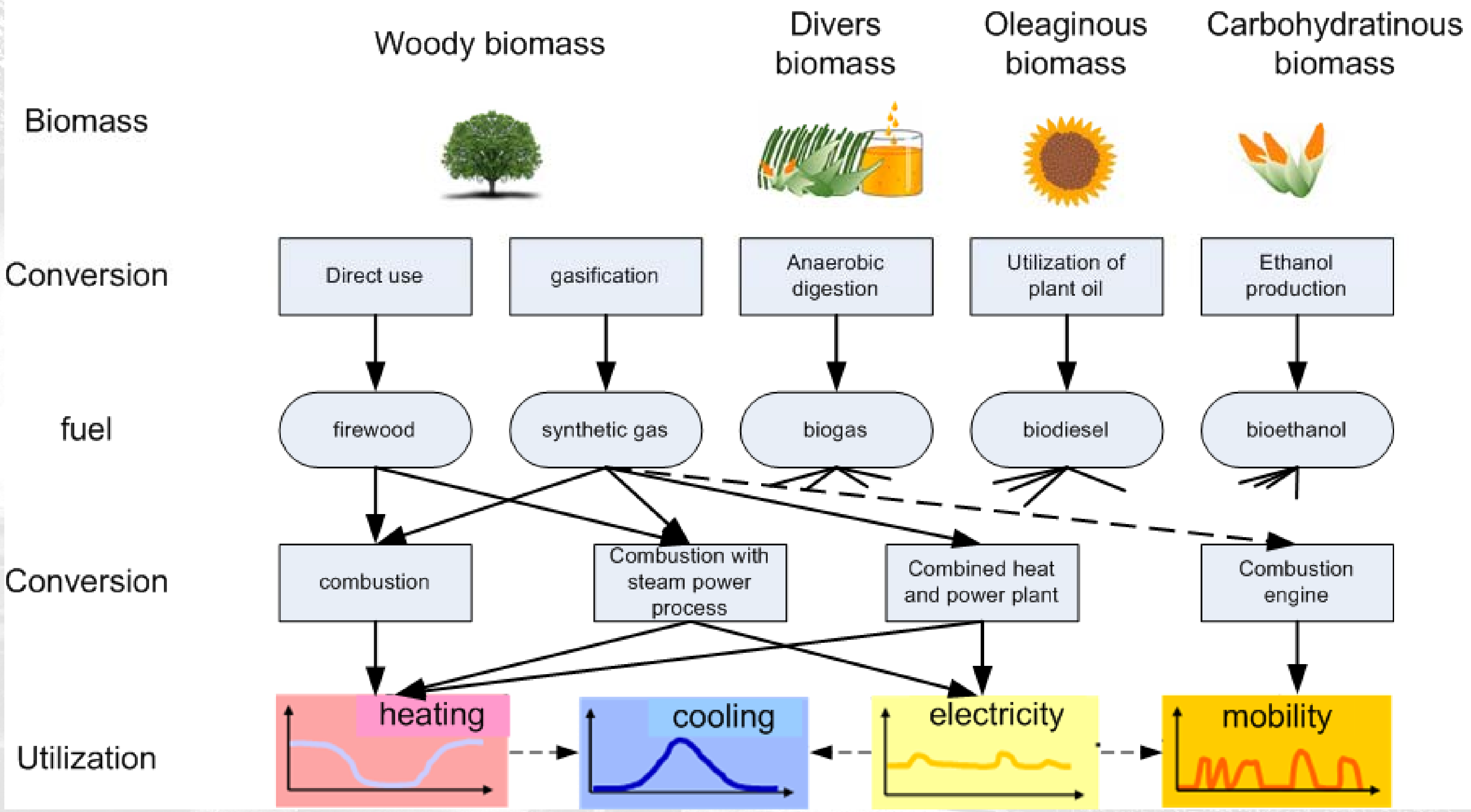
GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

Fuel Cells, Gasifier, Fischer-Tropsch Synthesis and Energy Park

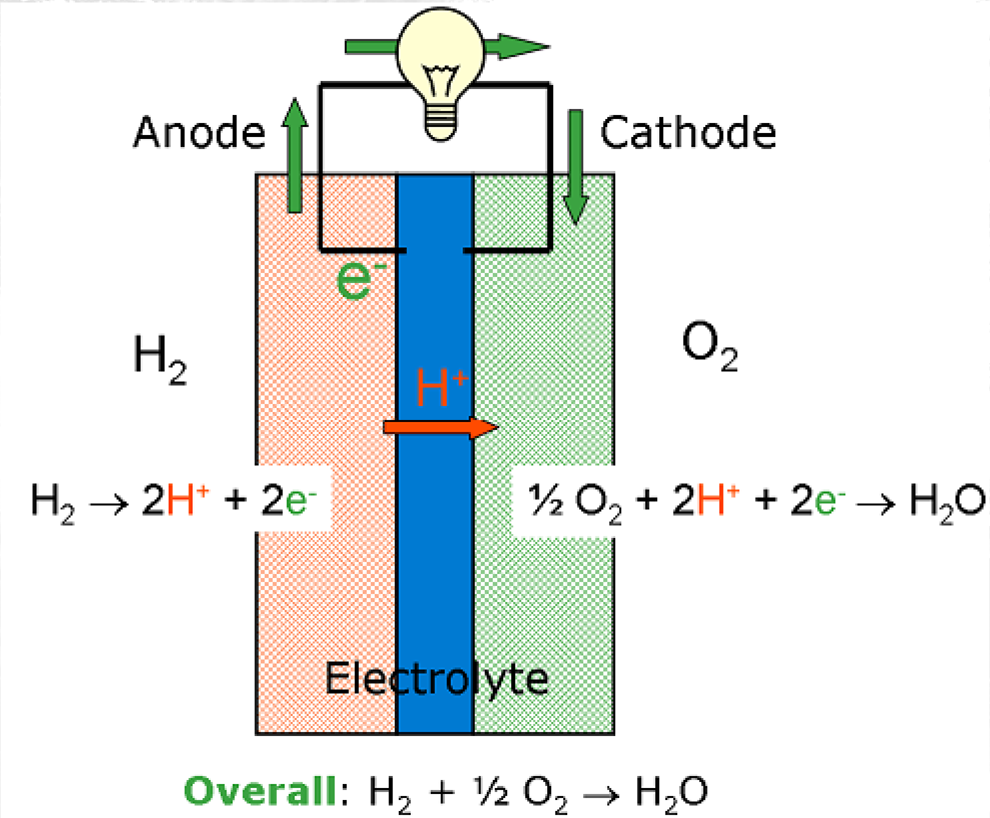
Preparation for study trip to the CUTEC-Institute

2nd of November 2009

Current utilization of biomass

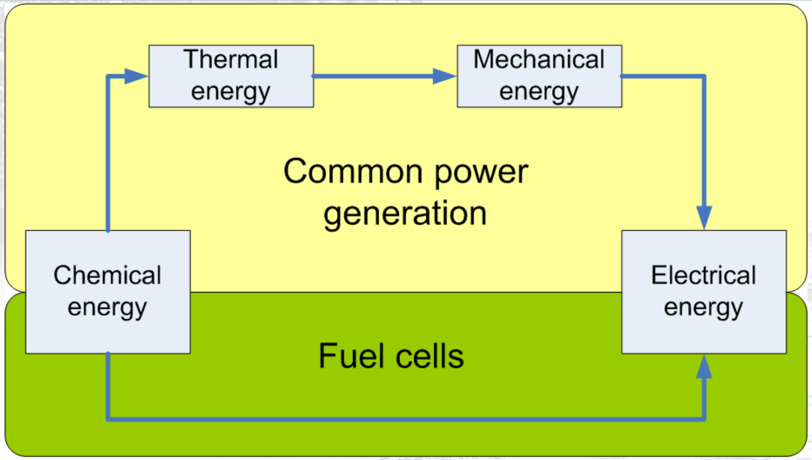


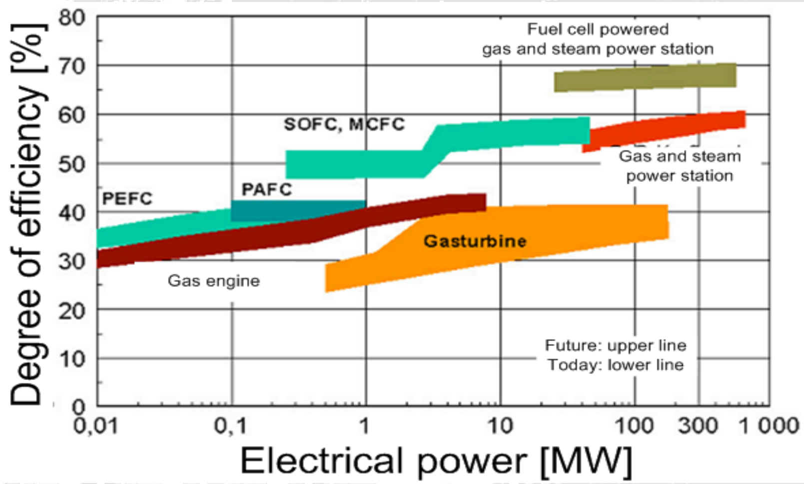
Fuel cells - basics



- Principle known since 1838
- Electro chemical „combustion“ separated by an electrolyte
- Example of a proton exchanging electrolyte
- Also oxygen ions exchanging electrolytes
- Basic construction: anode, electrolytes and cathode
- These three parts can consist of different materials depending of the fuel cell type

Fuel cells - basics





Advantages

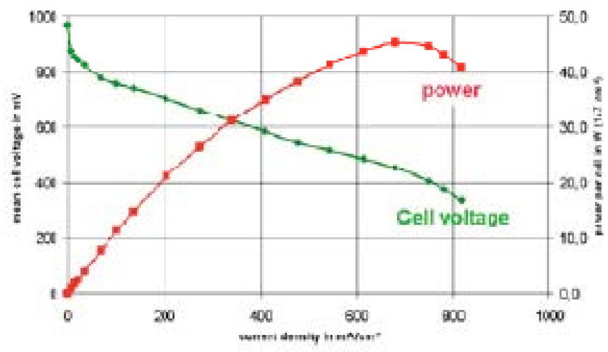
- High efficiency
- No emissions (NOx, SO2, CO)
- Low abrasion
- Low vibrations and silent
- Good scalability of power

Disadvantages

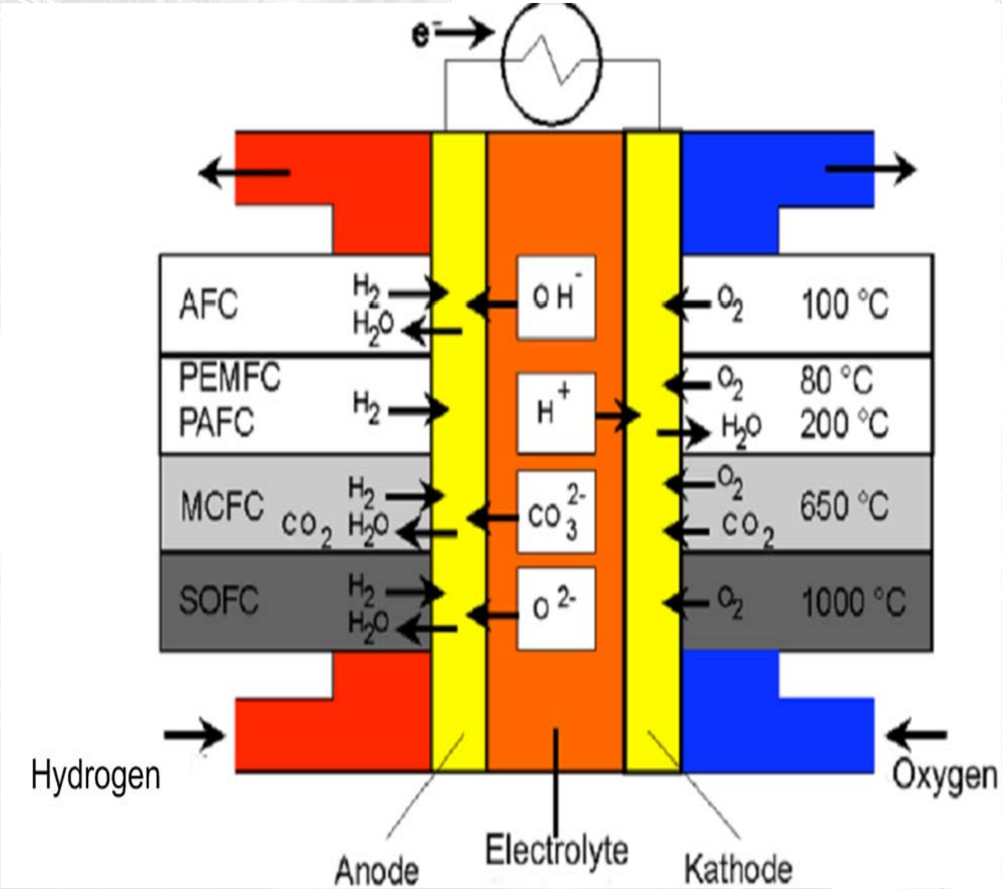
- Cleanness of fuel required
- Technology still under R&D
- High costs and low lifespan

Fuel cells - basics

- under normal conditions (25 °C, 1 bar) only 1,23 Volt
- to less for a technical application, but voltage can be increased by a serial connection of single elements → so-called „stacks“



Types of fuell cells



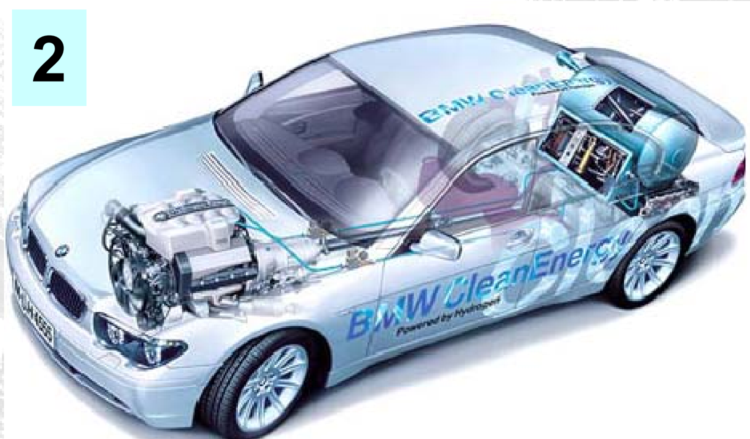
Differences in:

- Operating temperature
- Electrolytes
- Possible fuels
- Charge carrier
- Electrode/catalyst materials

Capabilities

1

Kordesch Austin, 1960er

2


BMW with combustion engine, 2000

3

Hydrogen fuelling station

4
Hydrogen Challenger


5
Cryoplane


Resumé

Fuel cells allow an electricity generation with:

- high electrical efficiency
- Possibility of waste heat utilisation
- Renewable fuels

Challenge

- Cost reduction
- Increase of lifespan
- Demonstration of suitability for daily use

Gasifier:

Definitions:

Combustion:

- $\lambda \geq 1$
- exothermal
- excess oxygen with air, pure 0_2

Gasification:

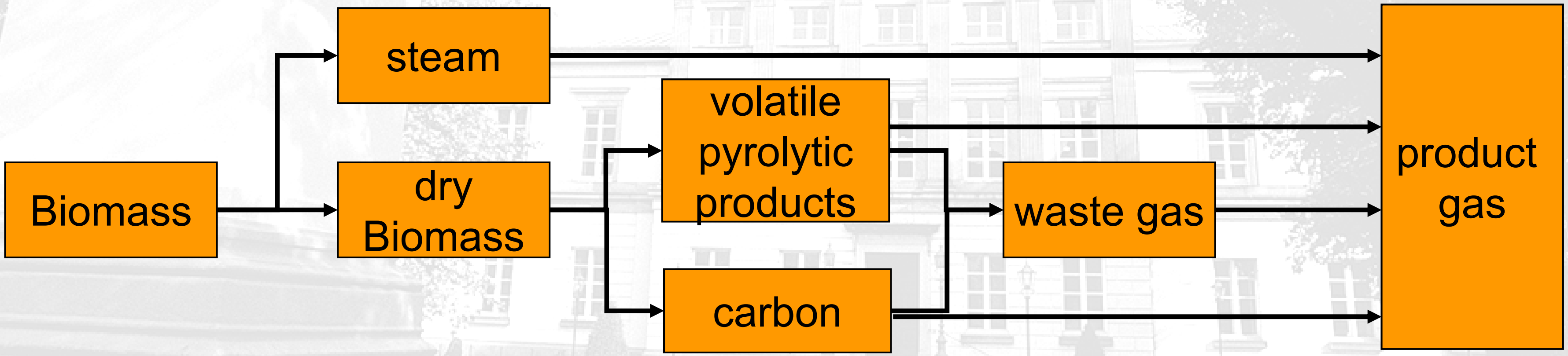
- $0 < \lambda < 1$
- endothermal / exothermal
- oxygen deficiency with air, pure O2, steam

Pyrolysis:

- $\lambda = 0$
- endothermal
- oxygen exclusion

Sub processes of the gasification

Heating and Drying	Pyrolysis	Oxidation	Reduction
100-200 °C	150-500 °C	500-2000 °C	800-1100 °C



heat input	heat input	oxygen input	heat input

Refernce: Kaltschmidt, Hartmann

Chemical reactions of the gasification

Gas/Solids-Reactions

Partial combustion	$C + O_2 \leftrightarrow CO_2$	- 123 kJ/mol
Heterogeneous water gas reaction	$C + H_2O \leftrightarrow CO + H_2$	+119 kJ/mol
Boudouard-Reaction	$C + CO_2 \leftrightarrow 2CO$	+162 kJ/mol
Hydrogenated gasification	$C + 2\,H_2 \leftrightarrow CH_4$	- 87 kJ/mol

Gas/Gas-Reactions

WGS-Reaction	$CO + H_2O \leftrightarrow CO_2 + H_2$	- 41 kJ/mol
Methanation	$CO + 3H_2 \leftrightarrow CH_4 + H_2O$	-206 kJ/mol

Drying

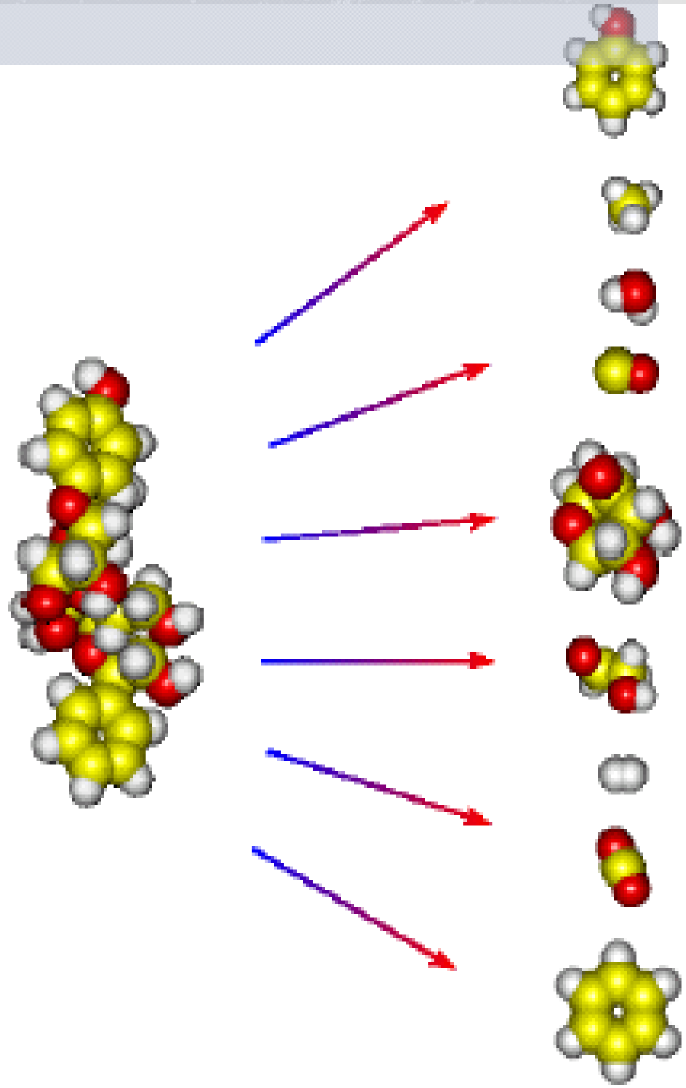
Evaporation of the water, which is included in the biomass

- Temperatures until 200°C
- Water vapour is transformed in the following water gas reaction
- No chemical transformation of the biomass
- Transformation of the structure of the material by macro- and microscopical cracks

Pyrolysis

Decomposition of the organic macromolecules

- Temperatures are dependent on the process: 200-500 °C
- Determinative factors:
  - Temperature
  - Rate of heating
  - Dimension of the fuel particle
- Tar creation up to 280 °C
- 350-400 °C creation capacity on its peak
- Tar concentration in the pyrolyses on its peak



Oxidation

Oxidation of the carbon and the water vapour for covering of the heat demand

- exothermal reactions, temperatures between 500 and 2000°C
- Heat producing for the endothermal reactions and heat loss of the reactor
- Combustion of only a part of the biomass
- Important reactions:

$C + O_2 \rightarrow CO_2$	$\Delta H = -393{,}5$ kJ/mol
$C + \frac{1}{2} O_2 \leftrightarrow CO$	$\Delta H = -123{,}1$ kJ/mol
$H_2 + \frac{1}{2} O_2 \leftrightarrow H_2O$	$\Delta H = -68{,}3$ kJ/mol

Reduction

Reduction of the Oxidation products CO_2 and H_20

- This products react with carbon
- endothermal reactions, Temperatures between 600 and 800°C
- Boudouard-Reaction

  $2\ C + CO_2 \leftrightarrow 2\ CO$ $\Delta H = 159{,}9$ kJ/mol

  $C + H_2O \leftrightarrow CO + H_2$ $\Delta H = 118{,}5$ kJ/mol
- Heterogeneous water gas reaction

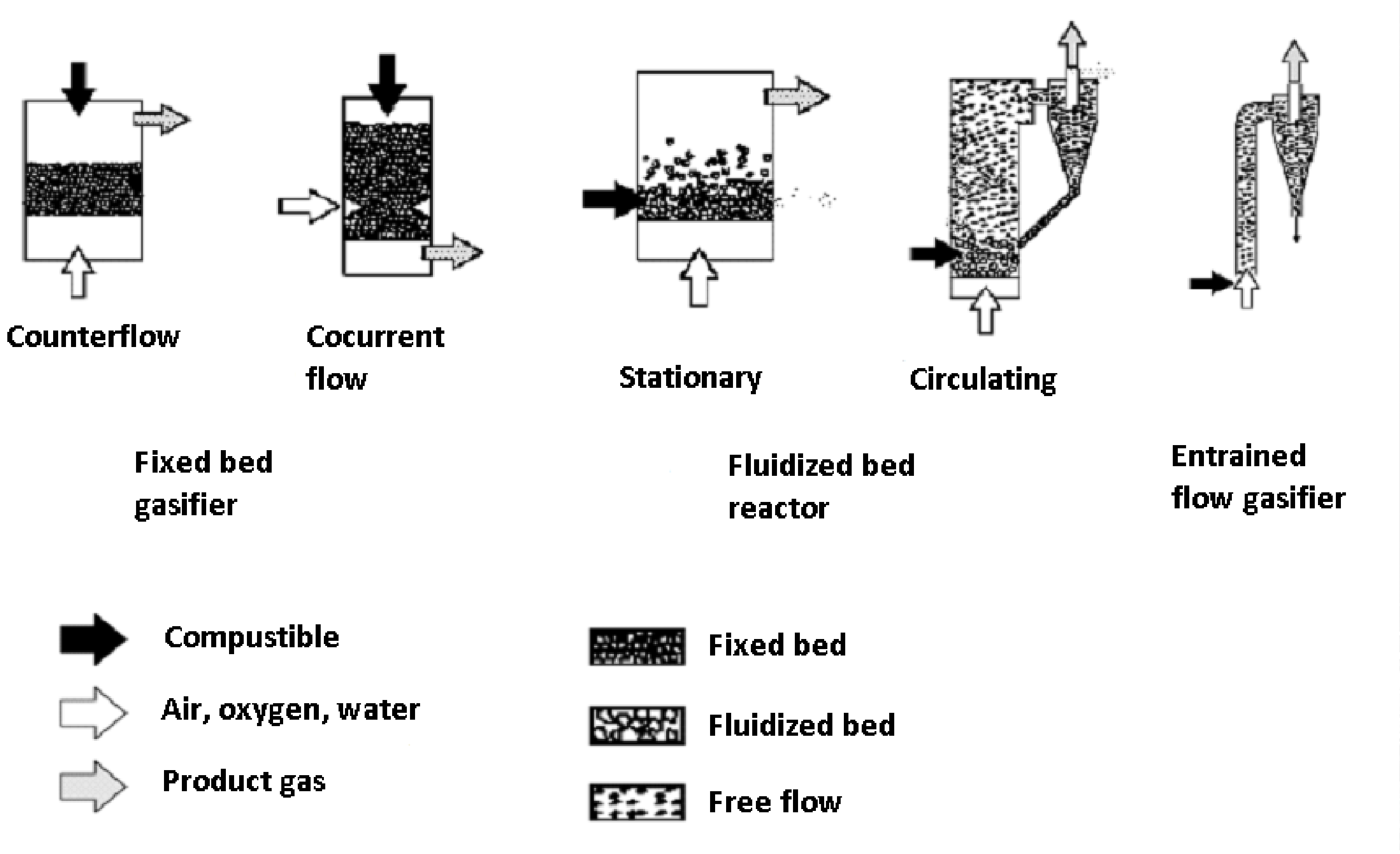
  $CO + H_2O \leftrightarrow CO_2 + H_2$ $\Delta H = -\ 40{,}9$ kJ/mol

  $C + 2\ H_2 \leftrightarrow CH_4$ $\Delta H = -\ 87{,}5$ kJ/mol
- Homogeneous water gas reaction

  $2\ CO + \frac{1}{2}\ O_2 \leftrightarrow CO_2$ $\Delta H = -\ 283{,}0$ kJ/mol

  $H_2 + \frac{1}{2}\ O2 \leftrightarrow H_2O$ $\Delta H = -\ 285{,}9$ kJ/mol

Gasification processes



Reference: Kaltschmitt, 2001

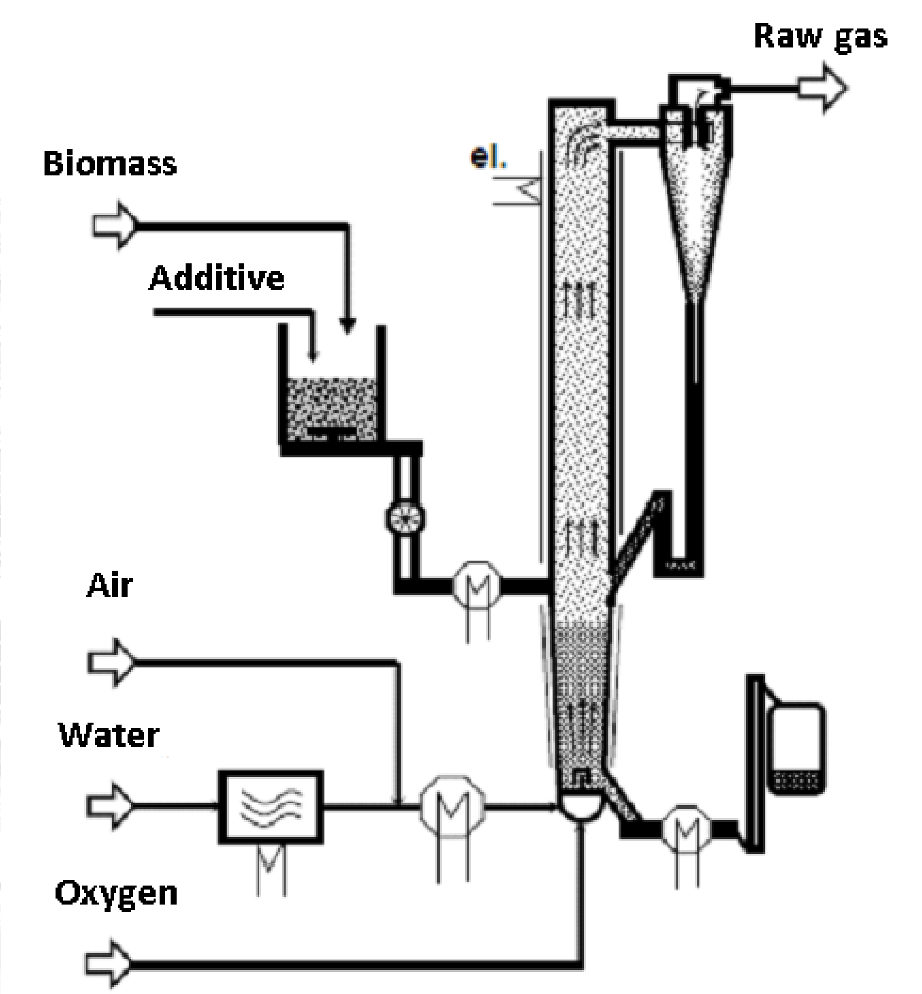
Functionality Fluidized bed reactor

- Bed material: mostly quartz sand
- Fluidized bed: the fumigator flows through the reactor, disperses the interior bed material and circulates around the combustible
- Mixture of the combustible particles with themselves and with the bed material
- No distinctive temperature and reactions zones
- Constant temperatures between 700 and 900 °C
- Differantiation between following process techniques:
  - Stationary fluidized bed reactor
  - Circulating fluidized bed reactor
  - Combination of more than one fluidized beds

CUTEC-Gasifier

Circulating fluidized bed reactor

- Constant temperature distribution
- Good interior heat transfer
- Easy technology, no moving particles
- Security, high availability, stable process
- Reduced tar formation during gasification of water vapour
- Constant gas quality because of constant conditions in the reactor
- Stationary fluidized bed possible
- Good Scale-Up possibilities



GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Fluidized bed reactor

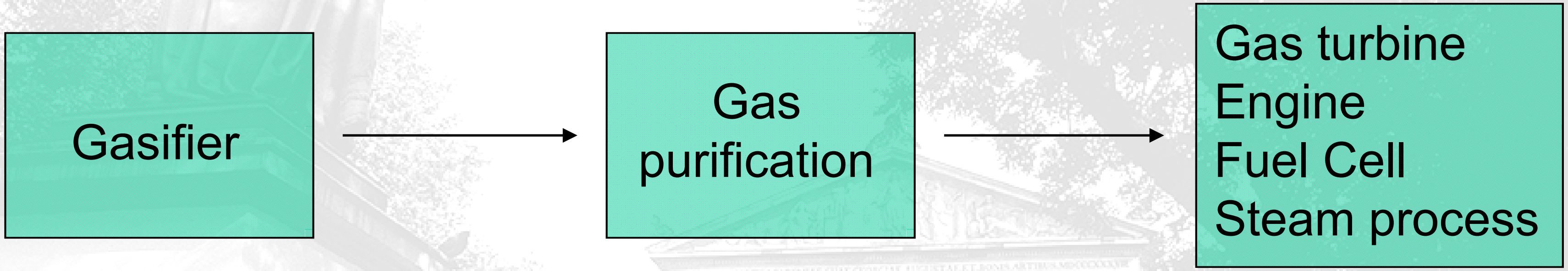
Advantages

- Heterogeneous and difficult combustibles can be used
- Long resistance time of the solid matters
- Robust system operation

Disadvantages

- High tar concentration in the product gas
- Heat transfer very complex

Utilization of the gas



Gas purification necessary because of:

1. Particle burden
2. Tar content
3. Residual components (NH_3, H_2S, COS, Alkalis)

→ Primary arrangements: Modification of the gasifier

→ Secondary arrangements:

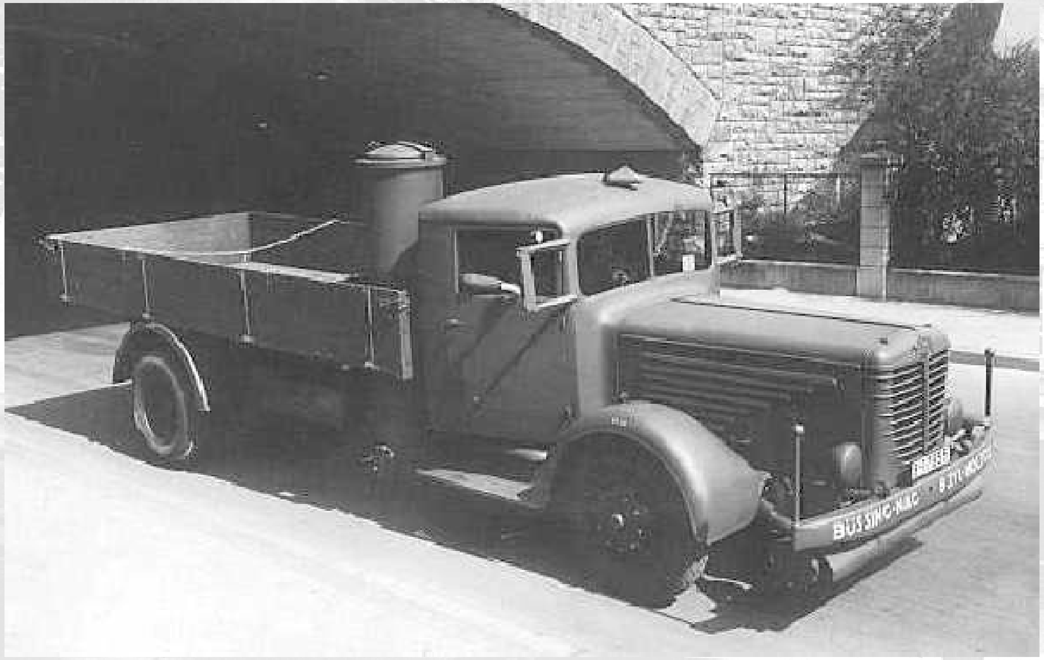
- Hot gas filter, cyclone, E-trap
- Scrubber
- Catalysts, e.g. nickel
- Dolomite as cracker

Fischer-Tropsch Synthese

- 1925 developed by Fischer and Tropsch
- 1934 the first time used in a large scale
- Transformation of synthesis gas (CO, H_2) into carbon hydrides
  - Temperatures between 200°C and 400°C
  - Pressure between 20bar and 40bar
  - Special catalysts
- Intention: production of von synthetic fuels (XtL)
- Basic material: Residual biomass (straw, wooden residuals, ...)

Wood gas powered cars

1941



today

Requirements on renewable fuels

- Low exhaust gas emission (CO, NOx, HC etc.)
- Good combustion
- High energy density
- Low residues
- Resistance to corrosion
- Secure manageability
- Acceptable costs
- Use of the petrol station infrastructure
- Compatibility to conventional fuels

Desired reactions

Fischer-Tropsch reactions

$CO + 2\,H_2 \leftrightarrow (-CH_2-) + H_2O$ ΔH = -159 kJ/mol

$2\,CO + H_2 \leftrightarrow (-CH_2-) + CO_2$ ΔH = -198 kJ/mol

Water gas conversion

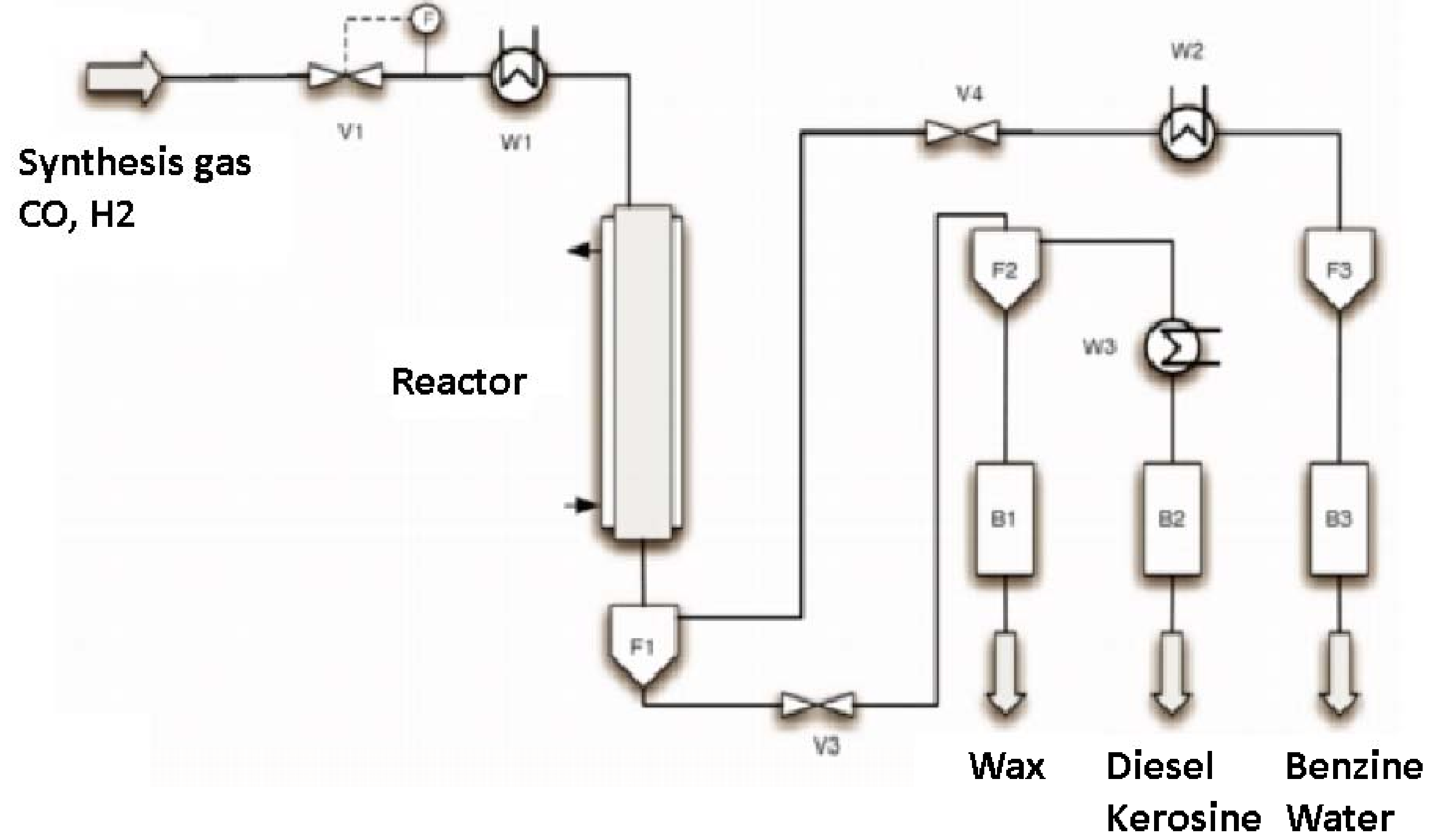
$CO + H_2O \leftrightarrow CO_2 + H_2$ ΔH = -40 kJ/mol

Others possible reactions

$3\,CO + H_2O \leftrightarrow (-CH_2-) + 2\,CO_2$ ΔH = -238 kJ/mol

$CO_2 + 3\,H_2 \leftrightarrow (-CH_2-) + 2\,H_2O$ ΔH = -119 kJ/mol

Fischer-Tropsch-CUTEC pilot installation

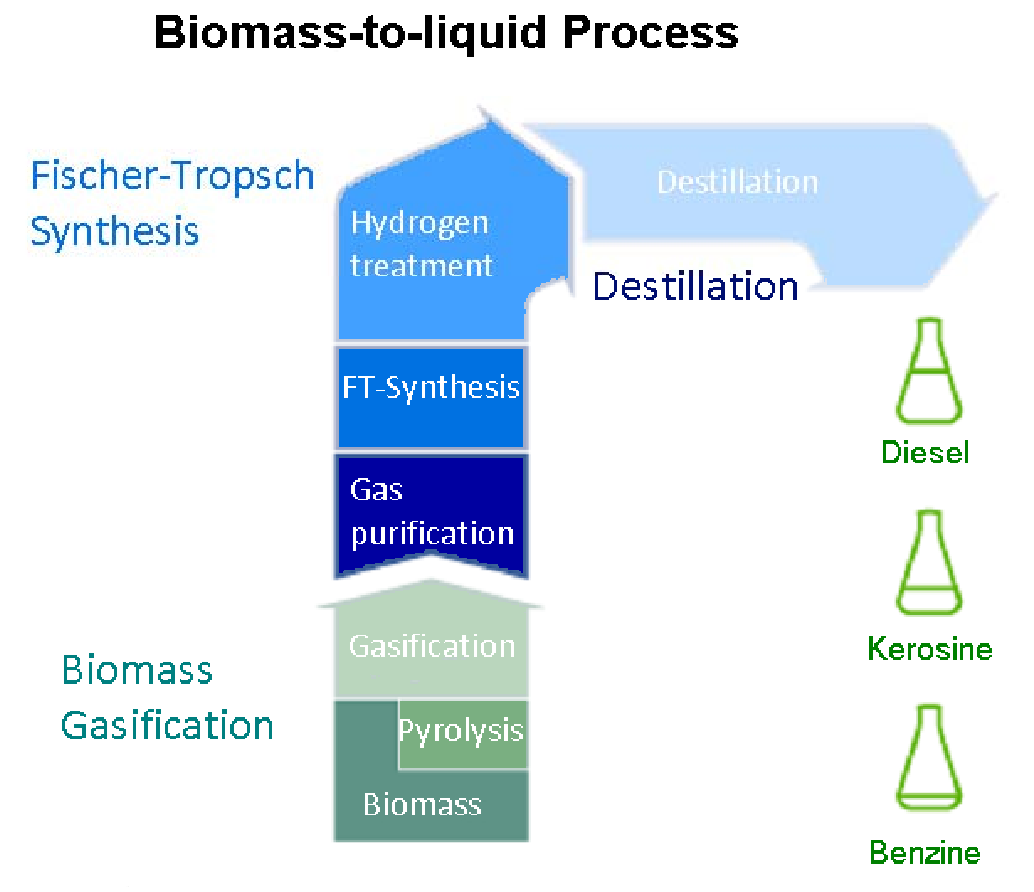


Practical Example: Sun fuel (Choren)

Out of 1 ton wood is produced 100 l Sunfuel

Optimization for the future:

210 l Sunfuel / t wood



Reference: Volkswagen AG

Advantages and disadvantages of FTS-Diesel

Advantages:

- Colour- and odourless, low toxicity
- Reduction of defect components during the combustion
- Fuels offered in the petrol station net
- No loss of engine power
- Possible use as airplane fuel
- Mixable with conventional Diesel in every ratio
- Synthetic fuels can be adopted to the desires of the engine manufacturers

Disadvantages:

- Bad cooling capacities
- Low flashpoint
- Complex process

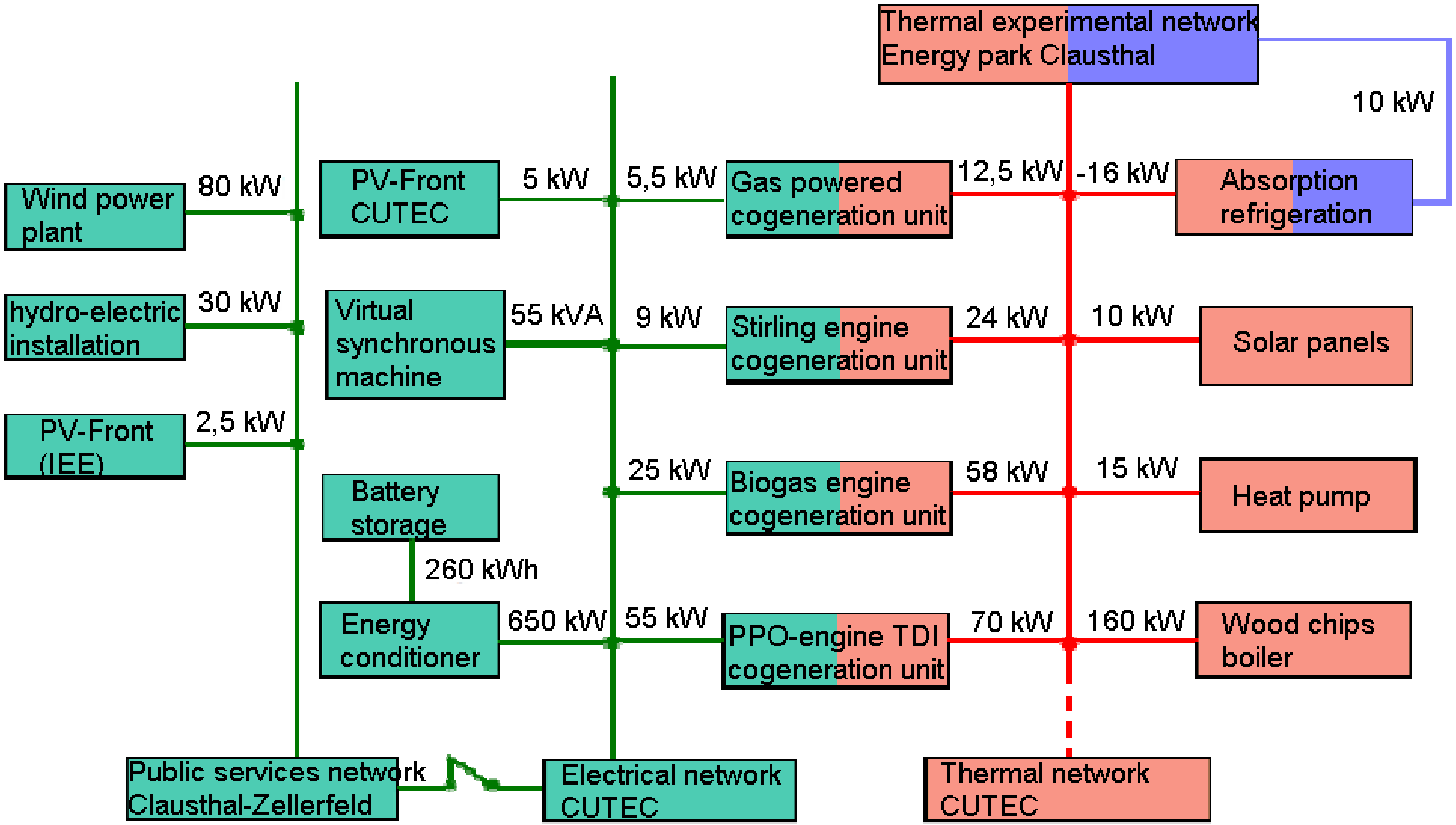
GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

CUTEC Project: Energy Park in Clausthal

- Complete supply of the block of buildings
- Completely of renewable resources
- Interconnection of relevant energy conversion processes
- Combination of non influenceable components with controllable components
- Reporting in dynamic small time segments (in seconds)
- Operation in isolated network

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Overview Energy park Clausthal

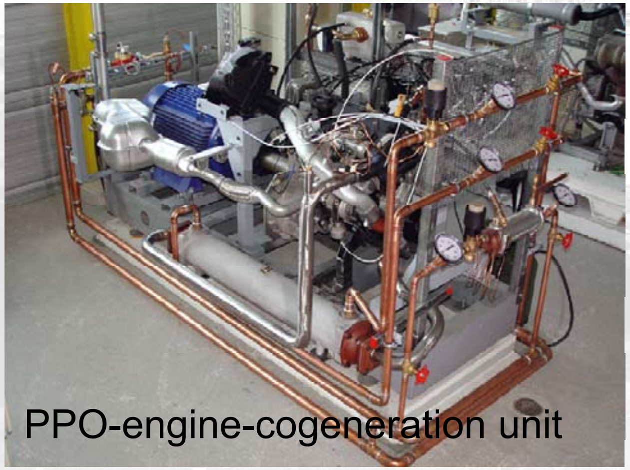


Integrated energy resources


PV-plant

Thermal use of wood chips

Biogas engine-cogeneration unit


PPO-engine-cogeneration unit