
Innovationsforen Mittelstand

Hybrid-Heating

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung


# Trends im Industrieofenbau (Hybrid Heating)

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IOB Institut für Industrieofenbau und Wärmetechnik | RWTH AACHEN UNIVERSITY

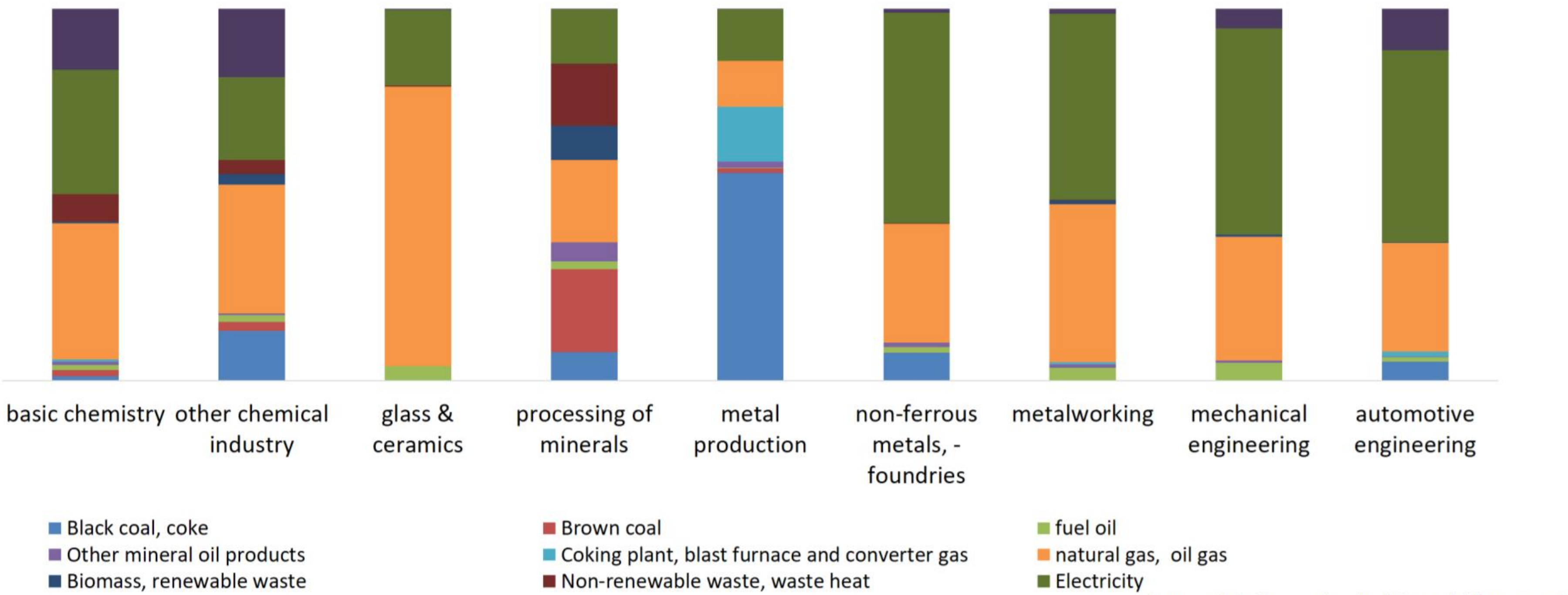
# Begriff der Thermoprozesstechnik / Industrieofentechnik

allgemeine Definition:

„**Prozess- und Anlagentechnik** zur **thermochemischen** und **thermophysikalischen** Behandlung von **Materialien** und **Werkstoffen***) derart, dass die **optimalen Produkteigenschaften** durch die **gezielte Einstellung und Regelung der Guttemperatur** und der **Prozessatmosphäre** **wirtschaftlich/ökologisch** eingestellt werden.“

*) Stahl, NE- und Leichtmetalle, Zement, Keramik, Glas,

# End energy consumption of industry in Germany by energy sources in 2016




Source: Arbeitsgemeinschaft Energiebilanzen e. V.

CECOF

Dr. Franz Beneke 70 years of Ebner in motion

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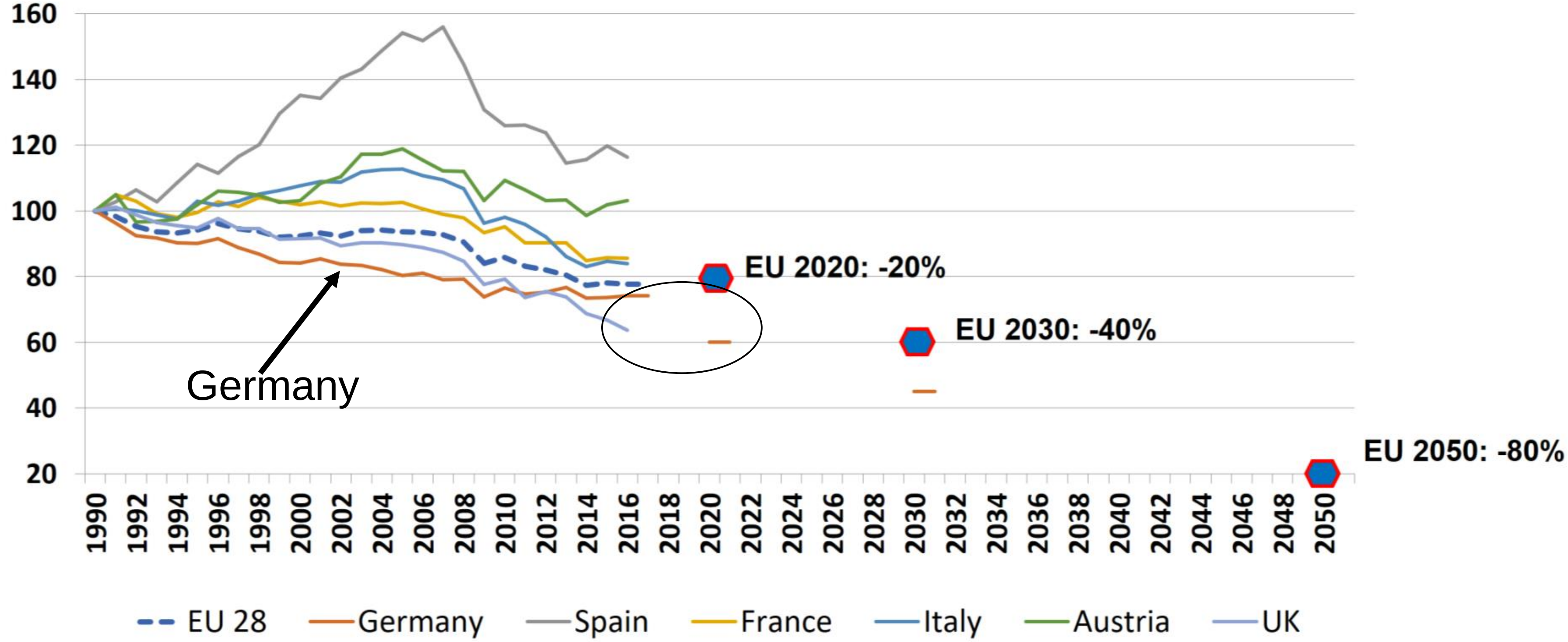
# Development of greenhouse gases in Europe since 1990 in %

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# Arc of suspense „Thermoprocess-Technology“

- Energy efficiency
- Loss of market segments (technological change e. g. electro-mobility)
- New high strength steel / aluminum strip materials and C-fibers
- Flexible (additive) manufacturing
- Renewable **electricity** in industry (C-free energy technology), bio fuels, **hydrogen, renewable NG**
- Young academics and future of furnace relevant research institutes
- Combustion: fuel properties and emissions

# Energiewende (energy transition) – Electrification of Industry

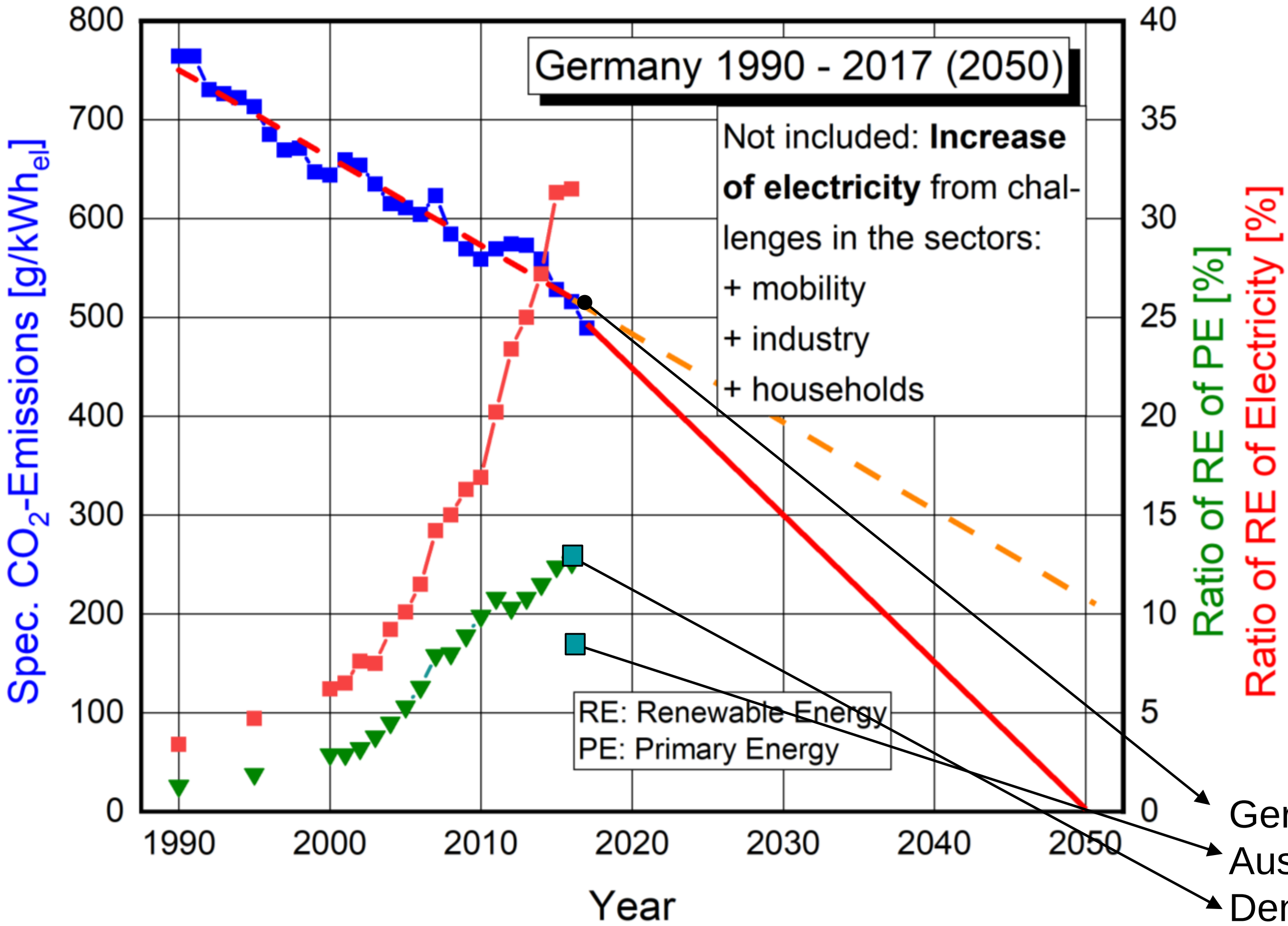
Extract from: Green house gas free Germany in **2050**, Umweltbundesamt[1)], October 2013[2)]
http://www.uba.de/publikationen/treibhausgasneutrales-deutschland-im-jahr-2050

„We consider in this study[2)], that in the steel industry the production of primary steel via blast furnace (**BF**) - basic oxygen furnace (**BOF**) route not further exists. Instead of this process the electric steel route (**EAF**) with scrap and direct reduced iron (DRI) will be extended massively. As energy source for the direct reduction of ore only renewable methane will be used and **the reheating furnaces for the hot rolling mills will be heated exclusively with renewable electricity**."

1) German Federal Environmental Agency (UBA)

→ Paradigm change in 32 years → technology not available yet → introduction of Technology → very high risk and very high chance to fail the climate goals

# Specific $CO_2$-emissions and ratio of renewable energies



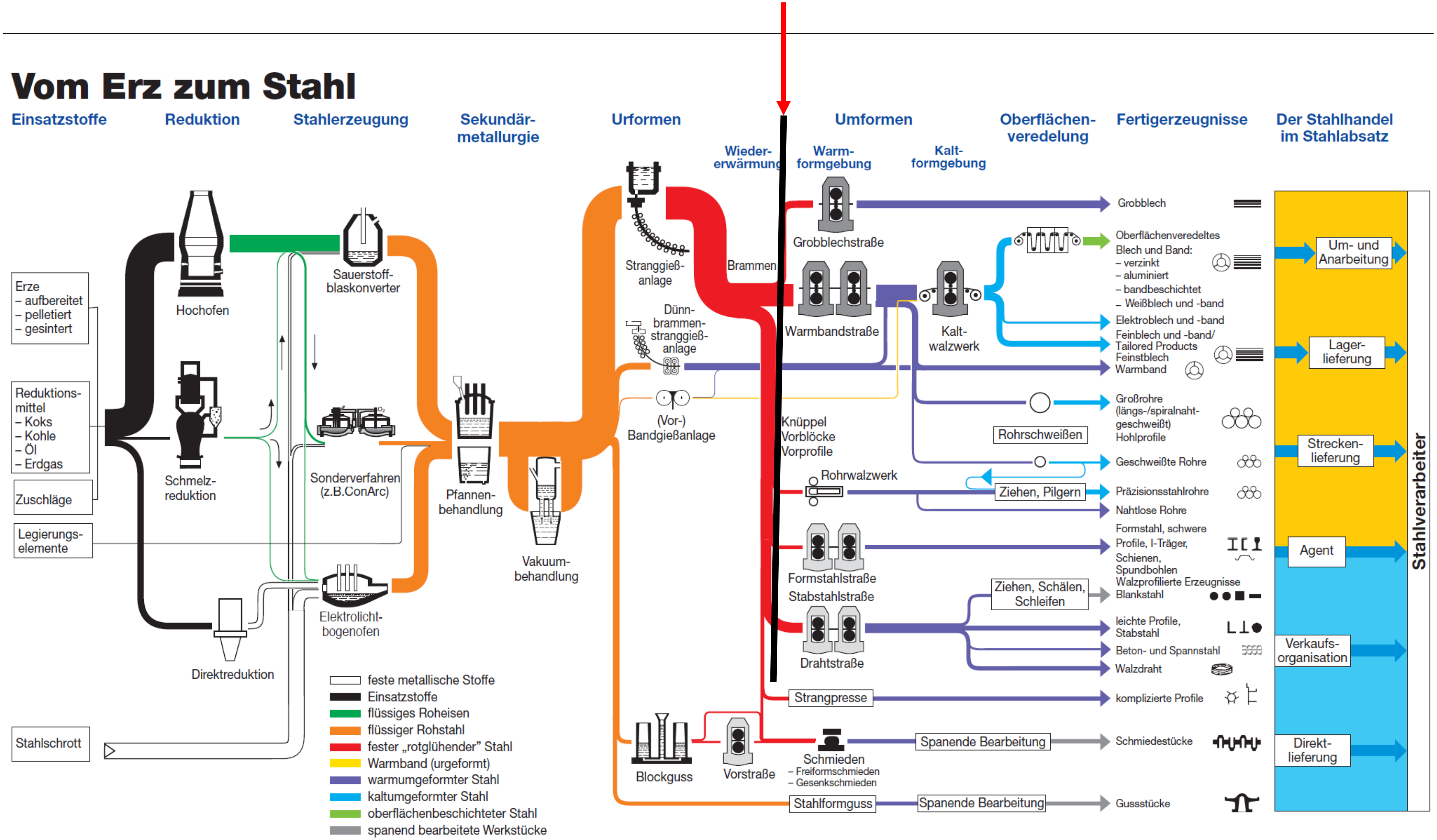

2016

Germany: 0,527 kg $CO_2$/$kWh_{el}$

Austria: 0,195 kg $CO_2$/$kWh_{el}$

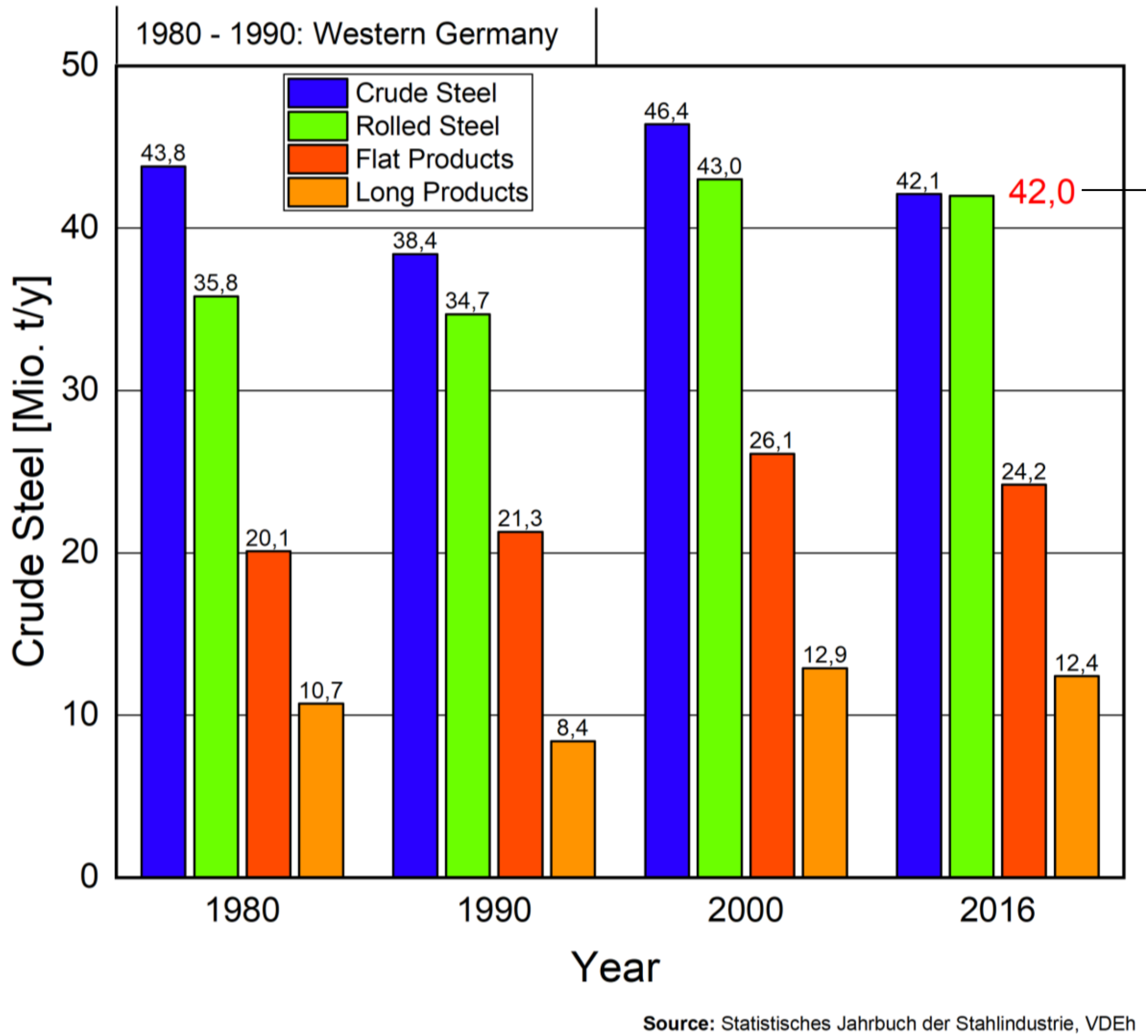
Denmark: 0,262 kg $CO_2$/$kWh_{el}$

# Vom Erz zum Stahl



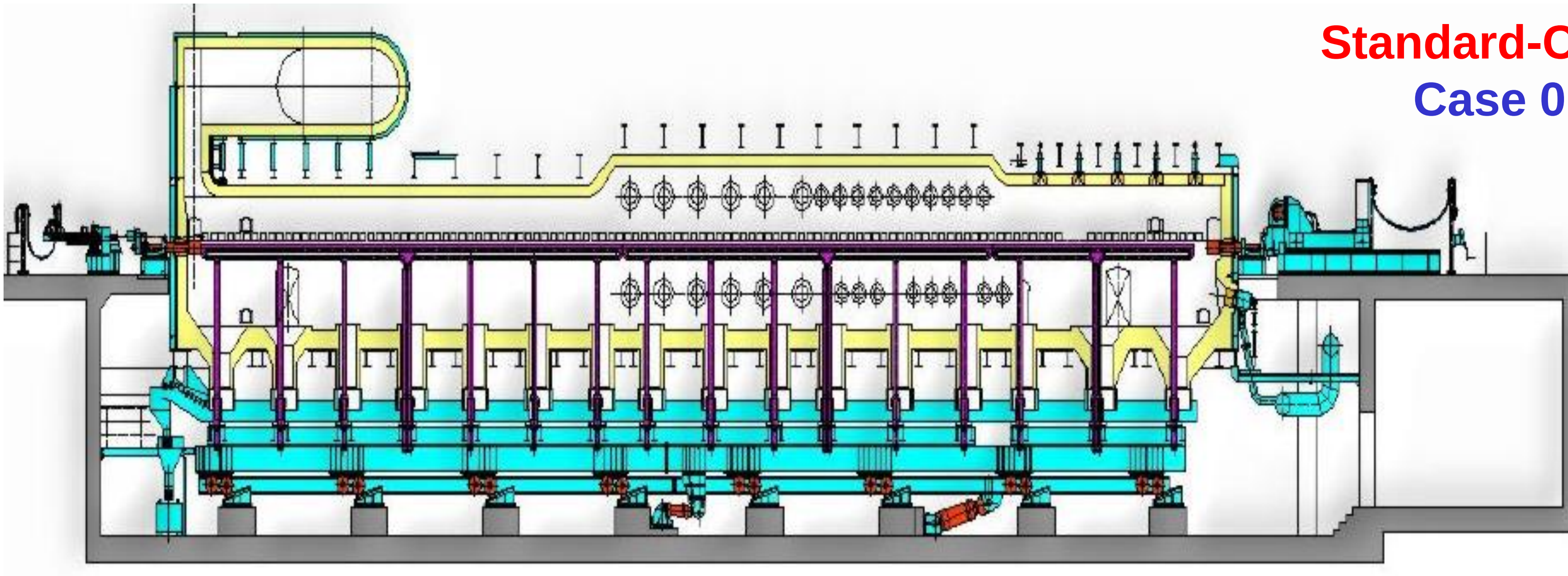

Herausgeber: Stahlinstitut VDEh, Düsseldorf

# Steel production in Germany




Basis for calculations

# Exemplary data for a 160 t/h walking beam furnace (GMH)



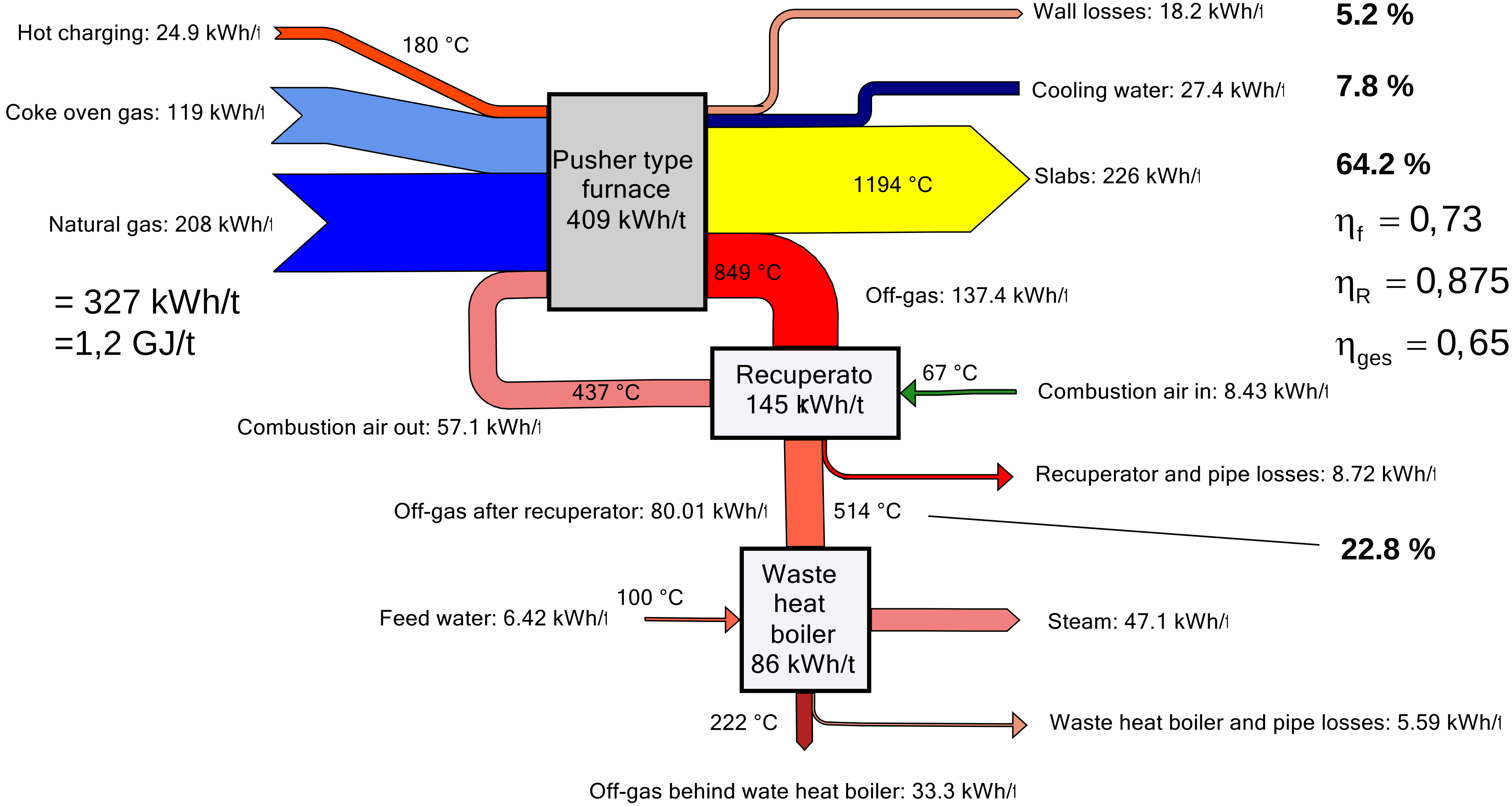
**Standard-Case**

**Case 0**

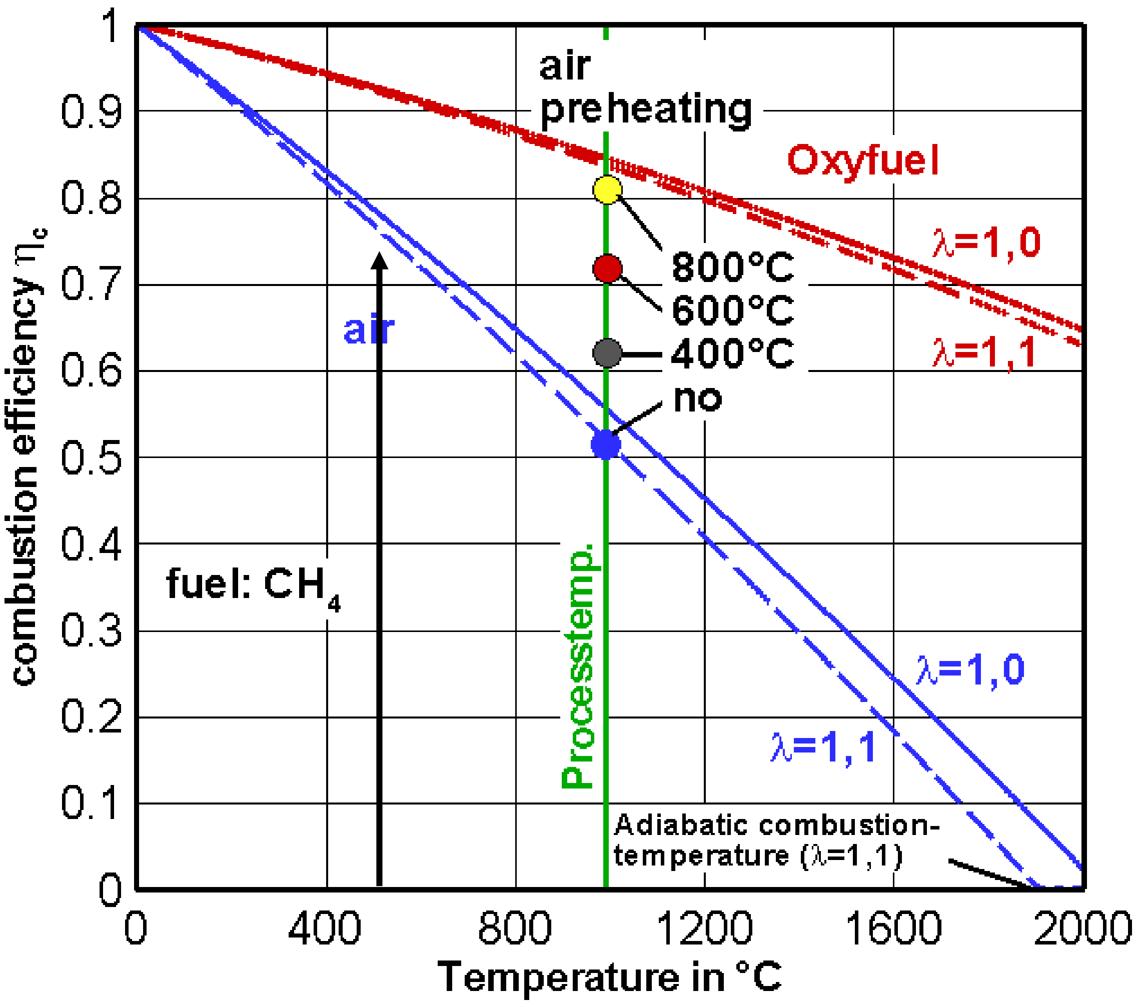
| | Guarantee | Guarantee test | Operation | | |
|---|---|---|---|---|---|
| Year | | = 320 kWh/t | 2005 | 2006 | 2007 |
| Productivity in t/h | 160 | > 160 | 113 | 127 | 140 |
| Energy consumption in GJ/t | 1.165 | 1.101 | 1.35 | 1.37 | |
| $NO_x$ in mg/m³ | < 150 | 49 (5 % $O_2$) | | | |

Productivity: 160 t/h   Natural gas installed: 7500 m³/h   Thermal power: 68 MW

# Energy flow diagram of a pusher-type furnace



# Combustion efficiency of Methane ($CH_4$)



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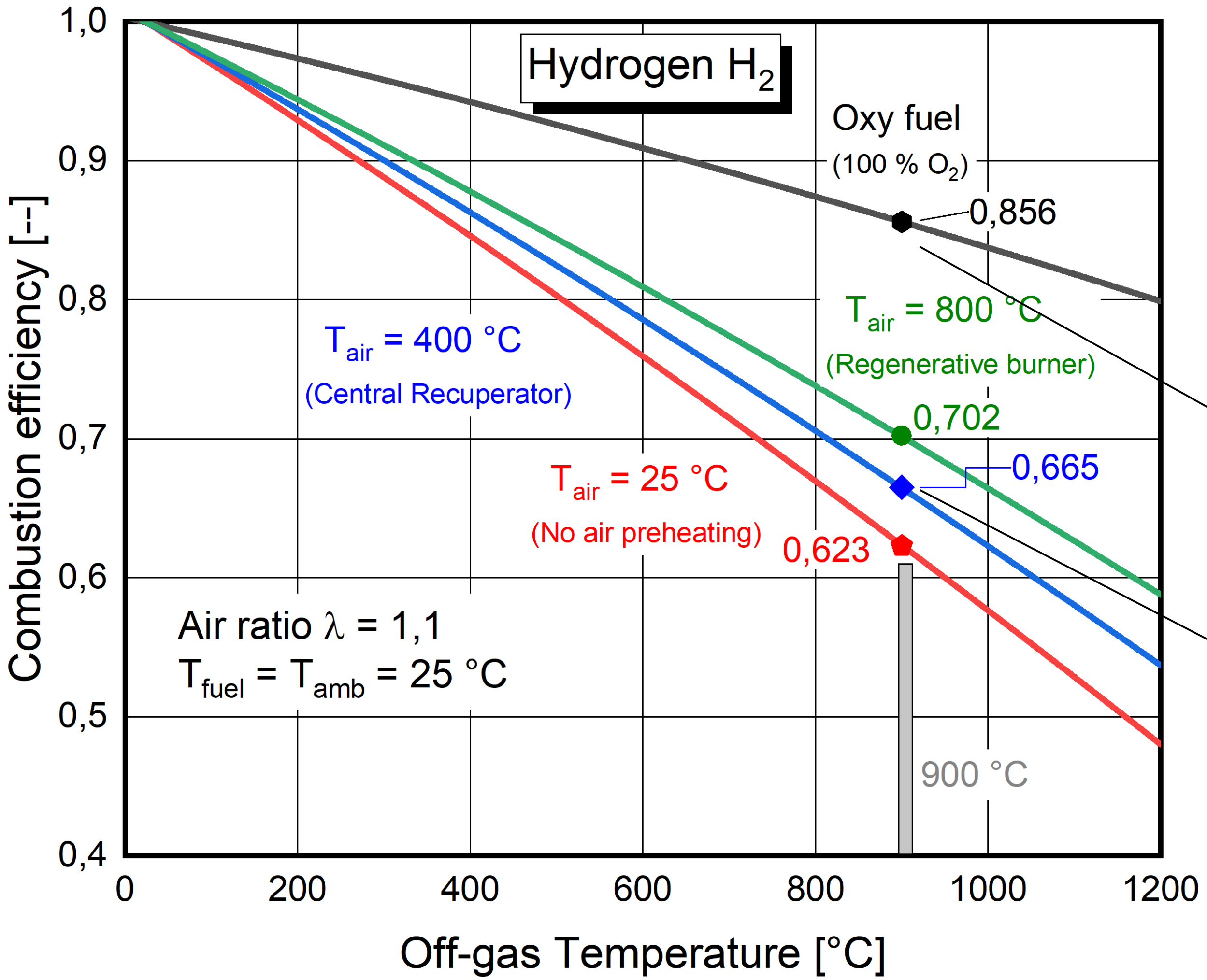
# Combustion efficiency of Hydrogen ($H_2$)




Hydrogen

$\Delta h_u = 3\,kWh/m^3_{stp}$

$o_{min} = 0,5\ m^3_{O_2}/m^3_{H_2}$

$l_{min} = 2,38\ m^3_{air}/m^3_{H_2}$

$v_{off\text{-}gas,min} = 2,88\ m^3_{off\text{-}gas}/m^3_{H_2}$

$T_{adiabatic} = 2242\ °C$

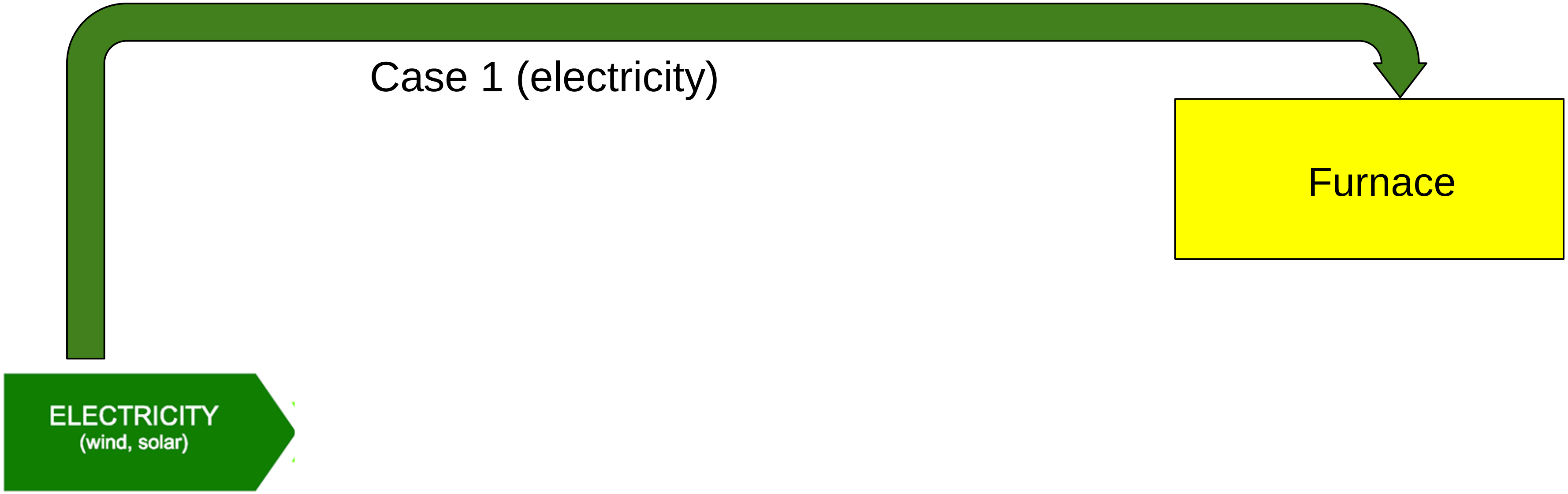
$T_{amb} = T_{air} = T_{fuel}$

Case 2 and Case 3

($H_2$+AP Oxy-Fuel)

AP: Air preheating

# Examplary power-to-gas process chain – electrification of industrial furnaces




Speicher-
Problematik
el. Energie

Source: Götz, M. et al.: Renewable Power-to-Gas: A technological and economic review, Renewable energy 85 (2016), p. 1371/90

# Energy balance and efficiencies for fuel and electrical heated furnaces

## Efficiency of fuel heated furnace

$$\dot{H}_{fuel} + \dot{H}_{air,f} = \Delta\dot{H}_{steel} + \dot{Q}_{losses,f} + \dot{H}_{off-gas,f}$$

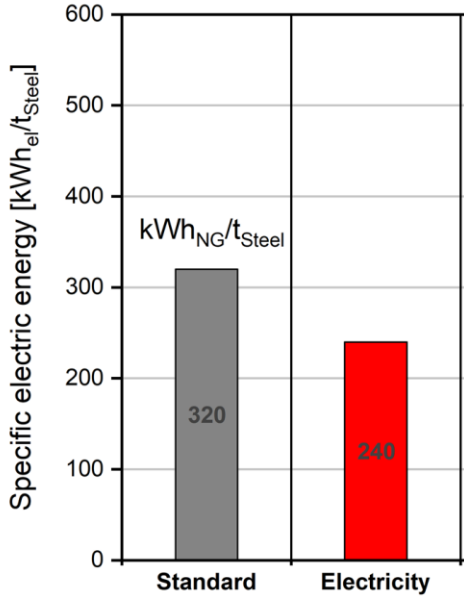
$$\eta_c = \frac{\dot{H}_{fuel} - \dot{H}_{off-gas,f}}{\dot{H}_{fuel} + \dot{H}_{air,f}} = 1 - \frac{\dot{H}_{off-gas,f}}{\dot{H}_{fuel} + \dot{H}_{air,f}}$$

$$\eta_R = \frac{\Delta\dot{H}_{steel}}{\dot{H}_{fuel} - \dot{H}_{off-gas,f}} = \frac{1}{1 + \frac{\dot{Q}_{losses,f}}{\Delta\dot{H}_{steel}}}$$

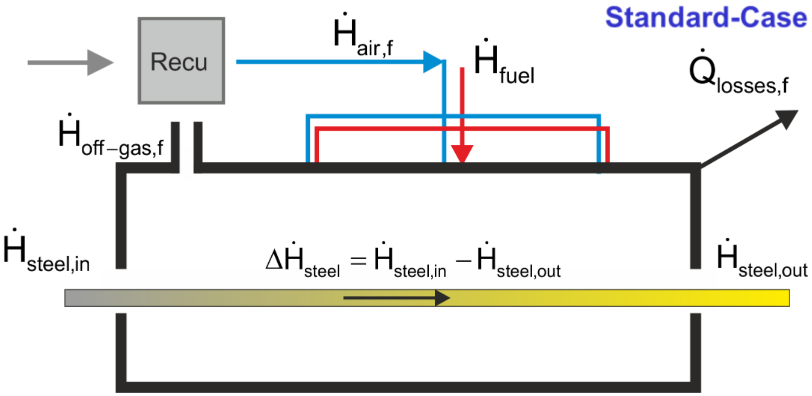
$$\eta_{tot,f} = \eta_c \cdot \eta_R = \frac{\Delta\dot{H}_{steel}}{\dot{H}_{fuel} + \dot{H}_{air,f}}$$

$$e = \frac{\dot{H}_{fuel}}{\dot{m}_f}$$

### Standard-Case 0




**Standard-Case** **Case 1**




## Efficiency of electrical heated furnace

$$P_{el} - P_{el,losses} = \Delta\dot{H}_{steel} + \dot{Q}_{losses,f}$$

$$\eta_{el} = \frac{P_{el} - P_{el,losses}}{P_{el}} = 1 - \frac{P_{el,losses}}{P_{el}}$$

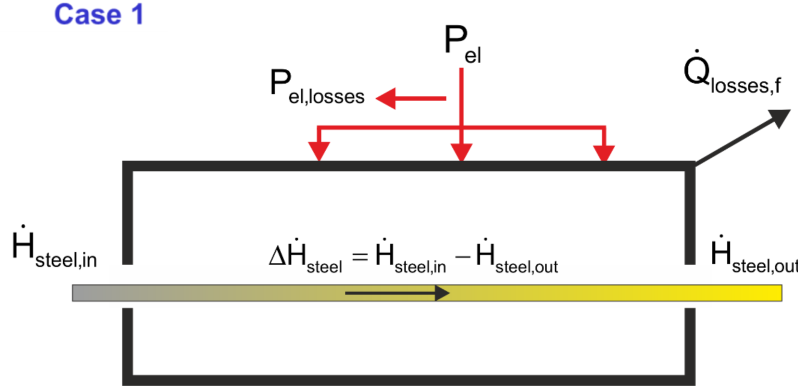
$$\eta_R = \frac{\Delta\dot{H}_{steel}}{P_{el} - P_{el,losses}} = \frac{1}{1 + \frac{\dot{Q}_{losses,f}}{\Delta\dot{H}_{steel}}}$$

$$\eta_{el} \approx 0{,}95$$

$$\eta_{tot,f} = \eta_{el} \cdot \eta_R = \frac{\Delta\dot{H}_{steel}}{P_{el}}$$

$$e = \frac{P_{el}}{\dot{m}_f}$$

### Case 1



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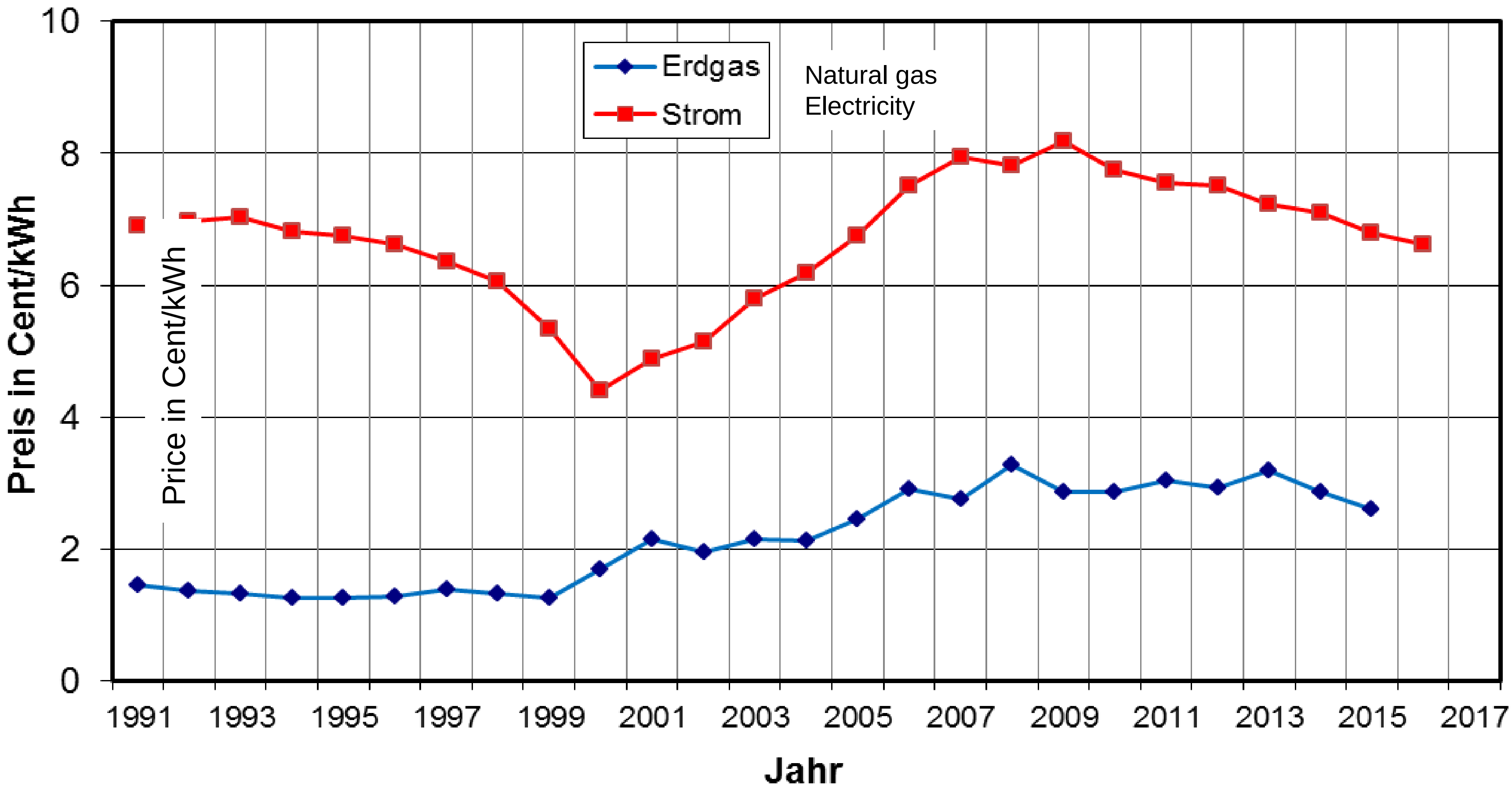
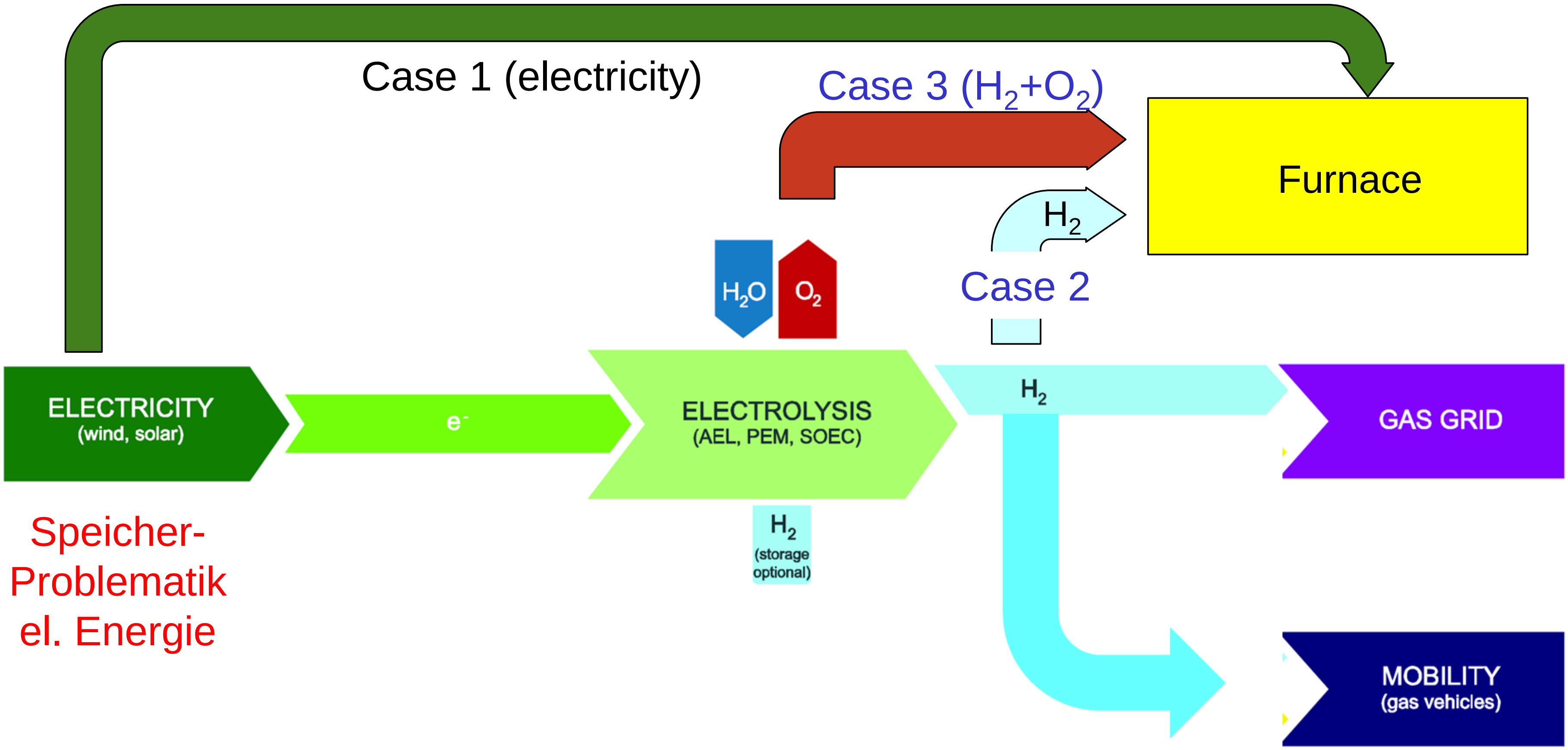
# Prices for Natural Gas and Electricity in Germany

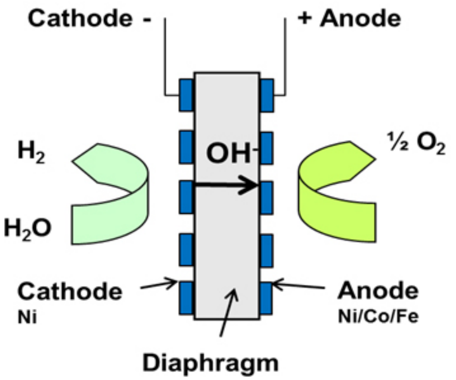


# Exemplary power-to-gas process chain




Source: Götz, M. et al.: Renewable Power-to-Gas: A technological and economic review, Renewable energy 85 (2016), p. 1371/90

# Water electrolysis

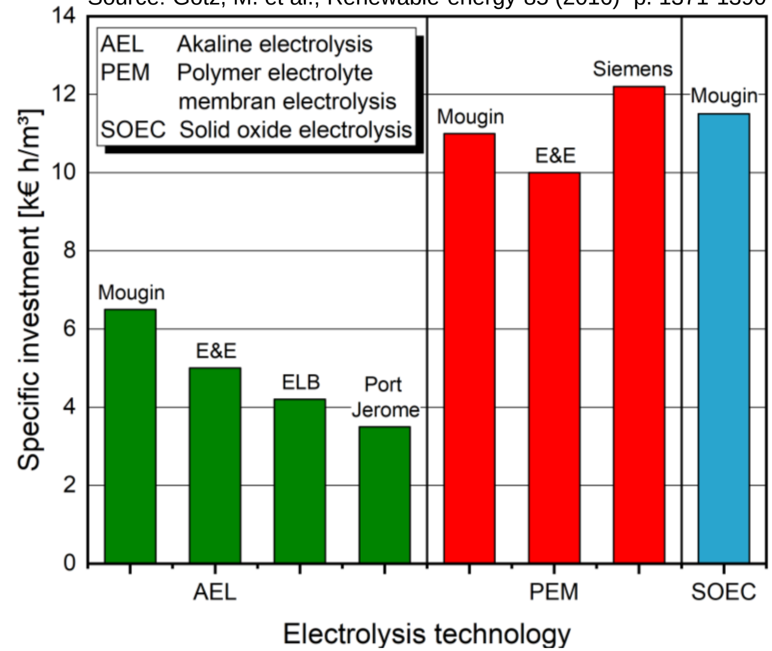



Alkaline Electrolysis 40 to 90 °C

| | | | |
|---|---|---|---|
| $2OH^-$ | → | $\frac{1}{2} O_2 + H_2O + 2e^-$ | Anode |
| $2H_2O + 2e^-$ | → | $H_2 + 2OH^-$ | Cathode |
| $H_2O$ | → | $H_2 + \frac{1}{2} O_2$ | Total reaction |

http://forschung-energiespeicher.info/wind-zu-wasserstoff/projektliste/projekt-einzelansicht/74/Neue_Membranmaterialien_fuer_die_PEM_Wasserelektrolyse/

Source: Götz, M. et al.; Renewable energy 85 (2016) p. 1371-1390




## Characteristic data for alkaline electrolysis AEL

### System power consumption

Current: $4.5 - 8.2 \frac{kWh_{el}}{m^3_{H_2}} \square 1.5 - 2.73 \frac{kWh_{el}}{kWh_{H_2}}$

Future: $4.2 - 5.7 \frac{kWh_{el}}{m^3_{H_2}} \square 1.4 - 1.9 \frac{kWh_{el}}{kWh_{H_2}}$

Efficiency *) : $\eta = 0.52 - 0.715$

*) ThyssenKrupp

Port Jerome (F)

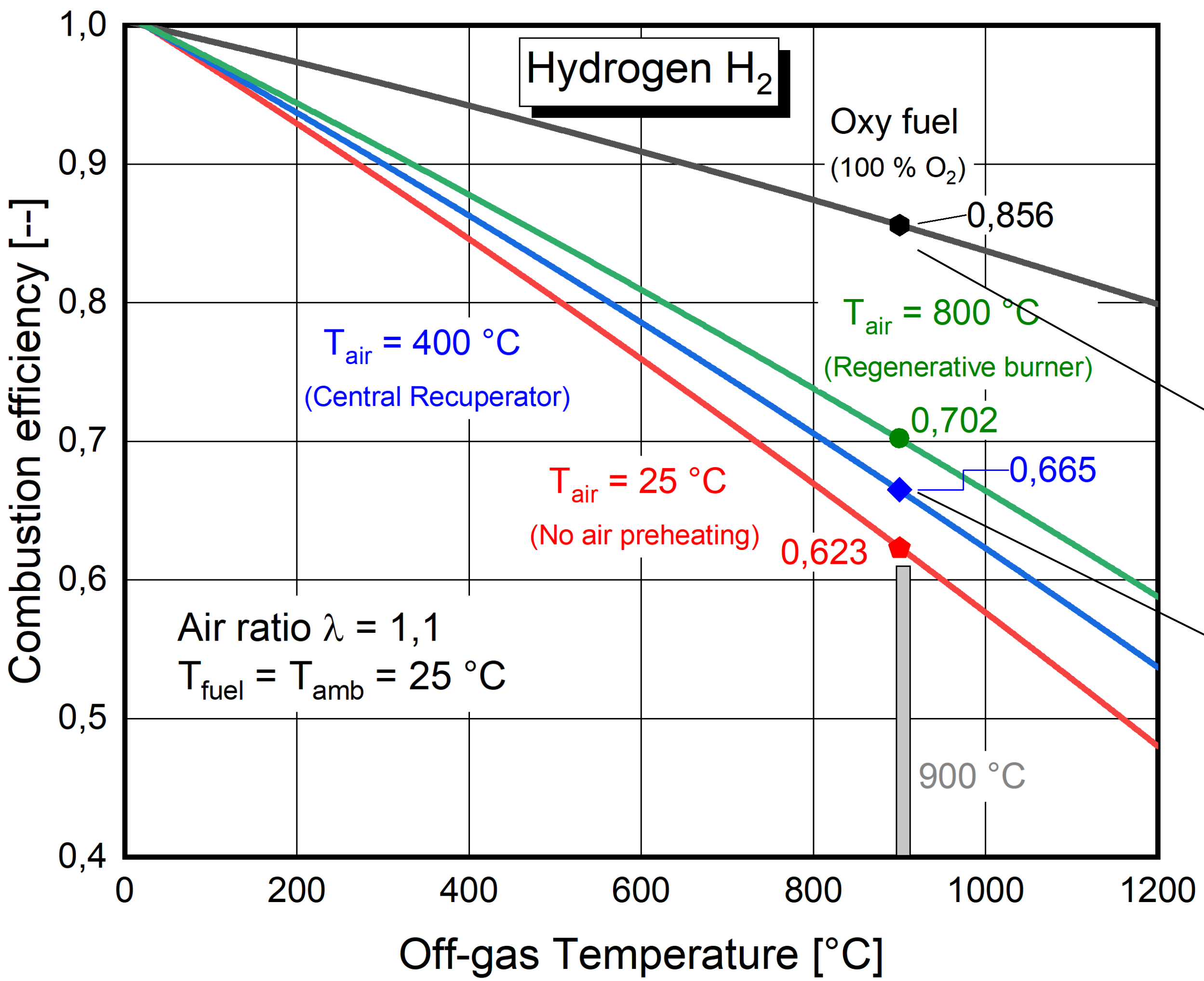
Proctivity: 100 000 t/y

Investment: 450 Mio. €

spec.investment: $3.5 \frac{k€}{\frac{m^3_{H_2}}{h}}$

Source: https://www.gtai.de/GTAI/Navigation/DE/Trade/…

# Combustion efficiency of Hydrogen ($H_2$)




Hydrogen

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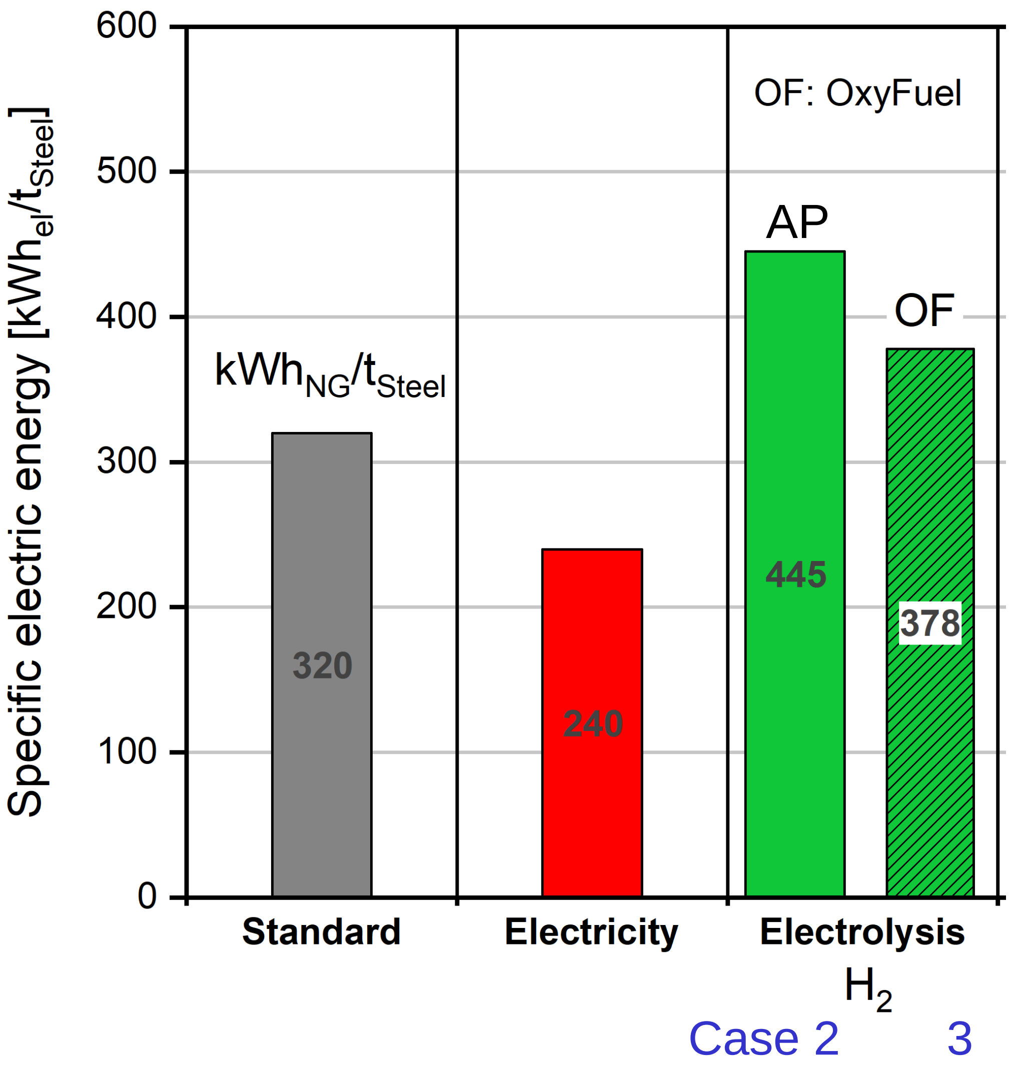
Case 2 and Case 3

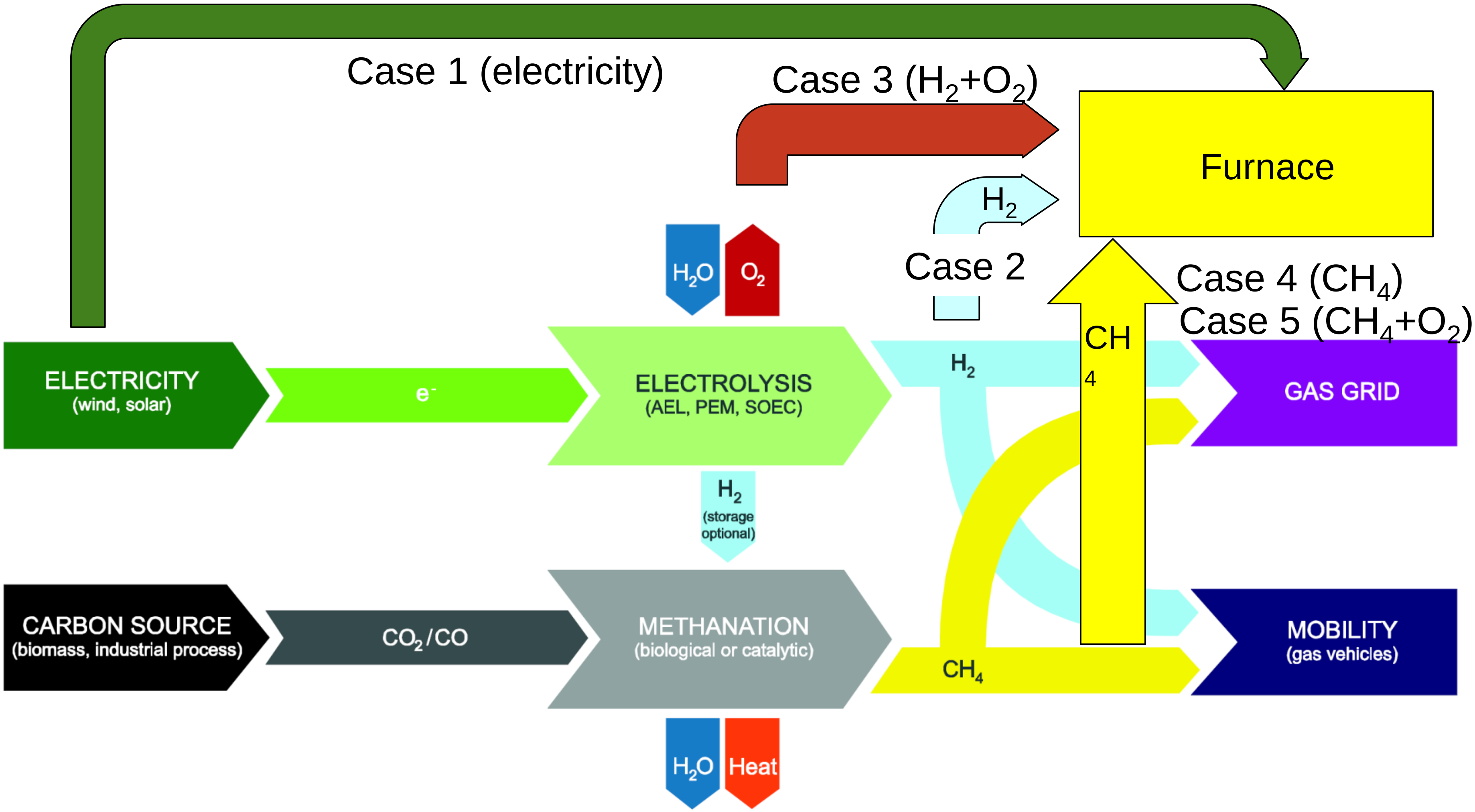
$H_2$+AP Oxy-Fuel

AP: Air preheating




AP: Air preheating

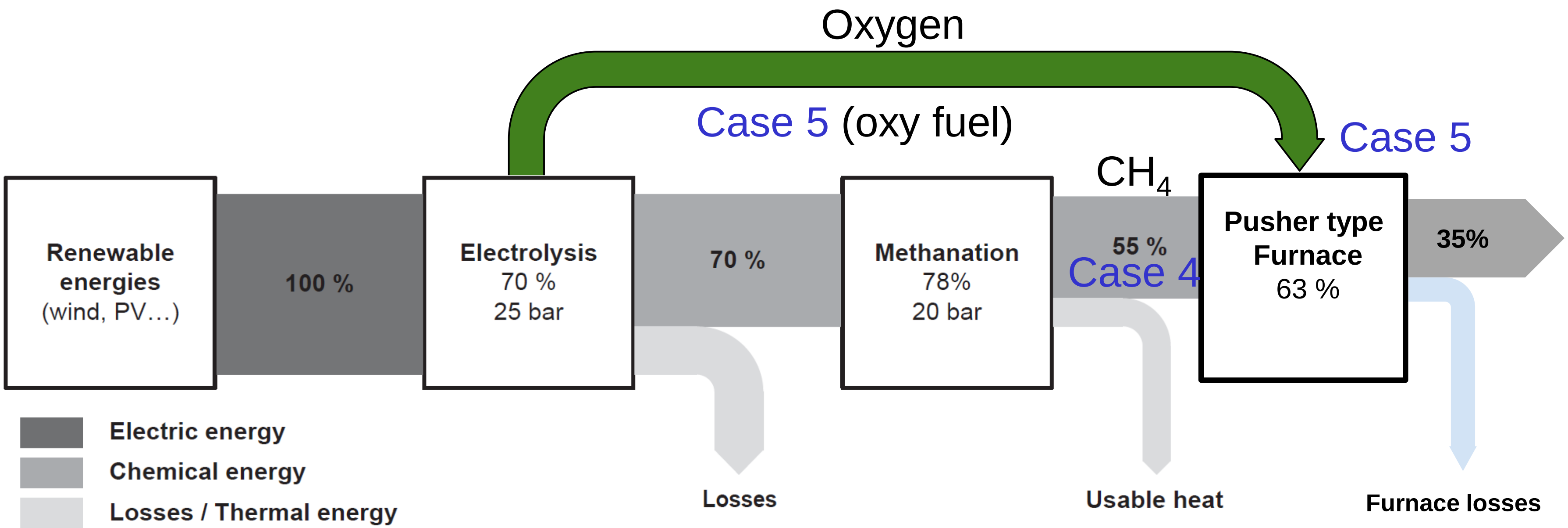
# Examplary power-to-gas process chain




Source: Götz, M. et al.: Renewable Power-to-Gas: A technological and economic review, Renewable energy 85 (2016), p. 1371/90

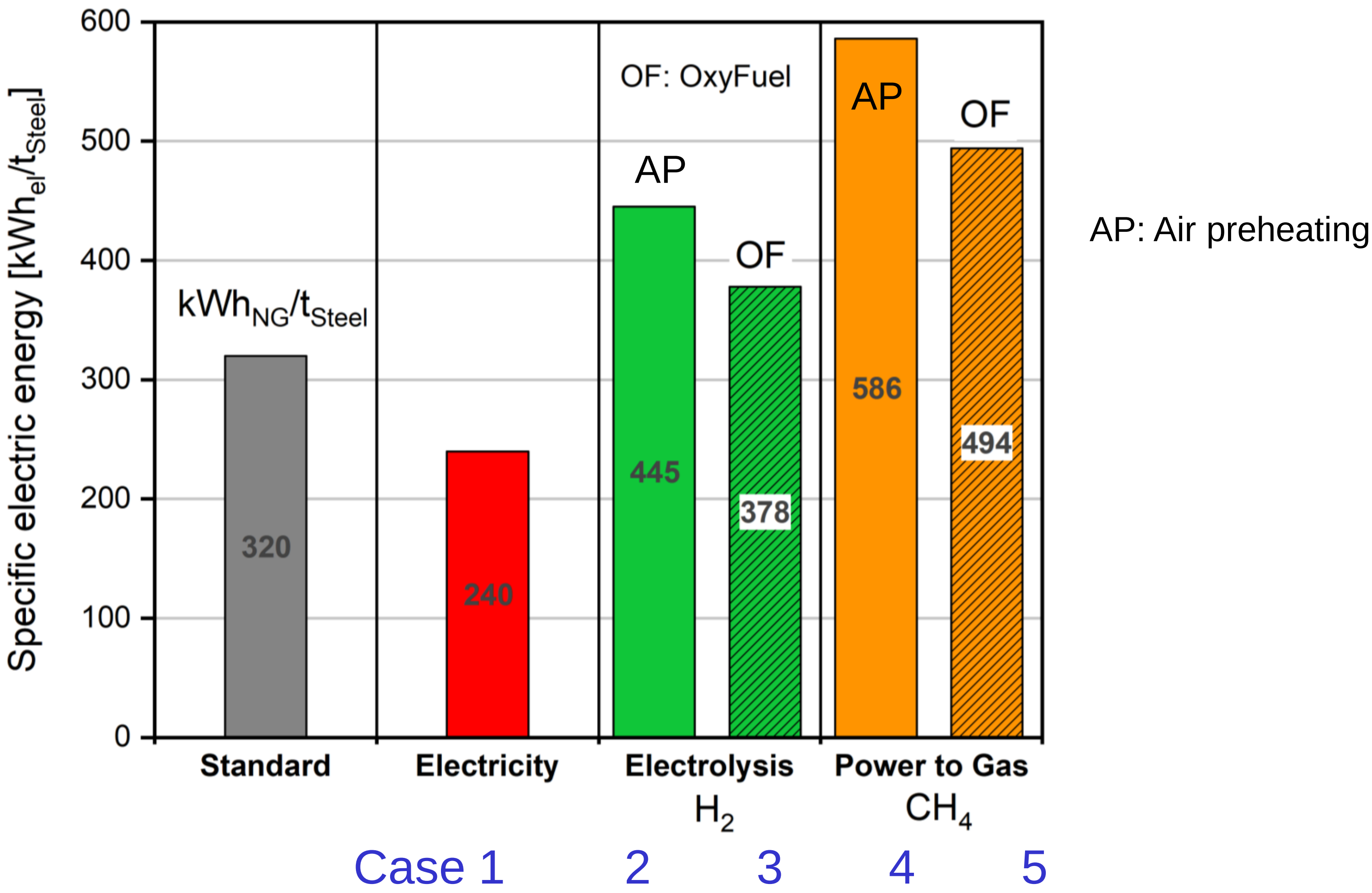
# Sankey diagram of the PtG (Power to Gas) process efficiency (heat integration is not taken into account)

Source: Götz, M. et al.: Renewable Power-to-Gas: A technological and economic review, Renewable energy 85 (2016), p. 1371/90




$$\eta_{electrolysis} = 0,70 \frac{kWh_{H_2}}{kWh_{el}} \qquad \eta_{Methanation} = 0,78 \frac{kWh_{CH_4}}{kWh_{H_2}}$$

Case 4 and Case 5


Specific electric energy [kWh$_{el}$/t$_{Steel}$]
600
500
400
300
200
100
0
OF: OxyFuel
kWh$_{NG}$/t$_{Steel}$
AP
OF
AP
OF
320
240
445
378
586
494
Standard
Electricity
Electrolysis
$H_2$
Power to Gas
$CH_4$
Case 1
2
3
4
5
AP: Air preheating

# Comparison of different heating scenarios for a 180 t/h pusher type furnace

Parameters: Productivity: 180 t/h; Furnace dimensions: L x B = 19,5 m x 14,8 m;
Discharge temp.: $T_{discharge}$ = 1130 °C; $T_{air}$ = 450 °C; $\lambda$ = 1,1; $\eta_R$ = 88,4 %

| Notation | Natural gas ($CH_4$) furnace (Standard)[1)] | Electrical heated furnace[2)] | $H_2$ heated furnace | Power to Gas ($CH_4$) |
|---|---|---|---|---|
| **Installed power** | 79 MW | 60 MW | 76 MW | 79 MW |
| **Spec. energy (cold charging)** | 350 kWh/t | 240 kWh/t | 335 kWh/t | 350 kWh/t |
| **Power for 180 t/h** | 55 MW | 42 MW | 53 MW | 55 MW |
| **Combustion (electr.) efficiency** | 71,7 % | 96,0 % | 74,0 / 87,2 %[3)] | 71,7 / 85,0 %[3)] |
| **Thermal efficiency furnace** | 63,3 % | 85,0 % | 65,4 / 77,1 %[3)] | 63,3 % / 75,1[3)] |
| **Spec. $CO_2$-Emissions (fuel, el.)** | 0,204 $kg_{CO_2}/kWh_{NG}$ | 0,516 $kg_{CO_2}/kWh_{el}$ | 0 kg $CO_2/kWh_{el}$[4)] | 0 kg $CO_2/kWh_{el}$[4)] |
| **Direct $CO_2$-Emissions** | 59 kg $CO_2/t_{Steel}$ | 126 kg $CO_2$/t | 0 kg $CO_2/t_{Steel}$ | 0 kg $CO_2/t_{Steel}$ |

1) Standard (State of the art)
2) Electricity mix Germany 2016
3) Oxy $H_2$-fuel
4) Green electricity for electrolysis
5) PtG (Power to Gas) - green electricity



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# Efficiency chains for different heating scenarios for a 180 t/h pusher type furnace

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|---|---|---|---|---|
| Power for 180 t/h | 55 MW | 42 MW | 53 MW | 55 MW |
| Spec. energy (cold charging) | 350 kWh/t | 240 kWh/t | 335 $kWh_{H_2}$/t | 350 kWh/t |
| Additional energy conversion | | | 1,44 $kWh_{el}/kWh_{H_2}$ | 1,83 $kWh_{el}/kWh_{CH4}$ |
| Spec. el. energy consumption | **350 $kWh_{CH4}$/t** | **240** $kWh_{el}$/t | **445** / **378** $kWh_{el}$/t2) | **585** / **494 $kWh_{el}$/t** |
| Advantages | Available techn.; Storage cap. of NG-grid; Costs | Low $CO_2$-Emissions (depending from energy resources) | Low $CO_2$-Emissions | Low $CO_2$-Emissions No new furnace design; Storage capacity of NG-grid |
| Disadvantages | $CO_2$-Emissions | Available space Storage cap. of electrical grid New furnace designs | High spec. energy demand; New $H_2$-infrastructure | High spec. energy demand $CO_2$-source |

1) Standard (State of the art) 2) Oxy $H_2$-fuel 3) Assumption: 100 % renewable electricity

# Electric resistance heated pusher type furnace

Temperature furnace: $T$ = 1000 to 1250 °C

Permissible surface load: $p$ = 60 to 35 kW/m² (av. 47.5 kW/m²)

Electric power $P_{el} \approx$ 60 MW

Surface need of heating elements: 60 000 kW/47,5 kW/m² ≈ **1250 m²**

Available roof surface: 290 m²

Available upper wall surface: 80 m²

} **370 m²** ⟷ **625 m²**/upper lower furnace

Space for resistance heating elements is not avilable!

**Other problems:**

- Installation of HE in the lower furnace not possible (scale on the bottom)
- Corrosion of HE in an atmosphere with species from casting powder
- Higher O2 and lower water content in the furnace atmosphere →amount and type of scale, descaling behavior
- Energy management and electricity load peaks (complex relation between hot rolling conditions and heating)

# Hydrogen electrolysis

| Property | Unit | AEL | PEM | SOEL |
|---|---|---|---|---|
| Stack-efficiency rel. to gross calorific value $H_2$ | % | 60 – 84 | 46 – 84 | > 100 |
| System efficiency | % | 51 – 79 | 47 – 79 | k.A. |
| Operation temperature | °C | 60 – 80 | 50 – 80 | 700 – 1000 |
| Max. operation pressure | bar | < 50 | < 350 | 1 |
| Current density | A/cm² | 0,2 – 0,4 | 0,6 – 3,0 | 0,4 – 2,0 |
| Minimal partial load ability | % | 20 – 40 | ~ 10 | k.A. |
| Standby at nominal power / cold start time | s / min | < 300 / some | < 10 / < 10 | hours |
| Available stack-size | Nm³/h | 800 | 250 | 5,7 |
| Precious metal demand | mg/cm² | - | 2 (Ir); 0,5 – 1 (Pt) | - |
| Life time | h | < 90.000 | < 60.000 | 3.500 |
| System size | kW | 1,8 – 5.300 | 0,2 - 400 | < 40 |
| Spec. energy consumption per Nm³ $H_2$ | kWh | 4,0 – 5,0 | 4,0 – 8,0 | k.A. |
| Invest | €/kW | 1.000 – 1.200 | 1.500 – 2.300 | 2.500 |

**AEL**:
Alkaline Electrolysis

**PEM**:
Polymer electrolyte membrane electrolysis

**SOEL**:
Solid oxide electrolysis

Quelle: Brinner, A.; Schmidt, M.; Schwarz, S.; Wagener, L.; Zuberbühler, U. (2017): Technologiebericht 4.1 Power-to-gas (Wasserstoff). In: Wuppertal Institut, ISI, IZES (Hrsg.): Technologien für die Energiewende. Teilbericht 2 an das Bundesministerium für Wirtschaft und Energie (BMWi). Wuppertal, Karlsruhe, Saarbrücken

# Methanization - indices

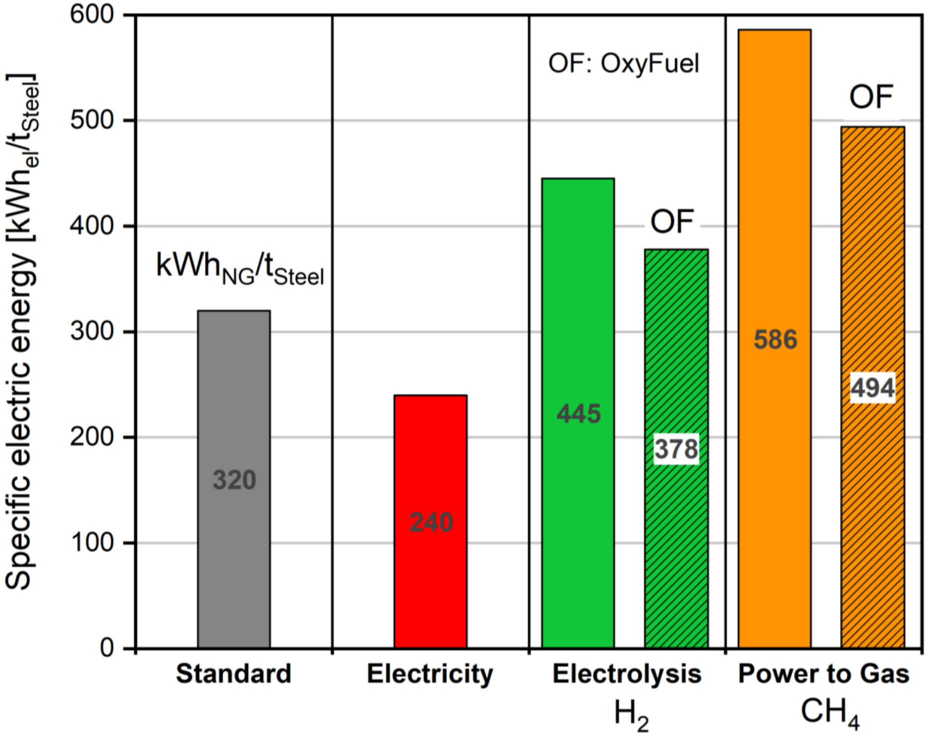
- Technical-economical indices of catalytic methanation (2015)

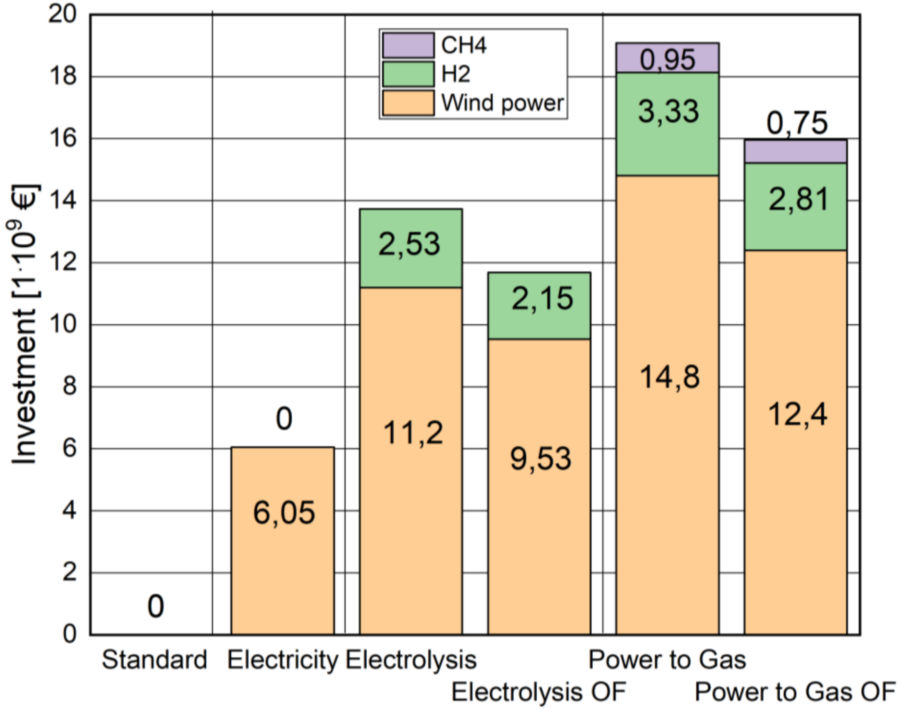
| Criteria | Unit | Value |
|---|---|---|
| Temperature | °C | 200 – 700 |
| Pressure | bar | 4 – 80 |
| $CO_2$-ratio | % | 80 – 95 |
| $CH_4$-selectivity | % | ≥ 99 |
| Commercial catalysis | - | Ni- or Ru-based |
| Efficiency | % | 70 – 85 |
| Spec. invest | €/kW SNG | 600 – 1.000 |
| Catalysis costs | €/kg | up to 250 |

Source: Schmidt, M.; Schwarz, S.; Stürmer, B.; Wagener, L.; Zuberbühler, U. (2017): Technologiebericht 4.2a Power-to-gas (Methanisierung chemisch-katalytisch). In: Wuppertal Institut, ISI, IZES (Hrsg.): Technologien für die Energiewende. Teilbericht 2 an das Bundesministerium für Wirtschaft und Energie (BMWi). Wuppertal, Karlsruhe, Saarbrücken

Quelle: Deutsche Energie Agentur GmbH, „Power to X. Technologien", 06/2018, Berlin

# Electricity demand and investment for different heating scenarios for a 180 t/h pusher type furnace




Wind: 1200 €/kW
Hydrogen: 0,41 €/(m³/y)
Methanation: 600 €/kW

# Industrial Furnaces – Further Challenges

- Loss of markets by other technologies (electrification of vehicles)

  → e.g. Case hardening of gear parts
- Electrification of large industrial furnace
- Further needs of burners, heat exchangers, control systems for burners?
- Combustion: Fuel quality and emissions (TA-Luft)

  (permanently stronger restrictions, e g. for $NO_x$)
- …….



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# Industrial Furnaces – Hybrid Heating

- Speichbarkeit von Elektrizität
- Flexibilität der Thermoprozessanlagen (Industrieöfen)
- Übergangstechnologie?
- Leistungssteigerung
- Kosten
  - Wind/Solar (überprop. Mehrbedarf)
  - Wasserstoffprod. und -verteilung
  - E-Methan

**Gegenwart:**

- Steigerung der Produktion
- Prozessoptimierung
- Flexibilität hinsichtlich

**Zukunft:**

- Flexibilität der Energieträger
- Energiespeicher
- „neue Energieträger“

…….

# Vielen Dank für Ihre Aufmerksamkeit

Prof. Dr.-Ing. Herbert Pfeifer

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