Approaches to optimize natural gas utilization for varying operation conditions

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DVGW-Forschungsstelle am Engler-Bunte-Institut des Karlsruher Instituts für Technologie, Karlsruhe, Germany

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- located on KIT (Karlsruhe Institute of Technology) Campus South
- Institute by DVGW and federal state of Baden-Württemberg

Mission of departments devoted to gas,

Research

- Optimization of (fossil/renewable) gas production, handling and utilization

Test laboratoy (certification testing)

- Processes, appliances, controls (hardware & software), sensors and materials ...

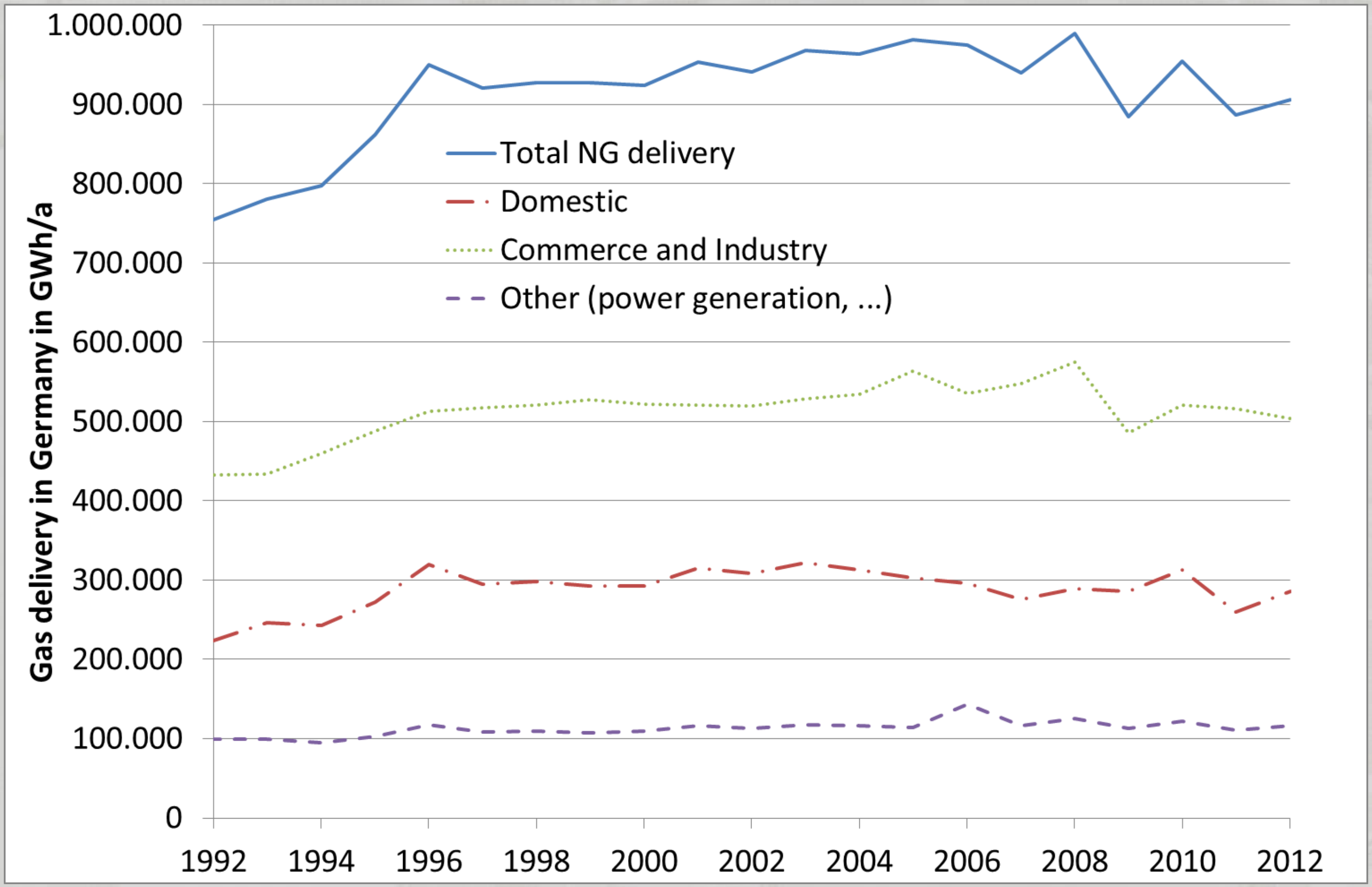
Outline

- Introduction to gas quality
  - Natural gas usage (D),
  - gas qualities,
  - requirements (technical rules) and
  - optimized gas utilization.
- Control concepts:
  - pre-, in- and post-combustion,
  - overview about gas quality sensors,
  - trends.
  - Current state and outlook
- Conclusions

Introduction to gas qualities of Natural Gas (NG)

NG is a versatile fuel widely for industrial, commercial and domestic use

- lowest carbon footprint of al fossil fuels
- well established infrastructure, important for industrial processes



Germany

~1 PJ/a

~2/3 non-domestic

~1/3 domestic

source [1]: Statistisches Bundesamt, Gasabsatz und Erlöse der Gaswirtschaft an ausgewählte Endabnehmergruppen, http://www.destatis.de, Wiesbaden, last access 01.08.2014.

Introduction to gas qualities

Gas quality depends on source, exploitation state, admixtures of biogas, air, ...

Vol-%	Russian gas [2]	North Sea [2]	Biomethane [3]
N_2	0,81	0,86	
CO_2	0,06	1,59	~3
CH_4	98,37	84,84	~96,5
C_2H_6	0,51	9,23	
C_3H_8	0,17	2,62	
C_4H_{10}	0,06	0,69	
C_5H_{12}	0,02	0,13	
C_6H_{14}	0,01	0,04	
O_2			<0,5

source [2]: Krause, H., Werschy, M., Franke, S., Giese, A., Benthin, J., Dörr, H., "DVGW-Forschungsauftrag: Gasbeschaffenheit Industrie - Untersuchungen der Auswirkungen von Gasbeschaffenheitsänderungen auf industrielle und gewerbliche Anwendungen (G 1/06/10 Phase I und II)", final report of DVGW research project G 1/06/10, 2014.

source [3]: Köppel, W., Schreck, H., Lubenau, U. Erler, R., "DVGW-Forschungsauftrag: „Monitoring Biogas II", final report of DVGW research project G 1/03/10, 2013.

Gas analysis results are typically snapshots

- Gas qualities vary by supply/demand relation
- 100 % Biomethane islands are temporally and locally possible (global contribution to NG supply is approx. 1 % in Germany - DENA report 01/2014)

Introduction to gas qualities requirements

Gas quality is defined by national technical rules (e.g. DVGW G 260) and a new H-gas group standard is in development (prEN 16726)

Example: Technical rule DVGW G 260, combustion related properties

reference conditions 0 °C/25 °C, 1013,25 hPa		permissible range (rated value)
Wobbe index	/kWh/m³	13,6 – 15,7 (15,0)
upper calorific value	/kWh/m³	8,4 – 13,1
relative density	/1	0,55 – 0,75

Further specifications for humidity, trace components, ...

- Permissive variations are quite large (e.g. Wobbe index approx. -10 %/+5 %)
- Increasing use of key parameter bandwidths due to market liberalization, changes in supply structure (according to Marcogaz survey of 2002 [4] only a third/fourth of ΔW compared to new survey 2013 [5] in Germany)

sources [4]: Marcogaz, National situations regarding gas quality, 2002. [5]: Kunert, M., et al., "DVGW-Forschungsauftrag: Vorstudie zur Untersuchung des Einflusses von dauerhaft wechselnden Wobbe-Indizes von H-Gasen auf häusliche und industrielle Gasanwendungstechnologien", final report of DVGW research project G 1/06/10, 2014.

Introduction to gas qualities requirements

Natural gas quality requirements have not/slightly changed, but why do we have now to face increasing gas quality fluctuations?

Former situation:

vertically integrated enterprises

Gas Supplier

Gas Grid Operator TSO / DSO

direct customer relationship

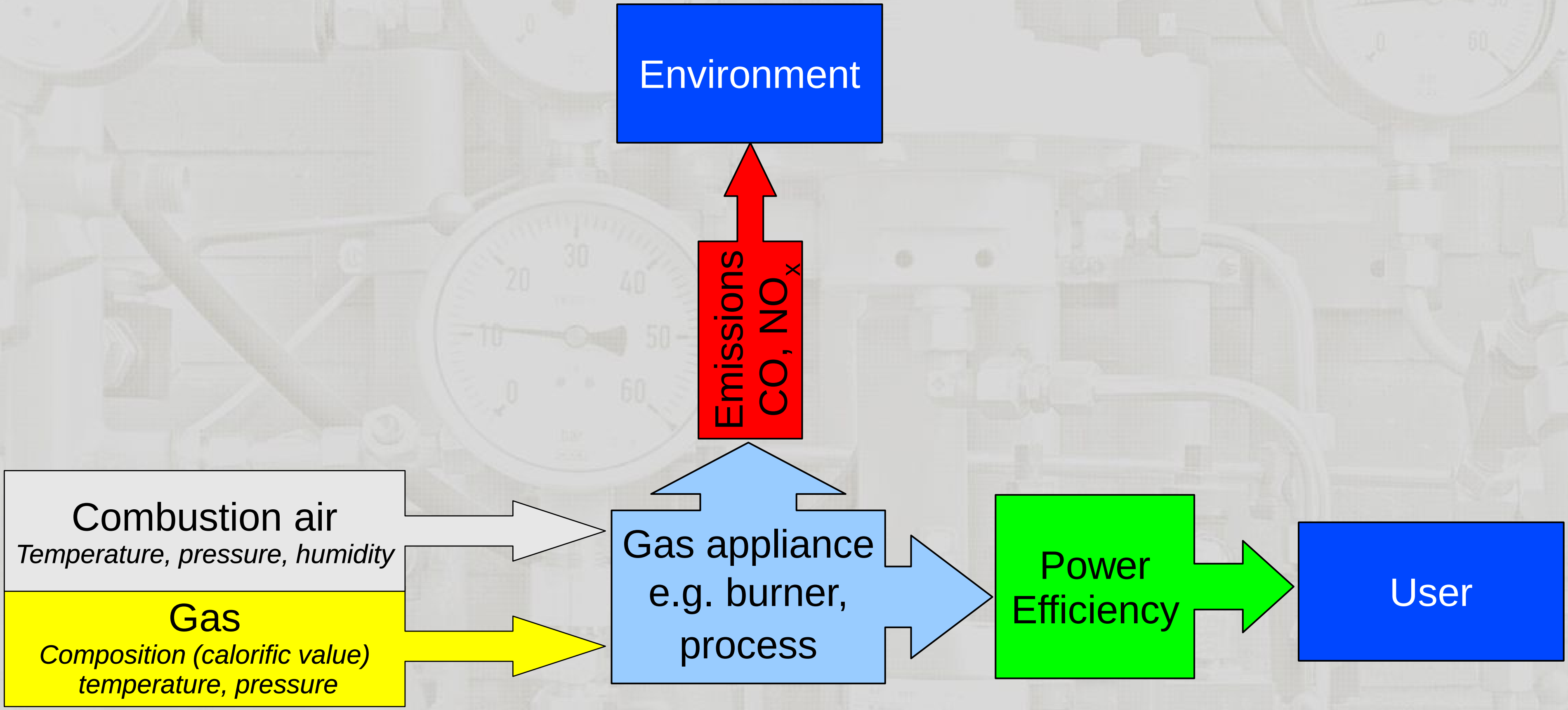
Gas User

By 2003/55/EC resp. 2009/73/EC new situation: missing direct customer relationship and missing control of supply chain!

Gas Supplier ⟷ **Gas Grid 1,2,3, ... Operator TSO / DSO** ⟷ **Gas User**

Introduction to gas qualities and optimized use

Combustion of gas is a complex chemical reaction



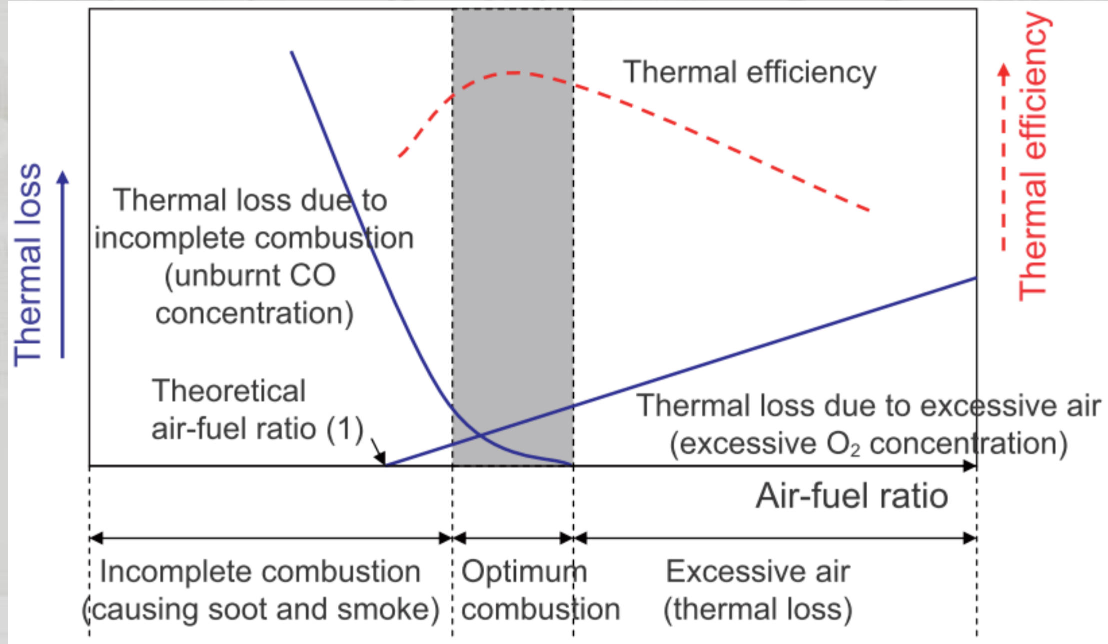
- Are all relevant parameters always been measured and controlled?
- Often some, e.g. gas quality, are assumed (!) to be quite stable.

\- Ideally: Closed feedback control for gas (power) <u>and</u> air (emissions) feed

Introduction to gas qualities and optimized use

Combustion of gas: air-demand is a key number

- Avoid lack of air for complete combustion (CO, C_xH_y, NO_x)!
- Avoid excessive air because of:
  - thermal losses and
  - CO-formation at very lean conditions.



source: Yuki, Y., Murata, A., Yokogawa Technical Report English Edition Vol.53 No.1 (2010), pp. 19 – 22.

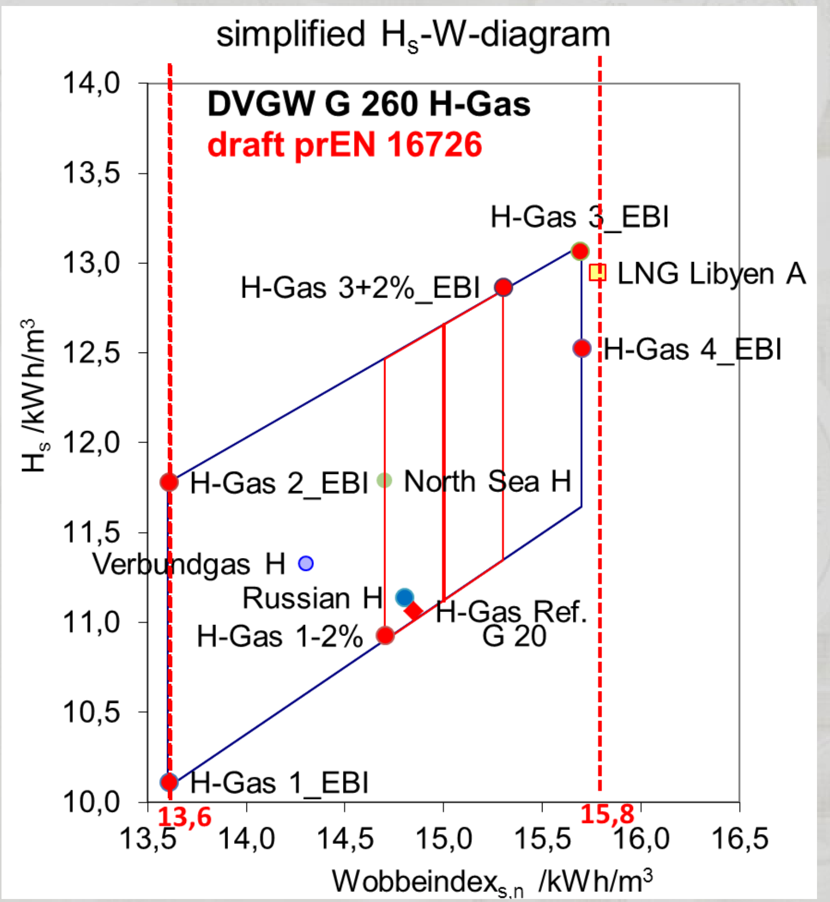
Often λ-settings of 1,05 to 1,15 adjusted to local and temporal gas quality.

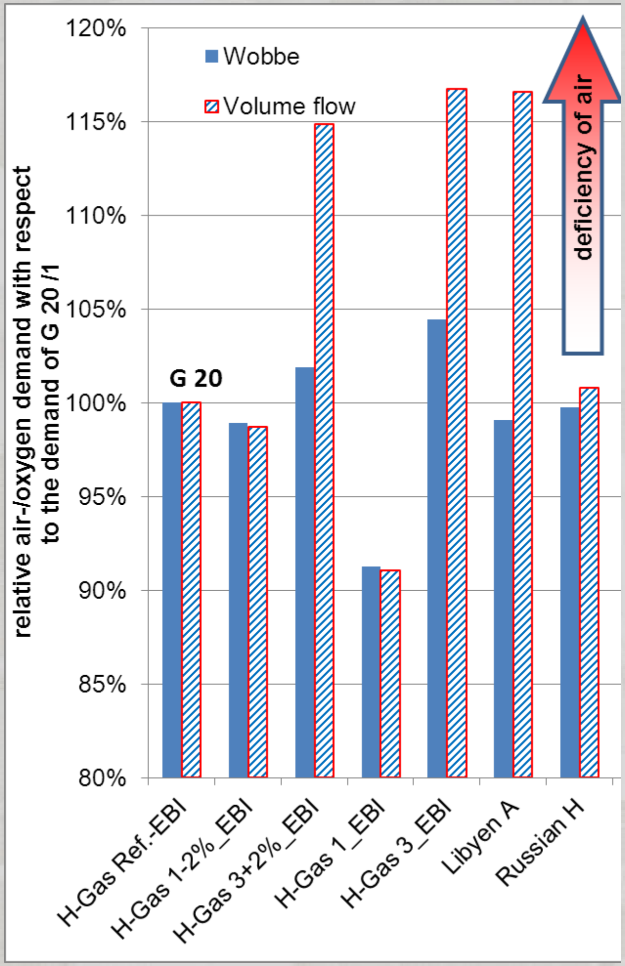
Relationship between Air-fuel Ratio and Heat Efficiency

typ. $1{,}03 \leq \lambda_{opt} \leq 1{,}15$ depending on burner design (mixing)

+ λ-buffer if no combustion control is applied, but often neglected!

Introduction to gas qualities fluctuations





source [5]: Kunert, M., et al., “DVGW-Forschungsauftrag: Vorstudie zur Untersuchung des Einflusses von dauerhaft wechselnden Wobbe-Indizes von H-Gasen auf häusliche und industrielle Gasanwendungstechnologien”, final report of DVGW research project G 1/06/10, 2014.

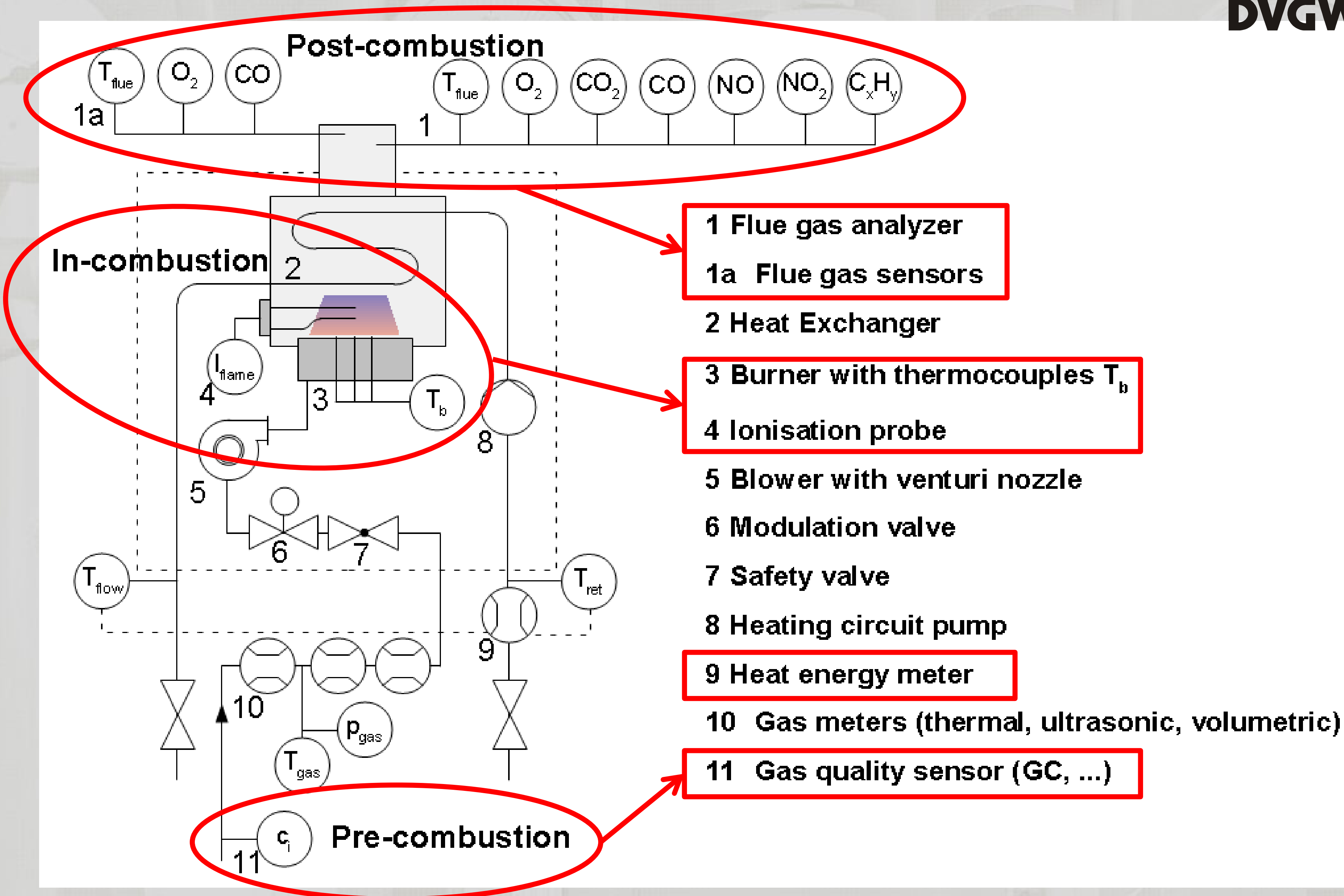
Even small ±2 % variations in Wobbe index can have large effects!

Additional requirements have to be defined for combustion (*H_s/ H_i, air demand*)

Requirements [5]: e.g. 2009/125/EG lowest emission limits

e.g. CO ≤ 50 mg/kWh, NO_x ≤ 56 mg/kWh, suggestion of λ = 1,15 (industrial)

Control concepts



MGARCP: A tool (condensing boiler) to investigate & improve pre-, in- and post-combustion control concepts

Control concepts

MGARCP: Multi-gas-air-ratio-control-platform

Sensitivity analysis: different gas qualities, fluctuation rates, load, ...

post-combustion (flue gas sensor)

- CO ZrO-based flue probes (non-domestic, less domestic)
- O_2-ZrO-based λ flue probes (non-domestic)
- CO/O_2-ZrO-based flue probes (non-domestic)

in-combustion (thorough parameterization necessary)

- Ionization based methods (SCOT and variants, domestic)
- temperature probe on burner surface (e.g. LambdaConstant, domestic)

validated for test gases of EN 437

pre-combustion

- gas quality sensor (non-domestic)

heat meter for power control (complementary to e.g. flue gas sensors)

Control concepts by gas quality sensors

Principle of function	Selection of models	Comments
GC: m-GC/PGC	numerous models *gold standard*	starting at 30 - 50 k€ versatile natural gas analysis (billing)
thermal mass flow meters/VOS combined with differential pressure metering and CO_2-NDIR sensor	Elster gas-lab Q1, RMG EC 500, Vergence Systems GasPT2 (VOS, GL Noble Denton)	Wobbe number, net / gross calorific value, methane number, extented precision model available
continuous combustion calorimeter	Union Instruments CWD 2005, Reineke RBM	Wobbe number, net / gross calorific value , density
stoichiometric method	AMS Rhadox 7X00, WIM hobre instruments Compas, VDEh-BFI Prototype *, GWI self-calibrating multi gas control system (combustion air requirement, ionization current)	combustion air requirement (*extension kit option for H_2)

Control concepts by gas quality sensors *cont.*

n.n.: state of availability/development questionable

Principle of function	Selection of models	Comments
infrared absorption	Precisive Tunable Filter Spectrometer*, Ruhrgas Methane number-Controller MaC (prototype n.n.)	Wobbe number, net / gross calorific value (*extension kit option for H_2-Sensor), Lab-FTIR-Systems with gas measurement cell are principally usable too
Raman effect	Enwave Optronics GasRaman NOCH-2	chemical composition for components > 0,025 Mol-%, net / gross calorific value, Wobbe number
thermal mass flow meters combined with differential pressure metering	Brooks Gas Property Identifier (discontinued), MEMS gasQS^{TM} gas quality sensor (in development)	Wobbe number, net / gross calorific value, density
velocity of sound, dielectricity	GasPT2, Gasunie/EON Ruhrgas e-Methode (prototype n.n.)	net / gross calorific value, Wobbe number, rel. density
viscosity	Bright Sensor S.A. Wobbe Index Sensor	Wobbe number

Control concepts by gas quality sensors trends

To increase use of gas quality sensors for combustion control:

- Focus on development of cheaper correlative sensors based on metering
  - thermal properties (heat capacity/conductivity),
  - viscosity or/and
  - speed of sound (VOS: velocity of sound).
- Price competiveness with in- and post-combustion controls.
- System integration have to be considered (interfaces, recertification)
  - standard EN 12067-2 (combustion control)
  - standard EN 746-2 (process control), SIL/PL issues

Overall gain of efficiency and maintenance - economic evaluation of ROI!

Current state and outlook

- Currently only 0.4 % of EU domestic gas appliances have adaptive gas control.
- Most systems rely on stable gas qualities i.e. modest fluctuations.
- Liberalized gas trading - separation of gas supplier and grid operators - supports usage of wider bandwidths within permissible ranges.
- Higher requirements concerning emissions and efficiencies have to be met.

Very active research at KIT and DVGW research centre: GASQUAL, DVGW financed research projects, industry projects ...

- Define challenges by fluctuating gas qualities.
- Anticipate new gas mixtures (H_2-admixture, desulphurized biogas, ...)
- Elucidate solutions or compensation approaches.
- Create awareness of successful ways to handle gas quality fluctuations.

Conclusions

- Gas quality fluctuations will occur more frequently and with higher amplitudes.
- Most installed systems (indust./comm.) are designed for quite stable gas qualities often with λ-settings of 1,05 to 1,15.
- There is a growing demand for cost effective compensation approaches for gas quality fluctuations (emission & efficiency requirements).
- There are solutions already available! Upgrade of plants is challenging.
- For gas quality sensors there is still the need for "cheap" variants with reduced requirements with regard to measurement uncertainty.
- Gas quality sensors have to compete with in- or post-combustion concepts.
- MGARCP is one tool of DVGW and KIT research activities to elucidate various compensation approaches within one domestic system even for future gas qualities!

Thank you for your attention!

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