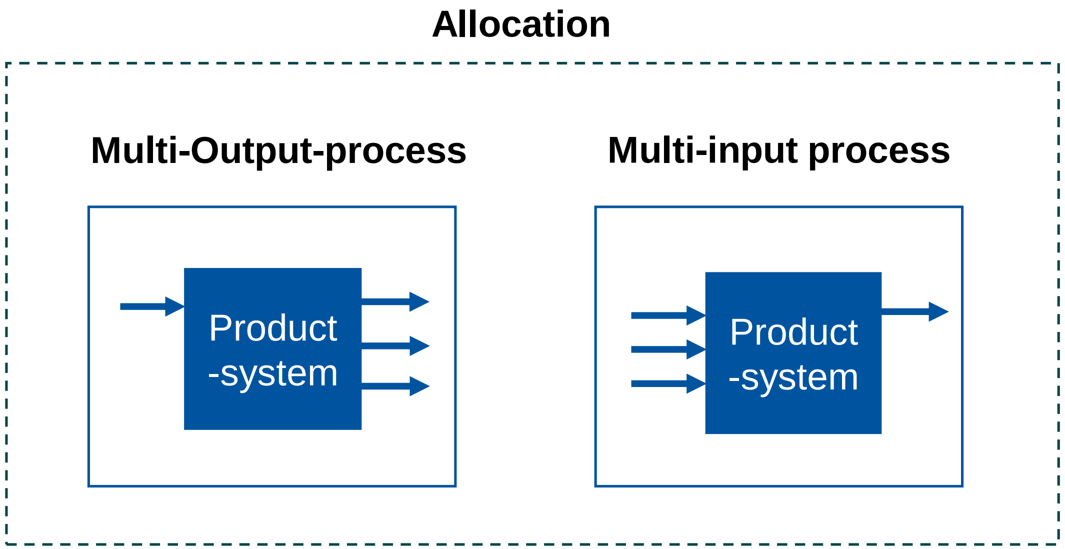
Source: [1] DIN EN ISO 14040, DIN EN ISO 14044, [2] Brunner et al. 2004

Methodology of Life Cycle Assesment calculation

Definition of the problem/objective and the scope of the investigation

- Definition of objectives
- Definition of the product system, functional unit and reference flow
- Definition of the scope and methodologies

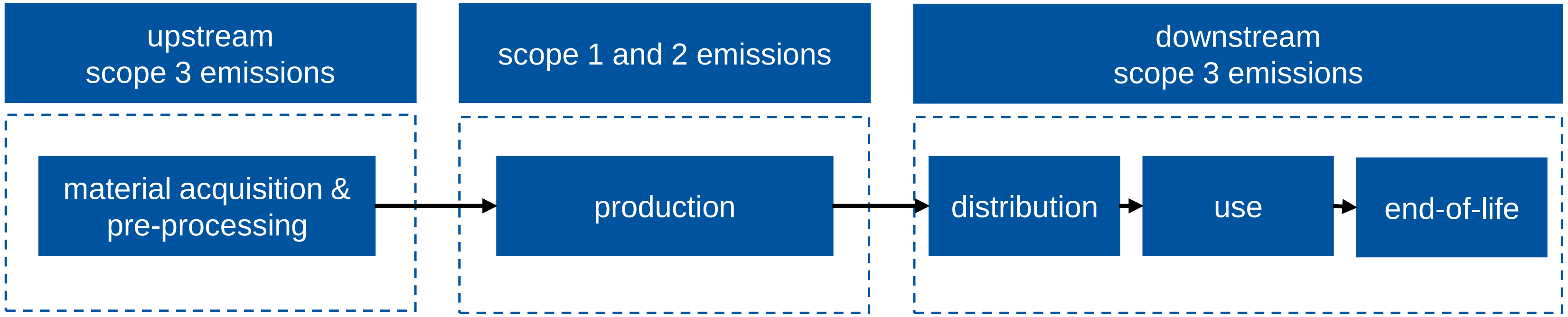




Source: DIN EN ISO 14040, Klöpffer (2017); Sundmacher (2002)

Methodology of Life Cycle Assesment calculation

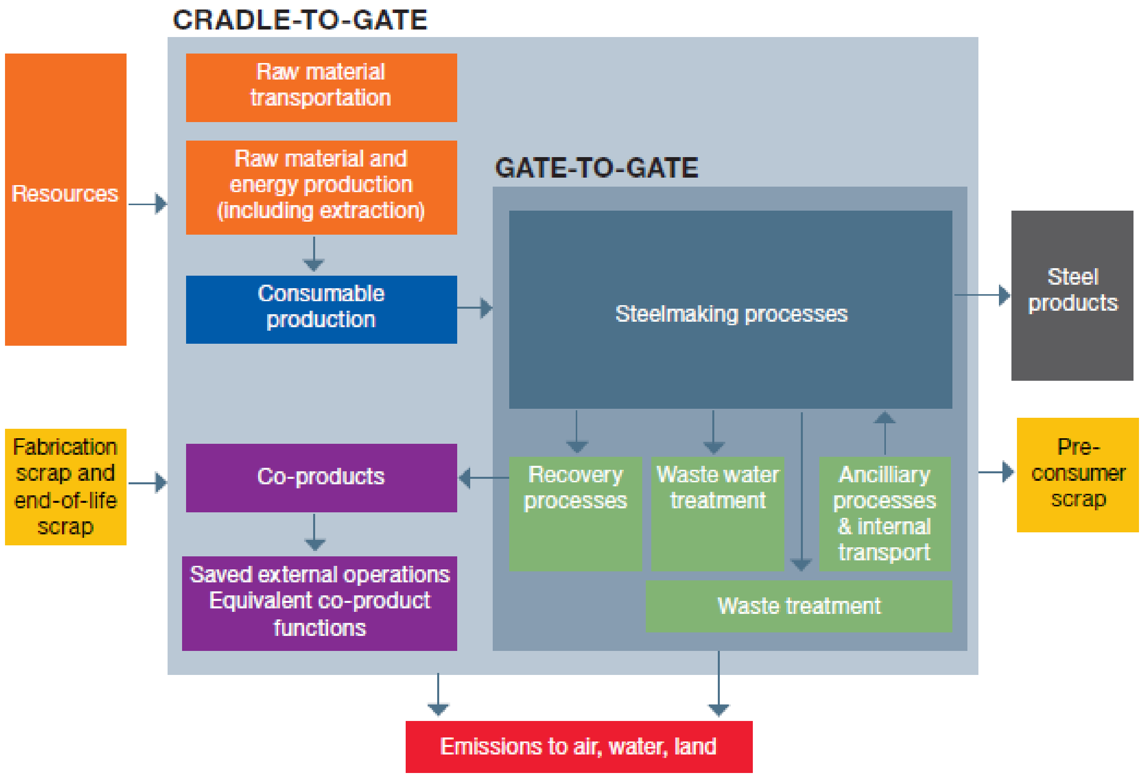
Relationship of scopes for calculating Carbon Footprints

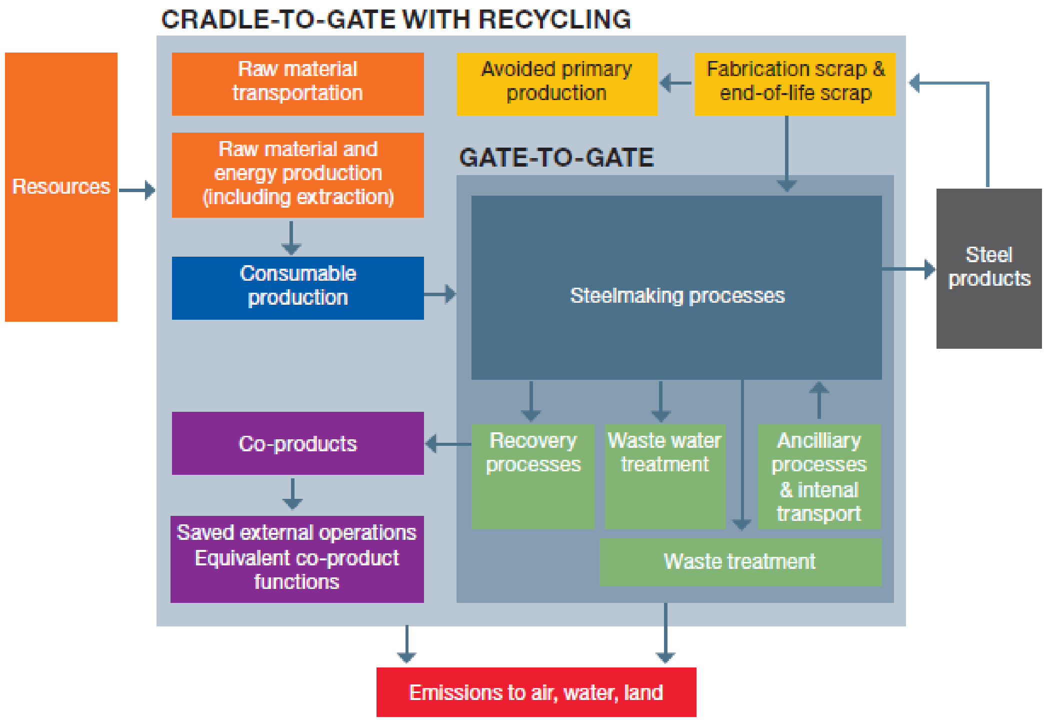


Level of complexity of the research framework	Description
Scope 1 (Direct GHG emissions)	Directly released GHG emissions that are directly attributable to the product system (e.g. exhaust gases from the combustion process)
Scope 2 (Indirect GHG emissions)	Indirect GHG emissions attributable to the product system (e.g. the emissions of the electricity mix used to provide the electrical energy required by the product)
Scope 3 (Other GHG emissions)	Other GHG emissions that can be assigned to upstream and downstream life phases of the product system (e.g. raw material extraction, recycling)

Methodology of Life Cycle Assesment calculation

Exemplary product systems and system boundaries of steel manufacturing

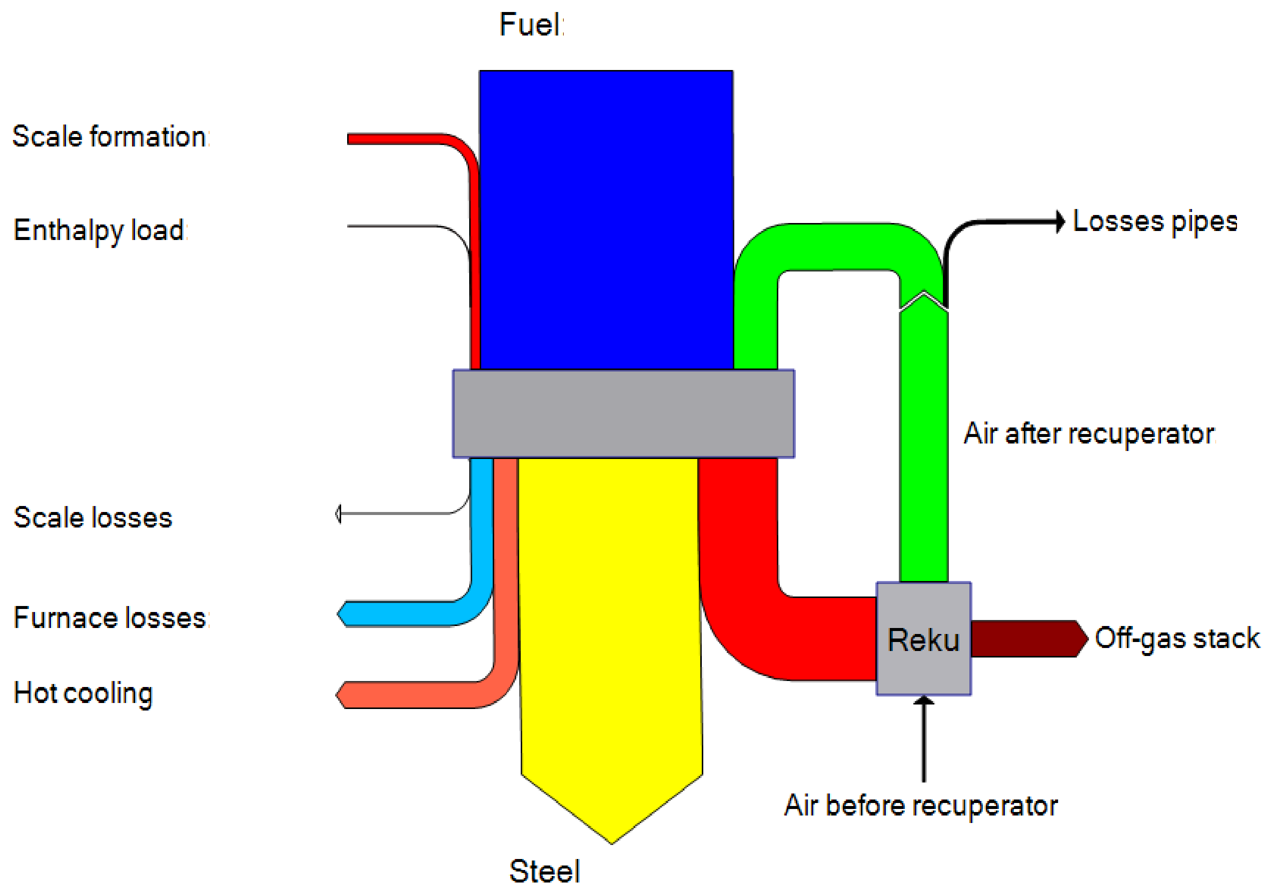




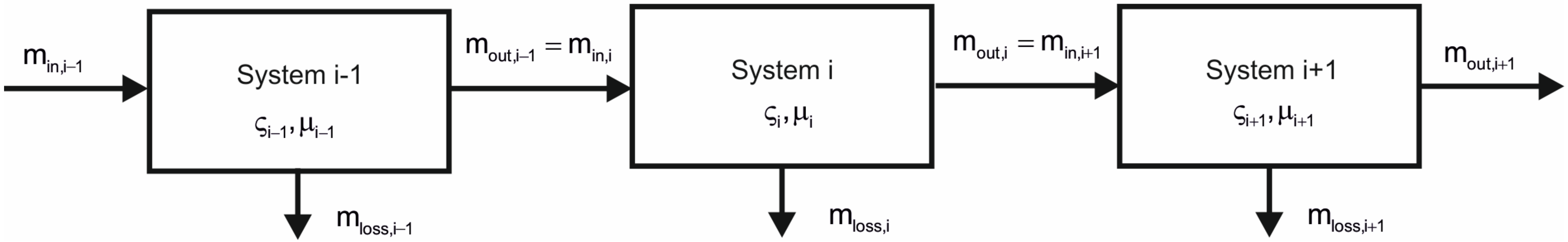
Methodology of Life Cycle Assesment calculation

Life Cycle Inventory and determination of material flows and stocks

- Data collection
- Data calculation
- Assignment to Process Modules
- Modeling of the product system



Mass balance principles

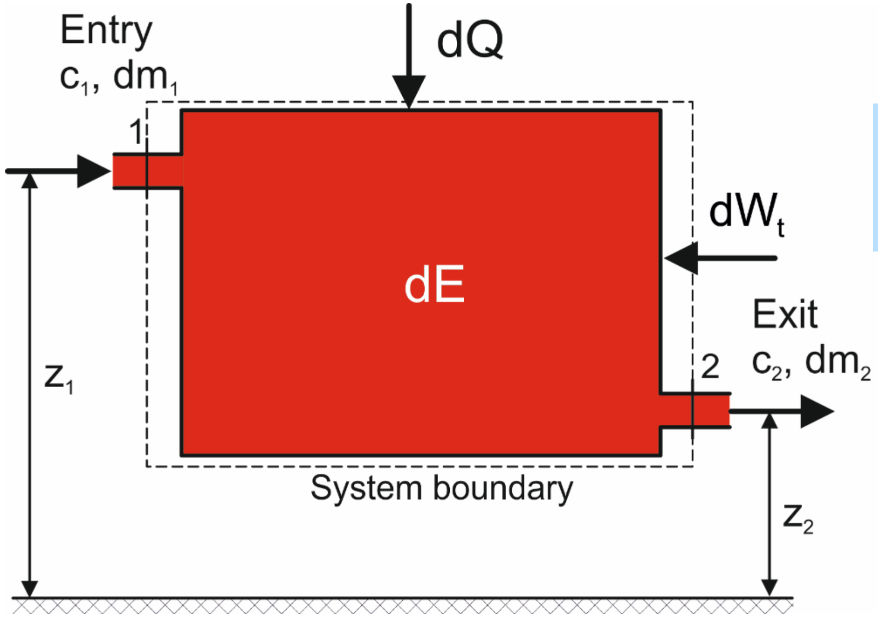


$$\varsigma_{tot} = \frac{m_{out,1}}{m_{in,1}} \frac{m_{out,2}}{m_{in,2}} \frac{m_{out,3}}{m_{in,3}} \ldots = \varsigma_1 \cdot \varsigma_2 \cdot \varsigma_3 \cdot \ldots = \prod_{i=1}^{n} \varsigma_i$$

$$\mu_{tot} = \frac{m_{in,1}}{m_{out,1}} \frac{m_{in,2}}{m_{out,2}} \frac{m_{in,3}}{m_{out,3}} \ldots = \mu_1 \cdot \mu_2 \cdot \mu_3 \cdot \ldots = \prod_{i=1}^{n} \mu_i$$

Energy balance principles

Sum of the entering energy flows	-	Sum of the outgoing energy flows	=	Time depended change of the stored energy in the control volume



$$dQ + dW_t + (h_1 + \frac{c_1^2}{2} + gz_1)\,dm_1 - (h_2 + \frac{c_2^2}{2} + gz_2)\,dm_2 = dE$$

Q	Heat	W_t	Technical work
h_i	Specific enthalpy	c_i	Velocity
g	Gravity	z_i	Geodetic hight
m_i	Mass	E	Energy

1 ≙ in 2 ≙ out

Mass- and energy balances of industrial processes

Data gathering

TRANSPORT (From storage to furnace)			
Transport medium (Truck, conveyor belt, forklift…)	**DISTANCE**	**UNIT**	**COMMENT**

ENERGY SOURCE (Energy source to provide heat)	**CONSUMPTION**	**UNIT**	**ORIGIN** (Where is this energy coming from? e.g. 100% Renewable, Nuclear, coal…)
Natural gas			
Electricity			
Other			

INPUT	QUANTITY	UNIT	COMMENT
Raw materials (materials entering the furnace)			
Consumables (Electrodes, oil, lubricants…)			
Water (cooling water, distilled water..)			

OUTPUT	QUANTITY	UNIT	COMMENT
Product (Material leaving the furnace)			
Co-product (Valuable material generated during the production of other material)			
product			
Emissions to air			
Emissions to water			
Emissions to soil			
Other			

- Data often based on ranges
- Depending on the product, data has to be converted to fit the format x/product or $x/t_{product}$

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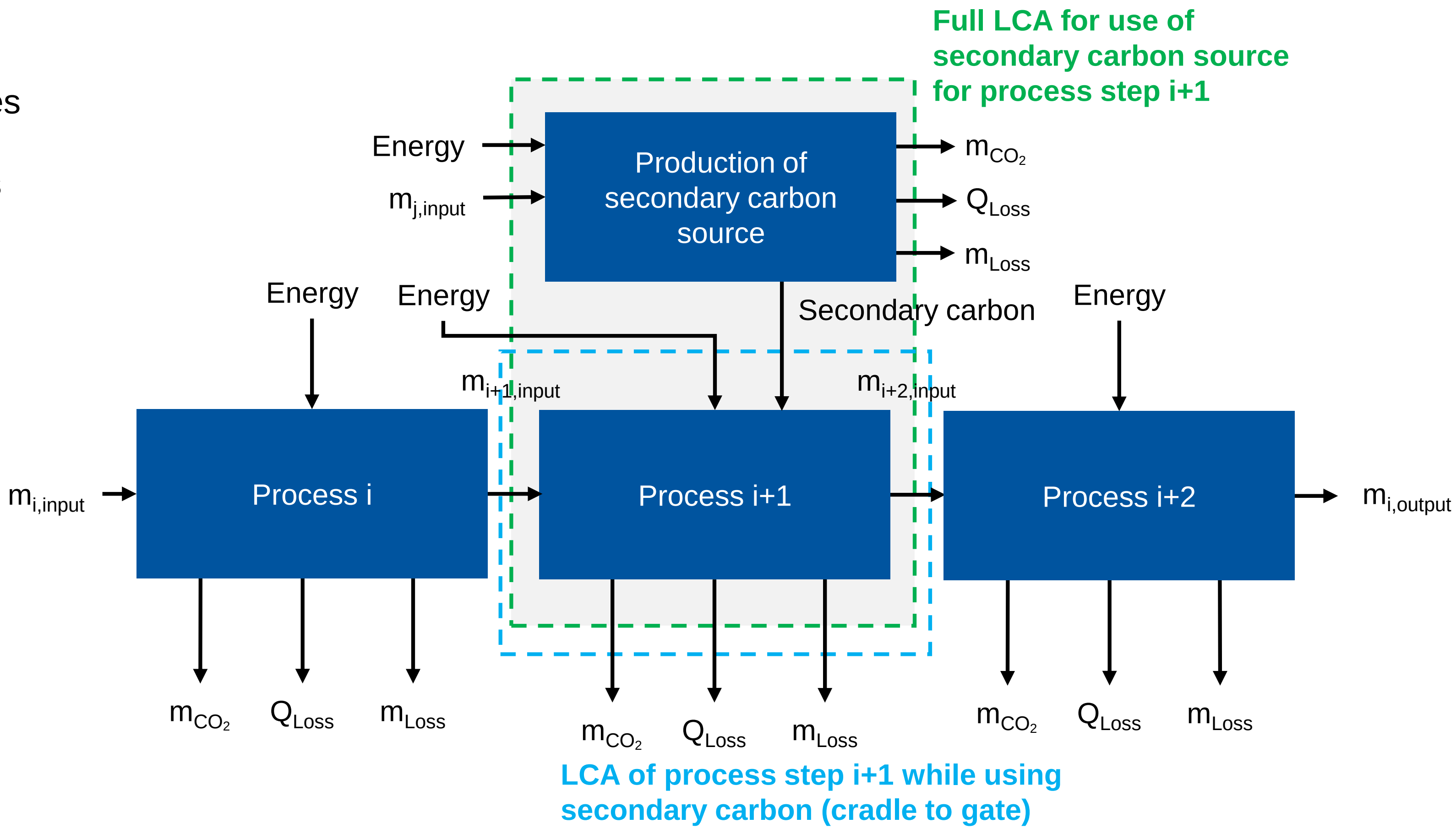
Use cases for utilization of secondary carbon sources in the steel industry

- Decarbonization through alternative fuels
  - Utilize biochar, agricultural waste, or municipal solid waste-derived carbon in blast and electric arc furnaces
- Injection of secondary carbon into furnaces
  - Replace partial pulverized coal injection with processed secondary carbon feedstocks
- Utilization of recycled carbon materials
  - Incorporate materials like coke breeze, recovered carbon black, or carbon from fly ash into the sintering process or electric arc furnace charge
- Carbon recovery and reuse from flue gases
  - Employ carbon capture and utilization (CCU) technologies to transform flue gas carbon into syngas for steelmaking or chemical production
- Secondary carbon for alloying and carburizing
  - Use recycled graphite or secondary carbon sources in carburization and alloying processes
- Biomass integration or hydrogen and secondary carbon blending in DRI (Direct Reduced Iron)
  - Use a mix of bio-syngas and hydrogen in DRI or blast furnace operations
- Plastic waste as a carbon source
  - Convert plastics into pyrolysis oil or synthetic gas and inject these into steel production processes

Use cases for utilization of secondary carbon sources in the steel industry

Evaluation of allocations and upstream and downstream processes

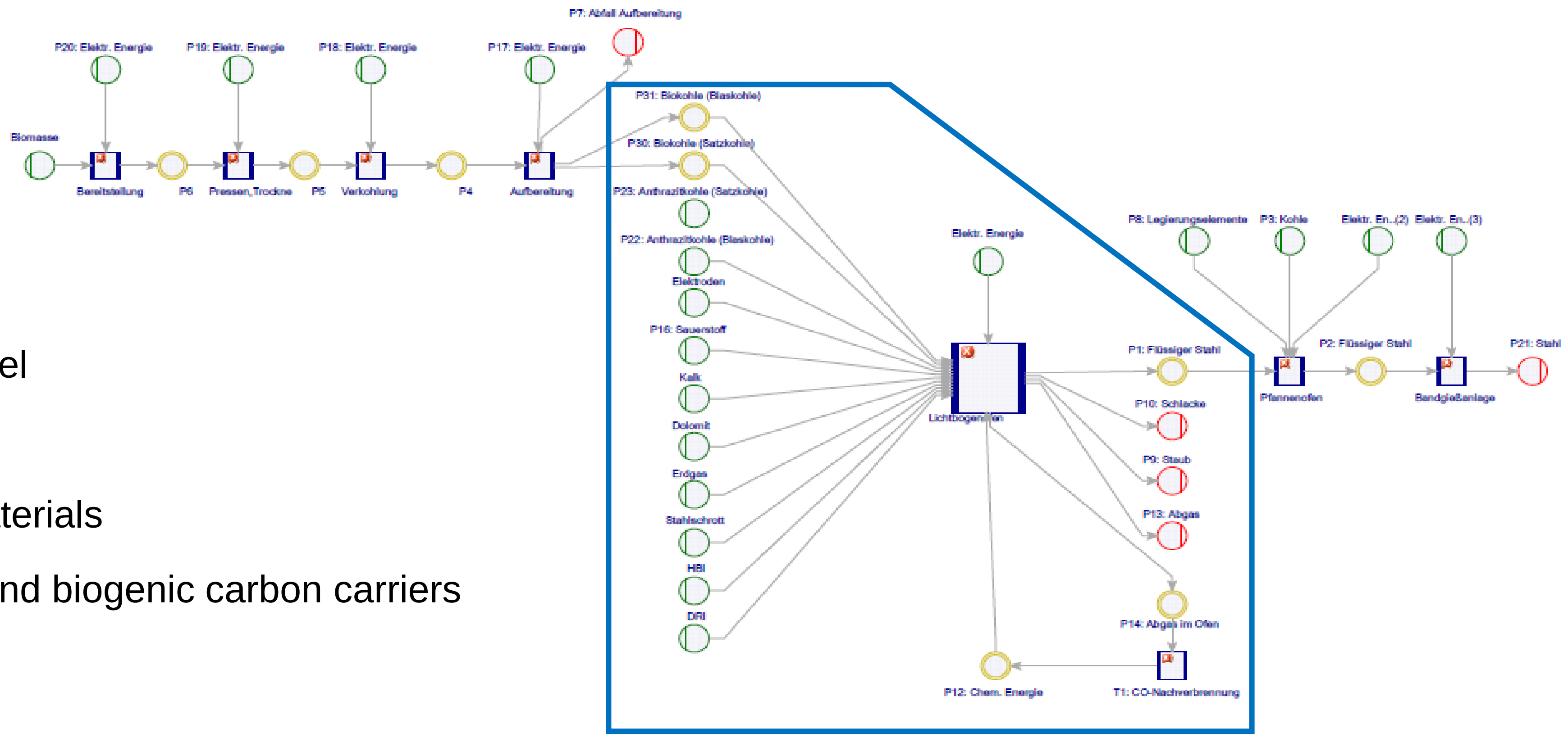
- Calculation with or without up- and downstream processes for the use of secondary carbon sources
- Solving of allocation problem for responding mass and energy flows of secondary carbon source through different approaches
  - Avoidance (e.g. through system expansion and system limitation)
  - Allocation by physical quantities
  - Allocation according to other variables (e.g. economic factors)
- Use of cut-off criteria for complex scope of investigation
  - Share of max. 1 % in the overall system as a criteria for cutting off material and energy flows



Use case A - Biogenic carbon as alternative fuels

Subsitution of fossil charge carbon with biochar in EAF

- Basic model and extended model
- Focus on the melting process
- All relevant input and output materials
- Analysis of the usage of fossil and biogenic carbon carriers



Basic model

Use case A - Biogenic carbon as alternative fuels

Subsitution of fossil charge carbon with biochar in EAF

- Substituting Fossil Charge Carbon with Biochar (Palm Kernel Shell PKS)
- Comparison of 3 different scenarios → 100% Fossil Carbon; 50% Fossil Carbon, 50% Biogenic Carbon; 100% Biogenic Carbon
- Functional Unit (FU): 1 kg Steel
- Emission Factors: Deutsche Emissionshandelsstelle (DEHSt)

	100% Fossil Carbon		50% Fossil Carbon 50% Biogenic Carbon		100% Biogenic Carbon		Emission Factor	
Fossil Charge Carbon	0.0089	kg/kg$_{steel}$	0.0039	kg/kg$_{steel}$	0.0000	kg/kg$_{steel}$	3.664	kg$_{CO2}$/kg
Biogenic Charge Carbon	0.0000	kg/kg$_{steel}$	0.0039	kg/kg$_{steel}$	0.0104	kg/kg$_{steel}$	0	kg$_{CO2}$/kg
Fossil Injecting Carbon	0.0120	kg/kg$_{steel}$	0.0129	kg/kg$_{steel}$	0.0139	kg/kg$_{steel}$	3.664	kg$_{CO2}$/kg
Electrodes	*0.0127	kg/kg$_{steel}$	*0.0127	kg/kg$_{steel}$	*0.0127	kg/kg$_{steel}$	3.6	kg$_{CO2}$/kg
Scrap	1.0607	kg/kg$_{steel}$	1.1431	kg/kg$_{steel}$	1.0689	kg/kg$_{steel}$	0.00549	kg$_{CO2}$/kg
Oxygen	0.0645	kg/kg$_{steel}$	0.0548	kg/kg$_{steel}$	0.0548	kg/kg$_{steel}$	-	kg$_{CO2}$/kg
Natural Gas	0.0025	kg/kg$_{steel}$	0.0024	kg/kg$_{steel}$	0.0024	kg/kg$_{steel}$	0.055	kg$_{CO2}$/kg
Dolomite	0.0275	kg/kg$_{steel}$	0.0286	kg/kg$_{steel}$	0.0299	kg/kg$_{steel}$	0.7848	kg$_{CO2}$/kg
Limestone	0.0191	kg/kg$_{steel}$	0.0165	kg/kg$_{steel}$	0.0118	kg/kg$_{steel}$	0.477	kg$_{CO2}$/kg
Steel	1.0000	kg/kg$_{steel}$	1.0000	kg/kg$_{steel}$	1.0000	kg/kg$_{steel}$	0.00549	kg$_{CO2}$/kg
Slag	*0.1059	kg/kg$_{steel}$	*0.1073	kg/kg$_{steel}$	*0.1045	kg/kg$_{steel}$	0.0070	kg$_{CO2}$/kg
Electricity	0.4463	kWh/kg$_{steel}$	0.4711	kWh/kg$_{steel}$	0.4277	kWh/kg$_{steel}$	0.29	kg$_{CO2}$/kWh

*estimated

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Use case A - Biogenic carbon as alternative fuels

Aggregated CO_2 emissions and off-gas

100% Fossil Carbon

0.1647 kg_{CO2}/kg_{steel}

50% Fossil Carbon
50% Biogenic Carbon

0.1497 kg_{CO2}/kg_{steel}

100% Biogenic Carbon

0.1375 kg_{CO2}/kg_{steel}

		100% Fossil Carbon	50% Fossil Carbon 50% Biogenic Carbon	100% Biogenic Carbon
CO	kg/kg_{steel}	0.0471	0.0435	0.0569
CO_2	kg/kg_{steel}	0.0189	0.0202	0.0255
N_2	kg/kg_{steel}	0.0183	0.0238	0.0195
O_2	kg/kg_{steel}	0.0000	0.0000	0.0000
H_2	kg/kg_{steel}	0.0013	0.0009	0.0015
H_2O	kg/kg_{steel}	0.0012	0.0012	0.0021
CH_4	kg/kg_{steel}	0.0002	0.0001	0.0002

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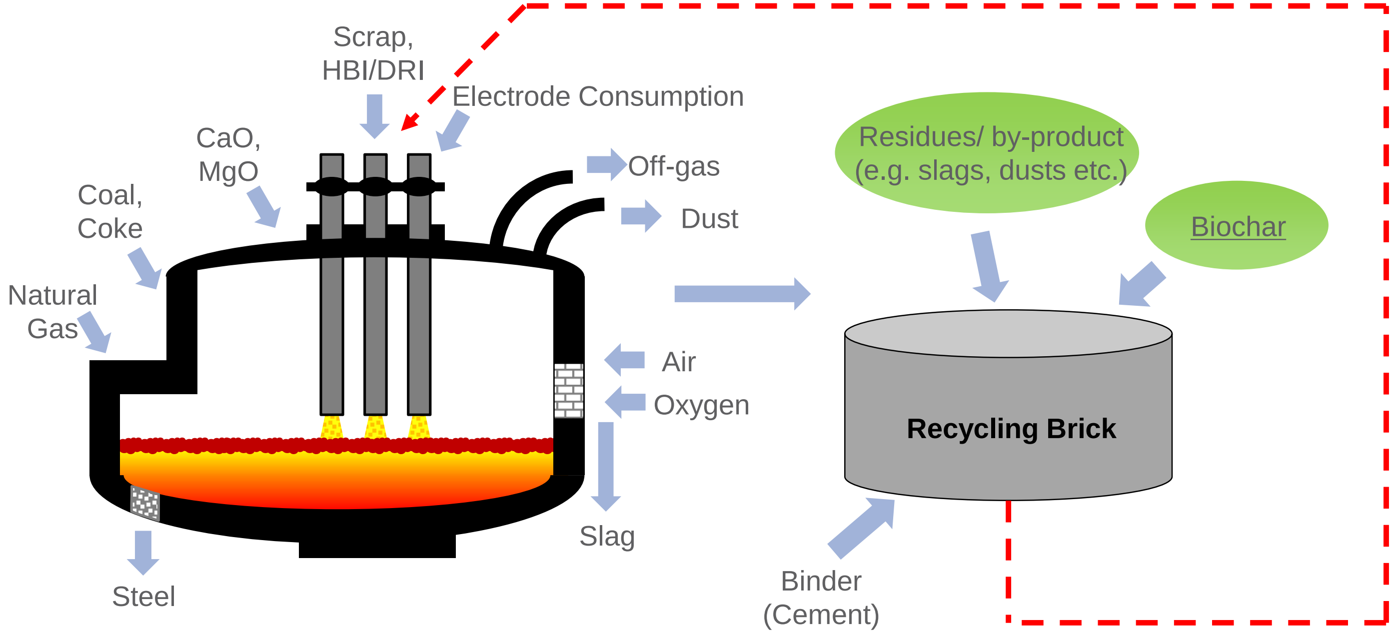
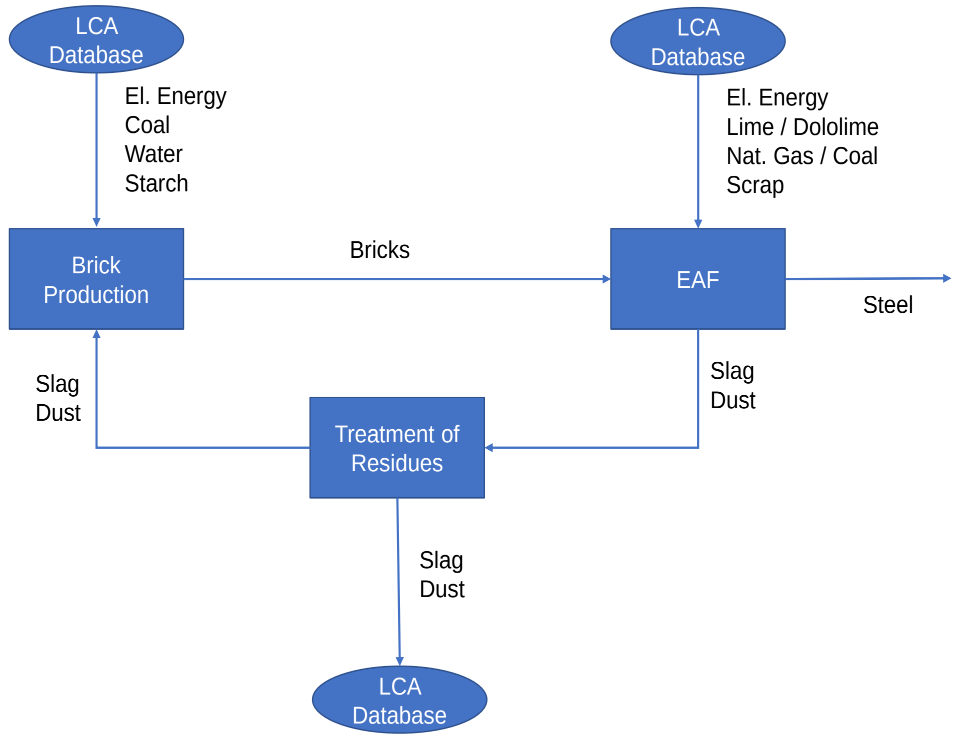
Use case B - Biogenic carbon in agglomerates

Use of agglomerates out of residues and by-products, with biochar as reduction agent or organic bio-binders



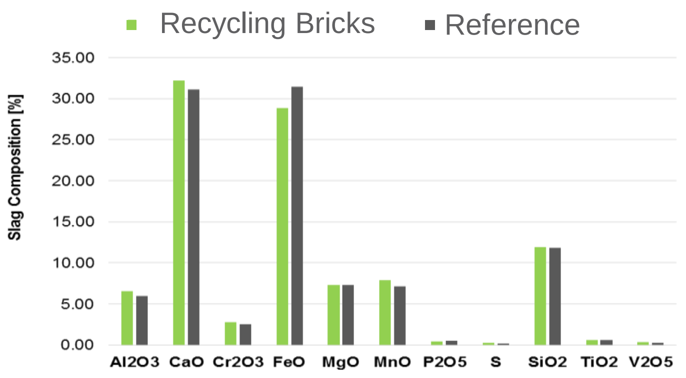
Use of biochar as reduction agent



Use of organic bio-binders

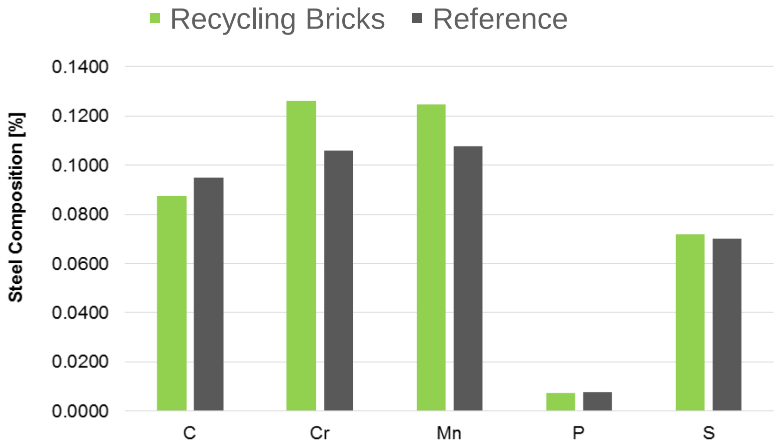
Use case B - Biogenic carbon in agglomerates (Biochar as reduction agent)

- Usage of 10% of agglomerates out of residues, biochar and cement binders



Results – Slag Analysis

- Average Al_2O_3 and CaO concentration of the slag is slightly higher
- Average FeO concentration of the slag decreases
- The basicity remains on the same level
- Differences are within the Standard Deviation

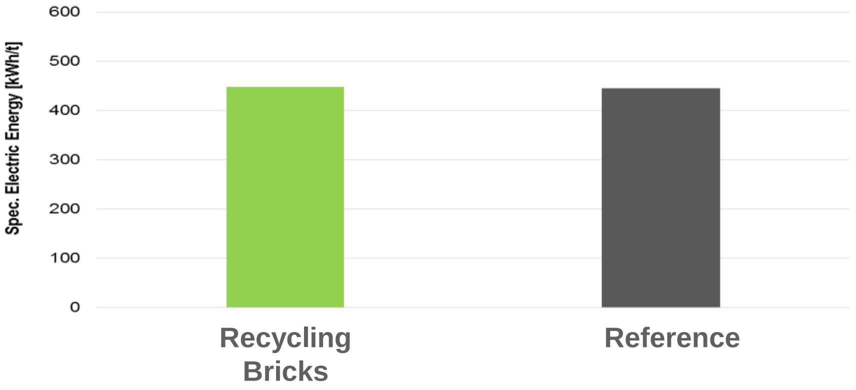


Results – Steel Analysis

- Average S and P concentration show no significant deviation
- Production program is not representative due to small test sample
- Differences are within the Standard Deviation

Use case B - Biogenic carbon in agglomerates (Biochar as reduction agent)

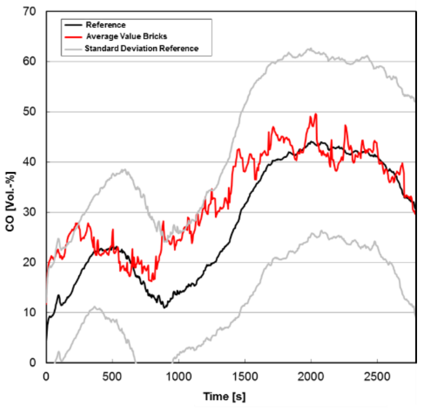
Results – Specific electric energy consumption



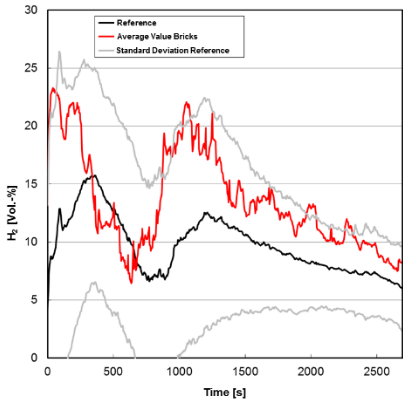
- The difference of the specific Electrical Energy Consumption is negligible

Results – Off-gas analysis

Off-gas (CO)



Off-gas (H_2)



- No significant deviation concerning the CO concentration of the off-gas
- Significantly increased values concerning the H_2 concentration of the off-gas (biochar)
- Differences are within the Standard Deviation

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Use case B - Biogenic carbon in agglomerates (Use of organic bio-binders)

- Usage of 10% of agglomerates out of residues, coal and organic bio-binders

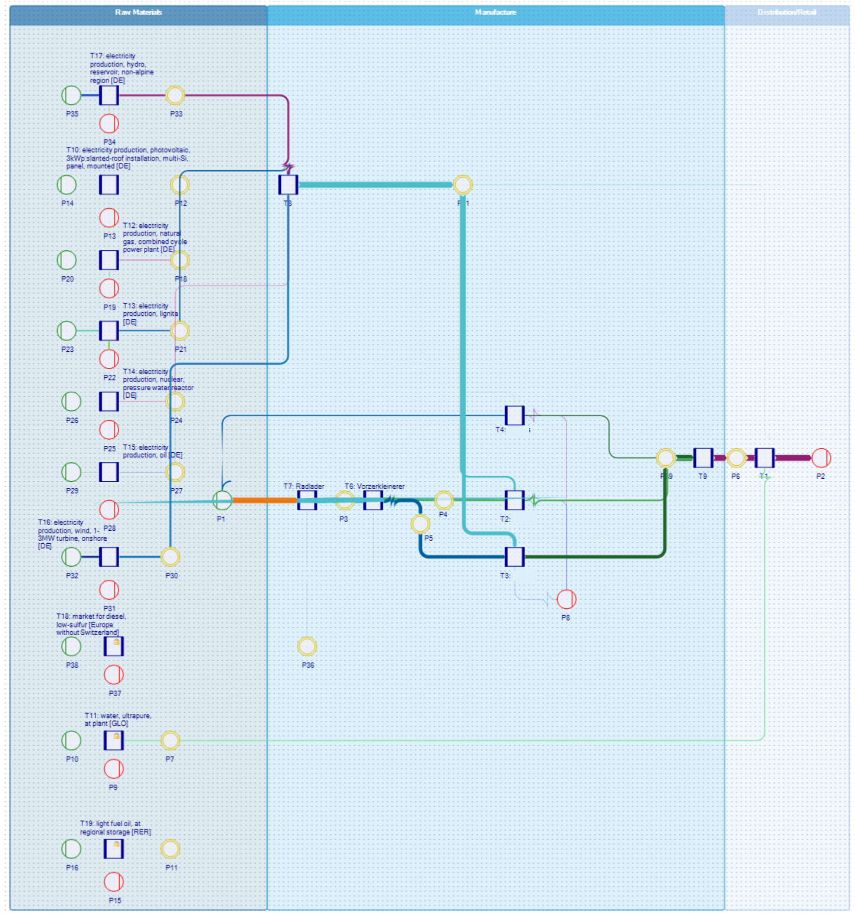
- The impact assessment in this LCA study is based on the eight impact categories:
  - Global Warming Potential (100 years), GWP100
  - Freshwater Eutrophication Potential, FEP
  - Terrestrial Acidification Potential (100 years), TAP100
  - Ozone Depletion Potential, ODP
  - Photochemical Oxidant Formation, POFP
  - Depletion Potential of Fossil Fuels, FDP
  - Metal Depletion, MDP
  - Human Toxicity Potential, HTP

	Reference	Recycling bricks
GWP100	100.00%	99.87%
FEP	100.00%	100.01%
TAP100	100.00%	100.16%
ODP	100.00%	100.04%
POFP	100.00%	100.93%
FDP	100.00%	99.87%
MDP	100.00%	100.01%
HTP	100.00%	100.16%

Use case C - Plastics for injection

Model structure plastics for injection (Scope 3)

- Plastic grinding waste is first dry-mechanically processed, then separated, crushed and finally classified. The recycled products are used as feedstock for steel production
- Calculation of a carbon footprint for the plastic grinding following DIN EN ISO 14067. This is then compared with conventional input materials for the steel industry
- Representation of the individual processes and material flows in the Umberto LCA+ software and ecoinvent database



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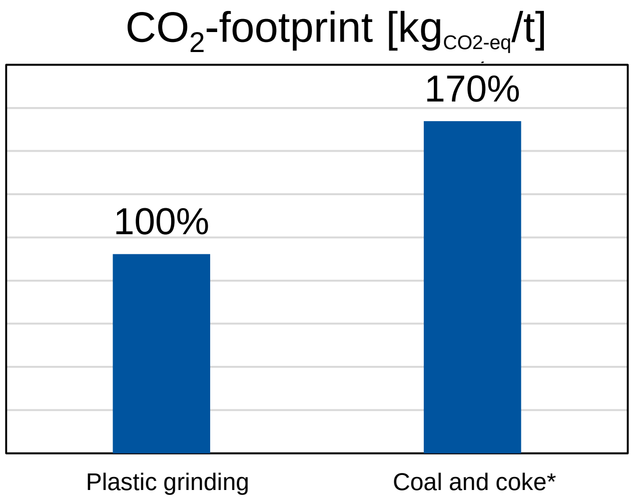
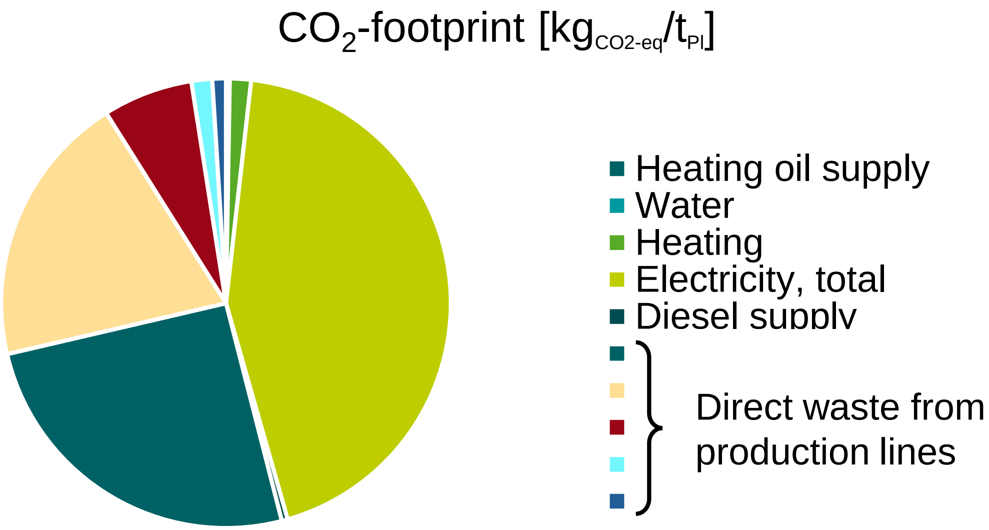
Use case C - Plastics for injection

Carbon footprint plastic grinding from recycling (composition and comparison)





- Carbon footprint per ton of product is ca. 1,7 times higher for coal
- Significant saving possible for representative production timespan

- Indirect emissions from electricity production make up the biggest portion of the CO_2-footprint per ton plastic product

* Reference value from ecoinvent-Database

Summary

- Main factors for LCA approaches for the ecological evaluation of the utilization of secondary carbon sources in the steel industry are:
  - Review of the total mass and energy balance (including raw material inputs and product outputs)
  - Verification of the completeness of the life cycle phases
  - Checking whether direct emissions are realistic, e.g. through a carbon balance
  - Review of data aggregation, data preparation, and the underlying modeling to calculate product inventory
  - Examination of the calculation formulas used
  - Plausibility check of the consumption of utility services
  - Review of the allocation methods used
  - Review of the secondary datasets selected for the upstream Scope 3 data
  - Data quality review
- Biggest limitations of the LCA
  - Data transparency (e.g. through suppliers)
  - Influence of the databases used
  - Partly simplification
- Comprehensive mass and energy balance for the process system is the most important foundation for LCA approaches

Thinking the Future
Zukunft denken

Thank you
for your kind attention!

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- **Flint et al.:** Scrap, carbon and cost savings from the adoption of flexible nested blanking (2019)
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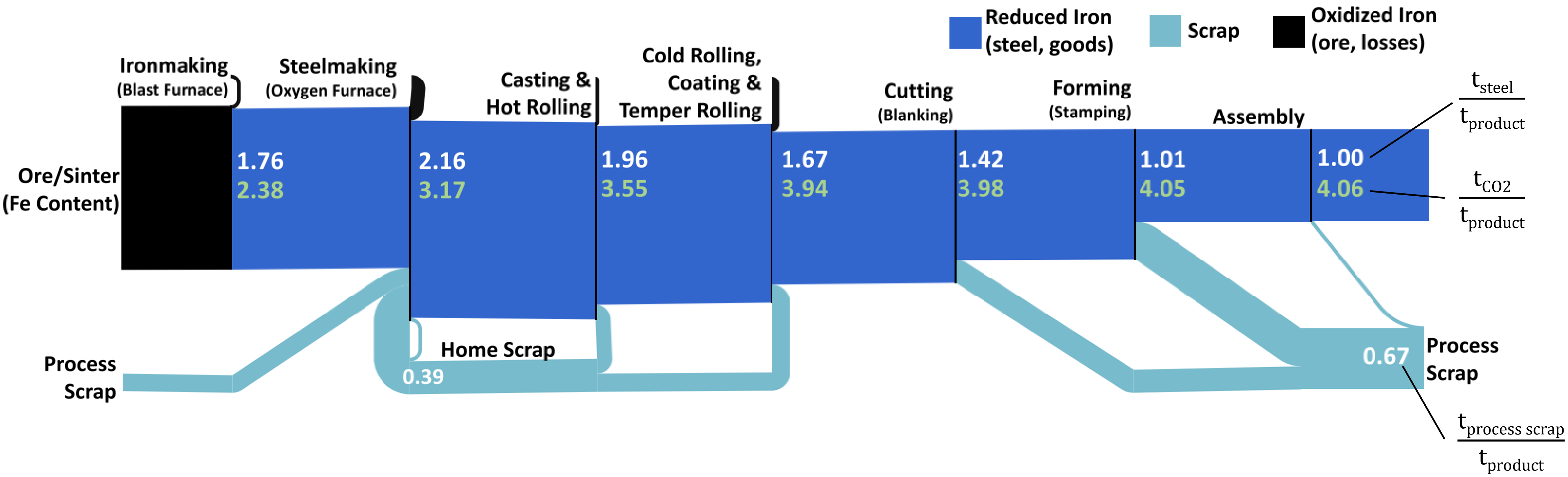
- **VDMA e. V.:** VDMA-Guideline “Berechnung des Product Carbon Fooотprint im Maschinen- und Anlagenbau“, 2022.

Mass- and energy balances of industrial processes

Influence of combining KPIs in a process chain



Source: Flint et al – Scrap, carbon and cost savings from the adoption of flexible nested blanking (2019)

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