











#### Prime movers' group on Gas Quality and H<sub>2</sub> handling

Knowledge sharing session on 'Mitigation measures for gas quality and H2 handling'

#6 meeting, 24<sup>th</sup> February 2021 (09:00 – 13:00 CET)

### **Agenda**

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Introduction to gas quality variation and H2 impacts and principles for mitigation strategies	09:05 - 10:05
<ul> <li>Gas quality/hydrogen: Impact on combustion processes and principles of mitigation by Jörg Leicher</li> <li>For feedstock industries by Jochen Wagner</li> </ul>	
Session 1 - Case studies on end-users' level: What are the principal mitigation options on the end-user side?	10:15 - 11:30
Residential appliances: Gas adaptive systems by Philipp Woerner	
Self-regulated gas boilers able to cope with gas quality variation by Jean Schweitzer	
Wobbe Index Measurements and Combustion Control for Industries by Philippe Buchet	
<ul> <li>Industrial feedstock processes - Lessons from the past in The Netherlands by Dirk-Jan Meuzelaar</li> </ul>	
Power Generation Gas Turbines: Mitigation of Issues Associated with Gas Quality Variation and Hydrogen Addition by David Abbott	
Wobbe Index sensitivity reduction reciprocating engines by Jacob Klimstra	
Coffee break	11:30 - 11:40
Session 2 - Case studies at grid level: What are the principal mitigation options at grid level?	11:40 - 12:55
Possible mitigation measures – use cases at Fluxys Belgium by Quentin Degroote	
The static gradient splitter by Peter van Wesenbeeck	
Online tracking and forecasting of gas quality by Stefan Rickelt	
The French case by Alice Vatin	
Concluding remarks	12:55 - 13:00

Introduction to gas quality variation and H2 impacts and principles for mitigation strategies



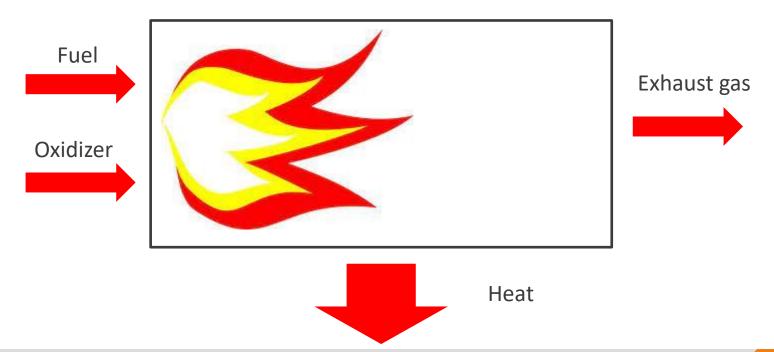
l www.gwi-essen.de

# Gas quality/hydrogen: Impact on combustion processes and principles of mitigation

Prime Movers' Group, February 24<sup>th</sup>, 2021
Jörg Leicher

#### Combustion: a very high-level description...

The vast majority of natural gas consumption is accounted for by **combustion processes**: residential heating/cooking, power generation, industrial process heat, transportation, ...





#### **Combustion and gas quality**

Every combustion process can be characterized by two process parameters:

- Firing rate: 
$$P = \dot{m}_{gas} \cdot (H_{i,spec}) = \dot{V}_{n,gas} \cdot (H_{i,vol})$$
 [W

- Air excess ratio: 
$$\lambda = \frac{\dot{V}_{n,air,actual}}{\dot{V}_{n,air,min}} = \frac{\dot{V}_{n,air,actual}}{\dot{A}ir_{min}} \cdot \dot{V}_{n,gas}$$
 [-]

	Unit	CH <sub>4</sub>	H <sub>2</sub>	50 % CH <sub>4</sub> / 50 % H <sub>2</sub>
H <sub>i,vol</sub>	MJ/m³	34.06	10.24	24.95
W <sub>S</sub>	MJ/m³	50.64	45.78	44.56
Air <sub>min</sub>	m³/m³	9.524	2.381	5.952



@15 °C / 15 °C

#### **Combustion and gas quality**

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 [W

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 [-]

- Gas quality variations can affect both P and  $\lambda$ , resulting in changes in temperatures, efficiency, pollutant emissions (CO, NO<sub>x</sub>, soot, ...), product quality (where applicable), ...
- In addition to changes to such **global parameters** as P or  $\lambda$ , changes in gas composition or quality can also have **more specific effects**, e. g. knocking, flash backs, thermo-acoustic vibrations, ... (particularly relevant in the context of  $H_2$ !)

#### Typical firing rates and air excess ratios (examples)

### Residential heating appliance



**P**: < 70 kW **λ**: 1.2 - 1.4

**Industrial furnace** 



**P**: 0.1 – 200+ **MW** 

**λ**: 1.05 - 1.15

### Gas turbine for power generation



 $P: < 1.5 \text{ GW} (< 600 \text{ MW}_{el})$ 

**λ**: ≈ 2.0



#### Why do we talk about Wobbe Indices?

- In many gas-fired applications, particularly residential appliances, the volume flow of fuel gas (and hence the firing rate) is controlled by the pressure in the nozzle of a burner and the nozzle diameter. The grid pressure can be a limiting factor.
- The Wobbe Index (WI) was introduced as a way to compare the impact of a fuel gas change on the heat input of such a system: if two gases have the same Wobbe Index, they will release the same amount of heat if they are burned at the same nozzle with the same nozzle pressure. Thus, the two gases are interchangeable for this system in terms of heat release. This is valid for residential or commercial appliances, but also many larger applications.
- The WI does **only** relate to the heat release, **not** to any other important aspects of combustion (emissions, efficiency, temperatures, ...). Also, its meaningfulness is severely reduced if **chemically very different** fuel gases are compared (=> H<sub>2</sub>).

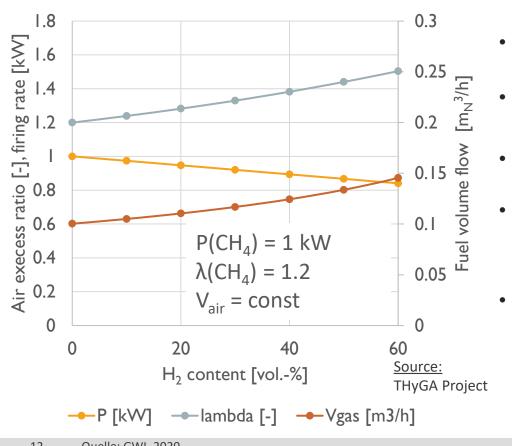
#### The limits of the Wobbe Index

	Unit	100 % CH <sub>4</sub>	94 % CH <sub>4</sub> / 6 % CO <sub>2</sub>	92 % CH <sub>4</sub> / 8 % N <sub>2</sub>	100 % H <sub>2</sub>
WI	MJ/m <sup>3</sup>	50.64	45.28	45.27	45.78
NCV	MJ/m <sup>3</sup>	34.06	32.02	31.34	10.24
GCV	MJ/m <sup>3</sup>	37.80	35.53	34.78	12.10
d	-	0.5571	0.6157	0.5901	0.0698
Air <sub>min</sub>	m <sup>3</sup> /m <sup>3</sup>	9.524	8.952	8.762	2.381
$T_{ad} (\lambda = 1)$	°C	1982	1971	1974	2096
s <sub>L</sub> (λ = 1)	cm/s	38.57	36.79	37.52	209
MN*	-	100	105	99	0

<sup>\*:</sup> MWM method



### Example: residential appliance <u>without</u> combustion control: effects of hydrogen admixture



- Firing rate:  $\frac{P_2}{P_1} = \frac{W_{i,2}}{W_{i,1}}$
- Fuel volume flow:  $\dot{V}_{Gas} = \frac{P}{H_i}$
- Air excess ratio:  $\frac{\lambda_2}{\lambda_1} = \frac{Air_{min,1}}{Air_{min,2}} \cdot \sqrt{\frac{d_2}{d_1}}$
- In the case of H<sub>2</sub> admixture, the firing rate of the burner decreases with higher levels of H<sub>2</sub>, while the fuel volume flow increases.
- If W<sub>i,2</sub> > W<sub>i,1</sub>(e. g. due to a change to a high-WI LNG), the situation is reversed:
  - firing rate goes up
  - air excess ratio goes down(=> CO)



#### **Additional aspects**

- In addition to the impact of gas quality on main combustion parameters such as firing rate or air excess ratio, gas quality changes can also have **more specific effects**, often only affecting certain types of equipment, e. g.
  - **flash back** or flame **lift-off** (relevant for premixed burners, e. g. in residential appliances or gas turbines)
  - **knocking**, i. e. premature self-ignition due to compression (gas engines)
  - thermo-acousting vibrations (gas turbines)
  - hydrocarbon condensation (gas turbines)
  - ...
- Often, these effects cannot be tied to global GQ criteria like WI or GCV, but are connected to the actual composition or require their own criteria, e. g. MN or C<sub>2+</sub>. H<sub>2</sub> with its very different combustion characteristics can be very relevant here.

### Mitigation strategies



#### Mitigation strategies

- In principle, there are several options of how the impact of gas quality on an enduser's process and equipment can be mitigated, e.g.:
  - a "robust" setting of the application
  - measurement and combustion control systems
  - measurement and local gas conditioning (including preheating fuel gas)
  - grid-level conditioning of gas
  - grid level flow control to minimize local GQ fluctuations
- Not all approaches are equally viable. Often, solutions have to be tailored to specific applications, processes and locations.



#### Robust settings: factory settings and test gases

- In the **residential/commercial sector**, appliances are (supposed to be) **adjusted by the manufacturer and** then **sealed**.
- Adjustment means that the nominal operational point of an appliance is set to a specified firing rate and air excess ratio. The air excess ratio is usually determined by measuring either the O<sub>2</sub> or CO<sub>2</sub> concentration in the flue gas. The volume flow of air is then tuned so that the measured concentration corresponds to a set point prescribed by the manufacturer.
- The adjustment is carried out with a **well-defined reference gas** (G 20, i. e. 100 %  $CH_4$ , for H-gas regions; G 25, i. e. 86 %  $CH_4$ , 14 %  $N_2$  for L-gas regions), and **operational safety** of the appliance is tested with a number of limit gases, specified in **EN 437**.

#### Reference and limit gases Group H (EN 437)

Table 2 – Characteristics of the test gases <sup>a</sup> gas dry at 15 °C and 1 013,25 mbar

Gas family and group	Test gases	Designation	Composition by volume <sup>e</sup>	$W_{\rm i}$	H <sub>I</sub>	$W_{\rm s}$	$H_{\rm s}$	
			%	MJ/m <sup>3</sup>	MJ/m <sup>3</sup>	MJ/m <sup>3</sup>	MJ/m <sup>3</sup>	d
Gases of the second family b								
Group H	Reference gas	G 20	CH <sub>4</sub> = 100	45,67	34,02	50,72	37,78	0,555
	Incomplete combustion and sooting limit gas	G 21	CH <sub>4</sub> = 87	49,60	41,01	54,76	45,28	0,684
		0.000	C₃H <sub>8</sub> = 13	40.07	00.50	47.07	04.00	0.440
	Light back limit gas	G 222	CH <sub>4</sub> = 77 H <sub>2</sub> = 23	42,87	28,53	47,87	31,86	0,443
	Flame lift limit gas	G 23	CH <sub>4</sub> = 92,5	41,11	31,46	45,66	34,95	0,586
			$N_2 = 7,5$					

Source: EN 437

**G20**: Air<sub>min</sub> =  $9.524 \text{ m}^3/\text{m}^3$  ; CARI =  $12.76 \text{ m}^3/\text{m}^3$ 

**G21**: Air<sub>min</sub> = 11.381 m<sup>3</sup>/m<sup>3</sup> ; CARI = 13.726 m<sup>3</sup>/m<sup>3</sup>

**G23**: Air<sub>min</sub> =  $8.333 \text{ m}^3/\text{m}^3$ ; CARI =  $10.681 \text{ m}^3/\text{m}^3$ 

**CARI**: Combustion Air Requirement Index:

$$CARI = \frac{Air_{min}}{\sqrt{d}}$$



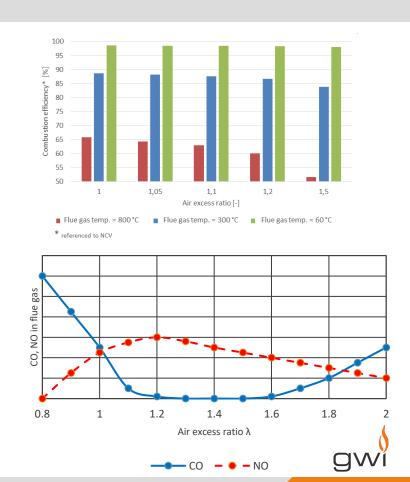
#### Adjustment with reference and test gases: a thought experiment

- A residential combustion process (with constant air flow) is adjusted to λ = 1.35 with G 20 by the appliance manufacturer.
   It is then supplied with 2 limit gases, G 21 and G 23, to test for safety (incomplete combustion and flame lift respectively).
   What happens?
- The air excess ratio of the process shifts according to  $\frac{\lambda_2}{\lambda_1} = \frac{CARI_1}{CARI_2}$ .
- Thus:  $\lambda_{G\ 21}$  = 1.25 ;  $\lambda_{G\ 23}$  = 1.61 => the appliance is always safe, **no danger of CO formation**.
- Now, the same exercise, but this time with an initial  $\lambda = 1.05$  (industrial setting): =>  $\lambda_{G.21} = 0.98$ ;  $\lambda_{G.23} = 1.25$

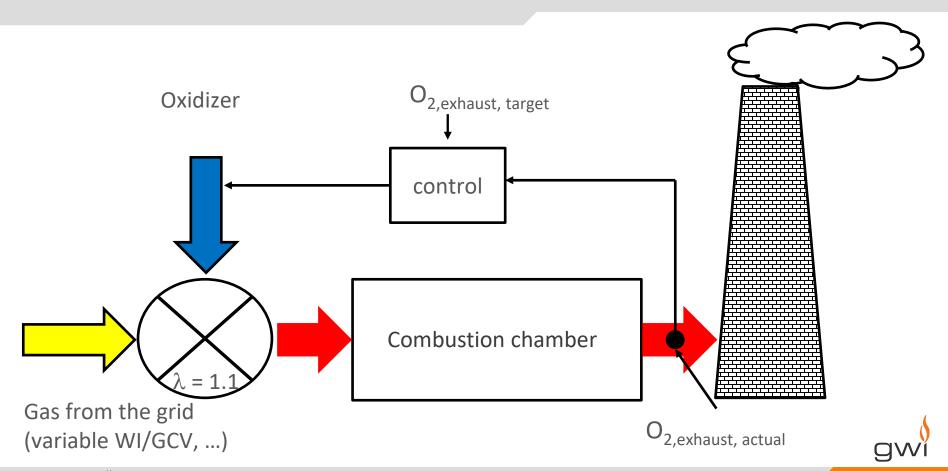


#### **Factory settings and reference gases**

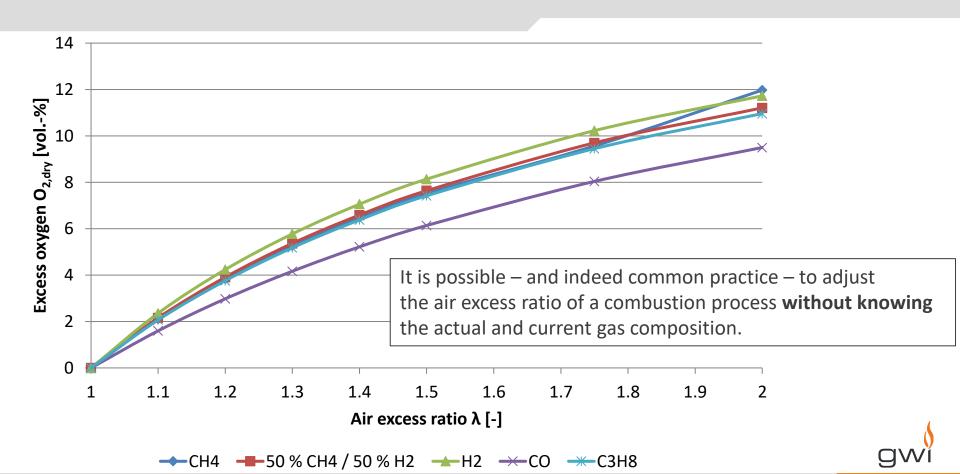
- Using reference gases and factory settings to mitigate gas quality fluctuations only works in combination with high air excess ratios and if one is not overly concerned about NO<sub>X</sub> emissions.
- For industrial users, it is generally not an option, due to the inherent losses in efficiency and the likely increase in NO<sub>x</sub>.
- There is also the question how to readjust after **maintenance**.



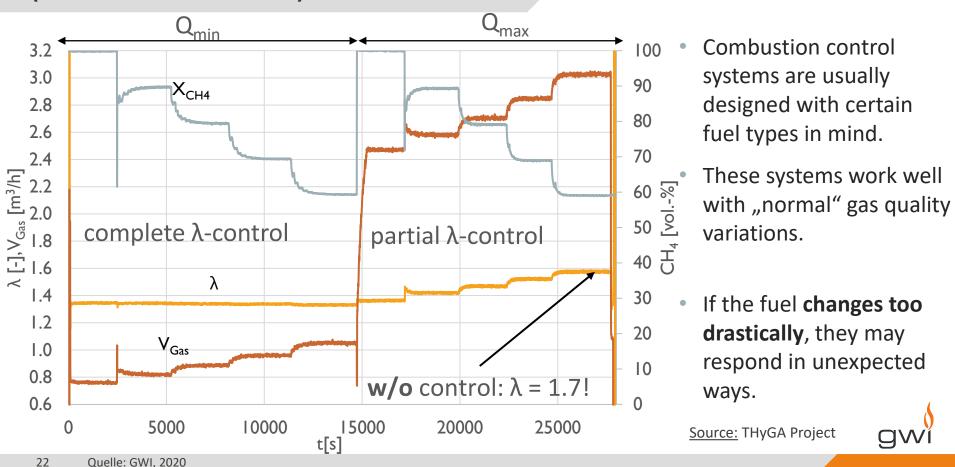
#### Combustion control via excess oxygen



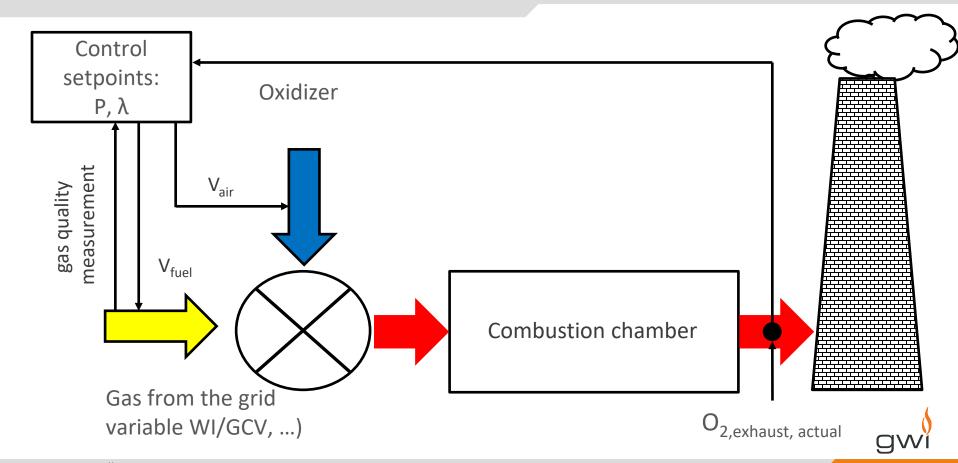
#### Air excess ratio λ and excess oxygen



## Combustion control in a residential appliance: effects of H<sub>2</sub> admixture (flame ionization sensor)



#### Combustion control via local GQ measurement and excess oxygen



#### Impact on an industrial non-premixed burner system (CFD study)

 $W_s = 0.4 \%$ 

 $\Delta$  H<sub>i</sub> = 4 %

#### Reference case:

Russian H-Gas (P = 200 kW,  $\lambda$  = 1.1)

#### No control:

North Sea H-Gas Volume flows constant (P = **208 kW**, λ = **1.056**)

↑ 4 % ↓ 4 %

#### **Control of firing rate and air excess ratio:**

North Sea H-Gas

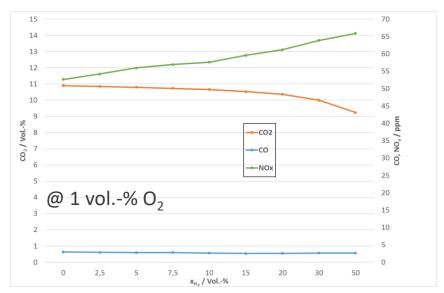
$$(P = 200 \text{ kW}, \lambda = 1.1)$$

Air and fuel volume flows adjusted



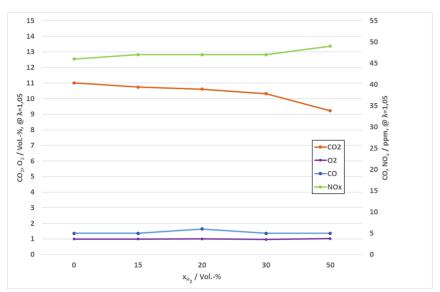
 $\Delta \approx 20 \%$ 

#### Effects of H<sub>2</sub> admixture on a non-premixed burner (test rig experiments)



#### Scenario I:

**no control intervention** at all, i. e. **volume flows** of **both fuel** and **air** remain **constant** (worst case).

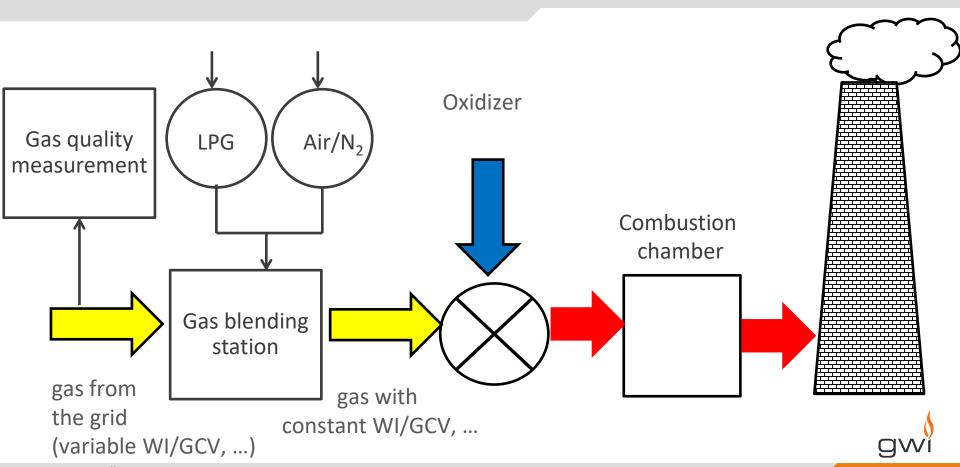


#### **Scenario III:**

**both burner firing rate** and **air excess ratio** remain **constant**, based on advanced gas quality monitoring (best case).

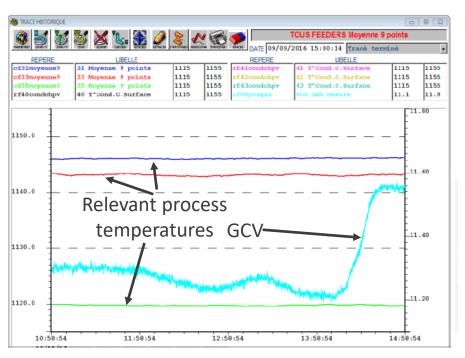
<u>Source:</u> Leicher, J., Nowakowski, T., Giese, A., Görner, K., Hydrogen in natural gas: how does it impact industrial end users?, World Gas Conference 2018, Washington D.C., USA

#### **On-site fuel conditioning**



#### Fuel gas conditioning on-site

#### Fuel gas conditioning a feeder (glass industry)

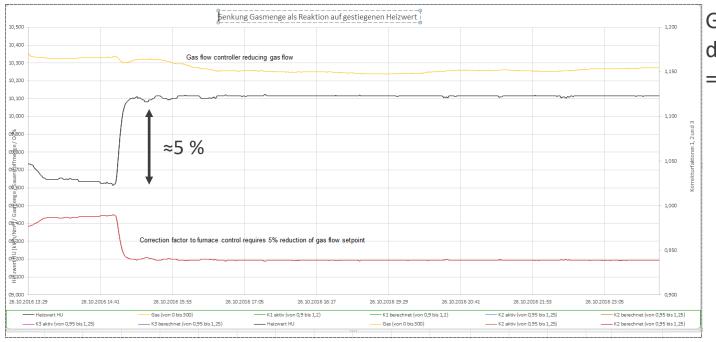


- Another option to compensate for gas quality fluctuations can be on-site fuel gas conditioning. Natural gas is blended with air or LPG to maintain a set NCV or WI.
- This usually is the more expensive approach, but it may be economically sensible if a system is extremely sensitive or contains a large number of burners, e. g. a feeder system in glass manufacturing.



<u>Source:</u> Lantoine, L., Ourliac, M., Buchet, P., Wobbe Index Measurement and Control for Industry: A Mature Technology Facing New Challenges, IGRC 2017, Rio de Janeiro, Brazil

#### How <u>not</u> to control a furnace in times of varying gas qualities...

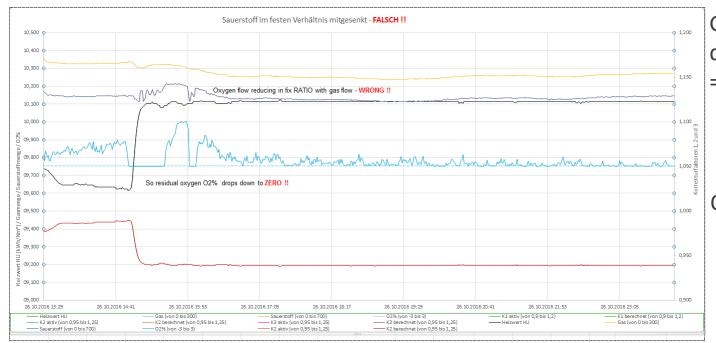


GQ measurement detects increased H<sub>i</sub> => V<sub>gas</sub> reduced

<u>Source:</u> P. Hemmann, Regelungstechnische Lösungen zur vorausschauenden Kompensation schwankender Gasqualität Workshop "Erdgasbeschaffenheitsschwankungen in der Prozessindustrie - Hintergründe, Auswirkungen, Lösungsansätze", Düsseldorf, Germany, 2018



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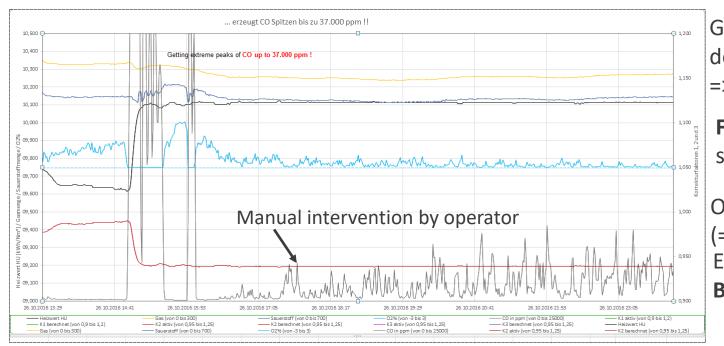
**Fixed ratio** of V<sub>O2</sub>/V<sub>gas</sub> set in furnace control

O<sub>2</sub> in flue gas drops to 0

<u>Source:</u> P. Hemmann, Regelungstechnische Lösungen zur vorausschauenden Kompensation schwankender Gasqualität Workshop "Erdgasbeschaffenheitsschwankungen in der Prozessindustrie - Hintergründe, Auswirkungen, Lösungsansätze", Düsseldorf, Germany, 2018



#### How <u>not</u> to control a furnace in times of varying gas qualities...



GQ measurement detects increased H<sub>i</sub> => V<sub>gas</sub> reduced

**Fixed ratio** of V<sub>O2</sub>/V<sub>gas</sub> set in furnace control

 $O_2$  in flue gas drops to 0 (=>  $\lambda$  < 1)

Extreme CO formation!

Bad idea!

<u>Source:</u> P. Hemmann, Regelungstechnische Lösungen zur vorausschauenden Kompensation schwankender Gasqualität Workshop "Erdgasbeschaffenheitsschwankungen in der Prozessindustrie - Hintergründe, Auswirkungen, Lösungsansätze", Düsseldorf, Germany, 2018



#### Conclusion

- Combustion processes are generally designed for a specified fuel. While a certain variation can usually be accommodated, there are limits, for reasons of safety, fitness for purpose, efficiency, emissions, ... . These limits are very different for different applications. Some applications are more sensitive than others in terms of gas quality.
- While the Wobbe Index is generally used as the main gas interchangeability criterion, other criteria may also be relevant for various applications and technologies.
   H<sub>2</sub> complicates matters significantly.
- There are options to mitigate the effects of gas quality changes on combustion applications, either by **reducing the variations** the equipment is exposed to (either **on-site** or on a **grid level**) or by using **measurement and control** technologies to re-adjust.

#### **Conclusions**

- These measures are often very specialized and need to be tailored to the concrete application and process.
- There are physical and technological limits to what mitigation systems can do.
   Response times can be an important aspect here: some end-use applications require a very quick response. For others, a slower response may be sufficient.
- Technological solutions at the end-user level also need to fulfill **additional requirements**, e. g. in terms of safety (failsafe, redundancy), OPEX/CAPEX, maintenance, robustness, ...



#### Thank you for your attention

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## Gas quality variation Impact on feedstock usage

Prime Movers' Group, 24th February 2021

#### **Agenda**

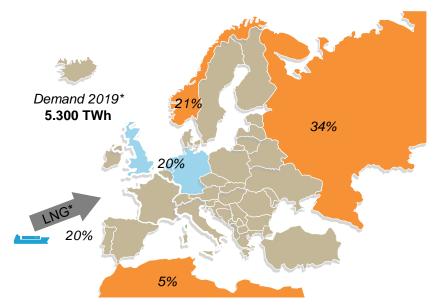
- Natural gas market and the chemical industry
- Gas quality Challenges for the chemical industry
- Summary



### Natural gas market and the chemical industry



### **Natural gas market Europe**



own production	20%
imports (pipeline)	60%
imports (LNG)	20%

\*Source: Wood Mackenzie, IHS, BASF

Approximately 80% of natural gas from few sources



### Chemical industry – natural gas usage

- Share of chemical industry
- Europe: ca. 11% (ca. 590 TWh)
- Germany: ca. 12% (ca. 120 TWh)

- Usage
- Ca. 75% heating (combustion)
- Ca. 25% feedstock (chemical processes)



#### **General**

- LNG, Biogas/Biomethane and Hydrogen can lead to more fluctuating gas quality in Europe
- Reasons
- ► LNG → broad spectrum of chemical composition
- Biogas/Biomethane, Hydrogen
  - Risk of fluctuating injection → Risk of stepchanges in gas quality at exit points close by injection points of Biomethane/Hydrogen productions
- Critical components for chemical industry
- Hydrogen, Nitrogen, Oxygen, higher Hydrocarbons and Sulphur



#### **General**

Tabelle A.2 – Typische Zusammensetzung von ausgewählten Erdgasen und aufbereiteten Biogasen (unodoriert)

Bezeichnung	Symbol	Einheit	Russ Erdgas H	Nordsee- Erdgas H	Dänemark- Erdgas H	Holland- Erdgas L	Deutschland Erdgas L	Biogas H	Biogas H + LPG
Methan	CH <sub>4</sub>	Mol-%	96,96	88,71	90,07	83,64	86,46	96,15	90,94
Stickstoff	N <sub>2</sub>	Mol-%	0,86	0,82	0,28	10,21	10,24	0,75	0,69
Kohlenstoffdioxid	CO <sub>2</sub>	Mol-%	0,18	1,94	0,60	1,68	2,08	2,90	2,68
Ethan	C <sub>2</sub> H <sub>6</sub>	Mol-%	1,37	6,93	5,68	3,56	1,06		
Propan	C₃H <sub>8</sub>	Mol-%	0,45	1,25	2,19	0,61	0,11		5,00
Butane	C <sub>4</sub> H <sub>10</sub>	Mol-%	0,15	0,28	0,90	0,19	0,03		0,50
Pentane	C <sub>5</sub> H <sub>12</sub>	Mol-%	0,02	0,05	0,22	0,04	0,01		
Hexane + höhere KW	C <sub>6+</sub>	Mol-%	0,01	0,02	0,06	0,07	0,01		
Sauerstoff	O <sub>2</sub>	Mol-%	< 0,001	< 0,001	< 0,001	< 0,001	< 0,001	0,20	0,19
Gesamtschwefel	S	mg/m³	< 3	< 5	< 3	< 3	< 3	< 3	< 3
Brennwert	H <sub>S,n</sub>	MJ/m³	40,3	41,9	43,7	36,8	35,4	38,3	41,9
Brennwert	H <sub>S,n</sub>	kWh/m³	11,2	11,6	12,1	10,2	9,8	10,6	11,6
Normdichte	$ ho_{n}$	kg/m³	0,74	0,81	0,81	0,83	0,81	0,76	0,83
Wobbeindex	W <sub>S,n</sub>	MJ/m³	53,1	52,9	55,0	46,0	44,7	50,0	52,3
Wobbeindex	W <sub>S,n</sub>	kWh/m³	14,8	14,7	15,3	12,8	12,4	13,9	14,5
Methanzahl	MZ	_	90	79	72	88	97	102	76

Source: DVGW G260



### **General**

	Nitrogen	Methane	Ethane	Propane	Higher Hydro- carbons	Gross Calorific Value	Wobbe Index
	%	%	%	%	C4 + %	MJ/m³	MJ/m³
Algeria-Arzew	0.56	87.98	9.00	1.99	0.47	41.68	52.62
Algeria-Bethiova 1	1.20	87.59	8.39	2.12	0.70	41.01	51.96
Algeria-Bethiova 2	0.92	91.39	7.17	0.52	0.00	39.78	51.41
Algeria-Skikda	1.02	91.19	7.02	0.66	0.11	39.87	51.42
Egypt-Damietta	0.08	97.70	1.80	0.22	0.20	38.39	51.03
Egypt-Idku	0.00	97.20	2.30	0.30	0.20	38.61	51.19
Libya	0.69	81.57	13.38	3.67	0.69	44.02	53.82
Nigeria	0.08	91.28	4.62	2.62	1.40	41.76	52.87
Abu Dhabi	0.29	84.77	13.22	1.63	0.09	42.45	53.16
Oman	0.35	87.89	7.27	2.92	1.57	42.73	53.27
Qatar	0.36	90.10	6.23	2.32	0.99	41.58	52.65
Trinidad	0.03	96.82	2.74	0.31	0.10	38.82	51.29
USA-Alaska	0.17	99.73	0.08	0.01	0.00	37.75	50.62
Australia-NWS	0.09	87.39	8.33	3.35	0.84	42.74	53.40
Brunei	0.05	90.61	4.97	2.89	1.48	42.09	53.06
Indonesia-Arun	0.06	91.16	6.01	1.84	0.93	41.32	52.64
Indonesia-Badak	0.02	89.76	5.06	3.54	1.62	42.61	53.34
Malaysia	0.16	91.15	4.96	2.79	0.94	41.52	52.70

Source: Guidebook to Gas Interchangeability and Gas Quality by BP/IGU



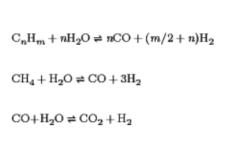
### **Gas quality – Challenges for the chemical industry**



- Natural gas is used as important raw material / feedstock in following chemical processes
- Steam methane reforming (Syngas)
  - Methanol
  - Ammonia
- Acetylene
- Hydrocyanic acid
- These chemicals are "base chemicals", which are used in several value chains
- Disruptions in these processes lead to disruptions in subsequent processes



Steam methane reforming



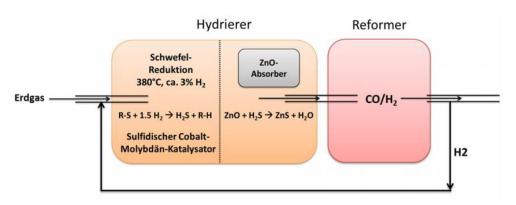


Abbildung 1. Schematische Darstellung der dem Reformierungsprozess vorgelagerten Erdgasentschwefelung mittels Hydrierung und Zinkoxid-Absorber.

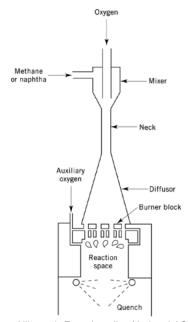
Source: Ullmann's Encyclopedia of Industrial Chemistry, VCI

Production of Carbon Monoxide (CO) and Hydrogen (H<sub>2</sub>), which are used in several subsequent processes to produce chemicals e.g., Methanol or Ammonia

- Steam methane reforming
- Nitrogen → reduction of plant capacity / production loss, CO might not be within specification (separation of Nitrogen from Methane difficult, requiring additional steps)
- Oxygen
  - Oxidation and deactivation of highly active catalysts (risk of safety shutdowns due to strongly exothermic reaction) leading to disruptions and/or plant damage
  - in case of hydrogenating desulphurisation by adding Hydrogen, risk of uncontrollable adiabatic temperature increase in the reactor possibly exceeding the design temperature > damage and mechanical failure of the reactor (detonation)
- Higher hydrocarbons → risk of coking of the catalyst in the reformer (can be handled via upstream "prereforming")
- Sulphur > catalyst poison (natural gas is pretreated in a desulphurisation before usage as feedstock / raw material in catalytic processes)



- Acetylene
- High temperature pyrolysis of methane



Source: Ullmann's Encyclopedia of Industrial Chemistry

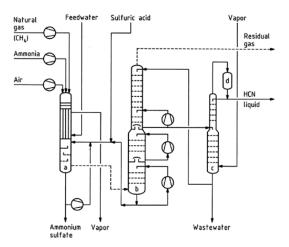
Used as intermediate to produce polymers (e.g., Polyurethanes, Polybutylene terephthalate), adhesives, coatings etc.



- Acetylene
- Nitrogen  $\rightarrow$  yield loss, reduction of plant capacity / production loss (also in subsequent steps)
- Oxygen -> at concentrations > 1 Vol% unwanted side reactions in the preheating step and therefore yield loss
- Higher Hydrocarbons → increased coking in the preheating step
- Hydrogen → Risk of pre-ignition leading to safety shutdown



- Hydrocyanic acid
  - ▶ Using Methane with Ammonia to produce Hydrocyanic Acid e.g., Andrussow- or BMAprocess



Source: Ullmann's Encyclopedia of Industrial Chemistry

▶ Used as intermediate to produce polymers (e.g., Polyamides), animal feed, pesticides etc.



- Hydrocyanic acid
- Nitrogen → reduction of plant capacity / production loss
- Oxygen > Oxidation and deactivation of highly active catalysts (risk of safety shutdowns due to strongly exothermic reaction) leading to disruptions and/or plant damage
- Higher Hydrocarbons → Risk of coking of catalyst
- Sulphur → Catalyst poison



### **Summary**



### Natural gas quality – future challenges

- Fluctuations in gas quality due to higher LNG-imports, Biomethane- and possibly Hydrogen-injections to be expected
- Separation of critical components for usage of natural gas in chemical processes not or only with increased efforts (including significant investments) possible
- By using additional analysis and control efforts in chemical processes plants can be safely shut down and severe damages can be avoided

Requires feasibility studies and impact analysis





We create chemistry

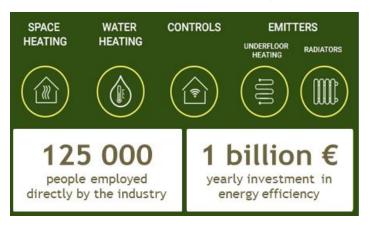
## **Q&A** session

principal mitigation options on the end-user side?

Session 1 - Case studies on end-users' level: What are the

## EHI brings together manufacturers of heating systems in Europe

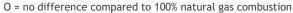






## Modern condensing gas appliances are compatible with up to 20% H2, even without adjustment\*

	Appliance safety	H2- NG 20 %	Function, robustness	H2- NG 20%	Features	H2- NG 20%
Appliances	Exhaust blockage	0	Ignition behavior	+	CO/NOx Emissions	+
equipped with	Condensate blockage	0	Ionization signal	-	Power	-
electronic combustion controls (gas- adaptive)	Exhaust recirculation	0	Calibration	0	Efficiency	0
	Flame flashback	0	Air number	0	Noise/Ignition	+
	Late ignition	-	Modulation	0	Thermo acoustics	0
	Exhaust blockage	0	Ignition behavior	+	CO/NOx Emissions	+
Appliances equipped with pneumatic electronic gas/air ratio	Condensate blockage	0	Ionization signal	-	Power	-
	Exhaust recirculation	0	Calibration	0	Efficiency	0
	Flame flashback	0	Air number	0	Noise/Ignition	+
	Late ignition	0	Modulation	0	Thermo acoustics	0



<sup>+ / - =</sup> improvement /drawback compared to NG only



<sup>\* =</sup> Manufacturers' laboratory data on residential appliances (<70kW), with G20 settings

## Gas appliances are increasingly fit for hydrogen – snapshot



### Old installed stock: 10 % H2

- •Influence of 10 % H2 on gas appliances is low
- Assessment: Existing equipment can tolerate up to 10 % H2
- It is being investigated whether the H2 share can be extended to 20 %

### Modern technologies: up to 20% H2

- •Safety and robustness are fully given
- •H2 provides positive contribution to emission reduction (CO/NOx)
- •Gas-adaptive devices: In the future compensation air number/power also possible with H2 (power output will be maintained)
- Certification ongoing
- •Standardisation activities ongoing
- •Appliances >70kW (commercial/industrial use) still need to be tested to up to 20%H2

### In the coming years: 100% H2 technologies

- Adaptation of components for H2 is required (ionisation etc)
- •100% Hydrogen boilers & hydrogen-ready boilers with a conversion kit are in development
- Standardisation activities ongoing
- Demonstration in pilot projects ongoing / planned



1. What end-use applications are gas adaptive systems good for?

Gas adaptive systems, e.g. based on the ionisation signal of the flame, are used for fully premix burners, such as:

- Condensing gas boilers <70kW</li>
- Cooking appliances



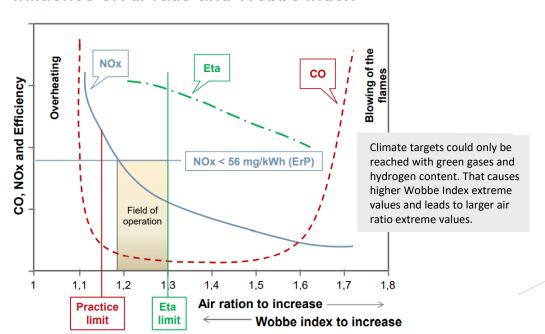
#### 2. Framing the gas quality issue for end-use appliances

Changes in Wobbe Index or high fluctuations of hydrogen blends may influence:

- Ignition behaviour
- Emissions
- Efficiency
- Combustion parameters
- Reliability
- Gas adaptive systems have been identified by manufacturers as a possible mitigation measure.

#### 3. Description of the gas quality issue

Influence of Air ratio and Wobbe index





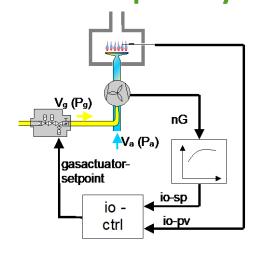
4. What is the chosen mitigation measure?

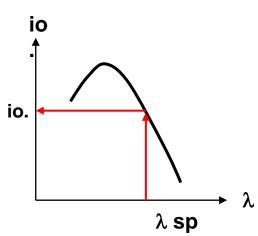
**Ionisation-based gas adaptive systems** keep the air/ gas ratio ( $\lambda$  value) constant (output remains constant even though gas quality changes).

Independently from the gas quality (from G271 to G21) or hydrogen blends up to 20% the combustion parameters remain stable.

Safe combustion is guaranteed.







#### How do ionisation-based gas adaptive systems work?

- Each ionisation value corresponds to a certain  $\lambda$  value
- Wobbe↑ => λ↓ =>Io↑=>gas↓=>Io↓=> λOK
- Wobbe  $\downarrow => \lambda \uparrow => lo \downarrow => gas \uparrow => lo \uparrow => \lambda OK$



#### 6. Potential of gas-adaptive systems in the EU market

#### Advantages:

Minimal impact of product costs, as mainly standard components are used

Several systems/suppliers available, such as:

- SCOT (resideo)
- iXQ (resideo)
- Sitherm Pro (Siemens)
- Elektra CMS (SIT)
- Egarc (B&P)
- Ebm-papst

#### **Disadvantages:**

- Some appliances in the installed stock cannot be converted



## Gas adaptive systems are not the only solution for end-use GQ issues

# ehit association of the European Heating Industry

#### Other mitigation measures are possible:

- For the installed stock, manual adjustment to G20 setting based on real time Wobbe Index value (accepting certain fluctuations on power output)
- Communication of gas quality data on daily basis from network operators for commercial & industrial appliances
- Research ongoing on gas quality sensors



# Self-regulated gas boilers able to cope with gas quality variation: State of the art and performances

**Project Partners** 

CETIAT, Nourreddine Mostefaoui ENGIE, Stéphane Carpentier E.ON, Petra Nitschke-Kowsky DGC, Jean Schweitzer Gas.be, Olivier Thibaut **Project Sponsors:** 

Gasunie Transport Services, Jelle Lieffering National Grid Gas Distribution Limited Lorna Millington

Tests of 5 condensing boilers equipped with combustion controls

2017-2019





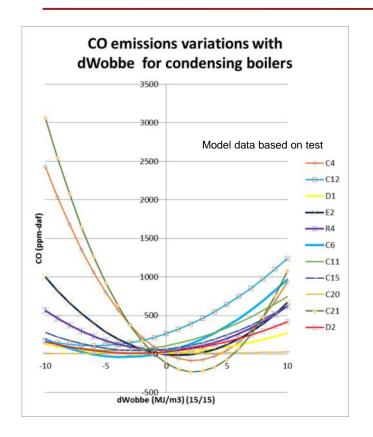
- what's the application?
- what is the GQ problem?
- what kind of problem is caused by gas quality changes

**Domestic and commercial gas boilers** 

Safety & Variation of performances with GQ

# Results from GasQual on CB's with variation of Wobbe number





- CO depends strongly on WS and increases on both sides of the range, effect depends construction.
- NOx increases with increasing WS
- The effect of Ws on boiler efficiency is negligible
- New CB´s adjusted to G20 normally cope to the WS range of group H.
- Installed aged CB's might be restricted to WS
- Installed CB´s might be not any more adjusted to G20 but to a local gas quality and loose by that their flexibility to the group H range of WS.

The technology of combustion-controlled appliances may overcome these difficulties, as they adjust steadily to the nominal operation point.



- what's the application?
- what is the GQ problem?
- what kind of problem is caused by gas quality changes
- what is the chosen mitigation measure and why was it chosen?

**Domestic and commercial gas boilers** 

Safety & Variation of performances with GQ

**Combustion control based on ionisation** 



- what's the application?
- what is the GQ problem?
- what kind of problem is caused by gas quality changes
- what is the chosen mitigation measure and why was it chosen?
- how was it implemented and what are the performances?

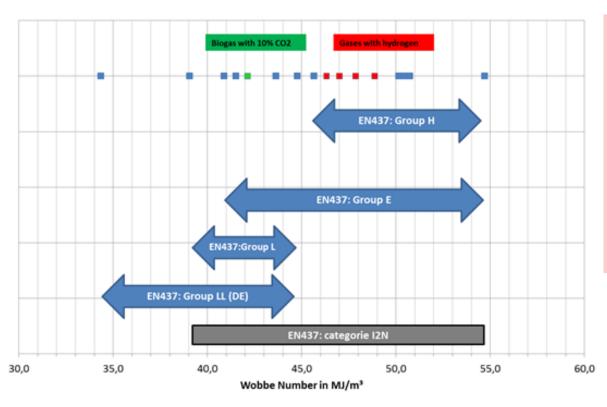
**Domestic and commercial gas boilers** 

Safety & Variation of performances with GQ

Combustion control (CC) based on ionisation
Air ratio constant

### Gases used for the testing





Test Gases over the whole range of natural gases.

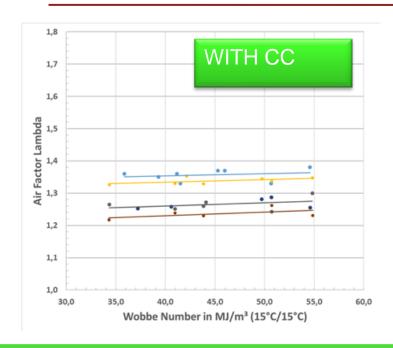
Including the German group LL

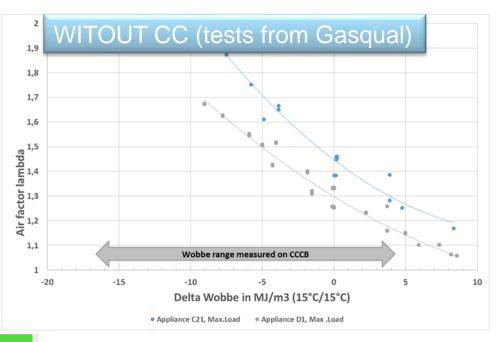
Including hydrogen admixture up to 30%.

Including biomethane - here CH4 with 10% CO<sub>2</sub>

### Air factor is maintained with CC





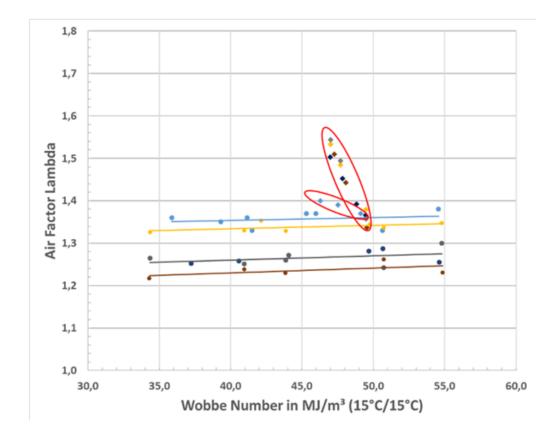


Air factor quite constant over the whole range of Natural Gases with Ws from 34.3 MJ/m³ to 54.7 MJ/m³.

Appliances are safe & performances are maintained

### Air Factor change with H2

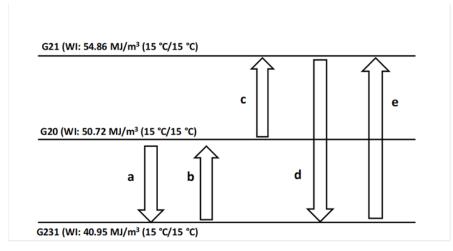




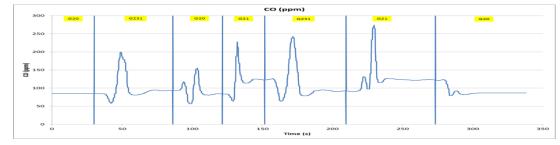
Ionization Combustion Control generally doesn't work well with H2 for but for one of the boilers the air ratio measured is almost constant.

# Operation under rapid change





All boilers are able to cope with instantaneous jumps of gas quality from minimum to maximum and vice versa without any interruption of operation. The time to return to nominal operation (stabilization time) is between 0,5 and 2 minutes (3 minutes was observed in one case)





- what's the application?
- what is the GQ problem?
- what kind of problem is caused by gas quality changes
- what is the chosen mitigation measure and why was it chosen?
- how was it implemented and what are the performances?
- costs
- main recommendation/lessons learnt?

**Domestic and commercial gas boilers** 

Safety & Variation of performances with GQ

**Combustion control based on ionisation** 

Air ratio constant

# Costs Conclusion Recomendations



- According interview with manufacturers the mass production of CC and implementation is not giving a significant cost increase to the boiler
- Beside this, boilers with combustion controls are potentially easier to install and maintain = savings on servicing
- The testing of boilers equipped with combustion controls (ionization) have proved that they can cope with very large variations of natural gas (from lowest L to highest H!). Some can also cope with H2.
- Having new boilers equipped with CC would be recommended!
- Checking retrofit possibilities?







# **Reserve slides**

# **Technology of CCCB's - Sensors**



#### Overview on Gas Quality Sensors, Device ...

upstream of combustion zone

- Gas chromatography
- Mass Spectrometry
- Infrared Spectrograph
- Wobbelis (engie)
- Micro Wobbe Index Meter
- Several in development

in the combustion zone

- Flame Ionization
- Flame temperature monitoring
- IR emission
- Flame shape

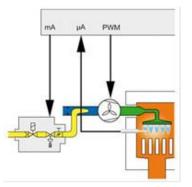
downstream of combustion zone

- O2-Measurement
- CO-Sensor

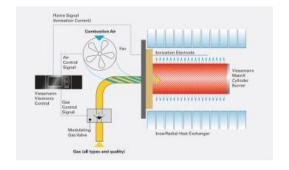
Currently three of these sensors are used in combustion controlled condensing boilers.

# Realized systems in CCCB based on Ionization Signal (Examples)

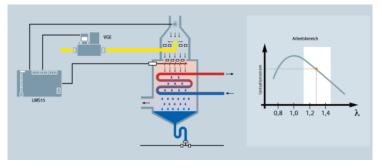




SCOT system Kromschröder



Lambda Pro system Viessmann



Sitherm Pro system Siemens



VESTASIT system SIT

Design of the realizations differ in evaluation of the signal, design of recalibration program and electronic control.

### **Manufacturer of CCCB**



Manufacturer	Load range	Year of market entry		
Ariston	?	?		
<b>Bosch Thermotechnik Buderus</b>	up to 20 kW	2017		
Bosch Thermotechnik Junkers	up to 20 kW	2017		
Brötje	15 kW-38 kW	2006		
Chappee	12 kW	2016		
Hansa	up to 36 kW	2018		
Interdomo	15 kW-68 kW	2012		
Rotex (Daikin)	15 kW – 28 kW	2017		
Max Weishaupt	15 kW-60 kW	2001		
Vaillant	up to 28 kW	2003		
Viessmann	13 kW-150 kW	2005		
Wolf	15 kW-30 kW	2013		

Combustion controlled condensing boilers are on the market since 2001.

Meanwhile 12 different manufacturers offer CCCB on the European market.



ENGIE LAB CRIGEN WOBBELYS Solutions: A Mature (>15 years) range of Technologies facing these new challenges

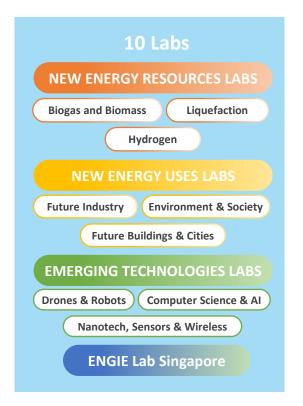


<u>Senior Global expert - Director of research</u> <u>programs - ENGIE</u> <u>philippe.buchet@engie.com</u>

### **ENGIE Lab CRIGEN in a Nutshell**

Master tomorrow technologies, bring them to maturity and prepare the zero carbon transition

€35 million employees revenues from 37 yrs 30 countries Average age 100 Patents in portfolio 11 nationalities 51 PhD facilities in Europe 10 Co-operative education students **ISO 9001** 19 Trainees certified



# Distributed Fuel-Gas quality variations in Europe/world are trending to increase!

#### A consequence of:

- •The increase of the natural gas demand :
  - ✓ Diversification of natural gas sources at deliverable points
  - ✓ Improvement of the interconnected gas Grids and more LNG resources
- New trends with Energy transition pathway:
  - ✓ Future will to "greener" distributed Fuel-gas (Biogas, bio-methane, H2...)
  - ✓ Decentralization and diversity of future Green Fuel-gas

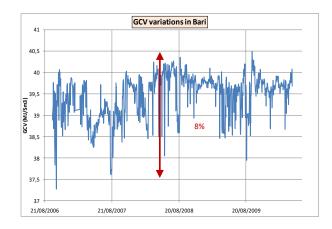
#### Today - EASEE-gas CBP on gas quality:

- √ 47 < Wobbe Index (WI) < 54 MJ (+/-7%)
  </p>
- √ 0,55<rd<0,7 (no spec. for GCV)
  </p>

For ex: in Italy (SNAM Rete Gas specifications):

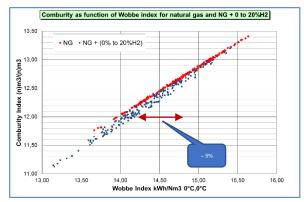
- 47.3<WI<53.3 MJ/Sm3
- 35.0<GCV<45.3 MJ/Sm3

More than 8% of variations is an issues for several industrial processes!



#### Examples of:

- GCV variations in Europe (red dots)
- and Variation of Wobbe index with NG+H2 blend (bleu dots)



# « Sensitivity » of gas-fired thermal process from variations in gas quality

Not sensitive

In industry, some processes are more sensitive to changes in gas quality; e.g. where:

- The flame is used as a tool (e.g. flame work in glassware industry),
- Process temperatures are very high (e.g. melting glass furnaces or glass feeders),
- Combustion products are used in the processing (e.g. direct contact firing and thermal treatment, in ceramics or metallurgy),
- Combustion sparks off a chemical reaction (e.g. lime production).

Main impacts are related to metering of fuel-gas quality and Control of the fuel-gas Combustion

	Variations in GCV or Wobbe index					
Thermal process	< 3%	3 to 5%	5 to 10%			
Shell boilers						
Air drying or drying oven						
Water-tube boilers						
Non ferrous metal melting						
Metals reheating						
Glass heating, decorating						
Tiles and bricks firing						
Gas turbines (premix burners)						
Metals heat treatments						
Lime or alumina calcining						
Finest ceramics firing (china)						
Glass flame working (bulbs)						
Glass melting and feeders						

Little sensitive

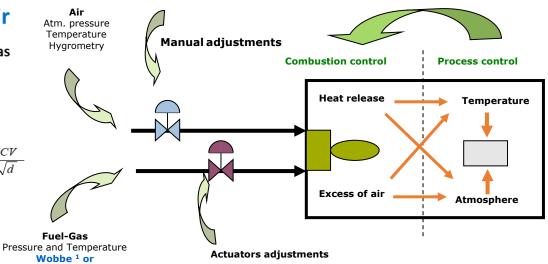


# In industrial processes: Control of the Combustion parameters are Keys factors in the performance of thermal processes (environmental and Energy efficiency and profitability)

GCV (gross calorific value)

### Control of power input & excess air

- Control of power input : P(kw) = Flow of fuel-gas (Qn)\* GCV
  - Flow depends of pressure drops; temperature and density :  $m{Q_n} = constant imes \sqrt{rac{\Delta p}{T \cdot d}}$
  - P(KW) is proportional to Wobbe Index (WI):  $WI = \frac{GCV}{\sqrt{d}}$   $P[kW] = constant \times \sqrt{\Delta p} \times WI$
- Control of air factor n:
  - R : Air/gas flows ratio , Va : Stoichiometric air flow  $n = \frac{R}{}$
  - Comburity Index B:  $B = \frac{Va}{\sqrt{d}}$



- → Continuous measurements of GCV or WI is essential for :
  - → Good design of burners /combustion systems
  - → Good control of Power input and combustion quality are function of Wobbe Index or GCV

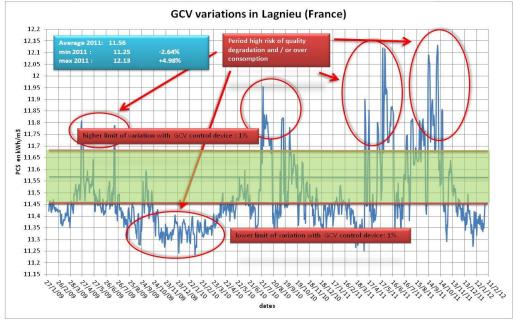
<sup>1</sup> Wobbe Iindex =  $GCV/\sqrt{density}$ : main combustion characteristic of a fuel gas

# Example of impacts of fuel-gas quality in high temperature process industry

GCV variations in container glass plant (France)

#### **Process impacts:**

- ✓ Increase of Energy consumption (2-10%),
- ✓ Increase Maintenance costs (Burner adjustments ex: Feeders, cleaning nose burner...),
- ✓ Production issues:
  - Variation of temperature of parison => variation of glass viscosity;
  - ❖ Increase of production returns (~several %);
  - ❖ Non-compliance with the specifications of the production ...)



# ENGIE lab Combustion control in the industrial gas-fired processesa Complete range of ENGIE SOLUTIONS

# System for natural gas WOBBE/ GCV index measuring





POCCILIS

# System for natural gas Wobbe index controlling



**INDELIS** 

#### **New systems (**Coming soon**)**:

- **WobHylis**<sup>®</sup>: An innovative device developed for Wobbe & GCV index for NG & natural gas-H<sub>2</sub> blends
- **J-NET**<sup>®</sup>: An innovative device developed for NG & natural gas-H<sub>2</sub> blends for distribution Grid



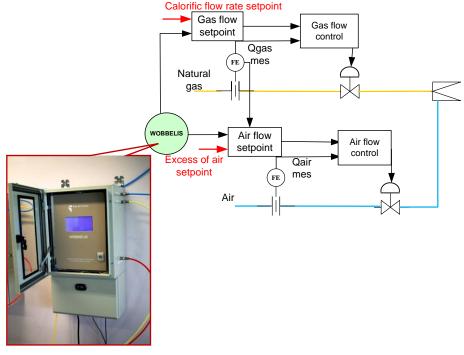
# Example: WOBBELIS® & POCCILIS® solutions implementation Combustion control with an GCV/WI correction

#### 2 solutions:

- If gas flow measured within a diaphragm or a venturi, then use WI (WOBBELIS)
- If gas flow measured within a volumetric meter, then use GCV (POCCILIS)
- Example : control flow sheet for the glass melting furnace

#### Main features:

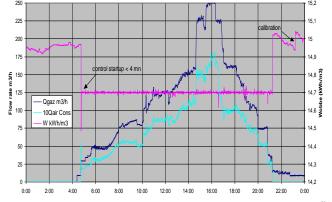
- Measure by correlation, without combustion or gas analyze (Engie patents)
- ❖ Small footprint, weight 9 kg; IP65 cabinet
- ❖ Pressure supply > 1bar
- ❖ Accuracy better than 1% for all the natural gases supplied in Europe
- Self calibration and automatic restart
- Continuous output signal 4-20 mA (or digital connexion in option)
- ❖ MMI by touch screen
- Complying with EMC European Standards



### **INDELIS®**: correction through regulation of the Wobbe index

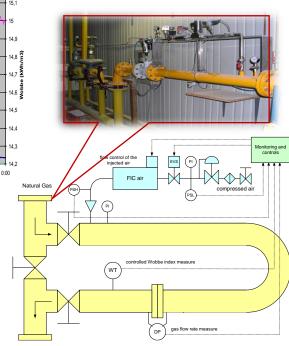
## A Wobbe index **control station** developed by ENGIE:

- Controlled injection of a small quantity of air into the gas
- Easily available up to 1000 Sm3/h of fuel-gas, to define above
- accurate control (<1%) of WI from 10 to 100% of the nominal plant gas flow rate



→ For container glass : melting &/or glass feeders/forhearth

→ Ceramics appliances implementation of Indelis reduce the reject rate very significantly



### WobHylis®: An innovative item developed for natural gas-H<sub>2</sub> blends

NEW

To enhance the measurement devices portfolio already managed by Engie Lab Crigen, a new apparatus has been developed to replace the Wobbelis range within a unique adaptative instrument.

**WobHylis**<sup>®</sup>: a complete product to determine precise Wobbe index and calorific value of blends from Natural Gas and H<sub>2</sub> by algorithmic correlation-based and introducing a continuous online H<sub>2</sub> measurement.

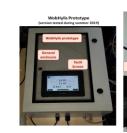
Designed	and	patei	nted	by		
Crigen,	this	рі	ototyp	e's		
developme	nt is	under	progr	ess		
within a p	artner	ship ir	ntegra	ting		
the provider Tecora.						

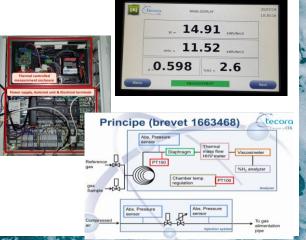
Item patented under reference  $N^{\circ}$  **WO2018122490A1** and finally named **WobHylis**<sup>®</sup>.

Instrument	Deb. mass	Diaph	Visco	Regu.	Catarc	w	PCI	H <sub>2</sub>	D	Inject
Wobbelis	Х	X				Χ				
Indelis	Χ	X				Χ				X
Poccilis	Х		Χ	Χ			Χ			
New Indelis	х	Х				X				х
New Indelis H2	Х	х			х	Х		X		Х
New Poccilis	Х	х	Х			Х	Х			Х
WobHylis	х	Х	Х		Х	х	Х	Х	х	x

#### **Ongoing Project:**

- Several experimental tests achieved in 2020 within blends up to 20% of H<sub>2</sub>.
- ➤ Enhancements in progress on industrialization steps to guarantee the most reliable H₂ measurement.







### J-Net system

#### Low-cost and correlative solution for Gas Calorific Value (GCV) measurements

#### Context:

The Gas Calorific Value (GCV) refers to the amount of energy released when a known volume of gas is completely combusted under specified conditions . The injection in the gas networks of different resources of Ng & new gases such as biomethane leads to variations of GCV over time and space .

Hence, European DSOs (Distribution System Operators) needs GCV monitoring solution to control gas quality on the biomethane injection plants, upgrade flow monitoring on the network and ensure a fair billing of industrial clients .

However, existing solutions to measure GCV are expensive, need a laboratory or a specific environment and cannot be deployed anywhere .

#### Added value:

ENGIE Lab CRIGEN developed the **J-net system**, a low-cost, connected and correlative solution for Gas Calorific Value (GCV) measurements . This system will allow, by adding new GCV measurement points on existing gas network,

to simplify billing depending on areas and to increase knowledge of gas flowing through the networks in terms of GCV .

The goal is to facilitate the injection of non-conventional gas into the network . More specifically it is to help biomethane development in France and in Europe by facilitating the injection on existing.

#### **PROJECT development**

#### 2018-2019:

Specification, design and manufacturing of five prototypes, laboratory validation of the architecture for every use case . Start of certification testing . Add of O2 and CO2 concentration measurements .

2020 -2021 : Finalization of industrialization . Test on Distribution Grid . Implementation of H2 measurements for NG/H2 blends, Accuracy <1% GCV evaluation up to 6% hydrogen blend
The targeted price < €1000





### Conclusions (1/2)

#### THE ENGIE SOLUTION SERVICE OFFERS

- Diagnostics on site of instrumentation and control system used for the process
- > Installation, starting up, hiring and maintenance of the appliance by ENGIE TEAM
- Specific ENGIE services contract without need of Customer's capex and including maintenance and calibration
- >Technical specifications:
  - ✓ IP65 cabinet, MMI by touch screen
  - √ Accuracy better than 1% for majority of natural gases
  - √ Self smart calibration and automatic restart
  - ✓ Turndown: from 8% to 100% of a nominal gas flow rate

#### >Stated benefits:

- √Energy savings (~2-5%)
- √Reduce of the number of operations for burners adjustments,
- ✓ And the most important : improvement of the quality in production (more than 50% for specific cases).









# Conclusions ENGIE lab CRIGEN :A complete range of ENGIE SOLUTIONS for variations of distributed gas quality











WOBBELIS

**POCCILIS** 

**INDELIS** 

**WOBHYLIS** 

J-NET

### A complete Range of solutions for management of variations of gas quality In the last 15 years more than 60 industrial references into:

- Glass industries (for supplying melting glass feeders), many references (Owens-Illinois; Niproglass; SGD, Geresheimer...);
- Ceramic industries ( batch furnaces: Bernardaud, Jars, Doralaine ...)
- Steel industries : ArcelorMittal, Ascometal, Alcan...
- Lime industries : Bocahut
- Other appliances : CHP plant ...





# Prime Movers' Group Gas quality & H2 handing knowledge sharing session on mitigating measures

Lessons from the past in The Netherlands



# Increase upper limit Wobbe Index in NL October 2014 Dutch 'regulation' gas quality

- Concern and uncertainty H-gas customers after announcement in 2009 to increase upper limit of the WI from 54 to 55,7 MJ/m3,
  - motive: EASEE-gas CBP and new LNG terminal (GATE)
  - Adjustment appliances before1 Oct 2014 (Dutch MR gas quality entry into force)
    - 80 H-gas customers consuming all H-gas ~equal to G-gas consumption
    - · Various regional bandwidths depending on regional entry specifications
  - G-gas WI Bandwidth 43,46 44,41 MJ/m3 (25:0) unchanged
- Responsibility:
  - MS (Ministry Economic Affairs): gas quality is political decision
  - TSO: to deliver gas according political specifications (we are only a transport company for a quality neutral gas market)
  - Customers: Responsible to accept all gas quality specifications and its variations between the widest legal bandwidths + forced to sign a connection 'agreement'

We could not refuse the gas
We could not choose our gas
TSO did not know which gas would be injected
We could not send the gas back
HOW COULD WE MANAGE OUR REPONIBILITY



## Case study ammonia plant

South Netherlands 8 – 12 May 2012

WI range: 50.3 – 53.7 MJ / m<sup>3</sup>

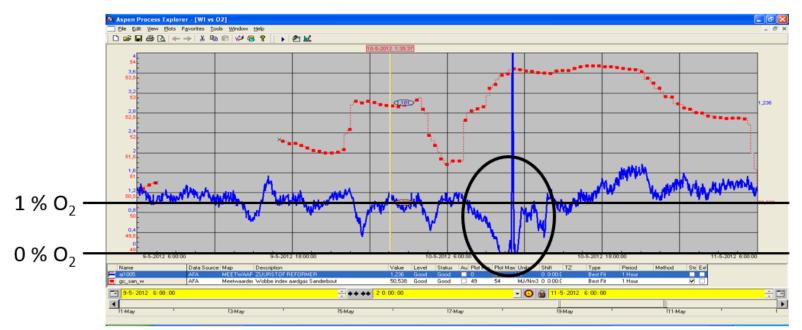
WI rate of change: max. 4 MJ / hour





### O<sub>2</sub> % after combustion

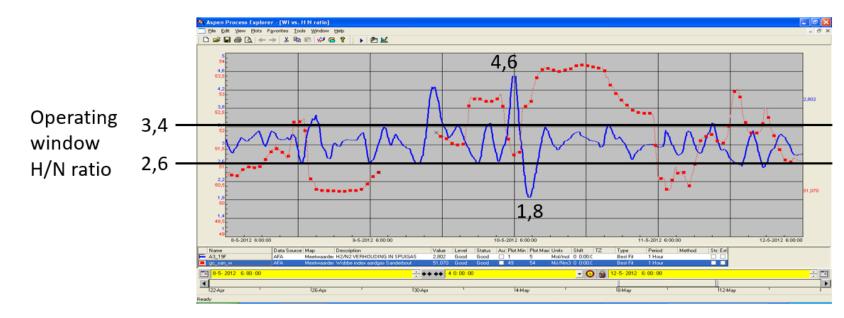
If O<sub>2</sub> % after combustion < 1 % → CO formation & flame instability = ! SAFETY RISK!





### H/N ratio in NH3 synthesis reactor

Normal operating window far exceeded → can eventually lead to plant trip
 =! SAFETY RISK!





## Take aways and mitigating measures

- High uncertainty if control room operator would be able to accommodate future fast changes
- Additional investments needed to maintain the same level of
  - Safety
  - Reliability
  - Efficiency
  - Emission should stay between the limits of the permits (LtO)
- Investments in Advanced Process Control based on Masse Spectrometer analysis, GasTurbine modifications,.....and some more
- no safeguards for future gases



Most important mitigating measure is to acknowledge the specified class as default incl. absolute limitations outside 1-99% probability range.....



CEN SFGas GQS: Recommendations and considerations on

Wobbe index aspects related to H-gas

. . . 5

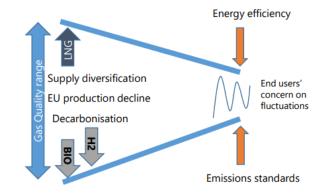
29th Madrid Forum: EC Mandate M/400 for harmonization of Gas Quality

#### 29th Madrid Forum - Oct. 2016:

- The Madrid Forum during its meeting of October 2016 encouraged CEN "to carry on the
  work on finding an agreement on a band for the Wobbe Index, elaborating on the
  possibility of regional bands, to be included in an updated CEN standard [EN 16726] [...]"
- "The Commission will reconsider further harmonisation activities in light of the outcome of the CEN revision work."

#### 31st Madrid Forum conclusions - Oct. 2018:

- Invitation to CEN to integrate renewable and low-carbon gases in European standard for H-gas quality
- · Assessment of effects and refurbishment costs of increasing hydrogen shares on
  - Gas grids, storage facilities, end-user appliances
- · Emphasis on the importance of
  - First experiences, sharing of best practices, digitalisation



M/400 issued Jan 2007 adopted 12<sup>th</sup> Madrid Forum

Production

TSOs & DSOs

End use

Getting ready for renewable gases Promoting gas as energy carrier Facing competing wishes across the network



.... which will also limit the risks of high variations and comply with the conclusions of the MF of April 2015



# CEN SFGas GQS: Recommendations and considerations on Wobbe index aspects related to H-gas

27th Madrid Forum April 2015:

29th Madrid

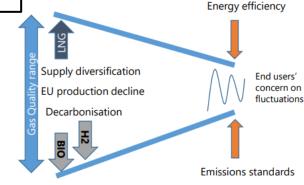
Encourages relevant stakeholders at national level to pursue the assessment of
potential future instabilities in the Wobbe values and the impacts that has on
the safe and secure operation on gas appliances and processes.

#### 29th Madrid Forum - Oct. 2016:

- The Madrid Forum during its meeting of October 2016 encouraged CEN "to carry on the
  work on finding an agreement on a band for the Wobbe Index, elaborating on the
  possibility of regional bands, to be included in an updated CEN standard [EN 16726] [...]"
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  - First experiences, sharing of best practices, digitalisation



Production

TSOs & DSOs

End use

Getting ready for renewable gases Promoting gas as energy carrier Facing competing wishes across the network



### Preconditions for identifying mitigating measures at the exit

- 1. Legal network codes with precise specifications about future gasses
  - Predictability: we need to know the gas composition in advance;
     H2 and Biomethane have seasonal profiles (storages?)
- 2. Inform the public in case of a change of the gas quality at the exits
  - as soon as TSOs/DSOs are aware of a foreseeable gas quality change outside the range of the downstream system in the past
- Near real time information is very much appreciated
- 4. Responsibilities should be clear, and risk should be manageable
  - Risk management always start with the source and never at of pipe (measure of last resort)
- 5. Compensation costs (Causer pay principle)
- 6. No 'one size fits all' solution for industrial customers
  - We need long validity duration of classes also with respect to long lead times (major adjustments only in 5years turnaround cycle)



# Power Generation Gas Turbines: Mitigation of Issues Associated with Gas Quality Variation & Hydrogen Addition

**Dr David Abbott** 

**ETN Emeritus Member** 

Visiting Fellow: Cranfield University

Technical Consultant: Uniper Technologies Ltd

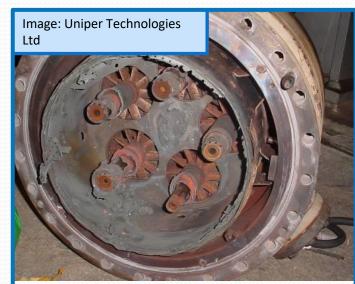
# Gas turbines are often considered to particularly sensitive to changes in gas quality and H<sub>2</sub> addition. Why?

- Gas Turbines combustors are highly tuned to give maximum cycle efficiency and low emissions:
  - > The most common low emissions combustion technology is lean premixed combustion
    - Prone to thermoacoustic pressure oscillations (pulsations/dynamics) and flame stability issues (flashback, blow-off)
    - Combustor tuning is optimised for a particular conditions including fuel composition: therefore they are sensitive to changing conditions
- Continuous high pressure combustion
  - ➤ Energy density is much greater (typically 10 to 30 times) than atmospheric pressure combustion
    - If issues occur damage happens more rapidly than for atmospheric pressure combustion

24th February Gas Turbines: GQ and H2 Issues

### High pressure combustion → High energy density

- Dynamics amplitudes tend to scale on mean pressure → increased risk of damage due to dynamics
- If overheating occurs (e.g. due to flashback), dissipation of the energy is more difficult due to increased energy density → damage more likely and occurs more rapidly
  - Greater risk of problems and more difficulty addressing them



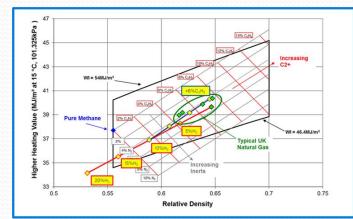
Damage following mechanical failure due to high frequency dynamics (~2kHz) followed by flashback

### Issues due to changing Wobbe Index and fuel composition

- 1.  $NO_X$  emissions increase as deviation from optimum fuel composition (WI, higher hydrocarbon content etc.) increases
- 2. Dynamics increase as deviation from optimum fuel composition (WI, higher hydrocarbon content etc.) increases
- Flame stability issues leading to dynamics and part load CO problems with Wobbe Index or low reactivity fuels
- Component overheating due to changes in flame shape and position (including flashback) due to changes in composition, particularly high reactivity fuels
  - Gas Turbine operational restrictions, de-loads and trips (1,2,3,4)
  - Increased component wear, reduced life, increased maintenance requirements (2,4)

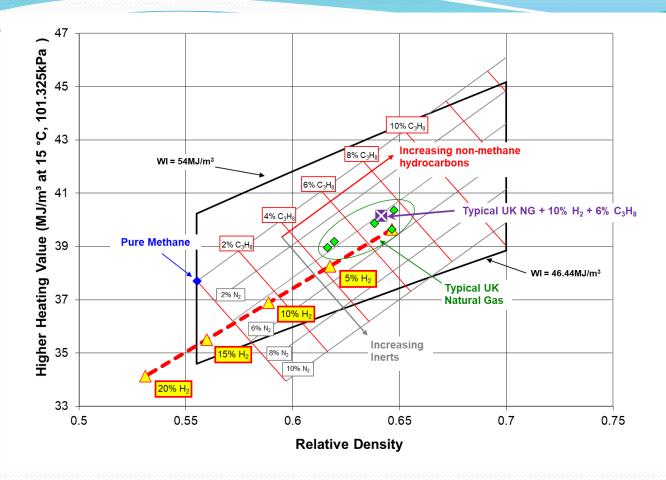
Gas Turbines: GQ and H2 Issues

Catastrophic component failure (2,4)



If the rate of change of WI is too high, control systems cannot respond quickly enough: OEM specifications range from 0.5%/s to 0.5%/min [1]
BUT: Difficulties is defining a

BUT: Difficulties is defining a meaningful rate of change



### Mitigation measures (1)

- What can be done in principle?
  - Modify the fuel properties
  - Modify the combustion system
  - Control it differently
- Measure Wobbe Index and change the effective WI using variable fuel heating
  - > Relatively low cost
  - Application only useful for systems particularly sensitive to WI
  - Not effective in reactivity related issues (will not help with H<sub>2</sub>)
- Combustion system redesign
  - Has effectively eliminated most flashback issues, but may not be the case for H<sub>2</sub>
  - Improvements in stability, emissions and dynamics

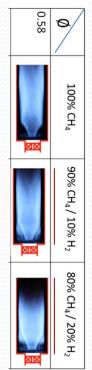
### Mitigation measures (2)

- Measurement of full fuel composition and compensation through control
  - > Issues with speed of composition measurement
- Rapid measurement of key fuel properties: e.g. Higher hydrocarbon content: compensate using variable control parameters
  - System specific applications, e.g. sequential combustion
- Control system response to changes in gas turbine behaviour (particularly emissions and dynamics) without fuel composition or property measurement
  - Closed loop control of dynamics
  - Automatic tuning systems
    - a) Closed loop control of dynamics and/or emissions according to a fixed set of rules
    - b) Closed loop control of dynamics and/or emissions through model based control using self teaching algorithms
    - c) Al based systems
  - > Can be very effective
  - ➤ Most OEMs and some 3<sup>rd</sup> party suppliers offer auto-tuning options for some gas turbines

### Hydrogen

- The above issues and mitigation measure apply equally to fuel variation caused by the addition of hydrogen,
  - > BUT: the complexity of the problem is increased due the additional variability and the very different combustion properties of hydrogen
- Gas turbine fuel specifications applicable to most of the existing low emissions fleet typically allow from trace to ~5vol% H<sub>2</sub> with some allowing in excess of 20vol% [3]
  - > OEMs are revisiting fuel specifications and allowing increased hydrogen for some systems and are developing upgrades to allow further increases
  - OEMs are investigating alternative combustion and control concepts for high hydrogen
  - ➤ It is currently not clear what level of hydrogen blending would be generally acceptable or what level/range of hydrogen addition can practicably be accommodated
  - Possible issues associated with alternative fuels for starting

Impact of hydrogen on flame shape (Shanbhogue et al [4]



### Summary

- A range of mitigation measures exist for the main issues associated gas quality variation,
   BUT:
  - Due to the wide range of designs and technologies in the existing fleet, suitable measures/upgrades are not available for all the current gas turbines
    - Some plant may not be able to operate economically with greater fuel quality variation
    - Issues with hydrogen are greater and many gas turbines will not be able to operate with high levels of hydrogen
  - ➤ Even were emissions and dynamics can be controlled within "acceptable" limits, increased fuel variation will lead to increased overall emissions and increased component wear
  - Many issues associated with using hydrogen blends are not fully understood and need further investigation

### References

- 1. European Turbine Network Position Paper, The Impact of Natural Gas Quality on Gas Turbine Performance, February 2009
- 2. D J Abbott, J P Bowers, and S R James, Impact of Natural Gas Composition Variations on the Operation of Gas Turbines for Power Generation, 6th International Gas Turbine Conference (IGTC12), October 2012, Brussels, Belgium, Paper ID Number: 27-IGT12
- 3. David Abbott, The Challenges for Gas Turbine Operators of Changing Fuel Compositions and the Availability of Alternative Fuels, 8th International Gas Turbine Conference (IGTC16), October 2016, Brussels, Belgium, Paper ID Number 79-IGTC16
- 4. S.J.Shanbhogue, Y.S.Sanusi, S.Taamallah, M.A.Habib, E.M.A.Mokheimer, A.F.Ghoniem, Flame macrostructures, combustion instability and extinction strain scaling in swirl-stabilized premixed CH 4 /H 2 combustion, Combustion and Flame 163 (2016) 494–507

# Wobbe Index sensitivity reduction reciprocating engines

February 24, 2021
Jacob Klimstra

# Not a single engine technology



**Gas-diesel** for accepting a wide range of gas qualities (e.g. flare gas)
Gas injection at 350 bar together with diesel fuel
Only economic at well heads for avoiding flaring and producing electricity.



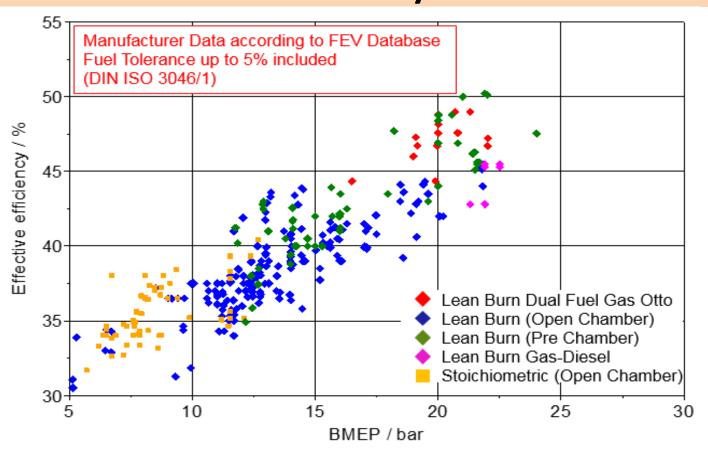
**Duel-fuel** for achieving high availability in case of gas supply failure and rapid response. High compression ratio needed for diesel ignition and therefore sensitive to WI increases. Applications at larger hospitals (emergency power) and in ships.



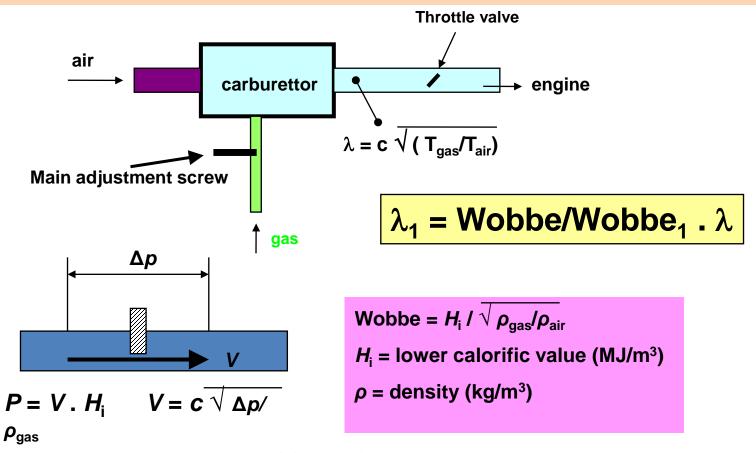
#### Spark-ignited

- open chamber, swirl chamber, pre-chamber
- rich burn, lean burn

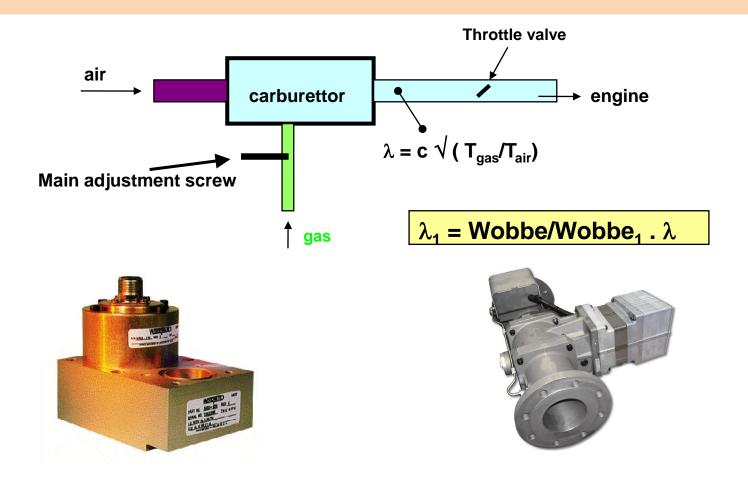
# BMEP reduction means more expensive engine + lower fuel efficiency



### The carburettor and Wobbe Index



### Adjusting the lambda to Wobbe Index changes



# Increasing Wobbe Index: - Lower air-to-fuel ratio - lower knock resistance

Reduce sensitivity by lower compression ratio and lower output:

- -Higher investment price + lower fuel efficiency + slower step response for carburettorbased engines.
- Install Tecjet or EGAVS: tailor made solutions for large existing population = expensive





### In summary

It is possible to make reciprocating engines less sensitive to gas quality variations

- Install knock detection + connected load reduction or ignition timing control
- Decrease the compression ratio (resulting in lower efficiency)
- Install electronic main-adjustment screws (often requiring a complete new control system)
- Decrease the specific load (resulting in a higher investment and a lower efficiency)

Statement: newly to be installed engines are generally more sophisticated and tolerant, but it is not really feasible for the existing population with manual adjustments to make them fit for a changing gas composition. The available additional life of these units is more than 10 years. They would need a complete refurbishment which would mean that the customers goes for an electric alternative.

During the preparation of this presentation, I got a telephone call from a major engine manufacturer stating that the older engines are starting to knock. The reason: the addition of nitrogen to natural gas in the L-gas system in order to keep the Wobbe Index within limits

## **Bibliography**

- 1. John Oakley, ed, 'Fuel Flexible Energy Generation', Woodhead Publishing series in Energy, number 91, 2016, ISBN 978-1-78242-378-2
- 2. Christos A. Frangopoulos ed. 'Cogeneration Technologies, Optimisation and Implementation', The Institution of Engineering and Technology, 2017, ISBN 978-1-78561-055-4
- 3. Jacob Klimstra, 'Power Supply Challenges solutions for integrating renewables', printed by Arkmedia, Vaasa, 2014, ISBN 978-952-93-3634-0
- 4. John B. Heywood, 'Internal Combustion Engines Fundamentals', Mc. GrawHill Book Company, 1988.
- 5. Jacob Klimstra (Gasunie), Angel Benito Harnaez (Enagas), Wim H. Bouwman (Gastec), Antoine Gerard (Distrigas), Vittoriuo Quinto (SNAM), Graham Robers (BG Technology) and Hans-Jürgen Schollmeyer (Ruhrgas), 'Classification methods for the knock resistance of gaseous fuels an attempt towards unification', ASME paper No. 99-ICE-214, 1999 Technical Fall Conference, Ann Arbor, Michigan, 1999.
- 6. Jacob Klimstra, 'Interchangeability of Gaseous Fuels The Importance of the Wobbe Index', Paper 861578, SAE International Fuyls and Lubricants Meeting, Philadelphia, Pennsylvania, October 6-9, 1986.
- 7. Jacob Klimstra, 'Catalystic Converters for Natural Gas Fueled Engines A Measurement and Control Problem', Paper 872165, SAE International Fuels and Lubricants Meeting, Toronto, Ontario, November 2-5, 1987.

### **Q&A** session

**Coffee break** 

See you at 11:50 CET



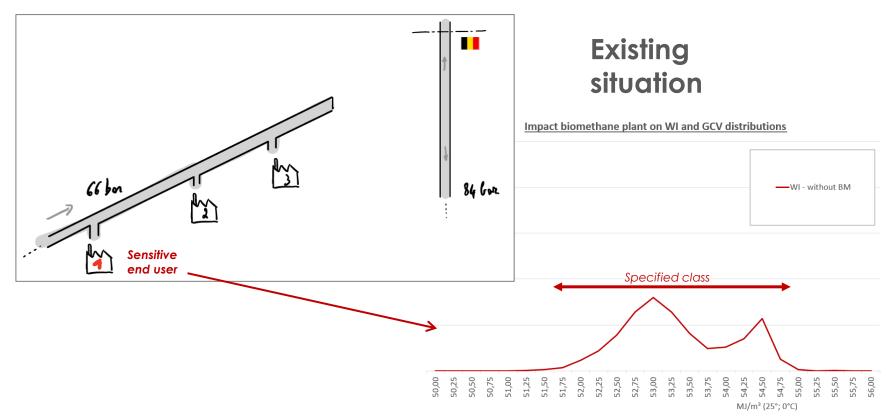
Session 2 - Case studies at grid level: What are the principal mitigation options at grid level?

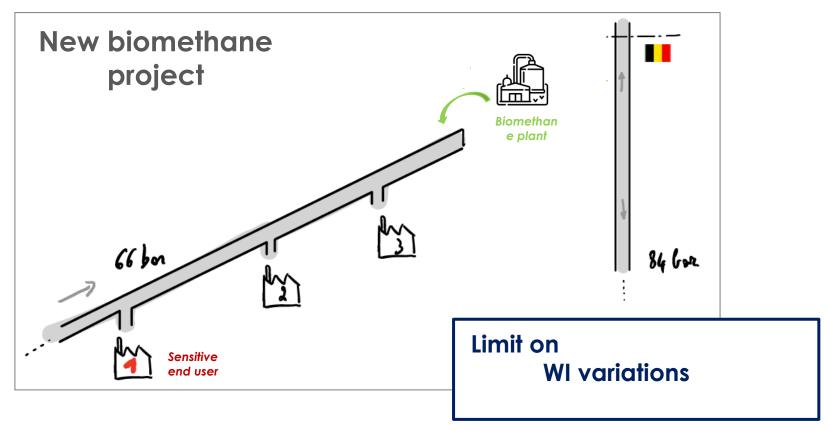


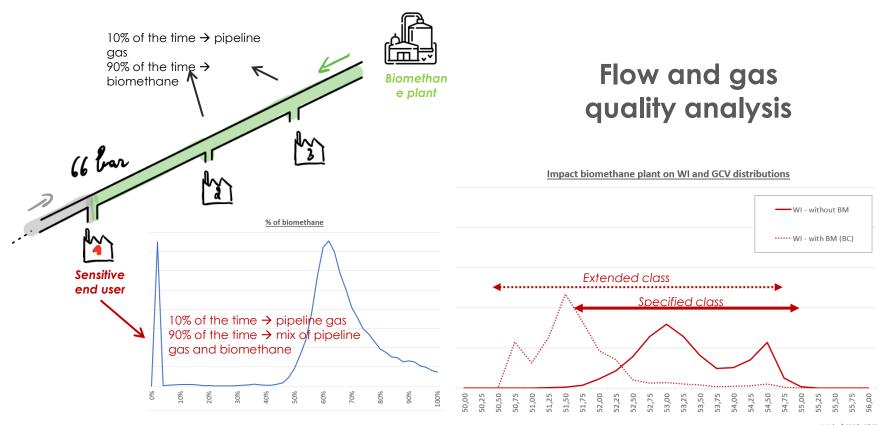
# PMG – Possible mitigation measures – use cases at Fluxys Belgium

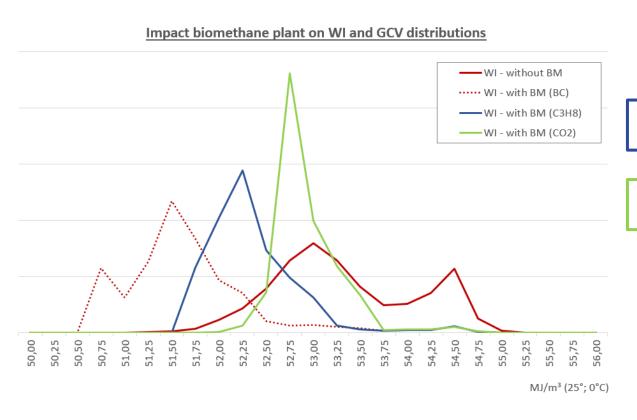


24/02/2021









# Mitigation measures (WI Range)

 $C_3H_8 0\% \rightarrow 3\%$ 

CO<sub>2</sub> 2,5% → 0,5%

CO<sub>2</sub> option preferred by biomethane producer (0,5% possible with membrane technology at reasonable cost)

WI variations

Unit MJ/m³ (25,0)

Mitigation measures (WI variations)

		wi variations		
		above 0,5 MJ	above 1 MJ	above 2 MJ
No biomethane injection	AS IS	0,785%	0,066%	0,000%
Biomethane injection	BC. 8000h profile without spreading	1,198%	0,638%	0,236%
	LC. 8760h profile (flat)	0,489%	0,020%	0,000%
	MM1. 8000h profile with spreading (8h)	1,005%	0,044%	0,002%
	MM2. 8000h profile with spreading (4h)	1,668%	0,226%	0,060%
	MM3. BC + CO2 at 0,5%	0,385%	0,143%	0,000%
	MM4. BC + C3H8 at 3%	0,733%	0,326%	0,042%
	MM5. BC + CO2 at 0,5% and C3H8 at 3%	0,387%	0,034%	0,002%
	MM6. MM2 + CO2 at 0,5%	0,218%	0,008%	0,000%

#### **CONCLUSIONS:**

- TSO already takes measures to limit gas quality variations for sensitive end users
- Case by case analysis is needed (flows and gas quality)
- Reference to existing situation (considered as acceptable) is key

without mitigation
measure: more
variations, especially >
1 MJ

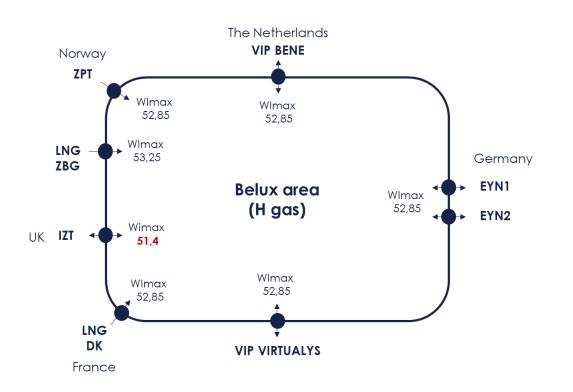
Large WI variations mostly
due to ramp-up/ramp-down
phases biomethane plant

Ramp-up/ramp-down
spreading over several
hours effectively reduce
large WI variations

Reducing the CO2 is more effective than adding C3H8 to decrease WI variations

With a mix of rampup/ramp-down spreading with reduced specification for CO2, WI variations are smaller than the existing situation for the sensitive end user





### Situation

WI max towards UK not aligned (smaller) with WI max at entries\*

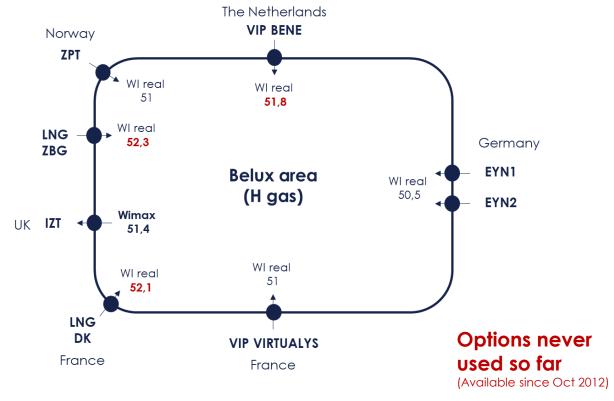
→ Mitigation measures needed



<sup>\*</sup> Process ongoing in UK to change applicable WI range → alignment on WI max expected

### 2. Mitigation measure at an Interconnection Point : Lower WI UK

Unit MJ/m³ (15,15)



### Mitigation measures

- Swapping a flow with a too high WI with a flow with an acceptable WI
- Blending two flows so that the mix has the right WI
- Ballasting NG with N2 to decrease its WI (at LNG ZBG or in network)
- 4 Gas quality constraints

### 2. Mitigation measure at an Interconnection Point : Lower WI UK

### Gas quality constraints

If other options  $(1 \rightarrow 3)$  not sufficient:

- 1. Identification of quantities that could not be swapped, blended or ballasted with N2
- 2. Identification of network users exporting gas to UK
- 3. Identification of the "polluting IPs" where gas enters the system with a WI > WI max UK
- 4. Interruption of entry nominations of those network users on those IPs (pro rata)
- 5. To respect their balancing obligations, network users that were interrupted can either
  - Reduce their exit nomination @ IZT (towards UK)
  - Increase their nominations @ IPs with WI < WI max UK</li>

Process fully automated but never used until now

#### **CONCLUSIONS:**

- TSO already takes measures to properly handle the gas quality
- Market driven mitigation measures can also be effective to help solve certain gas quality issues (but it might impact the free flow of gas between MS)



# fluxys



Prime Movers' Group: Mitigating measures for GQ & H2 handling

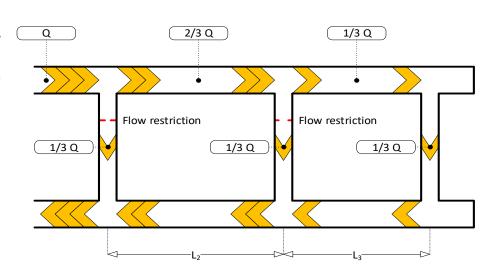
The static gradient splitter





### Static Gradient Splitter Functional specification

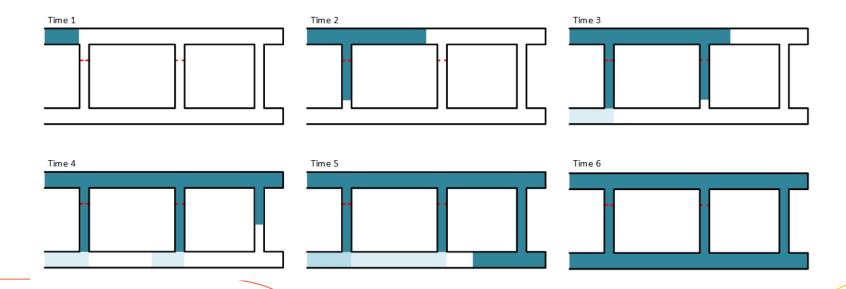
- Applicable up-, mid and downstream
- The static splitter is shaped like a ladder
- Design inputs: maximum flow, pressure, expected & desired gradients
- Flow distribution through branches determined by flow restrictions
- Avoid flow induced pulsations
- More branches possible but equal flow distribution becomes more difficult –
   Alternative more mixing organs in series
- Pressure drop causing possible additional costs





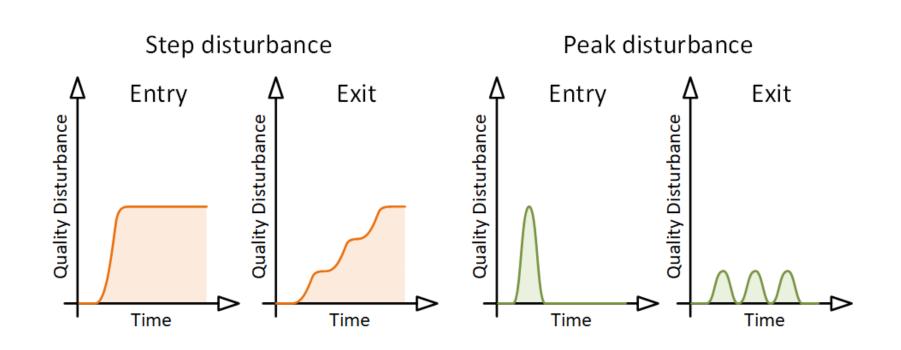
## Static Gradient Splitter *Principle*

The gas flow is broken up into several part streams, one or more parts of which gets a delay (detour) and subsequently is/are blended into the stream that didn't take a detour.





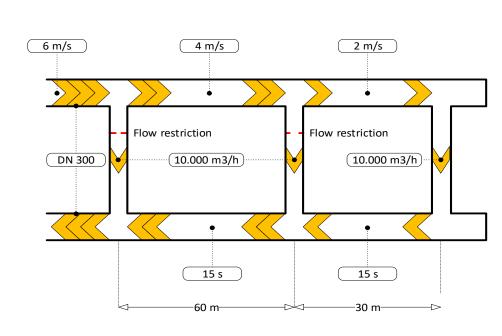
### Static Gradient Splitter Entry/Exit behaviour





### Static Gradient Splitter An example

- Design inputs
- Q: 30.000 m3/h (n) @ 20 bar(g)
- D: DN 300 -> v: 6 m/s
- QD<sub>entry</sub>: 3 MJ/m3 (n) peak disturbation
- QD<sub>exit</sub>: 1 MJ/m3 (n)
- Cost indication
- 300.000 500.000 EUR
- Remarks
- Available space may be leading
- Timescale measure: minutes
- Flow distribution is almost independent of flow
- Installation downstream of exit point in case of frontal flow situation



Feed A

Exit

Feed B

# Online tracking and forecasting of gas quality

Dr. Stefan Rickelt, SmartSim GmbH Prime movers' group, 24.02.2021

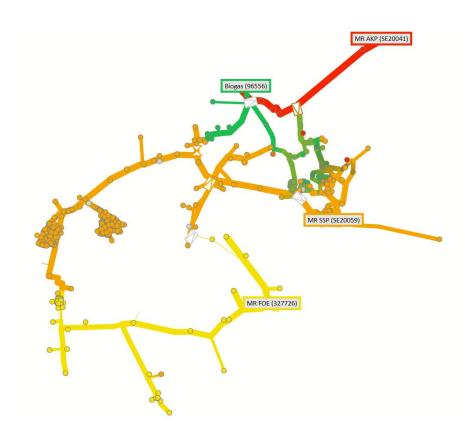




### Gas quality tracking



- Applies real data as input data volumes, pressures, gas quality...
- allows a dynamic simulation typically in hourly resolution
- gives TSOs/DSOs a clear picture about the gas distribution of a past period
- example: gas quality tracking of city grid of Malmö, Sweden
- capacity planning simulations provide a static steady-state simulation for a scenario (coldest/hottest day)

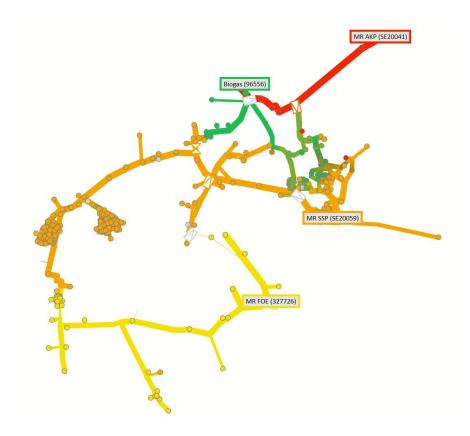


### State of the art



#### **Today**

- Important advances of simulation techniques during last years
- Some years ago, gas quality tracking and online simulation were only applied by TSOs
- More and more DSO also apply gas quality tracking in grids where exit points have no hourly volume metering
- First implementations in city grids
- Simulations at hourly resolution some online systems provide 3 minutes resolution (unvalidated data)



#### Progress in simulation tools



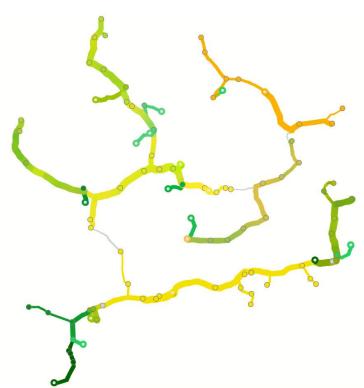
#### Next years

- Gas quality tracking feasible for more and more complex gas networks
- Forecasting as further development of gas quality tracking

key for developments are grid operators' demands e.g. forecasting for Wobbe Index exit classification for customers/exit nodes

#### and requirements

- temporal resolution
- accuracy for gas quality data



#### Grid simulations tools



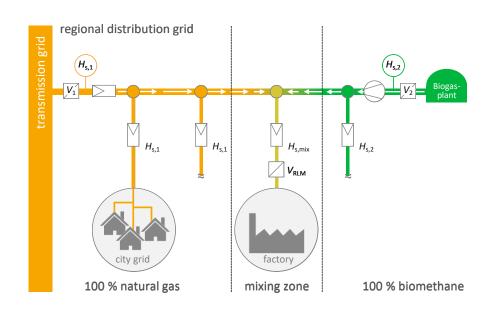
#### **Input data**

- Grid topology
- volume flows at entry and exit points
- yearly consumption/standard load profiles at exit points where no volume meters are available
- gas qualities (CV) at all entry points



#### **Calculation**

- provides output data max. in temporal resolution of input data
- → Measured data set possible resolution and accuracy/uncertainty of simulation



#### Key questions



## What time resolution is expected?

few seconds, 3, 15 or 60 minutes?

## What accuracy level is required?

±2 % for Wobbe-Index and calorific value?

#### Influence of measured data



#### **Temporal resolution**

- Volume meters
   Meters at DSO level or at large customers measure continuously but transfer data on an hourly basis
   Many customers have yearly meter reading. Hourly consumption can be derived.
- b. Gas quality measurement with GC
   measurement every three minutes → time delay from measurement time + additional
   delay for gas sample to travel to GC
- c. Data needs to be transferred, processed, e.g. corrected and simulation has to proceed

#### Influence of measured data



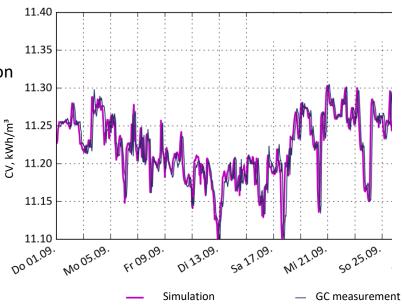
#### **Uncertainties**

- of input data govern uncertainty of gas quality calculation
- added from simulation tools is small
- have large impact on temporal resolution of gas quality calculation

#### **Example**

deviation of 0.1 bar at pressure measurement at entry point

- 1. 80 bar transmission grid, flow velocity 5 m/s distance between entry and exit point 100 km, travel time: 2000 s, resulting deviation: 25 s
- 4 bar distribution grid, flow velocity 0.1 m/s
  distance between entry and exit point
  100 km, travel time: 285 h, resulting deviation: 7 h



#### **Conclusions**



- Important advances of simulation techniques during last years
- Ongoing advances in the next years: grid complexity, data handling, simulation efficiency
- Systems rely on quality of input data (temporal resolution and accuracy)
- Challenges in online systems: instantaneous handling of missing and implausible input data
- Forecasting: some inevitable limitations due to unforeseeable incidents: dropout of biomethane production or of large customer

# Thank you for your attention!

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French situation – Key figures



- 2 TSO: TEREGA & GRTgaz
- 1 main DSO, GRDF, with 22 smaller GRD
- $\bullet$  > 37 000 km transmission network length
  - > 200 000 km distribution network length
- with access to:
  - 8 interconnection points
  - 4 LNG terminals
  - 14 UGS (STORENGY and TEREGA)
- 3 reverse flows sites between TSO/DSO (as Q1 2021)
- Biomethane injection sites (as Q1 2021)
  - 195 on DSO level
  - 23 on TSO level
- 1000 industrial end-users on TSO level including 14 CCGT Power Plants
- 11 Mil residential customers

# GQ measurement and provision of information to the end-customer

On TSO level (GRTgaz)

#### **G** GQ measurement

250 GCs are installed on the HP gas grid to measure GCV/WI. → Raw data delivered every 5 min.

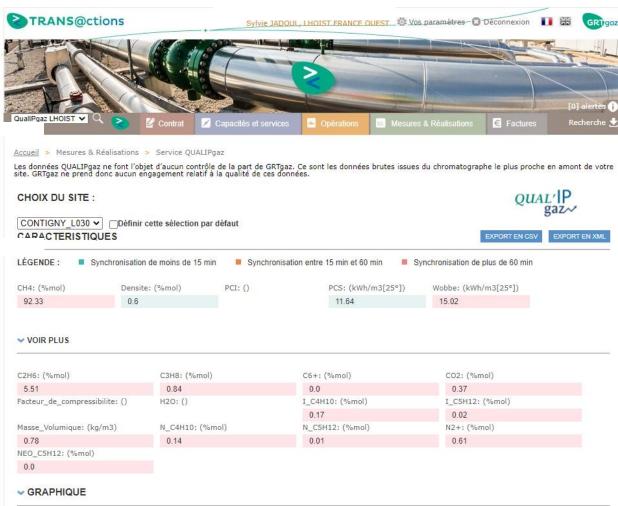
Nevertheless, for the time being most of them are sampling multiple streams, and can only give one value every 15 or 30 min for one specific stream.

#### Provision of infomation based on GC installed on the grid

GRTgaz provides GCV/WI information to its clients

- Access to an intranet *Qual'IPgaz* with all available data (service free of charge because only 530 out of 750 clients are elligible)
- Monitoring of GQ variations for the client 2 different amplitudes (service with a fee)
  - **409,2 €/y** (incl VAT) for a threshold of **0,3 kWh/m³(n)**, [1,08 MJ/m³]
  - **805** €/y (incl VAT) for a threshold of **0,15** kWh/m³(n). [0,54 MJ/m³]
  - Prevision of GCV/WI (short term) [Project to be finished in 2022]







# GQ measurement and provision of information to the end-customer

On TSO level (GRTgaz)

#### • GQ measurement at the exit point

GCs are also installed in front of the 14 CCGT power plants (> 80 000 (n) m³/h) and sometimes in front of big industrial customers, either for billing or GQ fluctuations.

GRTgaz installs at the exit point a GC with a type-certification from the french metrological laboratory (LNE), chosen by the client. GRTgaz operates, maintains the equipment and sends all relevant information to the end-customer.

- Installation of the GC + data analysis lab = custom quote ≈ 135 k€ (possibility of leasing)
- Operation and preventive maintenance and transmission of information: 3544 €/y (incl VAT).
- Repair, replace, renew operations: 12,5%/y of the installation/provision fee

#### On DSO level (GRDF)

No GQ information shared with the client so far except for the technical prescription of the gas operator



On TSO level (GRTgaz)

#### • In case of off spec gases (exceptional event)

The only time grid management (modification of gas flows, gas switch, co-mingling) is used to control GQ is in the case of an off spec gas.

The gas grid was not conceived with the intention to do co-mingling. Those tools were not put in place with the aim of controlling GQ, but they give some flexibility to the TSO. They are mostly a crutch in case of unexpected events and can not solve any situation.

- It really depends on the situation and on the topology of the grid. Sometimes it is not possible to do anything.
- It is counter-effective for the main role of the TSO (transport of gas). Doing it on a regular basis implies a degraded service of the transiting offer and less capacities available.

#### On DSO level (GRDF)

No possibility of gas blending or dilution

Grid management is done in response to gas consumption and to the demand of gas capacities from the shippers, not in order to regulate/control the Gas Quality on the network.



On SSO level (Storengy)

#### • Gas mixing in the Undergound Storage

- Blending of gas is not possible in Aquifers. The gas will come out in the reverse order as it went in.
- Blending of gas is possible in salt caverns → But only if they are filled with different gas quality!!
- During withdrawal, theoritically it could be possible to blend two gas qualities from different salt caverns.

UGS management is in response to gas consumption and to the demand of storage capacities from the customers, not to regulate/control the Gas Quality on the network.





On SSO level (Storengy)

Withdrawal of gas

Withdrawal of gas is a very careful operation → NOT an On-Off valve!

# UGS are flow regulated → Throttle valve Works like a [BIG] water tap

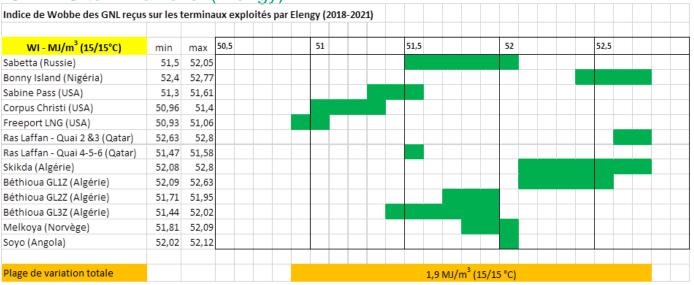
Flow of gas injected into the TSO gas grid is increased slowly to:

- Avoid bringing water with the gas from the UGS (Aquifers)
- Avoid draging glycols or Charcoal from the upgrading process into the gas stream

In a large aquifer UGS withdrawal flow rate can go from zero to a couple of hundreds thousands Nm<sup>3</sup>/h within an hour.



On LNG terminal level (Elengy)



Keep in mind that LNG ageing is happening while the LNG is stored at the LSO tanks. → WI gets higher. The LSO needs some flexibility/leeway in order to inject regazeified LNG into the grid.

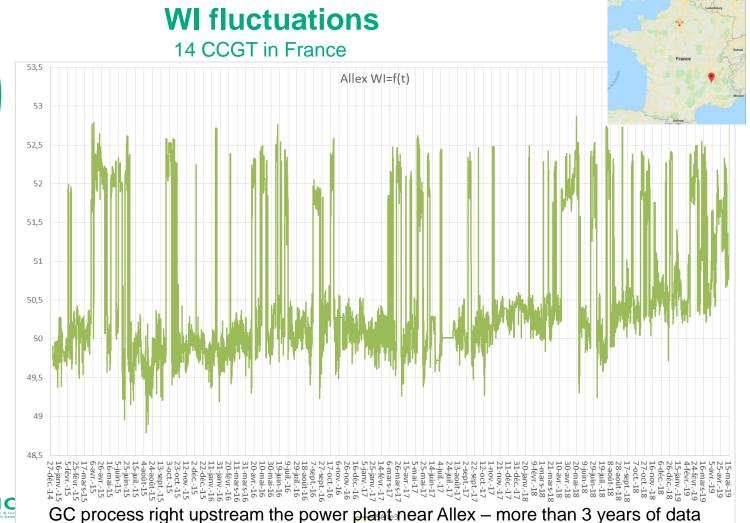
The 3 LNG terminals are built in a way that allows the withdrawing of LNG from 2 different storage units with different GQ at the same time.

→ There would be a blending time between the two qualities (transitional phase) which enables smoothing of the GQ variation

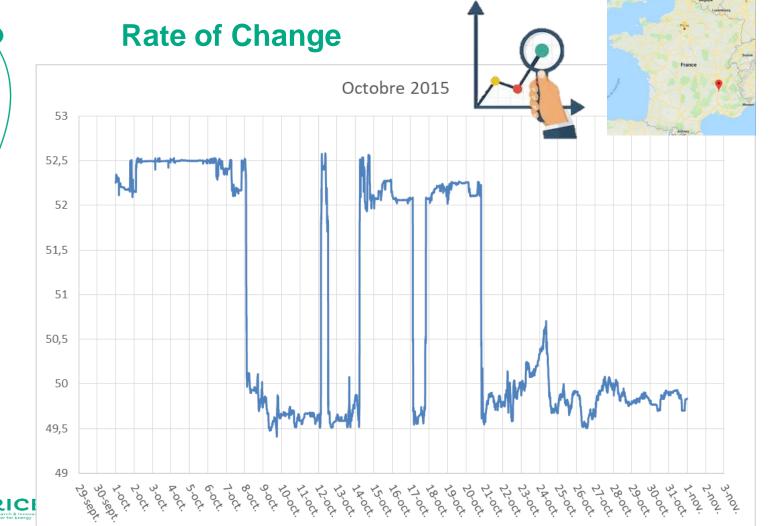


Annexes

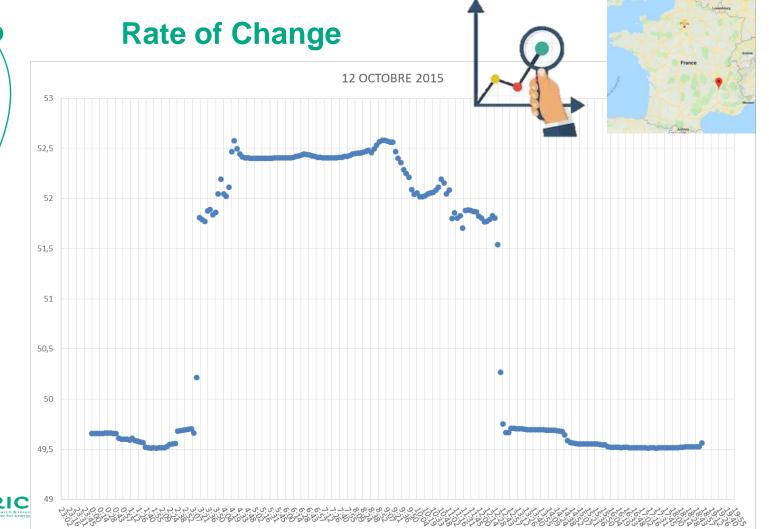
















## Renewables injection points

In France already **218 biomethane injection sites** (data from fev 21) are injecting biomethane into the gas grid, representing a production of **3962 GWh/y**.

The french energy transition law (2015) has a target of **10%** of renewable gases in the gas grid. Which represents more than **30TWh**.

It is expected by 2030, **between 400 and 1500 injection sites** according to the French Environment Agency ADEME (2013 Forecasts)

The gas operators have the ambition of injecting **90TWh** (**30%**) of renewables gases into the gas grid by 2030.

Source

https://opendata.reseaux-energies.fr/

https://www.grdf.fr/dossiers/biomethane-biogaz/unites-injection-gaz-vert-biomethane-reseau

https://www.ademe.fr/sites/default/files/assets/documents/biogaz\_depliant.pdf







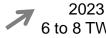
#### **Gas System Operators injection forecasts**





## French short term biomethane target

2018 1.7 TWh/y



Multiannual programming of energy (PPE) First orientations and actions 2016-2023 November 2015 French long term renewable gas target

"In 2030, renewable energies represent 10% of gas consumption"

August 2015 Energy Transition Law (LTE)

# Ambition of the French TSO and DSO 90 TWh renewable gas in 2030 (30%)



Source: Bilan prévisionnel pluriannuel gaz 2017

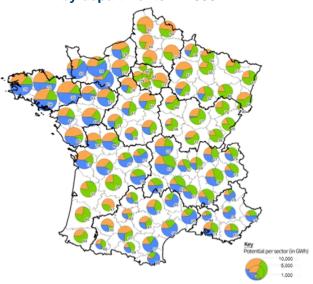


2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030

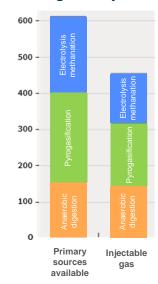


#### **Renewable Gases Value chain**





## Theoretical potential of **460 TWh** of renewable gases injectable in 2050















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## **Q&A** session

# **Concluding remarks**











# Thank you for your attention

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