High-temperature annealing: latest developments decarbonisation and energy efficiency

IWCC 2025

OTTOJUNKER

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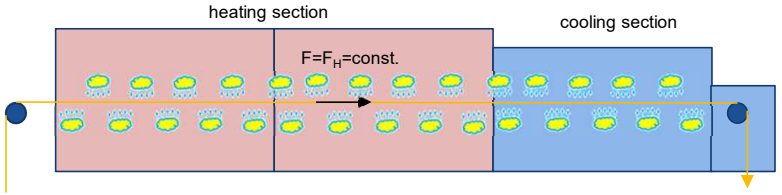
The purpose of this presentation is to guide programs benefiting the copper industry and to provide attendees with information to make independent business decisions.

Strip Annealing Line

Heat Treatment of Copper and Copper alloys

Source: https://kupfer.de/kupferwerkstoffe/kupfer/eigenschaften/

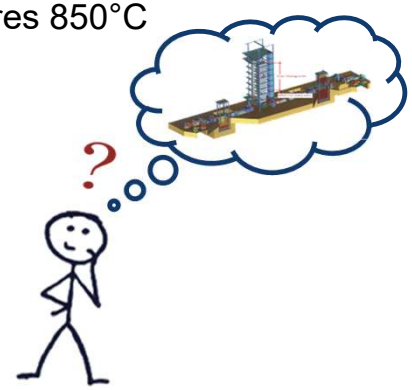


Copper, brass, bronze and nickel silver ⇒ max. furnace temperatures 750°C

High Performance alloy´s, e.g. CuNiSi (C7025) ⇒ max. furnace temperatures 850°C

New requirements because of high-temperature annealing

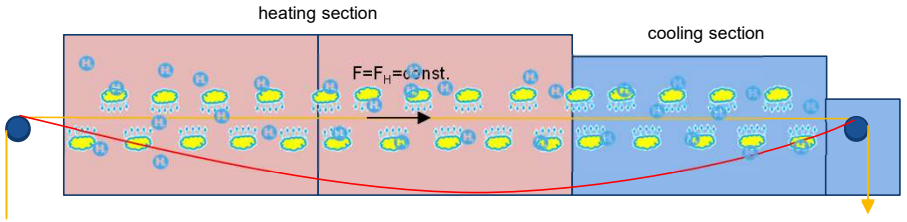
- Annealing up to 1.000°C
- Hydrogen atmosphere

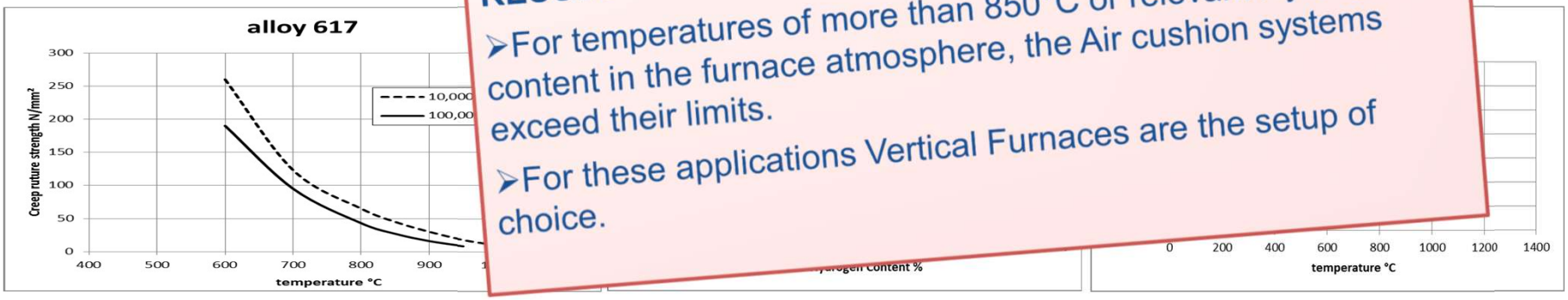


Strip Annealing Line

Air cursion - relevant impacts at high temperatures

- **Density of the Floating Air/ Gas**
  - **Density decreasing with increasing temperature**
  - **Density decreasing with increasing Hydrogen H_2 content**
- **Capability of circulation fans**
  - **Creep rupture strength dropping tremendously a elevated temperatures**





RESULT

- For temperatures of more than 850°C or relevant Hydrogen content in the furnace atmosphere, the Air cushion systems exceed their limits.
- For these applications Vertical Furnaces are the setup of choice.

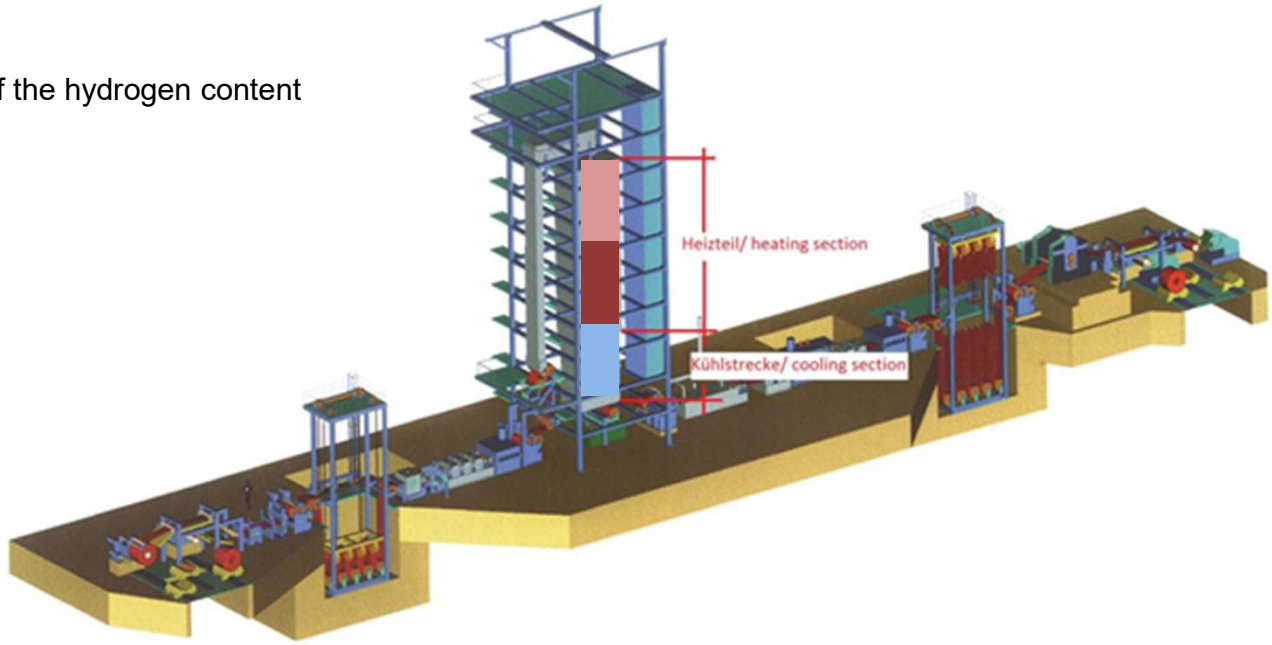
alloy 617 data according to ThyssenKrupp VDM datasheet No. 4119

Strip Annealing Line

Vertical furnace

caracteristics of a high temperature vertical furnace:

- Material temperatures of 1.000°C applicable
  - Up to 850°C in the convection zone
  - Up to 1.150°C in the radiation zone
- No disadvantages because of increasig of the hydrogen content



Vertical furnace

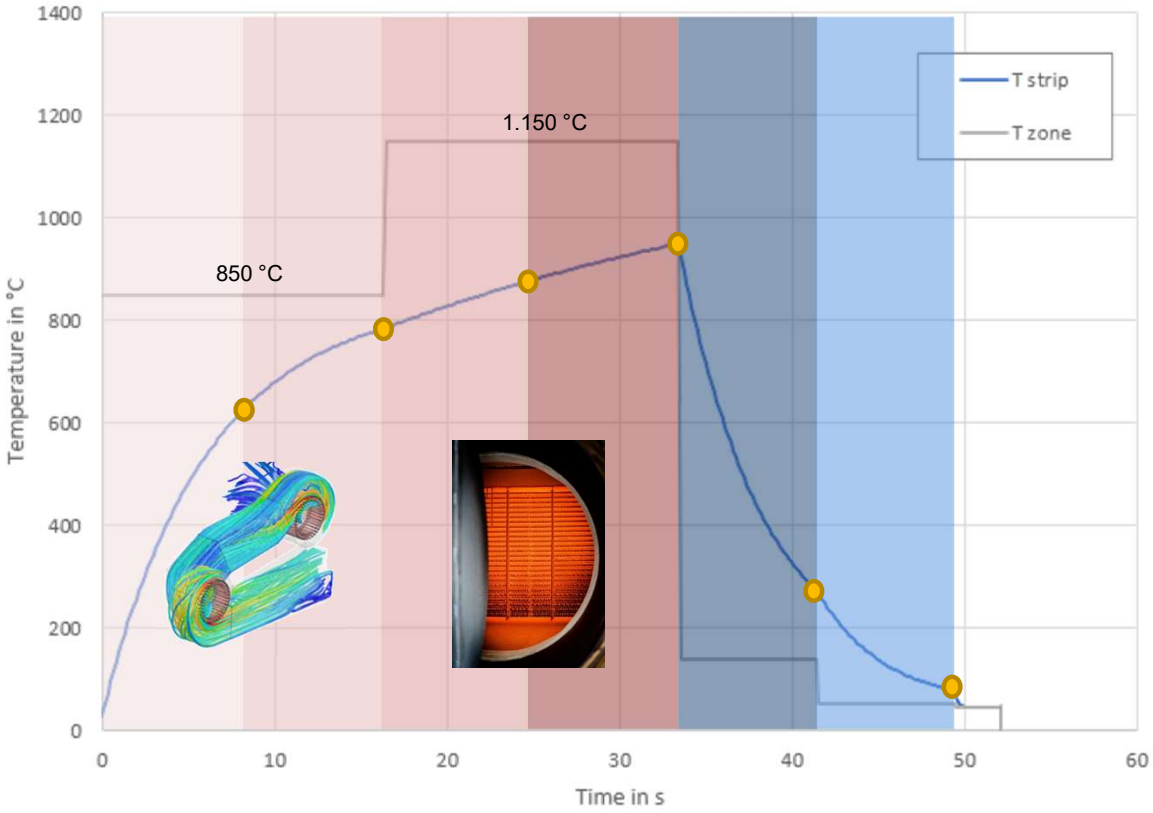
Example of a design calculation

C70250 - $T_{material}$ = 950°C - H_2 3,5 %

Band- und Prozessdaten	
Dicke [mm]:	0,4
Breite [mm]:	650
Geschwindigkeit [m/min]:	22
Anfangstemperatur [°C]:	30
Legierung:	C70250

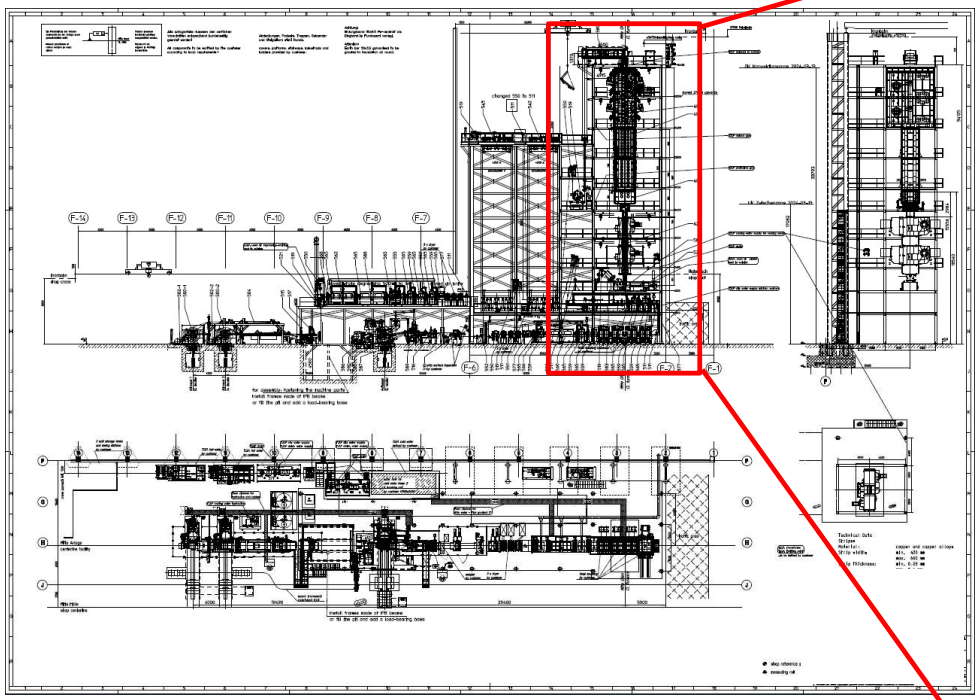
Kennzahlen	
Durchsatz [t/h]:	3,03
Gesamtwirkungsgrad [%]:	66
Heizwert Gas [MJ/Nm3]	31,4
Spezifischer Verbrauch Gas [Nm3/t]:	16,4
spezifischer Verbrauch Strom [kWh/t]:	111,7

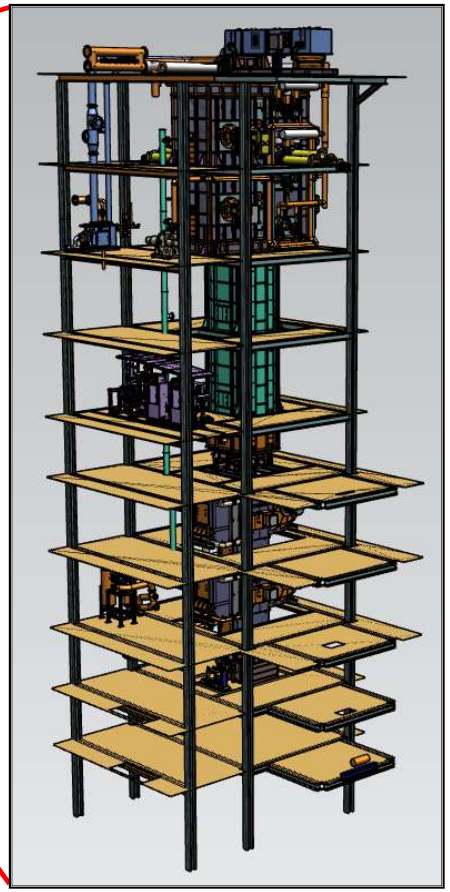
Zone	Typ	Temp.[°C]	T Band am Ende [°C]
1	Heizen Konvektion	850	631
2	Heizen Konvektion	850	787
3	Heizen Strahlung	1150	882
4	Heizen Strahlung	1150	954
5	Kühlen	139	269
6	Kühlen	52	77
7	Wassertasse	42	42



Vertical furnace

Example of a layout

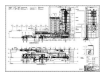




Techn. Data:

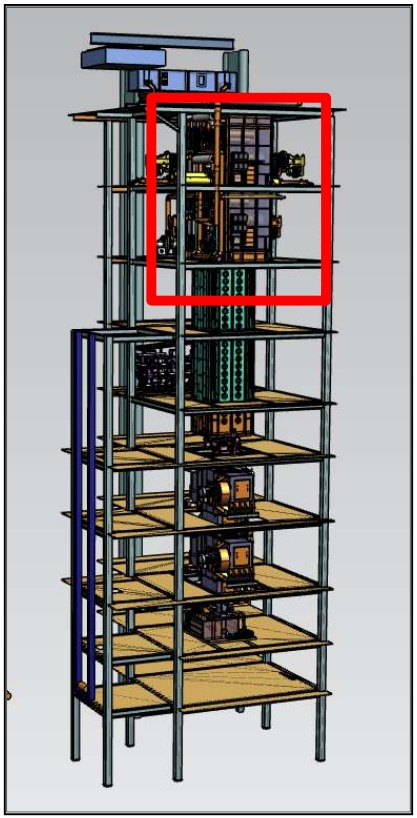
Material: copper and copper alloys

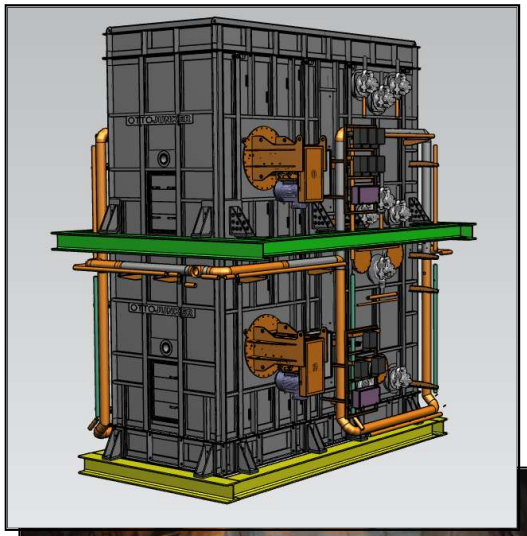
strip width:	min. 420 mm max. 660 mm
strip thickness:	min. 0,03 mm max. 0,4 mm
strip speed:	up to 120 m/min in the furnace section
material temp.	to 850°C convection zone to 1.000 °C radiation zone

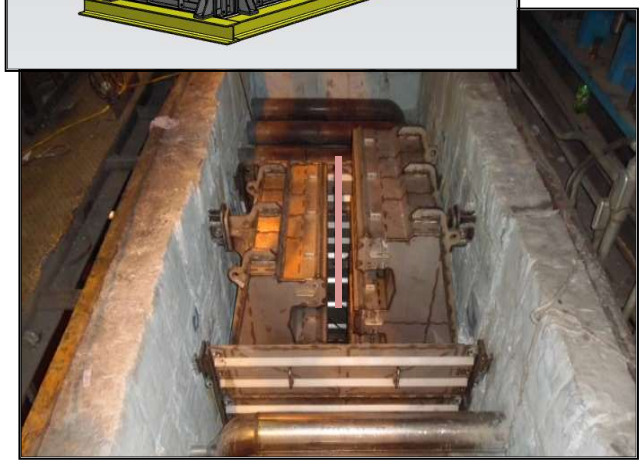


Vertical furnace

Convection zone

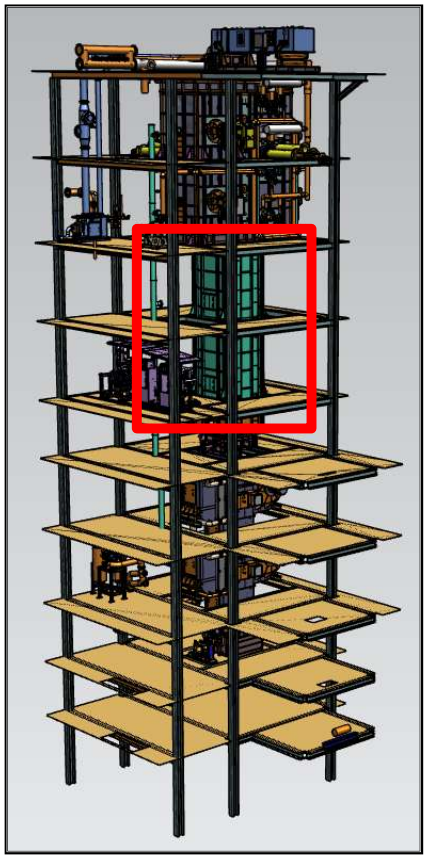


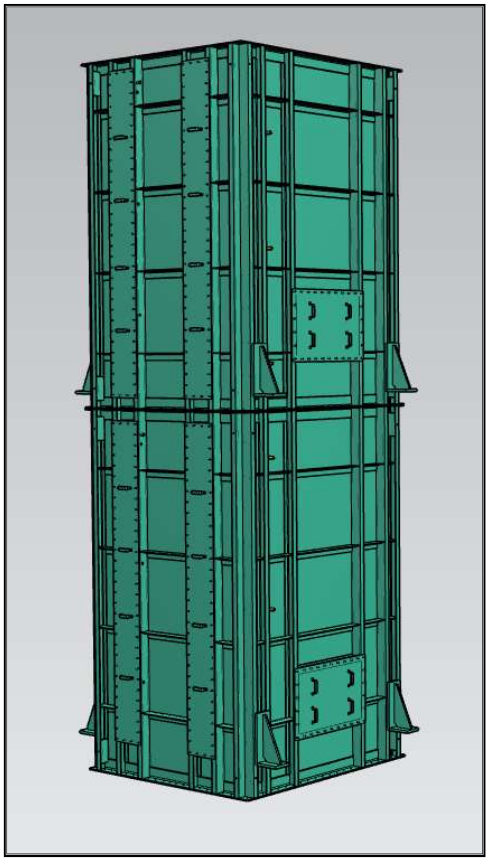


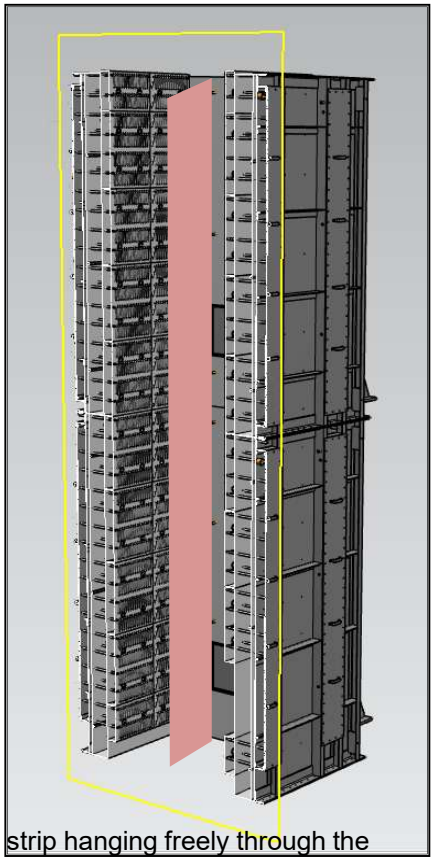


Vertical furnace

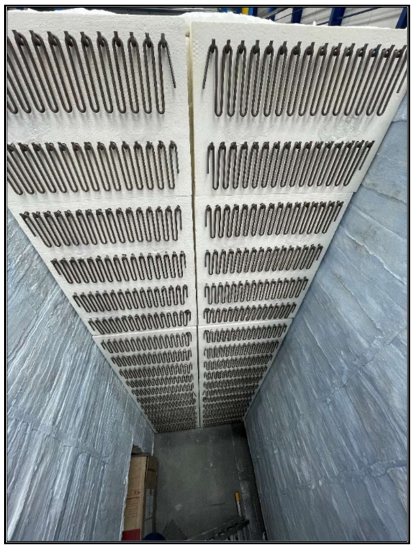
Radiation zone





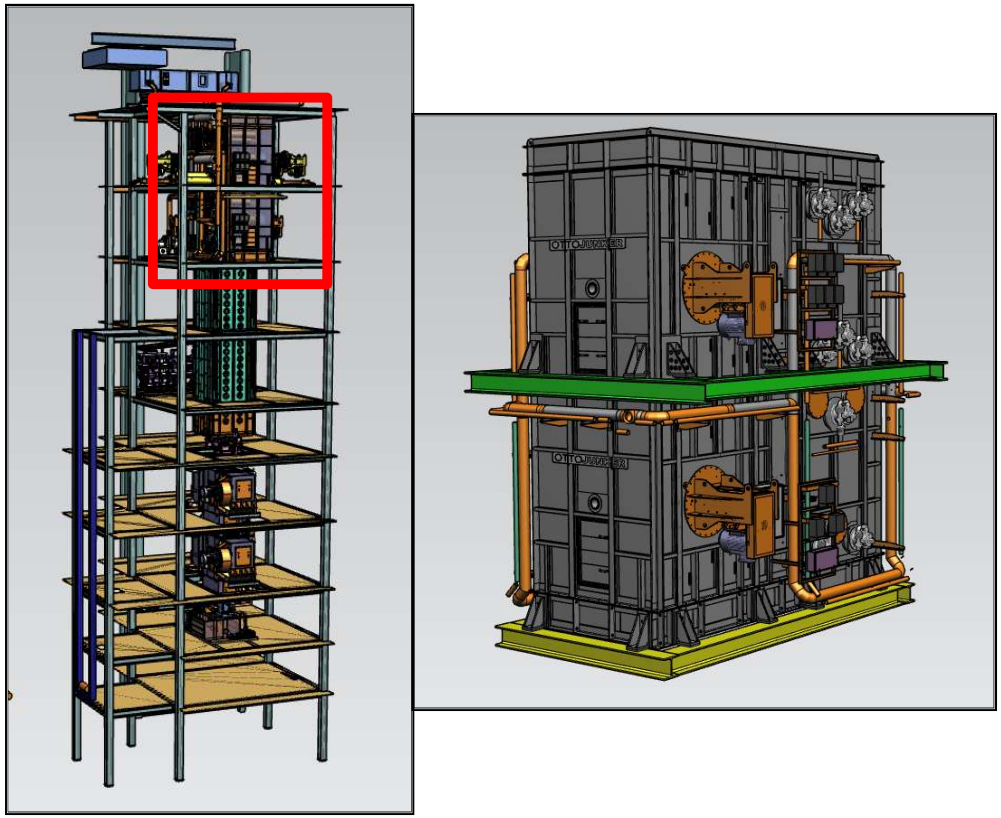


strip hanging freely through the radiation zone

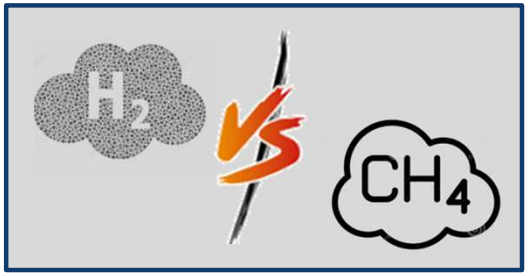


Vertical furnace

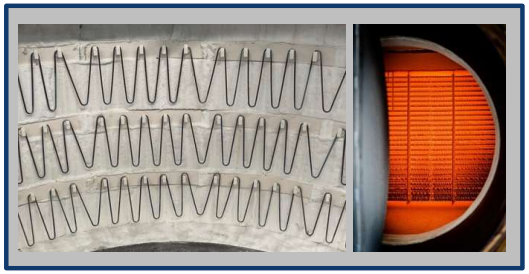
First possibility of decarbonization



1 Substitution of natural gas combustion to hydrogen combustion



2 Electrification of the heating system



Hydrogen combustion

Benefit

- Decarbonization
- Change to a sustainable industry

BUT

- Cost checking
- NOx verification

METHAN (natural gas) COMBUSTION

$CH_4 + 2\ (O_2 + 3{,}76\ N_2) \rightarrow CO_2 + 2H_2O + 7{,}52N_2 + NOx^*$

Combustion products:

CO_2 = 9.5 %Vol.

H_2O = 19 %Vol.

N_2 = 71.49 %Vol.

Adiabatic flame temperature (LuVo 20°C) = ~1980 °C

Hydrogen combustion

$2H_2 + O_2 + 3{,}76\ N_2 \rightarrow 2H_2O + 3{,}76N_2 + NOx^*$

Combustion products :

CO_2 = 0.0 %Vol.

H_2O = 34.71 %Vol.

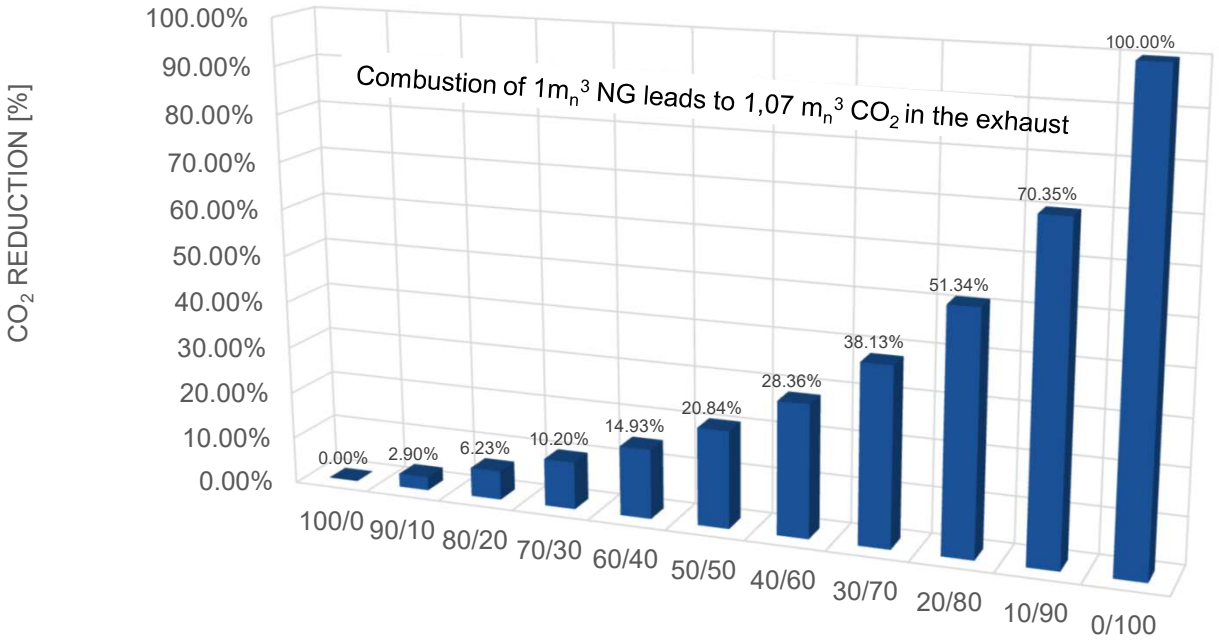
N_2 = 65.29 %Vol.

Adiabatic flame temperature (LuVo 20°C) = ~2130 °C

* Formation of thermal NOx emissions depends on the combustion technology used

Hydrogen combustion

CO_2 reduction depending on the hydrogen gas mixture



the diagram shows the percentage CO_2 saving in relation to the CO_2 content in the exhaust gas volume

CO_2	1,07 m$_n^3$ CO2 / m$_n^3$ Gas (9,5% of the exhaust)
90/10	Reduction from 1,07 to 1,039 - 2,9%
10/90	Reduction from 1,07 to 0,317 - 70,35%

1 m$_n^3$ CO$_2$ weights 0,541 kg

Hydrogen combustion

Hydrogen content in natural gas 20 %

Depending on the fuel composition, the mixing ratio can be calculated in a control system and set in a gas mixing station. Using the example of 20% hydrogen in natural gas, the following fuel composition results

BRENNGASZUSAMMENSETZUNG:			
Komponente:	Einheit	Brenngas	Oxidator
CO	[Vol.-%]	0,00	-
H_2	[Vol.-%]	20,00	-
CH_4	[Vol.-%]	72,72	-
C_2H_4	[Vol.-%]	0,00	-
C_2H_6	[Vol.-%]	4,43	-
C_3H_8	[Vol.-%]	0,56	-
C_4H_{10}	[Vol.-%]	0,17	-
$C_5H_{12}+C_nH_m$	[Vol.-%]	0,06	-
H_2O	[Vol.-%]	0,00	1,25
CO_2	[Vol.-%]	1,38	0
O_2	[Vol.-%]	0,00	20,75
N_2	[Vol.-%]	0,68	78
Summe		100	100
		Ok!!!	Ok!!!

BRENNGAS-CHARAKTERISIERUNG:		
Dichte (0 °C)	[kg/m_N^3]	0,6534
Dichte (0 °C) des Oxidators	[kg/m_N^3]	1,2816
Heizwert (vol.)	[MJ/m_N^3]	31,94
Heizwert (spez.)	[MJ/kg]	48,88
Heizwert	[kWh/m_N^3]	8,87
Brennwert (vol.)	[MJ/m_N^3]	35,52
Brennwert (spez.)	[MJ/kg]	54,37
Brennwert	[kWh/m_N^3]	9,87
unterer Wobbe-Index	[MJ/m_N^3]	44,93
untere Zündgrenze*	[Vol.-%]	4,67
obere Zündgrenze*	[Vol.-%]	17,25
min. O_2-Bedarf	[m_N^3/m_N^3 Gas]	1,753
min. Oxidator-Bedarf	[m_N^3/m_N^3 Gas]	8,451

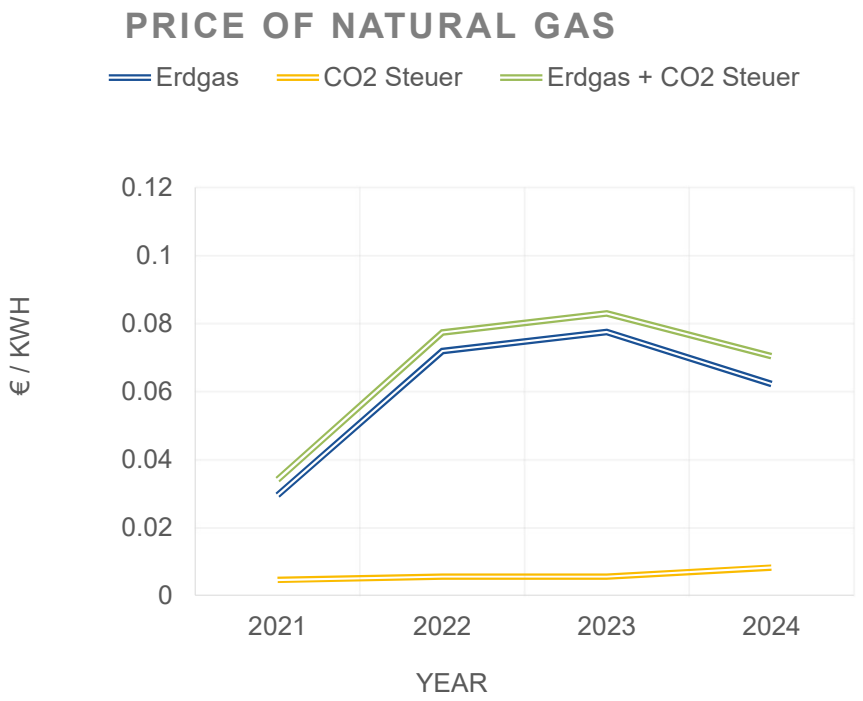
max. throughput 3,03 t/h
required capacity 394kW/h

Total fuel:	44,41 m_n^3/h
Hydrogen:	8,88 m_n^3/h
Natural gas:	35,5 m_n^3/h
Combustion air	394 m_n^3/h (λ=1,05)

Because of the reduction of the caloric value (~10 of natural gas) the required fuel volume increases

Hydrogen combustion

Fuel price information



Volume flow [m_n^3/h]	38,1				
caloric value [kWh/m_n^3]	10,34				
capacity [kWh]	394				
price [€/kWh]	0,07036				
sum price	**27,72 €**	**9,15 €/t**			
	80% NG	**20% H2**			
Volume flow [m_n^3/h]	35,5	8,88			
caloric value [kWh/m_n^3]	10,34	3			
capacity [kWh]	367	27			
price [€/kWh]	0,07036 €			future	
price [€/m_n^3]		0,3776 €		0,16820 €	
sum price	**29,18 €**		**9,63 €/t**	**27,32 €**	**9,02 €/t**
	100% H2				
Volume flow [m_n^3/h]	131,48				
caloric value [kWh/m_n^3]	3				
capacity [kWh]	394		future		
price [€/m_n^3]	0,3776 €		0,16820 €		
sum price	**49,65 €**	**16,39 €/t**	**22,11 €**	**7,30 €/t**	

* The shown prices are valid for Germany

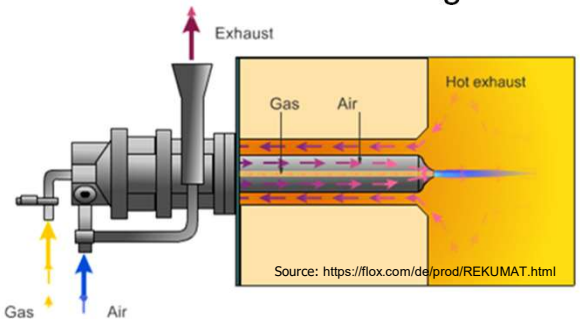
Hydrogen combustion

techn. Challenges of the hydrogen combustion

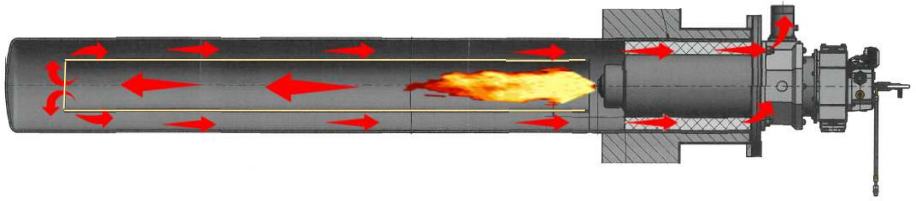
- Burner adjustments by changing the volume flow and the flame temperature
- Gas mixing station
- NO_X increase
  - direct heating – not critical due to flue gas circulation and reduction of the flame temperature
  - indirect heating - Flue gases are trapped in the flame tube / radiant tube, recirculation is not possible

gas mixing station

direct heating



indirect heating



Electrification of existing systems


Bild-Berichte

über Industrie-Öfen und Hilfsmaschinen für die E- und NE-Metallhalbzeugindustrie

Bild 1: Ansicht von der Beschickungsseite.
Vor dem Ofen der Auflegetisch mit den Umlenkrädern für die Transportkette
(Werkstattmontagebild)

Elektrisch beheizter Durchlaufofen
zum Anlassen von Leichtmetall-Kolben bei Temperaturen bis 300° C

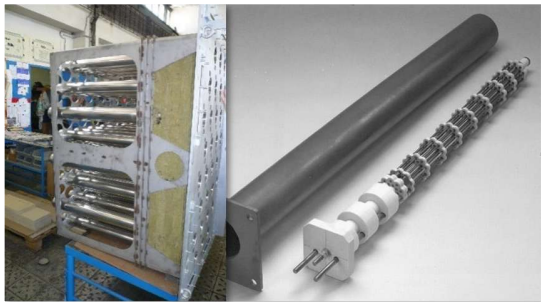
LAMMERSDORF ÜBER AACHEN 1 OTTO JUNKER GMBH GEVELSBERG POSTFACH 71

Electrical heated continous furnace / example of a furnace flyer of 1956

Electric resistance heating is state of the art

BUT

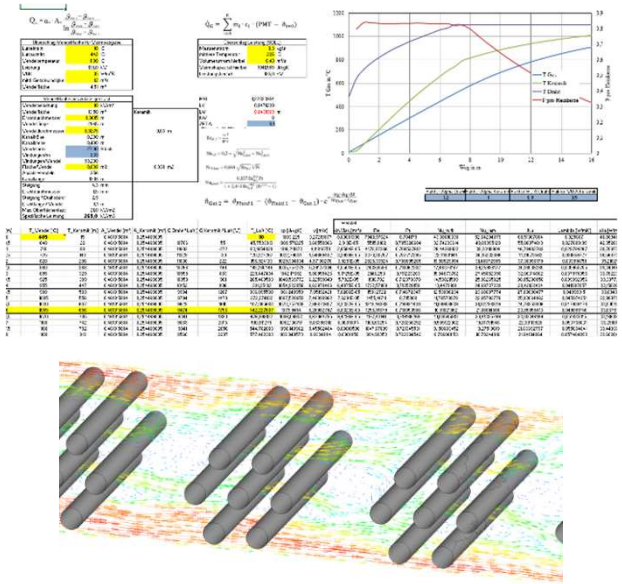
We need space for the installation of the electrical power



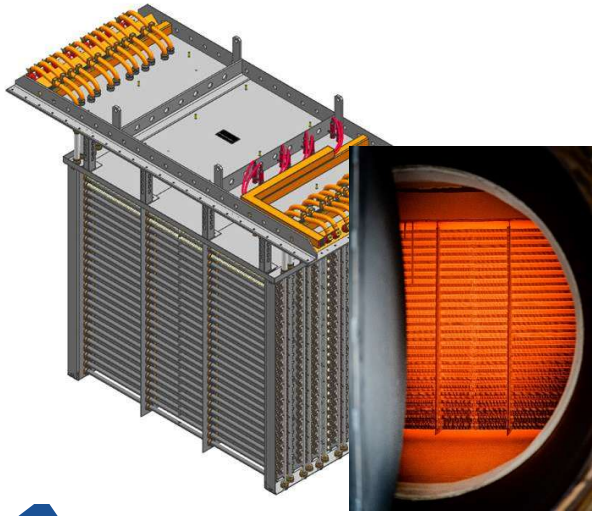
Increasing the power density by Research and Development

Experimental setup at Otto Junker R&D

Proven numerical and analytical models



Increased performance and power density up to 300kW/m^3

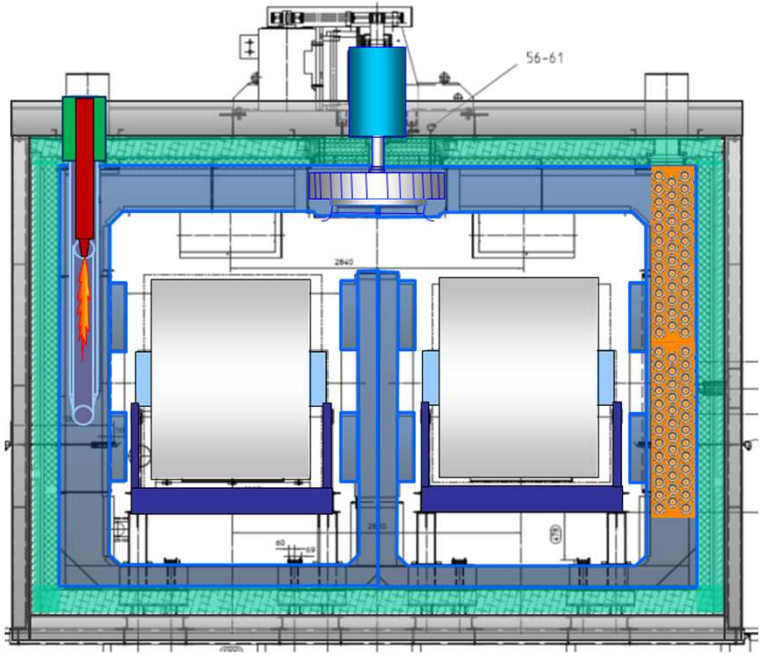


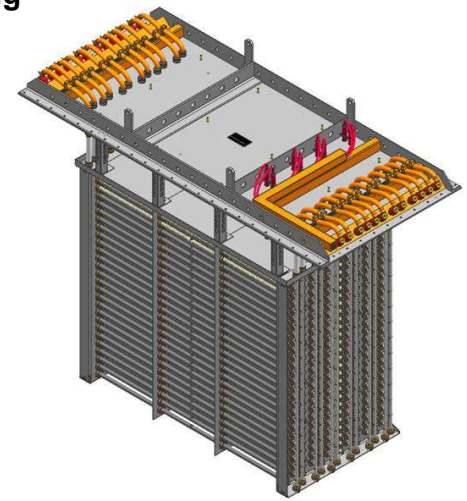
For applications with 800°C furnace temperature

Decarbonization of annealing furnaces

Natural gas burner → **Electrical resistance heating**

- Approx. 600 tons* CO_2 per year
- Efficiency: 76 %

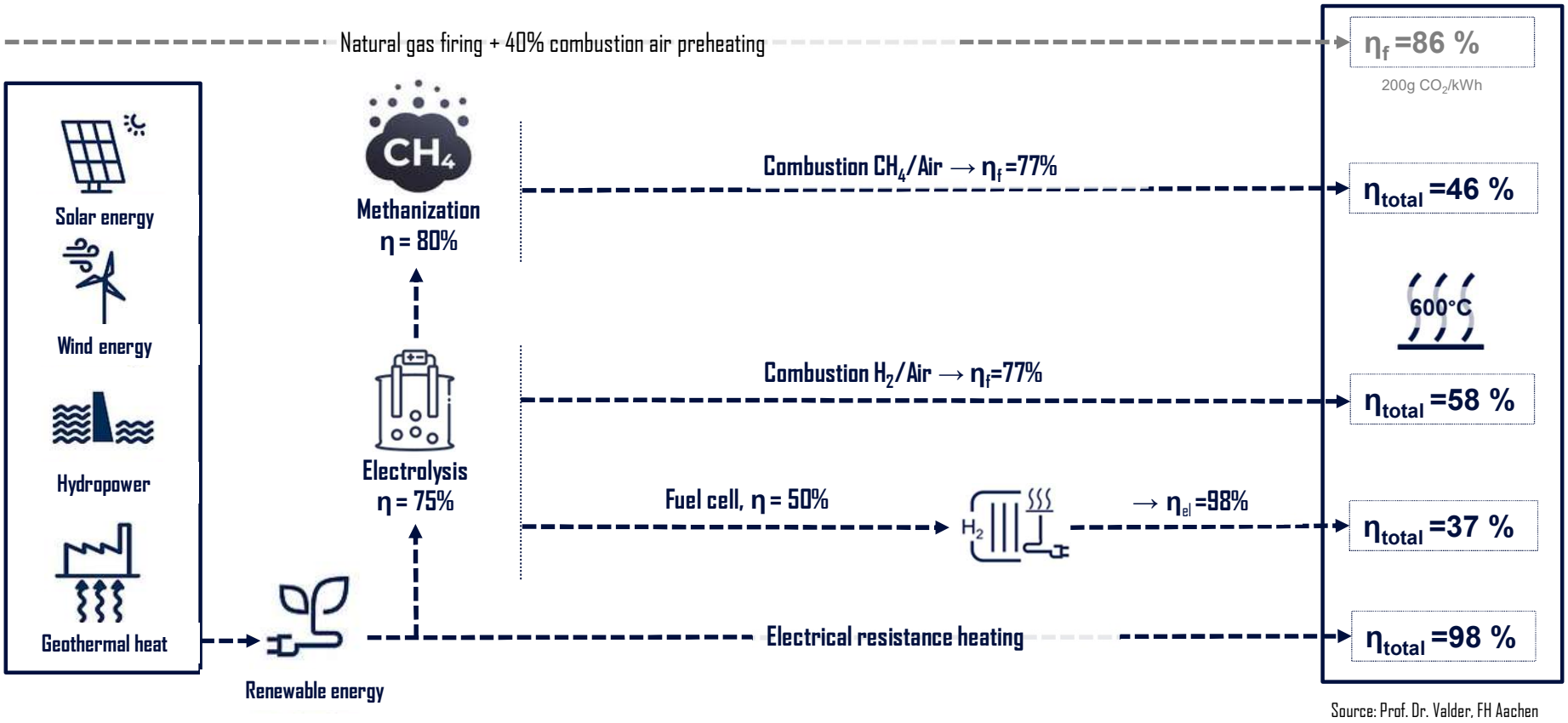




- No direct CO_2-Emission
- No direct NOx-Emission
- Efficiency: 98 %
- Annealing processes up to 1200 °C can be electrified

*) Installed capacity of 1 MW and 3000h operating hours [0,2 kgCO_2/kwh]

System efficiency



Source: Prof. Dr. Valder, FH Aachen

Thank you for your attention!

OTTOJUNKER GREEN FURNACE TECHNOLOGY

Dipl. Ing. (FH) Uwe Pallaß, MBA

Senior Sales Manager

Thermoprocessing Plants for Copper Based Alloys

Phone: +49 (0)2473/601-540
Mobile: +49 172 60 21 552
Uwe.Pallass@otto-junker.com