Hydrogen Burner Development

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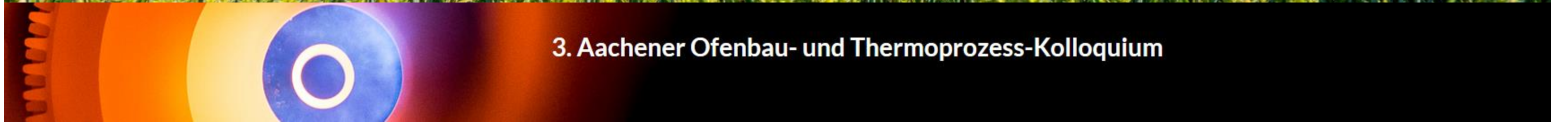
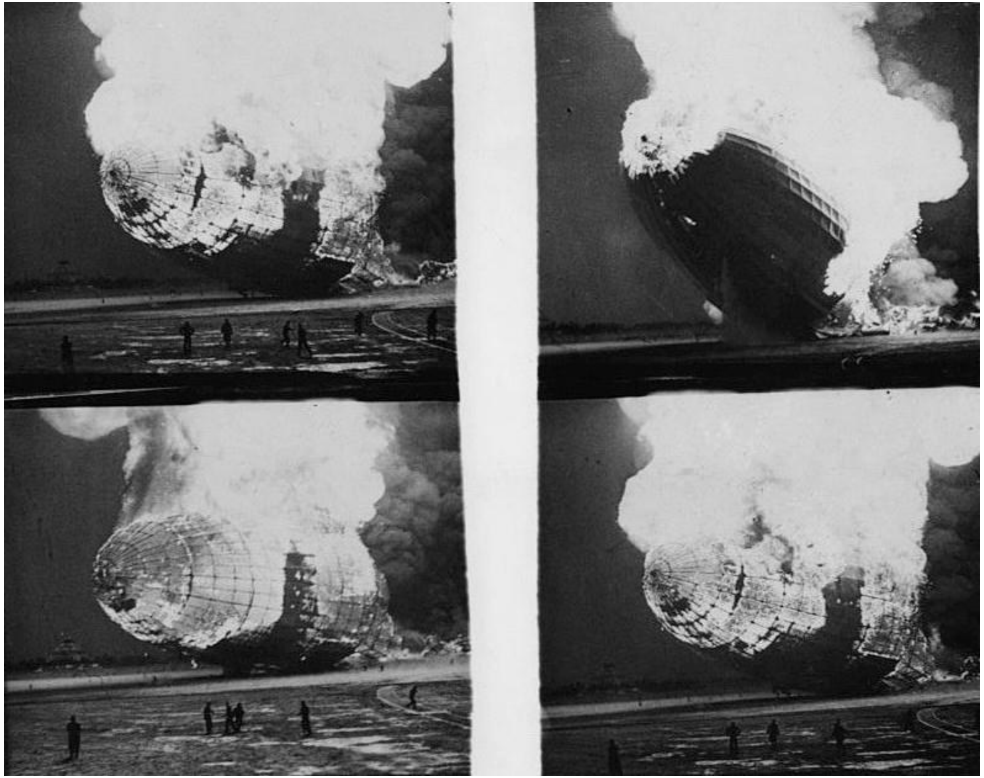


Fact Sheet Hydrogen

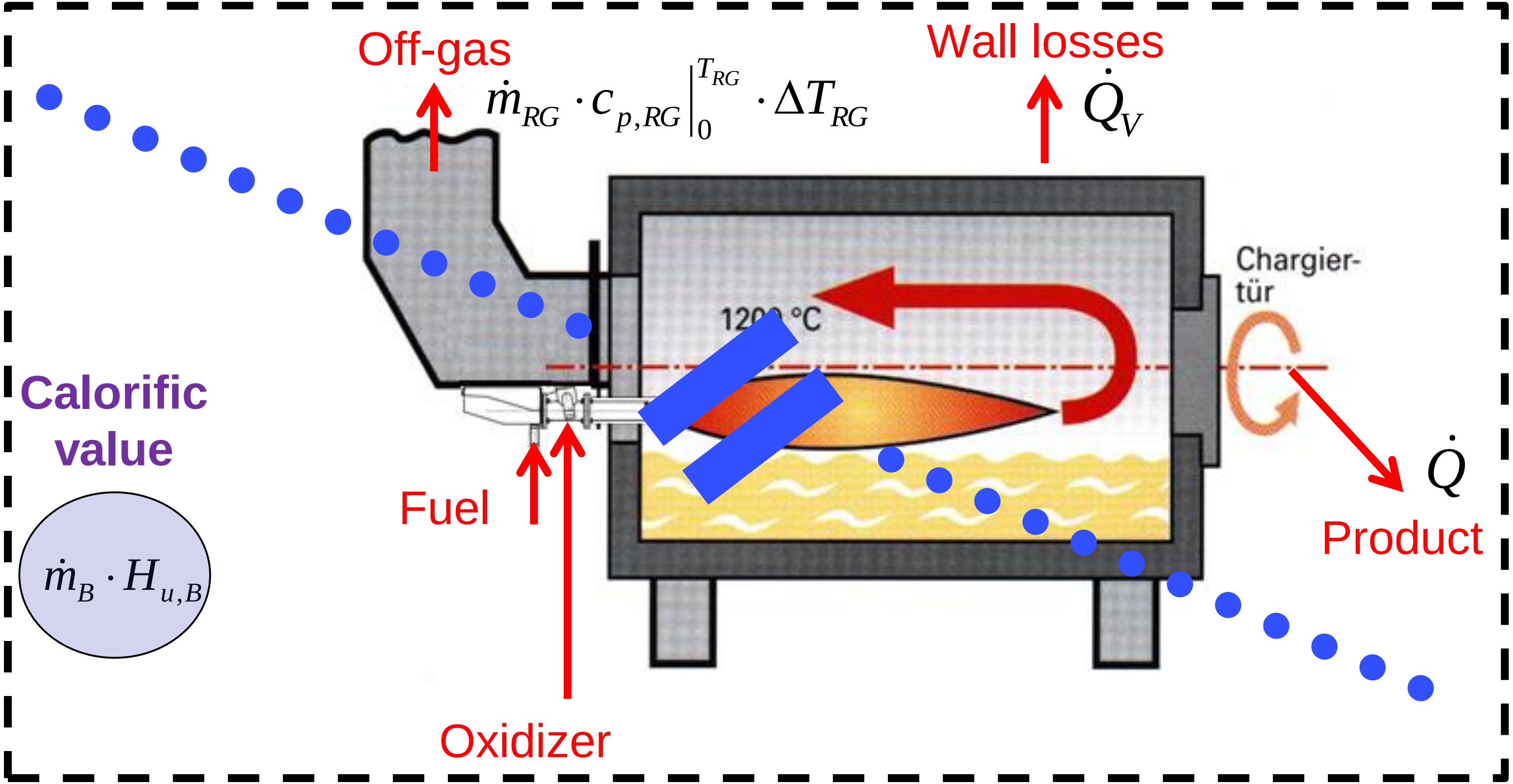
- Odorless, colorless, very light
- Low ignition energy often leads to combustion but not explosion (H_2: 0.017 mJ; CH_4: 0.23 mJ)
- Safety for regulations
  - No enclosure
  - Purge with Nitrogen
  - Welded stainless steel pipes
  - But „technically tight“ is enough
  - Forced aspiration of skid with Hydrogen sensor recommended



Hindenburg, Wikipedia

Energy Balance

$$\dot{m}_B \cdot H_{u,B} = \dot{m}_{RG} \cdot c_{p,RG}\Big|_0^{T_{RG}} \cdot \Delta T_{RG} + \dot{Q} + \dot{Q}_V$$



No fuel or oxidizer preheating

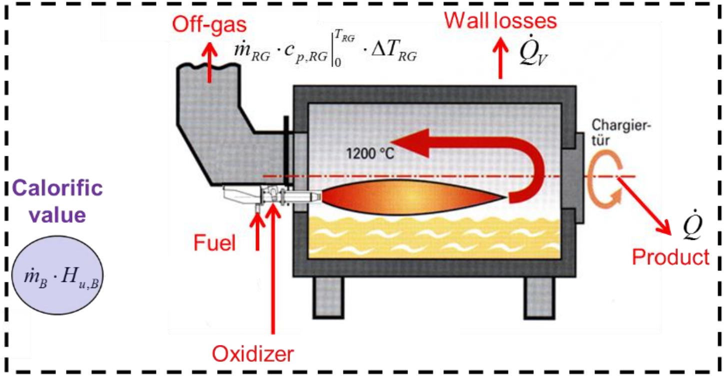
Combustion Efficiency

"All thermal energy not lost through the off-gas, related to the fuel usage"

$$\eta_F = \frac{\dot{Q}_V + \dot{Q}}{\dot{m}_B \cdot H_{u,B}}$$ **= 42,4%**

Air-fuel furnace @ 1200 °C

No preheating



Calorific value fuel | **Off-gas losses** | **Prod.**

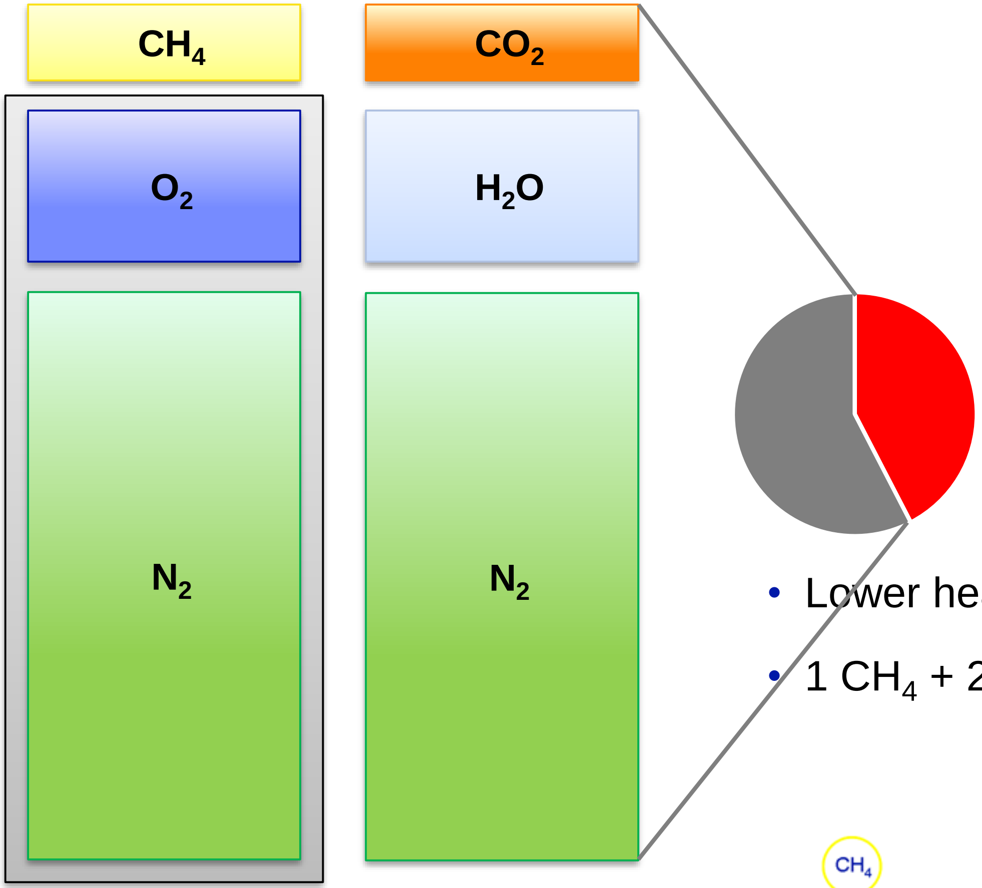
$$\dot{m}_B \cdot H_{u,B} = \dot{m}_{RG} \cdot c_{p,RG}\Big|_0^{T_{RG}} \cdot \Delta T_{RG} + \dot{Q} + \dot{Q}_V$$

57.6%

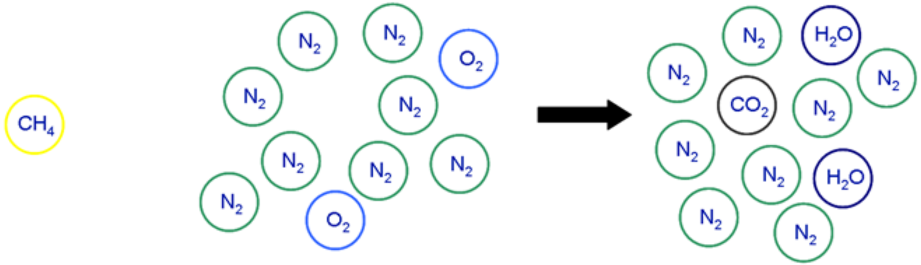
Off-gas losses

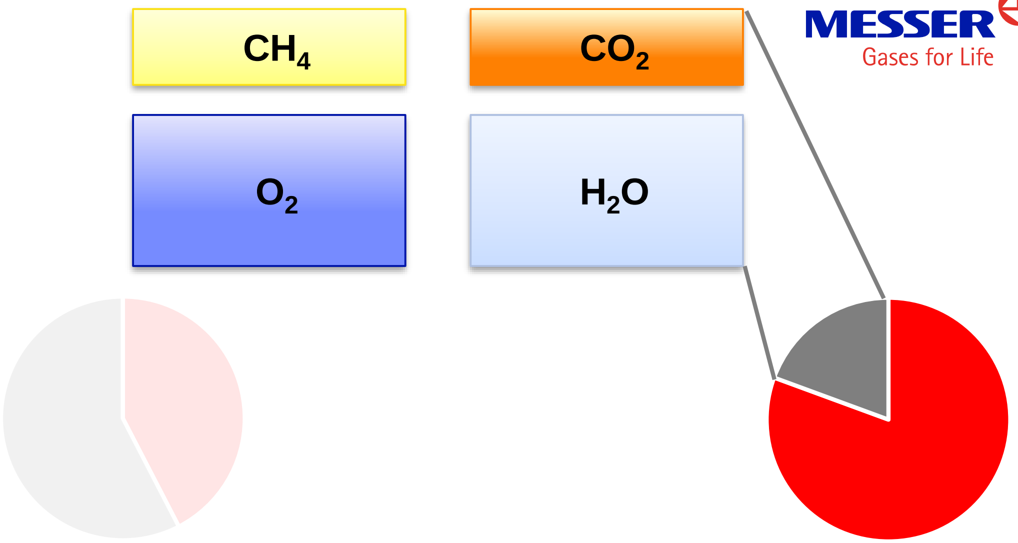
42.4%

Product & wall losses

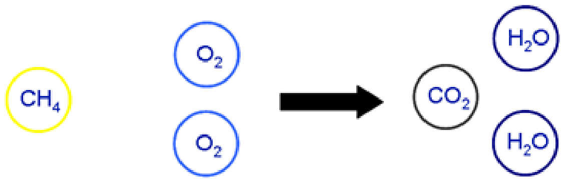


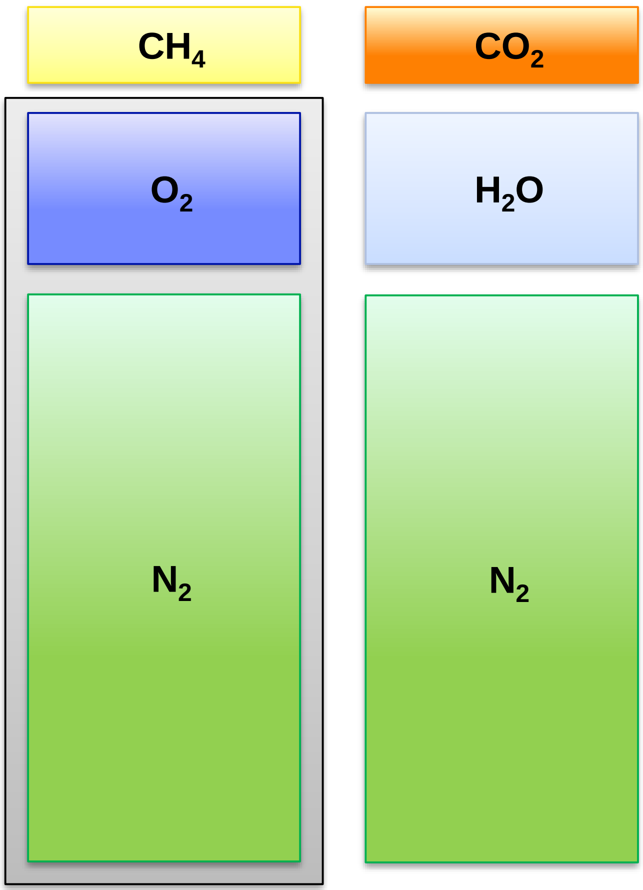
- Lower heating value natural gas H: 36 000 kJ/Nm³
- $1\ CH_4 + 2\ O_2 + 7{,}52\ N_2 \rightarrow CO_2 + 2\ H_2O + 7{,}52\ N_2$

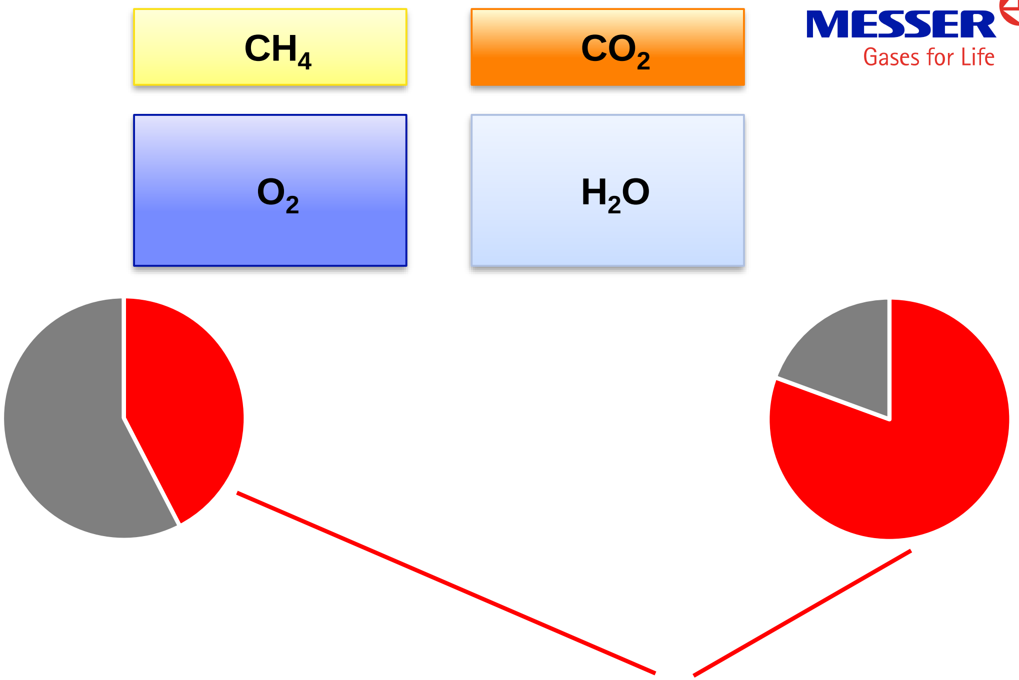




- Lower heating value natural gas H: 36 000 kJ/Nm³
- 1 CH_4 + 2 O_2 → CO_2 + 2 H_2O

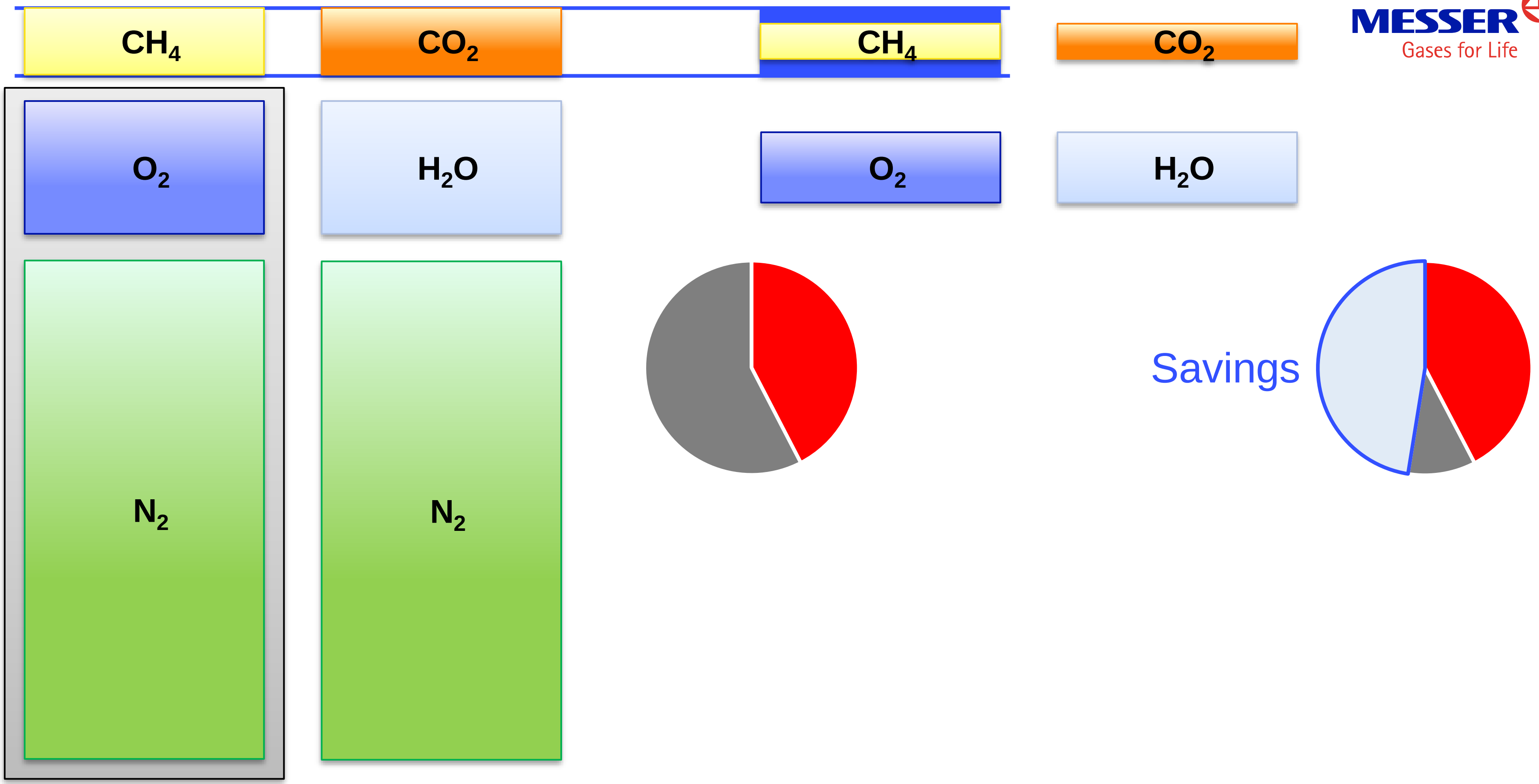






Without production increase: 42.4% efficiency has to stay the same!

Reduction of fuel



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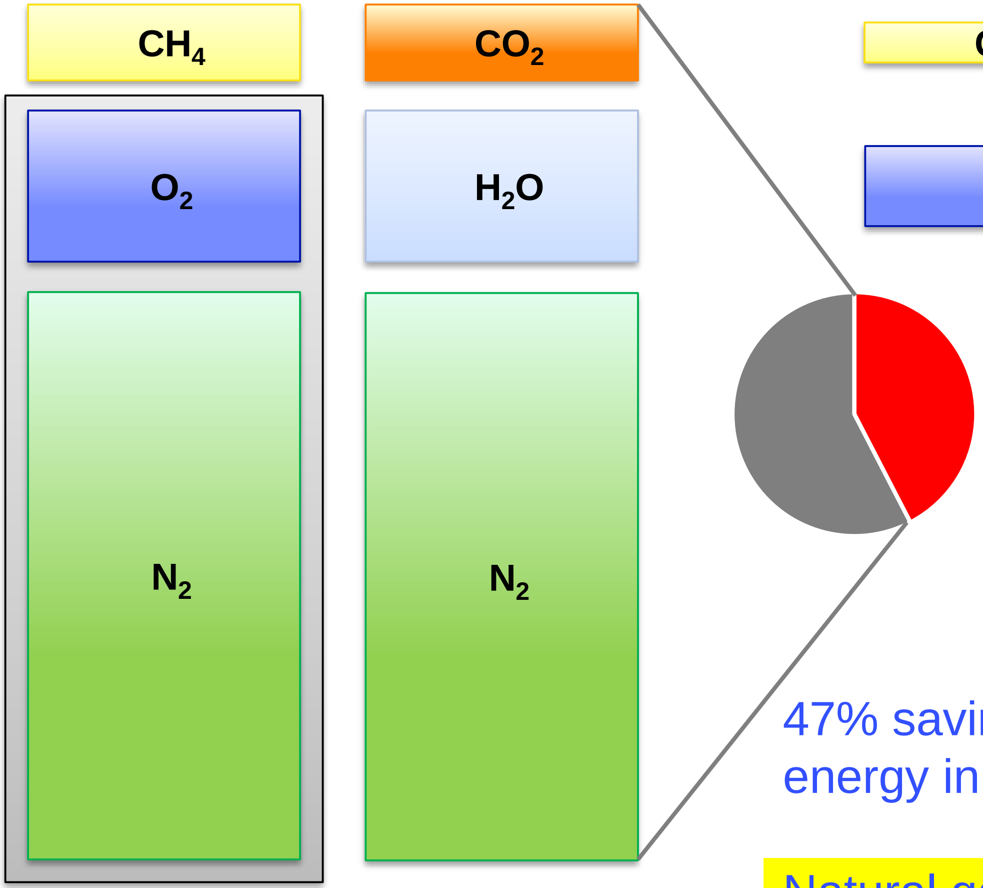
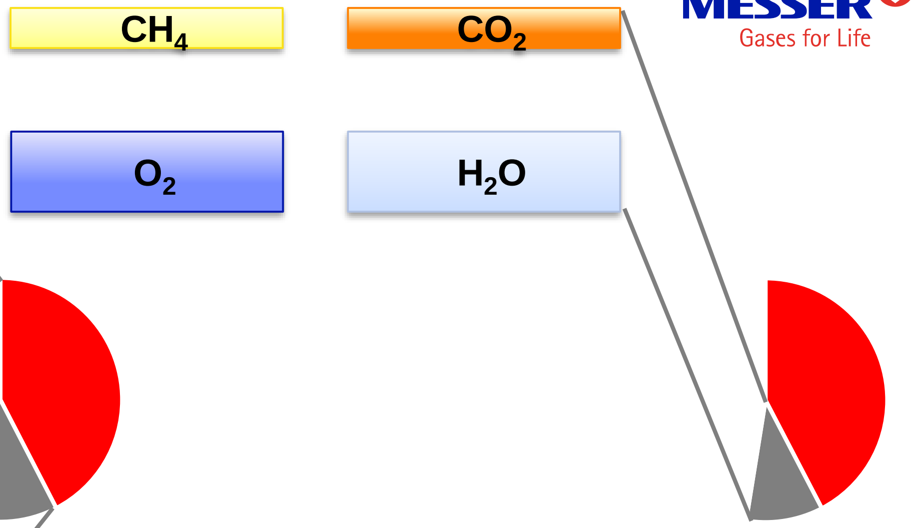
Gases for Life





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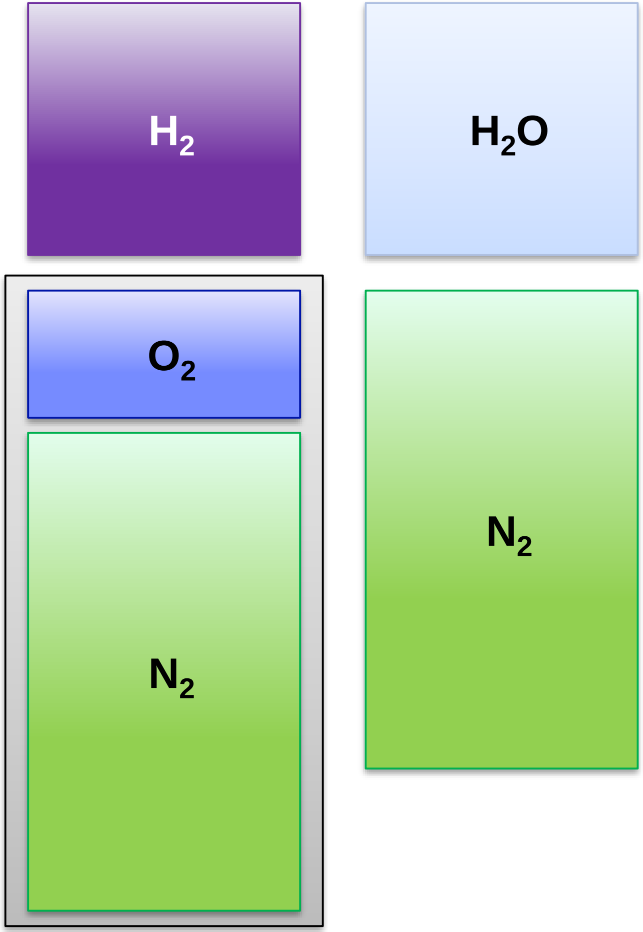
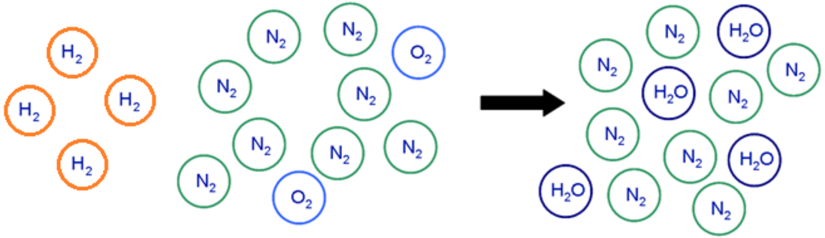
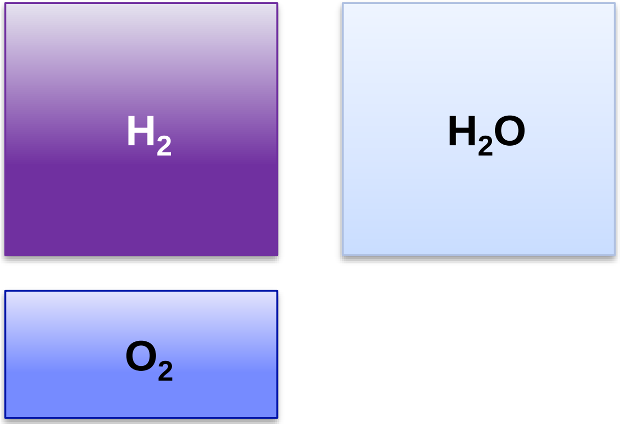
47% savings with oxy-fuel to have the same energy input for **product and wall losses**

Natural gas flow is reduced to 53% as well as the **off-gases**

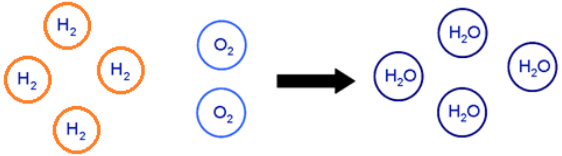


- For the same burner power [kW]:
  - 3,33 times higher flow rate as natural gas H
  - 84% of stoichiometric combustion air
  - No CO_2, only H_2O as reaction product
  - 91% of off-gas
  - A bit more efficient than natural gas air-fuel
- Lower heating value hydrogen: 10 780 kJ/Nm³
- $1\ H_2 + 1/2\ O_2 + 1{,}88\ N_2 \rightarrow 1\ H_2O + 1{,}88\ N_2$





- Only H_2O (water vapor) in off-gas (measurement?)
- Lower heating value hydrogen: 10 780 kJ/Nm³
- $1\ H_2 + 1/2\ O_2 \rightarrow 1\ H_2O$



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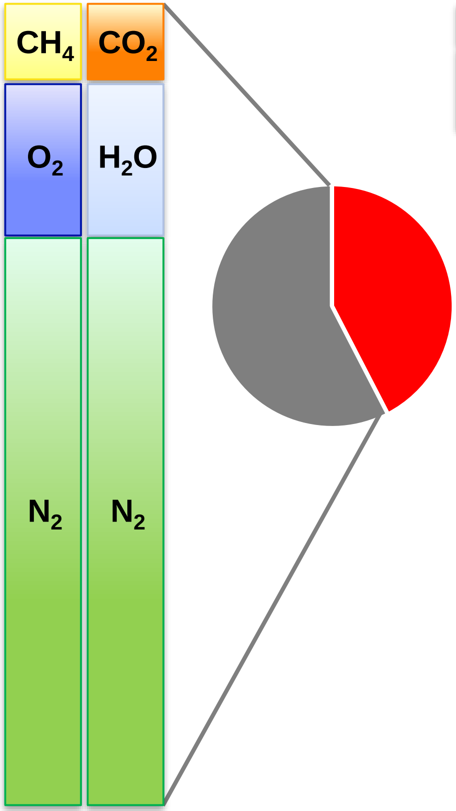
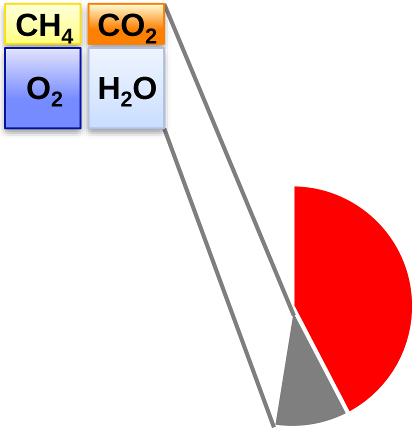
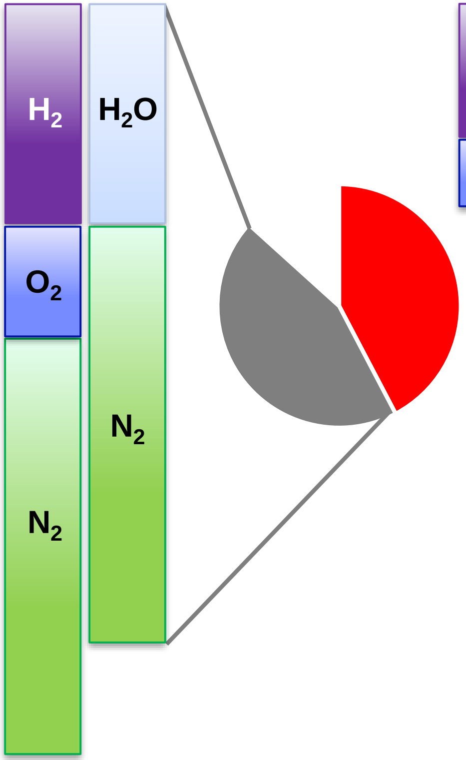
CH_4 + 9.5 air



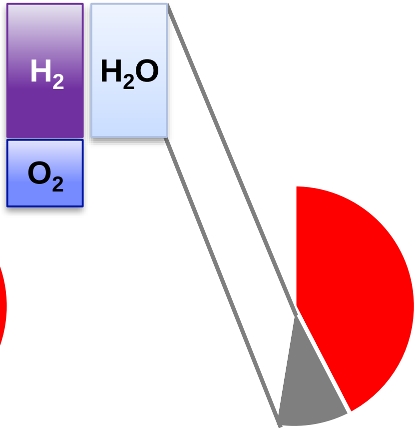
CH_4 + 2 O_2



H_2 + 2.38 air



H_2 + ½ O_2



CH_4 + 9.5 air | CH_4 + 2 O_2 | H_2 + 2.38 air | H_2 + ½ O_2

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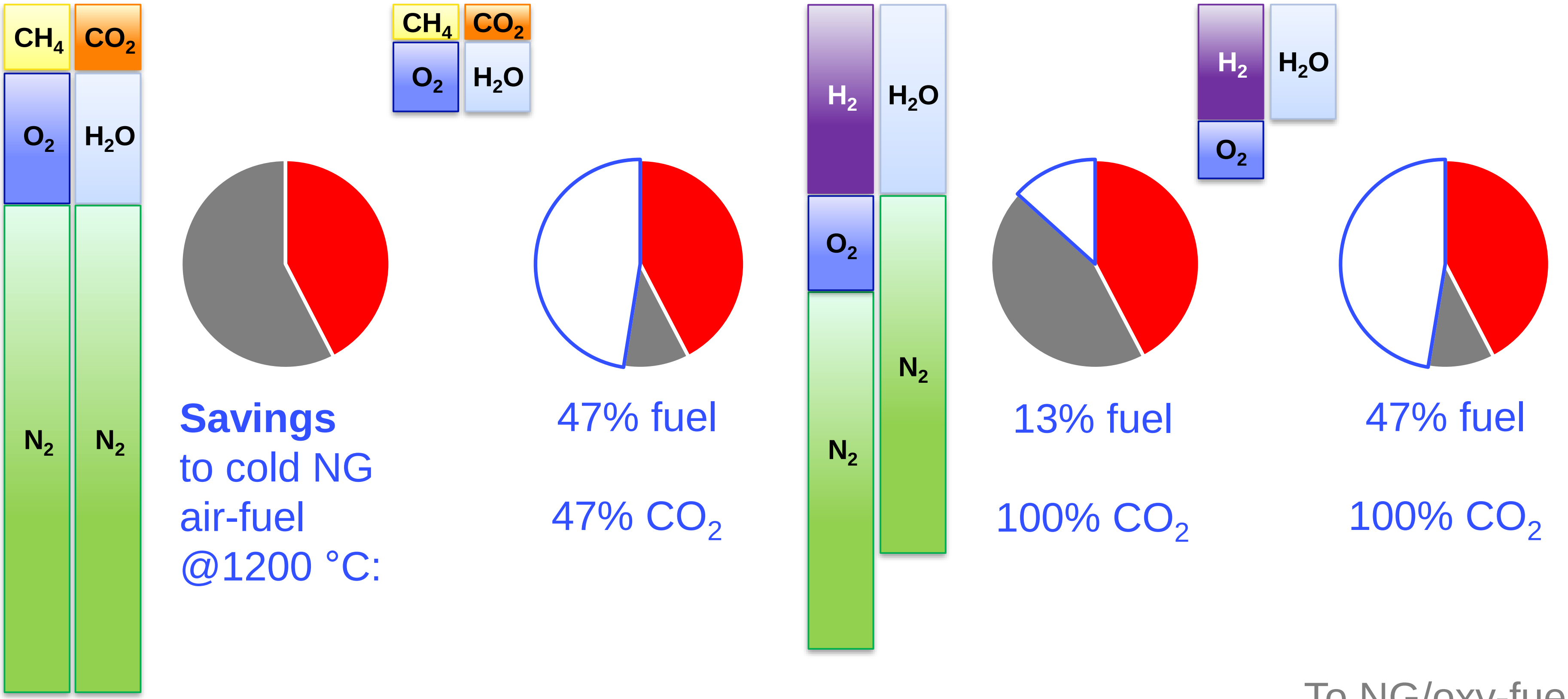
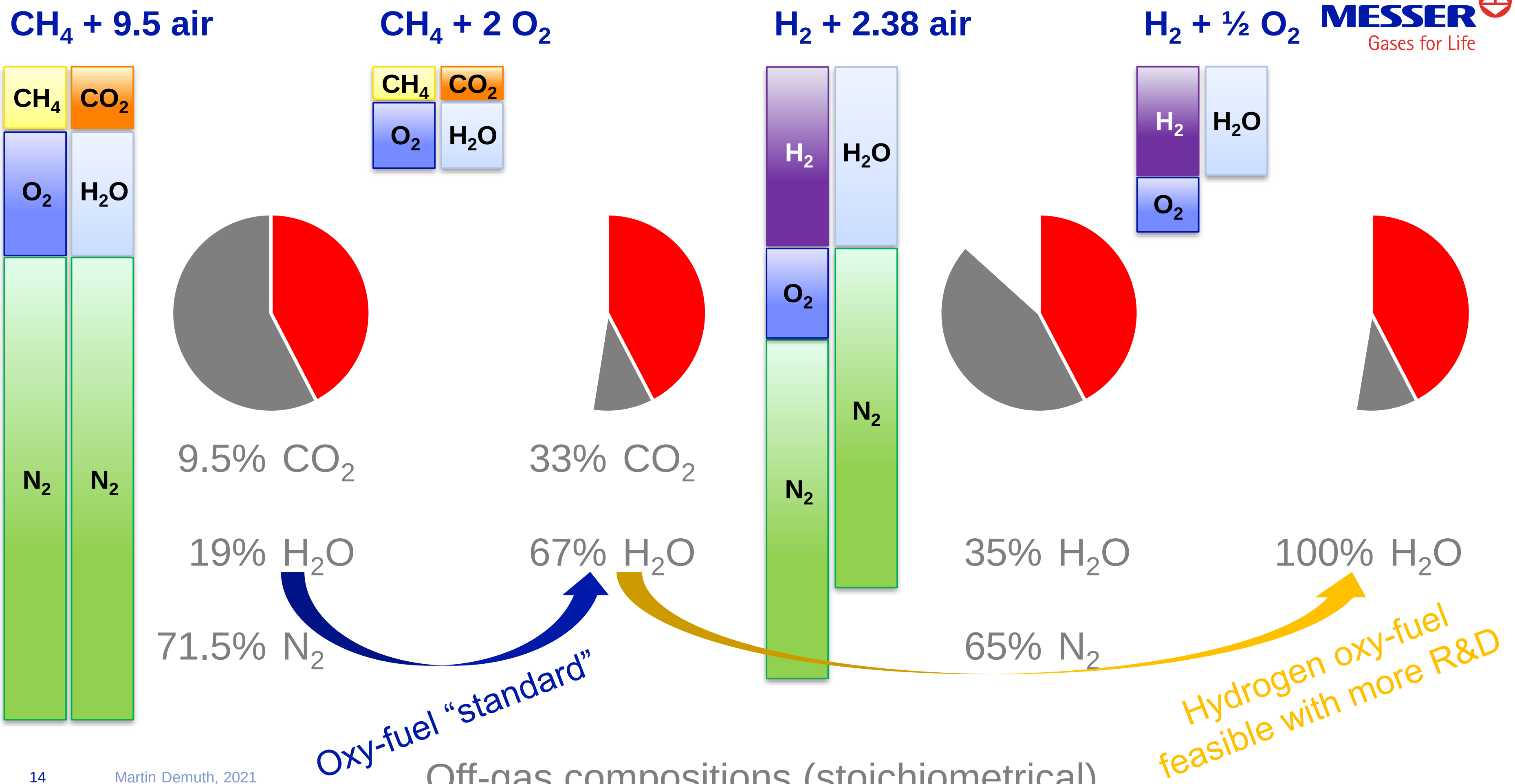


To NG/oxy-fuel:
17% O_2



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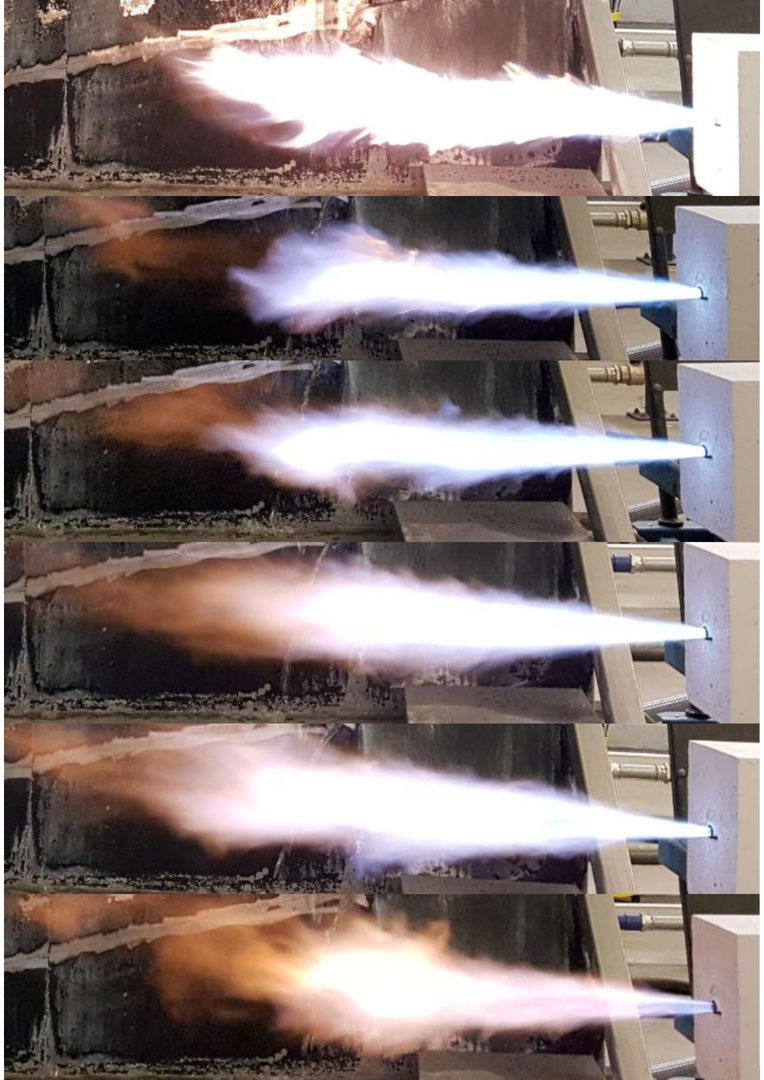
Off-gas compositions (stoichiometrical)

CH_4-H_2/O_2-Burner

Oxipyr-F @ 200 kW

- Mix of natural gas and hydrogen in every ratio possible
- Similar flame length
- Similar temperature distribution
- H_2-O_2-flame is highly visible (H_2-air-flame is quite invisible)



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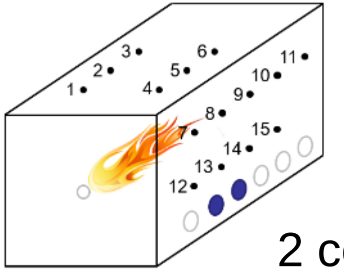
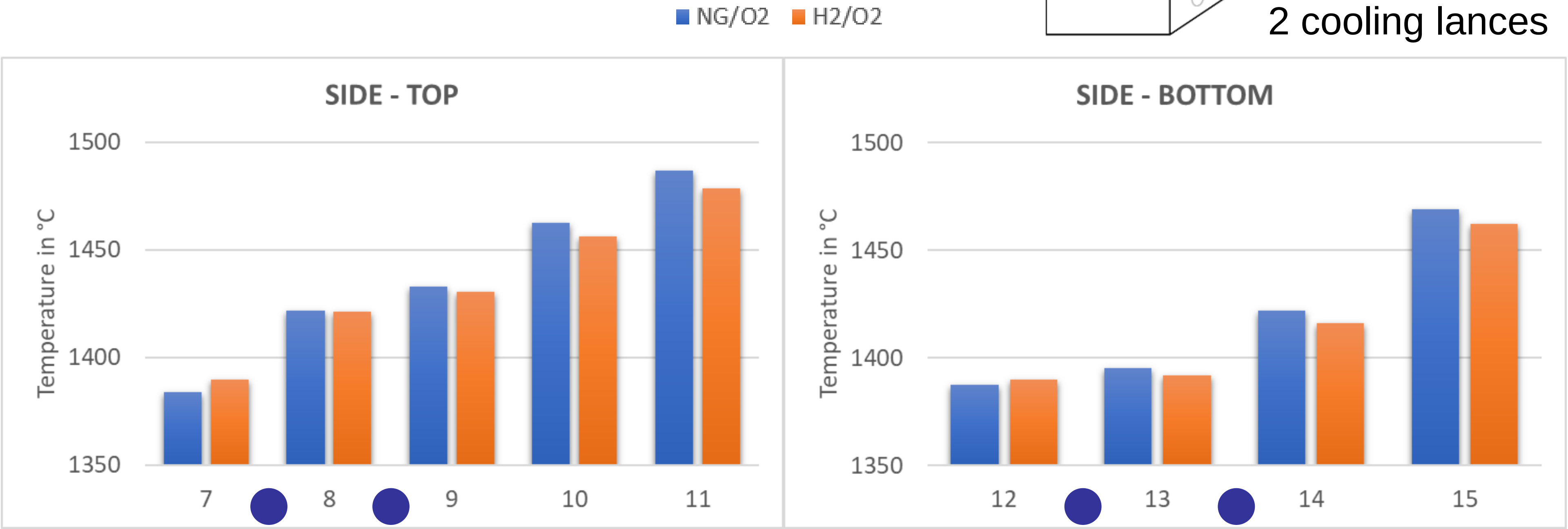
100 % CH_4	0% H_2
80 % CH_4	20% H_2
60 % CH_4	40% H_2
40 % CH_4	60% H_2
20 % CH_4	80% H_2
0 % CH_4	100% H_2

Stationary Temperature Distribution

Oxipyr-F @ 250 kW



2 cooling lances



Same temperature profile with NG and H_2

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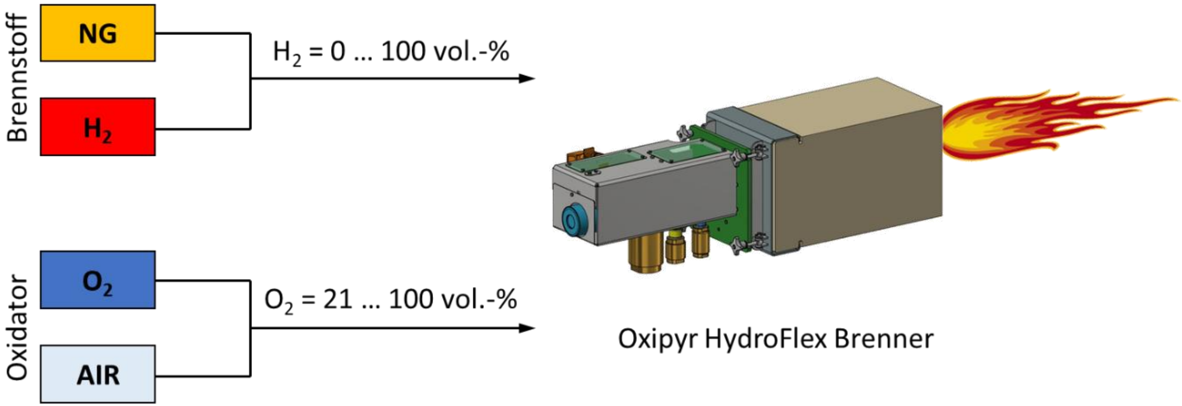
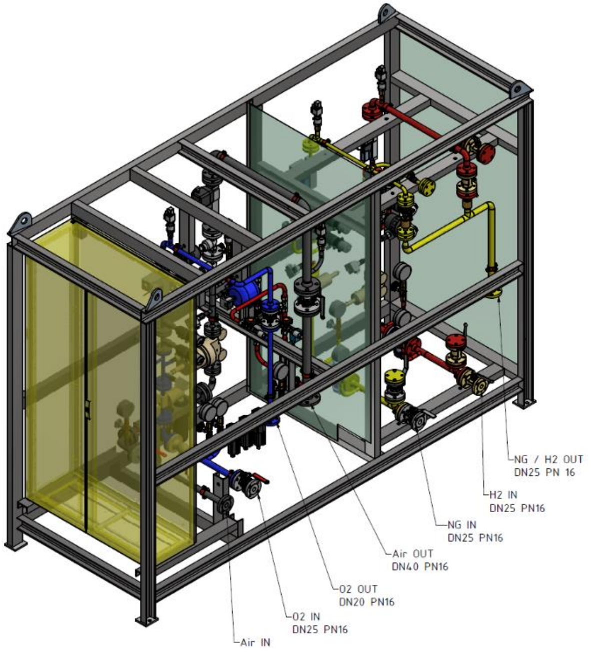
Oxipyr-HydroFlex @ 150 kW

- Mix of natural gas and hydrogen in every ratio
- Mix of air and oxygen in every ratio



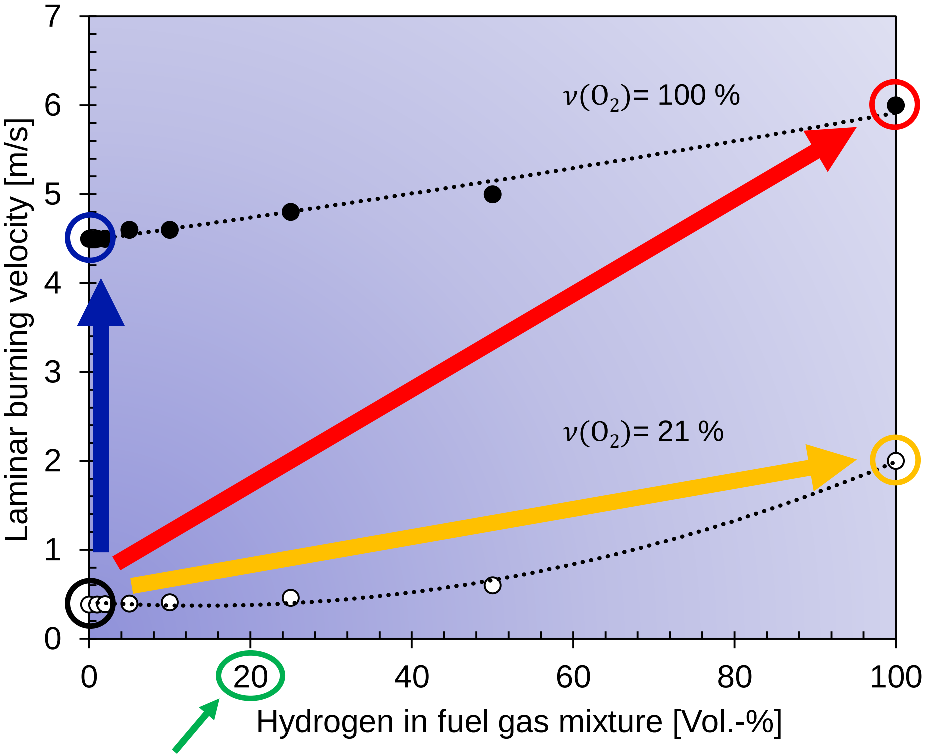


 Martin Demuth, 2021

Hydrogen combustion Oxipyr-HydroFlex

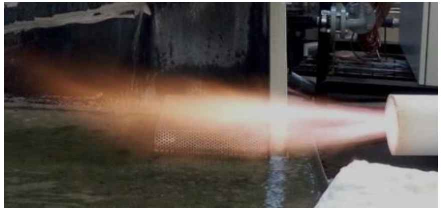
NG
O_2
Burning velocity x10

NG
Air
Burning velocity x1 (ref.)



Only 7% power substitution

H_2
O_2
Burning velocity x15



H_2
Air
Burning velocity x5

A. Mazas, D. lacoste und S. T., „Experimental and numerical investigation on the laminar flame speed of CH4/O2 mixtures diluted with CO2 and H2O,"
M. Kuznetzov, R. Redlinger, W. Breitung, J. Grune, A. Friedrich und N. Ichikava, „Laminar burning velocities of hydrogen-oxygen-steam mixtures at elevated temperatures and pressures,"
M. Ilbas, A. Crayford, I. Yilmaz, P. Bowen und N. Syred, „Laminar-burning velocities of hydrogen–air and hydrogen–methane–air mixtures: An experimental study,"

Fuel/Oxidizer-Flows Oxipyr-HydroFlex

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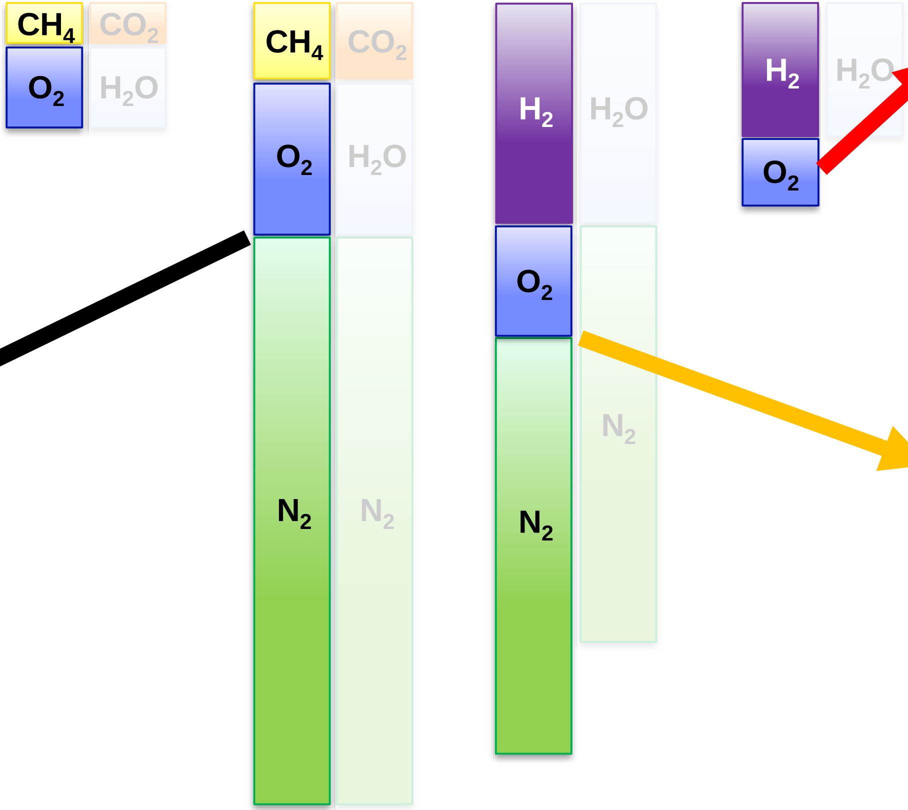
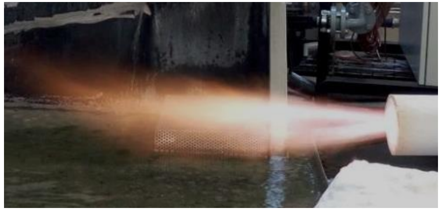
NG 1
O_2 2
Burning velocity x10

NG 1
Air 9.5
Burning velocity x1 (ref.)



H_2 3.3
O_2 1.7
Burning velocity x15

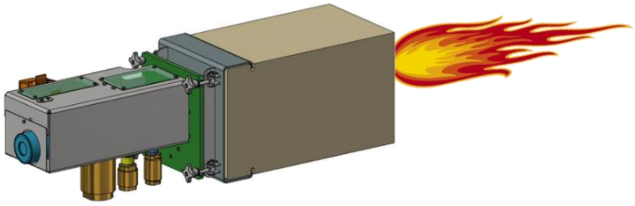


H_2 3.3
Air 8
Burning velocity x5

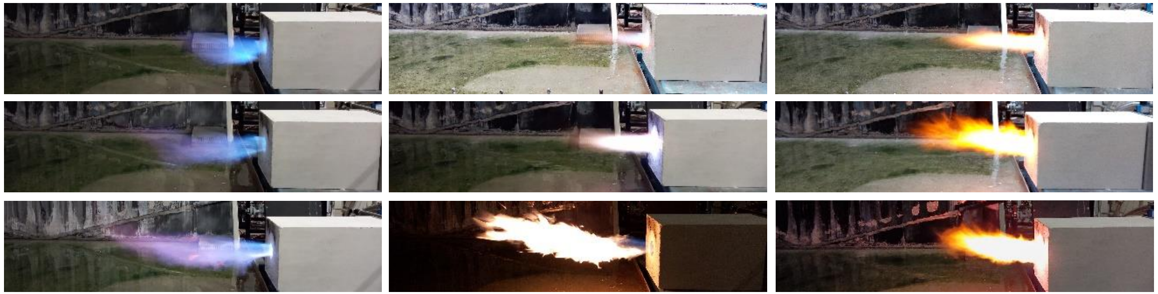
Maximum Flexibility

Oxipyr-HydroFlex @ 150 kW

- Mix of natural gas and hydrogen in every ratio
- Mix of air and oxygen in every ratio
- Ideal for adding H_2/O_2 to NG/air continuously
- Oxy-fuel burner surrounded by swirl air & shifting device



Oxipyr HydroFlex Brenner

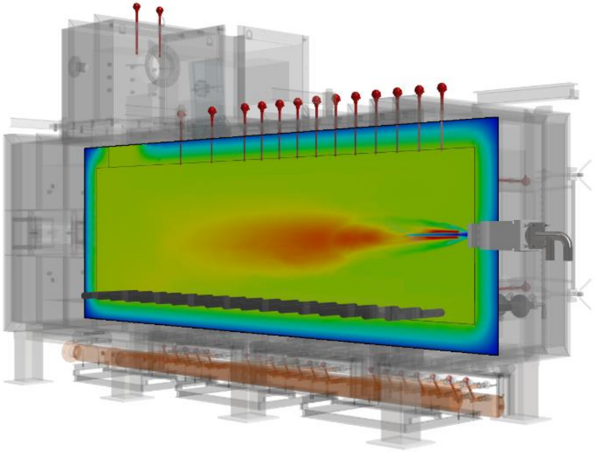


Patent pending

Hydrogen Future HTP

Opportunities

- Messer burners are H_2-ready, H_2/NG/air/O_2 available
- H_2 regulations available, H_2 trial regulation being built
- H_2 burner trials possible @ Messer R&D center
- A lot of funded H_2 projects: Perfect for tailor made solutions
- O_2 can also partially decarbonize and is a lot cheaper



Challenges

- Green H_2/electricity sourcing & logistics for trials
- Electrolyzers are potential game changers (H_2 & O_2)

Hydrogen Burner Development

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Price Comparison Hydrogen

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	Hydrogen	Natural gas H
Actual costs	0.9 €/Nm³	0.25 €/Nm³
H_2 from fuel station	10 €/kg	0.34 €/kg
(industry trials 150-300 €/MWh)	**300** €/MWh	**25** €/MWh
Certificates 50 €/t CO_2		**10** €/MWh
Projected costs	0.18 €/Nm³	0.50 €/Nm³
H_2 from electrolyzer	2 €/kg	0.68 €/kg
Max. 30-40 €/MWh_el_green	**60** €/MWh	**50** €/MWh
Certificates 100 €/t CO_2		**20** €/MWh

50 Shades of Grey (and Blue and Green) H_2*

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Hydrogen	
Brown	Brown coal gasification
Black	Black coal gasification
Grey	**Steam reforming from natural gas**
Turquoise	Steam reforming from natural gas & Carbon production / CCU
Blue	**Steam reforming from natural gas & CCS**
Yellow	Electrolysis with electrical power mix OR solar power only
Pink	Electrolysis with nuclear energy
Green	**Electrolysis with renewable energy**

*Energy Cities (*citation of the title)*

Fact Sheet Hydrogen

	Hydrogen (H_2)	Methane (CH_4)
Lower explosive limit	4.0 Vol%	4.4 Vol%
Upper explosive limit	77.0 Vol%	17.0 Vol%
Limiting oxygen concentration	4.3 Vol%	9.9 Vol%
Max. explosion pressure	8.3 bar	8.1 bar
Pressure buildup over time [K_G]	800 bar / (m * s)	52 bar / (m * s)
Maximum experimental safe gap	0.29 mm	1.14 mm
Minimum ignition energy	0.017 mJ	0.23 mJ
Ignition temperature	560 °C	595 °C

BAM (Bundesanstalt für Materialforschung und –prüfung) VH 2539: Sicherheitstechnische Eigenschaften von Erdgas-Wasserstoff-Gemischen

Combustion 1 MW Burner Power

	CH_4 & Air	H_2 & Air	CH_4 & O_2	H_2 & O_2
Fuel	100 Nm³/h CH_4	333 Nm³/h H_2	100 Nm³/h CH_4	333 Nm³/h H_2
Oxidizer	950 Nm³/h Air	800 Nm³/h Air	200 Nm³/h O_2	170 Nm³/h O_2
Off-gas (wet)	1050 Nm³/h	960 Nm³/h	300 Nm³/h	333 Nm³/h
Off-gas (dry)	850 Nm³/h	630 Nm³/h	100 Nm³/h	0 Nm³/h
Off-gas CO_2	100 Nm³/h CO_2	0 Nm³/h CO_2	100 Nm³/h CO_2	0 Nm³/h CO_2
Comb. efficiency	42,4%	48,8%	80,6%	80,5%
@ 1200°C				

Combustion 1 MW "Effective Power"

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	CH_4 & Air	H_2 & Air	CH_4 & O_2	H_2 & O_2
C. eff. 1200 °C	42,4%	48,8%	80,6%	80,5%
Fuel	236 Nm³/h CH_4	682 Nm³/h H_2	124 Nm³/h CH_4	414 Nm³/h H_2
Oxidizer	2242 Nm³/h Air	1638 Nm³/h Air	248 Nm³/h O_2	207 Nm³/h O_2
Off-gas CO_2	236 Nm³/h CO_2	0 Nm³/h CO_2	124 Nm³/h CO_2	0 Nm³/h CO_2
for 5000 h/a:				
Off-gas CO_2	2317 t/a CO_2	0 t/a CO_2	1217 t/a CO_2	0 t/a CO_2
Savings CO_2	Reference	2317 t/a CO_2	1100 t/a CO_2	2317 t/a CO_2