Consequence of the choice of H_2 quality specification on fuel gas consumption based on burner adjustment requirements

Note

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1. H_2 quality specifications

Currently, a common European H_2 quality standard/specification is lacking. As a result, there is a high amount of ongoing activity to investigate different aspects of choosing a certain quality specification, either by using an existing specification or by creating a new standard/specification. Some of the possible options are listed in Table 1 together with the minimum H_2 concentration in mol%, lowest allowed Wobbe-index and the contamination leading to this "worst case" situation.

Table 1 Hydrogen quality specification/standards referred to in the note, along with the minimum H_2 content and a worst-case estimate for contaminants leading to the lowest Wobbe-index and highest density.

Specification/standard	Minimum H_2 concentration (mol%)	Worst case allowed contaminant (mol%)	Lowest Wobbe-index[a] (15°C/15°C) (MJ/m^3)	Highest density[b] (g/m^3)	Target dry, air-free O_2 concentration at burner adjustment[c] (vol% O_2)
Pure H_2	100%	-	45.89	89.9	3.02
ISO 14687 Grade B	99.9%	0.1% CO_2	45.37	91.8	3.27
Grade A+ proposal[d]	99.5%	0.5% Ar	43.65	98.4	4.08
CEN/TS 17977	98%	ca. 0.91% Ar[e]	42.00	105.4	4.85
ISO 14687 Grade A	98%	2% CO_2	37.78	127.4	6.76

[a]: Either a specific limit listed in the specification (denoted by underlined numbers) or calculated from the worst-case contaminant situation (denoted by a dotted line under the number).
[b]: At 0°C and 101.3 kPa.
[c]: Based on earlier DGC note [1]. Unburnt fuel tipping point (O_2 concentration in flue gas when H_2 concentration increases rapidly) at 1% O_2 concentration in the flue gas, 1000 mbar air pressure and 20°C air temperature.
[d]: Proposed by Kiwa for the Dutch hydrogen backbone [2].
[e]: Calculated from the lower Wobbe-index limit listed in the specification and shown in the table.

The specifications in Table 1 were chosen as the most relevant ones for the discussion about the future European H_2 quality standard.

- Pure (100 mol%) H_2 is included as all the specifications discussed are minimum specifications. This means that pure H_2 fulfils all the specifications and thereby serves as a lower limit for density and an upper limit for the Wobbe-index.
- ISO 14687 is the only accepted and valid standard for H_2 quality containing different "grades" and thereby different quality levels. Grade A (min. 98 mol% H_2 content) and Grade B (min. 99.9 mol% H_2 content) were chosen as they are the ones corresponding most to the other quality levels discussed at the moment. ISO 14687 Grade A represents the "worst case", i.e. highest efficiency loss, in this note.
- Grade A+ proposal: This specification is currently being discussed on the European level and was suggested for utilization in the Netherlands. The specification is supported by a report from Kiwa with a cost-benefit analysis (based on the situation in the Netherlands) [2]. This specification could serve as the basis for a common European H_2 quality standard.
- CEN/TS 17977: an existing technical specification for H_2 quality in converted pipelines created by CEN. For some time, it was informally regarded as the basis for a joint European quality standard.

As shown in a previous note from DGC [1], the allowed impurities and their levels in H_2 have a significant effect on the adjustment of burners, especially in condensing gas boilers. Consequently, choosing a certain specification might lead to significant efficiency decrease in application with burning of H_2. This is due to the need of additional air excess to accommodate for the allowed changes in the gas quality (and thereby Wobbe-index). This loss in efficiency can present additional costs either in the form of additional H_2 needed to produce the same amount of energy or by a requirement of an O_2-trim system in the burners and boilers.

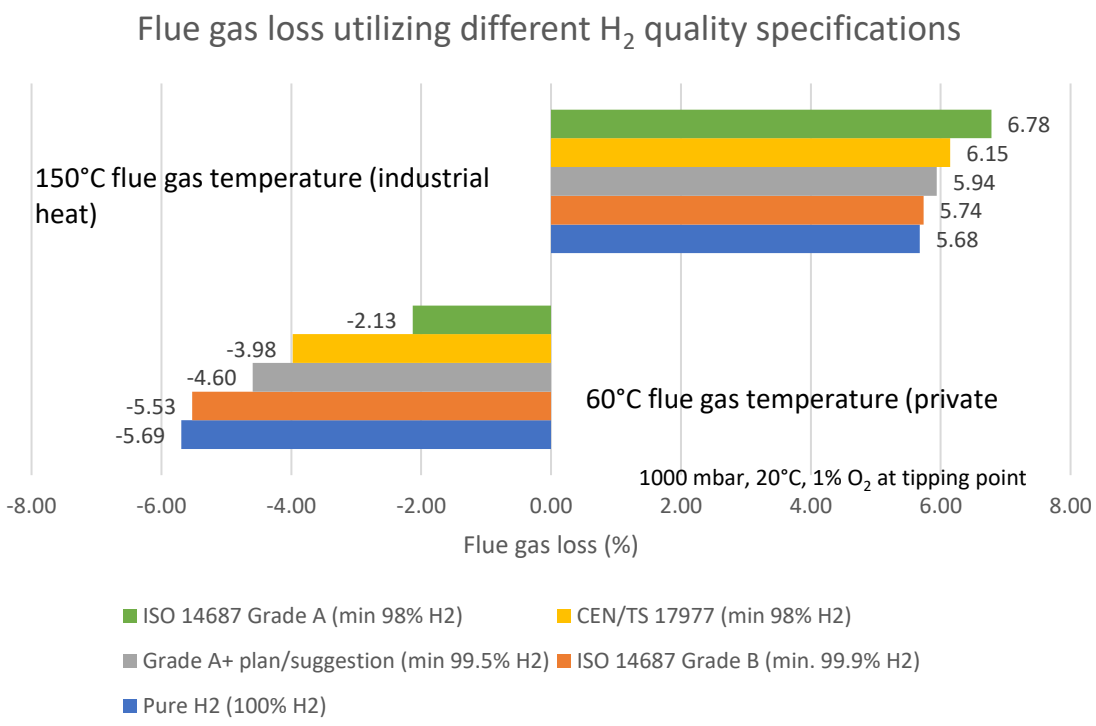
2. Loss of efficiency due to additional air excess

The efficiency differences under specific conditions in combustion applications can be estimated by calculating the flue gas losses under these conditions[1]. Figure 1 shows the flue gas losses as a function of the H_2 quality specifications assuming two different flue gas temperatures corresponding to a private condensing boiler and an industrial burner.

In case of the higher flue gas temperature corresponding to industrial heating applications (150°C) the flue gas losses are relatively close to each other, with a maximum efficiency difference at around 1 percentage point. However, in case of a private household boiler (60°C flue gas temperature) the differences are potentially larger. Adopting ISO 14687 Grade A and adjusting the burner/boiler to accommodate the potential gas quality change leads to an efficiency loss of ca. 3.5 percentage points compared to 100% H_2. A more realistic situation would be the adoption of either CEN/TS 17977 or the new Grade A+ proposal. In this case an efficiency loss between ca. 1.8-2.5 percentage points can be expected. Note that the negative numbers for flue gas loss indicate an efficiency gain due to condensation, as the flue gas temperature is under the dew point under these conditions.

The difference in efficiencies can be calculated under different assumptions as well and more detailed efficiency loss curves can be found in the Annex in Section A.2.

[1] This is true, if the other losses, such as the boiler loss, can be assumed to be the same under the conditions investigated.



a

Figure 1: Flue gas losses as a function of H_2 quality specification chosen at 60°C flue gas temperature (heating) and 150°C (industrial heat) flue gas temperature. The different losses are due to differences in the burner adjustments to accommodate the possible Wobbe-index variations in the specification. Negative numbers represent efficiency gains from condensation (negative losses = efficiency gains). Source: internal DGC calculation software

3. Consequences based on the projected European H_2 demand for heating

There are several projections for the consumption of H_2 for heating applications in the future. The calculations shown here are based on data from the European Hydrogen Backbone project [3] and are summarized in Table 2.

Table 2: Projected European H_2 demand for heating applications based on a report from the European Hydrogen Backbone project in 2030 and 2050 [3].

Projected demand (TWh/year)	2030	2050
Heating	11-13 (12[a])	150-160 (155[a])
Industrial heat	56	217
[a]: In the calculations the average of the given range is used.		

3.1. Projected fuel gas consumption

Based on the calculated flue gas losses and the lower heating value of H_2, a projected H_2 consumption can be calculated based on the worst-case scenario the different quality specifications allow (Table 1) both on volumetric basis and mass flow basis as shown in Figure 2 for heating applications in 2050. Further data can be found in the Annex in Section A.3.
Compared to using 100% clean H_2 for combustion, the additional gas consumption stems both from the decreased efficiency discussed earlier, but also from the fact that the standards allow gases with lower heating values, meaning that even at the same efficiency, additional gas amount needed to be used.

In the H_2 industry mass flow is usually used to measure flow and prices are also calculated based on kg of H_2. Based on this metric, a significant amount of additional fuel gas can be expected to be used in 2050 (Figure 2a), namely up to approx. 49.5% more in the worst-case scenario (ISO 14687 Grade A), corresponding to 2184 kt/y in 2050 extra gas consumption on a European level. Taking the most probable scenarios, up to approx. +10.5% (Grade A+ proposal) or up to approx. +20% (CEN/TS 17977) consumption can be expected.

However, on a volumetric basis the maximum difference is in the worst case only approx. +5.5%, meaning 2.7 billion nm^3/y additional consumption in 2050 on a European level (CEN/TS17977: +2.5%, Grade A+: +1%). The relatively smaller increase in the volumetric flow is the result of the large density difference between H_2 and the contaminants investigated here. Due to this effect, even small amounts of contaminants lead to a significant increase in gas density (Table 1). This effect also shows that fiscal flow metering of H_2 is challenging if the gas quality can change over time, especially at customers with low consumptions where quality monitoring cannot be established in an economically viable way.

The additional consumption shown in Figure 2a (mass flow) is calculated assuming that the fuel gas burned is the worst case the different specifications allow (Table 1). This is not necessarily the case as there can easily be a situation in which the burner is adjusted to accommodate all the allowed changes in gas quality, while the gas supplied is high quality. This can be if Europe adopts a quality specification requiring only 98% H_2 content, while the supply of H_2 in a certain country or region comes primarily from electrolysers (min. 99.5% H_2 content). The calculated additional 49.6% consumption on a mass basis is made up of a part which is due to the efficiency loss and differences of the burner adjustment and the major part which is due to the contamination(s) (and thereby heating value and density changes). Approx. 5 percentage points of the extra consumption (ca. 222 kt/y) are due to efficiency losses due to burner adjustment and the remaining ca. 44.5 percentage points are due to the higher density (and lower heating value) of the fuel gas with the contaminants in it.

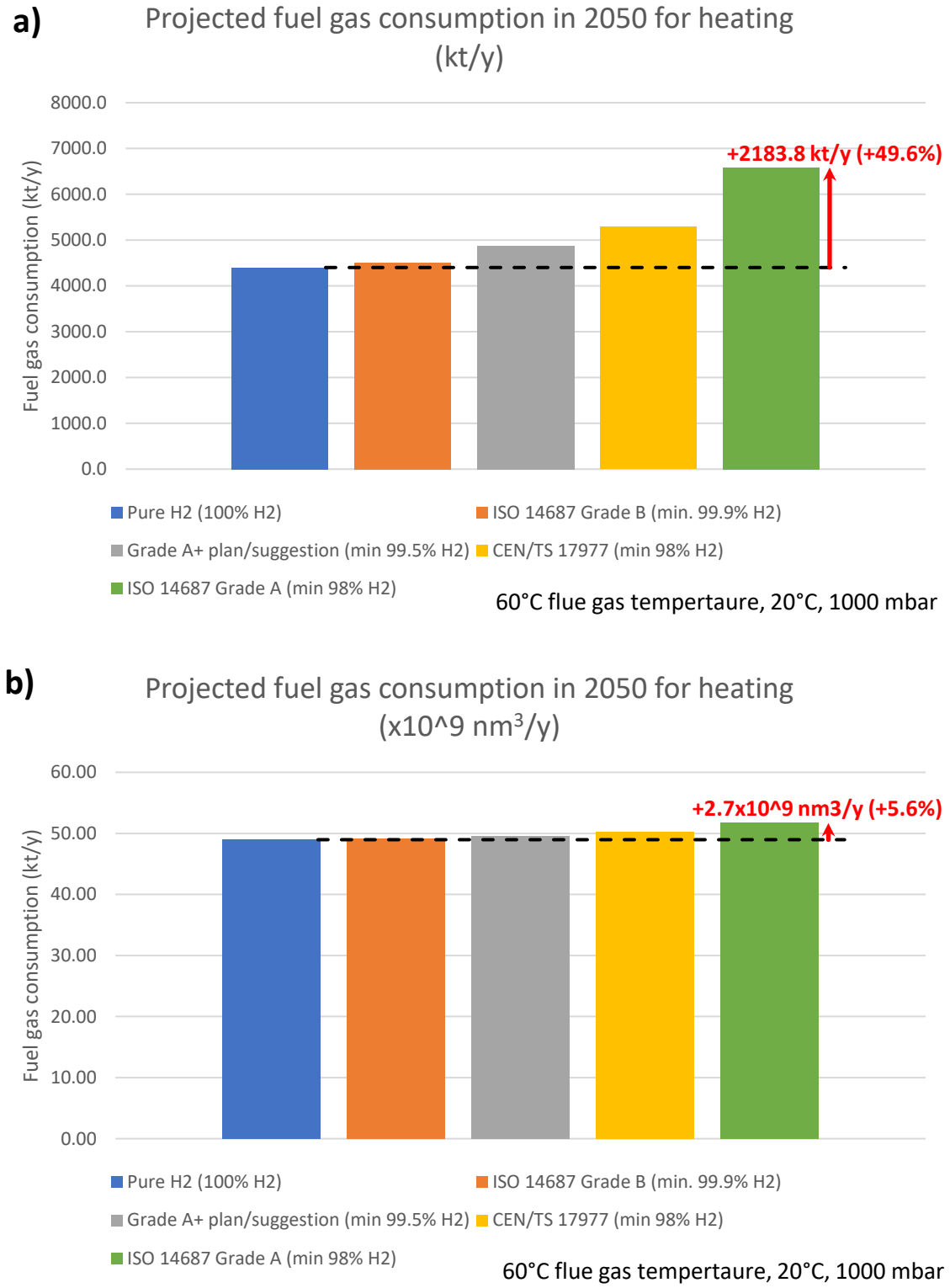


Figure 2: Projected fuel gas consumption in 2030 for heating purposes on mass flow (a) and volumetric flow basis (b).

3.2. Economic consequences

In order to give a basic estimate of the economic consequences the projected cost of H_2 in 2030 and 2050 should be determined first. Unfortunately, different organizations publish different forecasts and on different time horizons. As a first step, the levelized cost of H_2 ($LCOH_2$) should be estimated. Additionally, apart from green H_2, other (gray and blue) production methods should also be considered, which can be significantly cheaper than green H_2. Based on multiple projections and reports [3–6] a $LCOH_2$ of 2 €/kg for 2030 and 1 €/kg for 2050 is used in this note. These figures represent the lower end of the price estimates, but at the same time provide conservative end results regarding the additional costs.

Apart from the estimated $LCOH_2$, it is assumed that billing of H_2 supplied by the infrastructure will be based on the "number of H_2 molecules". This means, that customers will pay per kg of H_2 supplied or per heating value from H_2 supplied. This is due to a significant portion of consumer demand originating from the chemical industry, where other molecules supplied together with H_2 are either valueless or straight up represent additional costs. Taking this assumption into account, additional costs caused by choosing a H_2 quality standard allowing larger variations of gas quality will only come from the lowered efficiencies, as in an ideal world the same amount of H_2 molecules would be needed to produce the needed (same) amount of energy, even though the absolute amount of gas supplied is higher due to the contaminant molecules. Thus, only the part of the additional mass flow caused by decreased efficiency should be accounted when calculating the potential additional costs.

Taking all of the above into account, implementing ISO 14687 Grade A as a specification can be expected to lead to approx. 59.5 mil. EUR/y in 2030 and approx. 205 mil. EUR/y in 2050 additional cost on a European level if no mitigation efforts is being implemented. While implementing the Grade A+ specification leads to only 14 mil. EUR/y additional cost in 2030 and approx. 48 mil. EUR/y in 2050, which is an approx. 75% reduction compared to the additional costs associated with implementing ISO 14687 Grade A.

4. Summary and mitigation possibilities

The effect shown in this note is ultimately due to allowed variations in H_2 quality. The advantage of having a more forgiving quality standard for a common European H_2 network is that it favours H_2 producers and incentivises H_2 production which might be needed in the initial phases of the infrastructure roll-out. However, due to the unusual properties of H_2, even relatively small amounts of contaminants can change the physical properties of the gas significantly. An example of this effect is the Wobbe-index, which has a direct influence on burners and boilers. In order to keep the operation of these appliances safe, having a standard with a larger allowed Wobbe-index variation requires additional air excess leading to an efficiency loss. As shown before, if no mitigation measures are implemented this can lead to up to approx. 3.5 percentage points loss of efficiency in the worst-case scenario (Figure 1) and an additional cost on a European level of approx. 145 mil. EUR/y in 2050.
The effects and extra costs shown in this note can be avoided by:
(a) implementing or requiring an O_2 trim system on burners/boilers and/or
(b) introducing stricter limitations to quality variations within standardisation.

Apart from the additional costs associated with the loss of efficiency, the significant influence of even minor contaminants on the density of H_2 can also lead to the transportation of a high amount of “non-useable” mass in the infrastructure with the associated additional expenditures.

5. References

[1] Niels Bjarne Rasmussen, Adjustment of large burners – natural gas and hydrogen, 2024. https://www.dgc.dk/nyheder/?category=Case+study.

[2] E.A. Polman, M.L. Doelman, S. van Greuningen, J.W. Turkstra, M. van Essen, H. Vlap, A follow-up study into the hydrogen quality requirements for the Dutch Ministry of Economic Affairs and Climate Policy (EZK), 2023. https://www.eerstekamer.nl/overig/20231009/rapport_kiwa_dnv/document (accessed July 29, 2024).

[3] Analysing future demand, supply, and transport of hydrogen, 2021. https://ehb.eu/files/downloads/EHB-Analysing-the-future-demand-supply-and-transport-of-hydrogen-June-2021-v3.pdf (accessed July 29, 2024).

[4] Hydrogen Insights 2023, 2023. https://hydrogencouncil.com/en/hydrogen-insights-2023-december-update/ (accessed July 29, 2024).

[5] Hydrogen Forecast to 2050, 2022. https://www.dnv.com/news/hydrogen-at-risk-of-being-the-great-missed-opportunity-of-the-energy-transition-226628/ (accessed July 29, 2024).

[6] Global Hydrogen Review, 2023, Paris, 2023. https://www.iea.org/reports/global-hydrogen-review-2023 (accessed July 29, 2024).

Annex A

A.1 Background of the calculations shown in the note

This note contains some indicative calculations of losses originating from Wobbe-index variations of the H_2 supplied to burners to compare the consequences of different H_2 quality specifications. In the calculations different quality specifications were compared and some assumptions have been made which are introduced below.

It is important to note, that the differences between the specifications leading to lower efficiencies are not due to low quality hydrogen fuel. What leads to the need of high air excess and thereby lower efficiencies in case of a burner is the allowed variations in the quality and thereby Wobbe-index and the need for safe operation within a given specification. This means that even a specification of low quality H_2 could avoid the efficiency disadvantages detailed here if the specification is narrow enough.

A.1.1 Assumptions and background for calculations

In order to be able to give an estimate on the efficiency loss and thereby additional gas consumption in heating applications the following assumptions were used:

- Calculation of Wobbe-indices, densities and heating values according to ISO 6976.
- The model and calculations only consider the losses due to the need to set burners to higher λ values to accommodate the possible changes in H_2 quality.
- All O_2 values mentioned are based on dry, air-free flue gas.
- λ values and target values for the O_2 content in the flue gas used for the calculation are based on an earlier DGC note [1].
- In the calculations only losses due to flue gas losses are taken into account and other losses are assumed to be constant (independent of the flue gas loss) and negligible in the light of the main point of the report.
- When determining the air excess the following were assumed: tipping point, meaning the air excess where unburned fuel emission starts to increase (while lowering air excess) is at 1% O_2 in the flue gases, combustion air temperature of 20°C, atmospheric pressure of 1000 mbar and no additional information about the gas quality than what is contained in a given specification.
- Flue gas temperature of 60°C for low temperature heat (private households) and 150°C for high temperature applications.

A.2 Flue gas losses due to burner adjustment

In order to determine the necessary dry, air free O_2 content of the flue gas to which the burners should be adjusted, the calculation method shown in an earlier DGC note [1] has been used. Assuming 1% O_2 content in the flue gas at the tipping point, no information of the actual gas quality at the time of adjustment and the parameters listed in Section A.1.1, the target flue gas O_2 concentrations for burner adjustment are given in Table 1 as a function of the H_2 quality specification adopted.

As expected, the broader the allowed Wobbe-index range the higher air excess (and higher O_2 content in the flue gas) burners will have to be adjusted to. Especially assuming ISO 14687 Grade A as H_2 quality specification leads to a high air excess as it has no explicit Wobbe-index limit or a specific limit for the CO_2 concentration.

A.2.1 Influence of the flue gas temperature on relative efficiency losses

To further explore the possible efficiency loss two cases can be investigated further, comparing ISO 14687 Grade A (Figure 3) and Grade A+ (99.5% min. H_2 content) proposal (Figure 4) to 100% H_2. These two represents the worst-case scenario and a probable scenario, respectively.

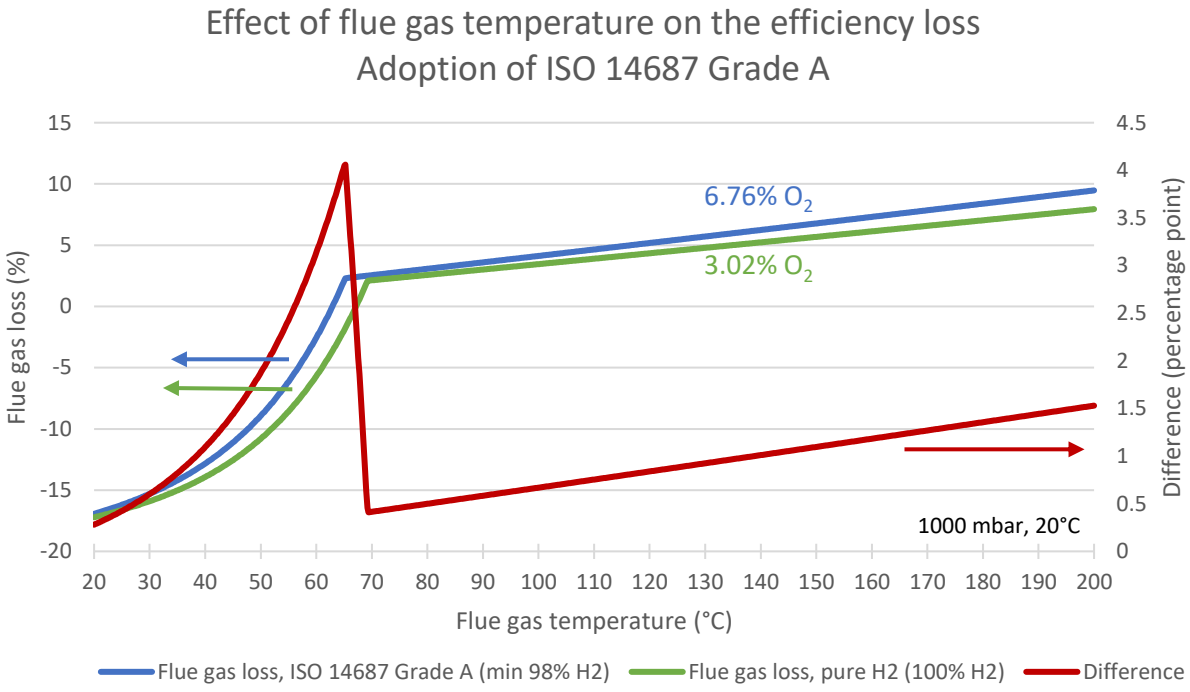


Figure 3: Flue gas losses as a function of flue gas temperature assuming 100% pure H_2 gas supply or gas supply following ISO 14687 Grade A. Along with the flue gas losses the difference between the losses in percentage points is also shown. This difference (and thereby efficiency loss) can be considered as the upper limit case on losses due to different H_2 specifications and the need to regulate burners to a higher air excess. Source: internal DGC calculations.

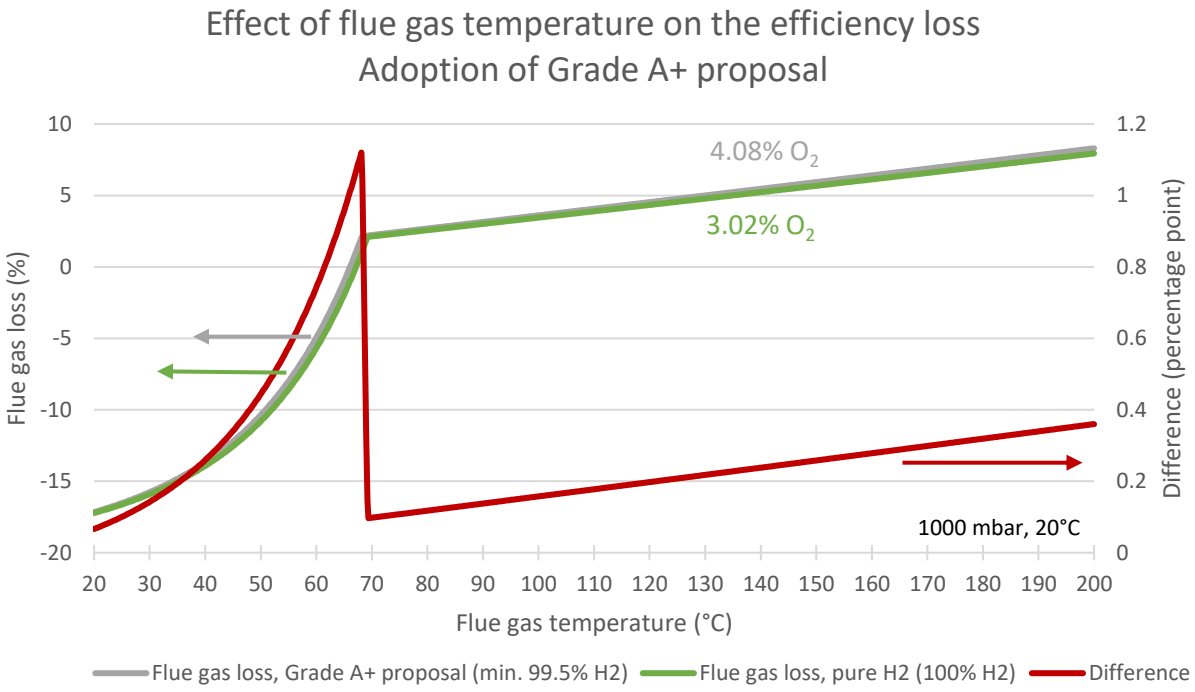


Figure 4: Flue gas losses as a function of flue gas temperature assuming 100% pure H_2 gas supply or gas supply following the Grade A+ (min. 99.5% H_2 content). Along with the flue gas losses the difference between the losses in percentage points is also shown. This difference (and thereby efficiency loss) can be considered as a probable scenario. Source: internal DGC calculations.

As expected, the flue gas losses are changing significantly with the flue gas temperature below the dew point. In this regime the flue gas loss difference (efficiency difference) is also increasing sharply. Around the dew point (approx. 65°C) the efficiency difference between 100% H_2 and H_2 after ISO 14687 Grade A has a maximum of approx. 4 percentage points. If the proposed Grade A+ specification is adopted, the efficiency difference maximum is only approx. 1.1 percentage point. Above the dew point the difference of the flue gas losses drops sharply and then start to increase linearly with the flue gas temperature. Based on this data, exactly in the range which typically would be for a condensing household boiler (flue gas temperature between 40-70°C) the efficiency difference has a maximum. Above the dew point, meaning industrial applications, the efficiency difference is close to being negligible.

A.2.2 Influence of air temperature and pressure

As described in [1] the air pressure and temperature at the time of burner adjustment has an influence on the target O_2 concentration in the flue gas at the time of burner adjustment. This can be presented by a simple thought experiment:
If on a cold winter day, when the temperature is low and the air is relatively dense a burner is adjusted close to λ=1, the burner will end up working in under-stoichiometric conditions when the weather heats up (summer) and the density of air decreases, even if the air pressure remains the same. Similarly, the air-pressure has an effect as well, regardless of the temperature. Thereby the air temperature and air-pressure at the time of adjustment compared to the expected yearly average temperature and air-pressure has an influence on the adjustment target O_2 concentration in the flue gas.

Calculations show that the changes in the weather (parameters) at adjustment, e.g. a typical cold winter day having cold temperature and high air pressure, have no significant influence on the results. Qualitatively, the efficiency loss curve does not change significantly. The highest energy loss is somewhat different, but the main conclusion is the same.

A.3 Additional fuel gas consumption

Additional projected fuel gas consumptions for heating are shown here to add further data to Section 3.1, along with projected increase in fuel gas consumption for industrial heating applications.

A.3.1 Heating applications

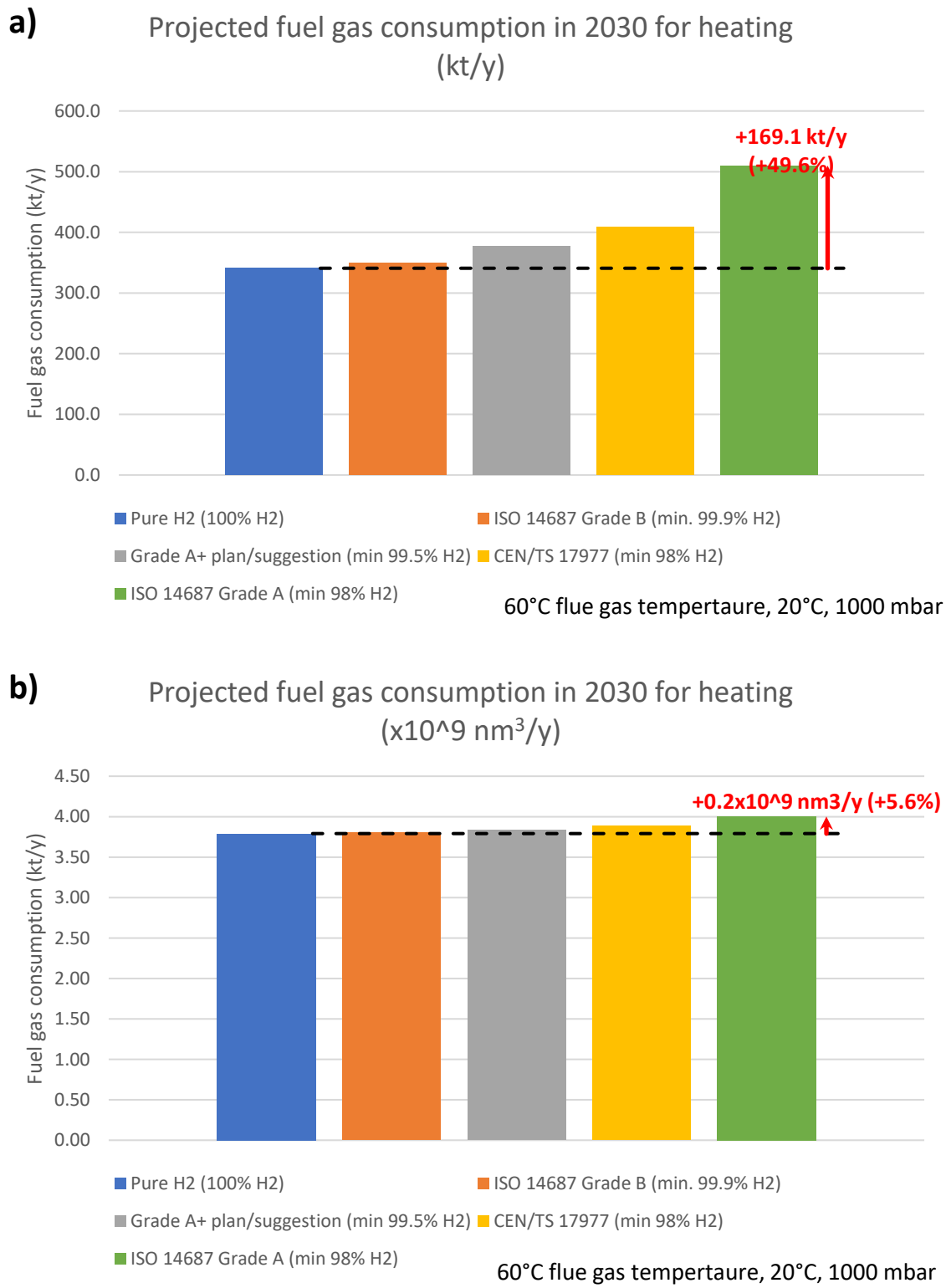


Figure 7: Projected fuel gas consumption in 2030 for heating purposes on mass flow (a) and volumetric flow basis (b).

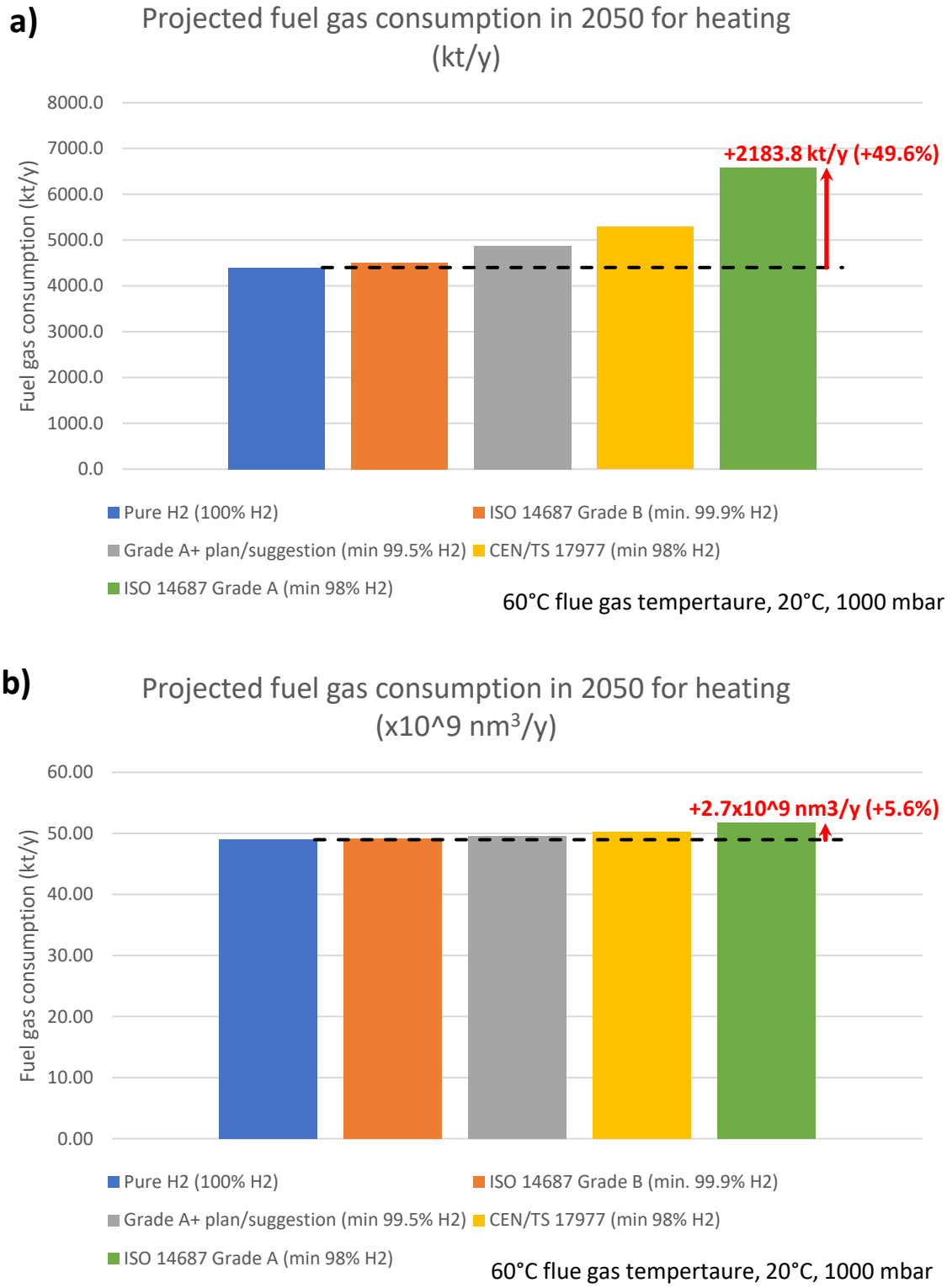


Figure 8: Projected fuel gas consumption in 2030 for heating purposes on mass flow (a) and volumetric flow basis (b).

A.3.2 Industrial heat

Similarly, the projected consumption for industrial (high temperature) heat can also be compared. In this case the assumption is 150°C flue gas temperature, which also means that condensation does not play a role and the efficiency difference due to burner adjustment is relatively low. Similarly, as before, the projected consumption in 2030 (Figure 9) and in 2050 (Figure 10) can be shown both based on a mass flow and on a volumetric flow basis.

In high temperature applications the relative projected additional fuel gas consumption change on a mass basis is smaller as in the case of the heating application (+49.6% vs. +46.3%). This is due to the smaller efficiency difference between the different O_2 levels the burners have to be adjusted to. However, due to the higher projected energy demand for these high temperature applications, in absolute value the additional fuel gas consumption is significantly more than in case of heating applications. As the efficiency difference is only about 1 percentage point, most of the +46% fuel gas consumption is due to the contaminants in the gas increasing the density and decreasing the heating value. Only approx. 4.2 kt/y (2030) and 54.8 kt/y (2050) additional consumption is originating from the lowered efficiency due to burner adjustment. On a volumetric flow basis, the relative fuel gas consumption difference is even less than in heating applications (+3.2% vs. +5.6%).

A.3.3 Additional mass flow in the infrastructure

As shown in the previous figures, calculations indicate the possibility of a significant additional mass flow in the infrastructure consisting of molecules which are “unusable”. This additional mass flow leads to increased transportation costs which should be noted, but is not investigated further in this report.

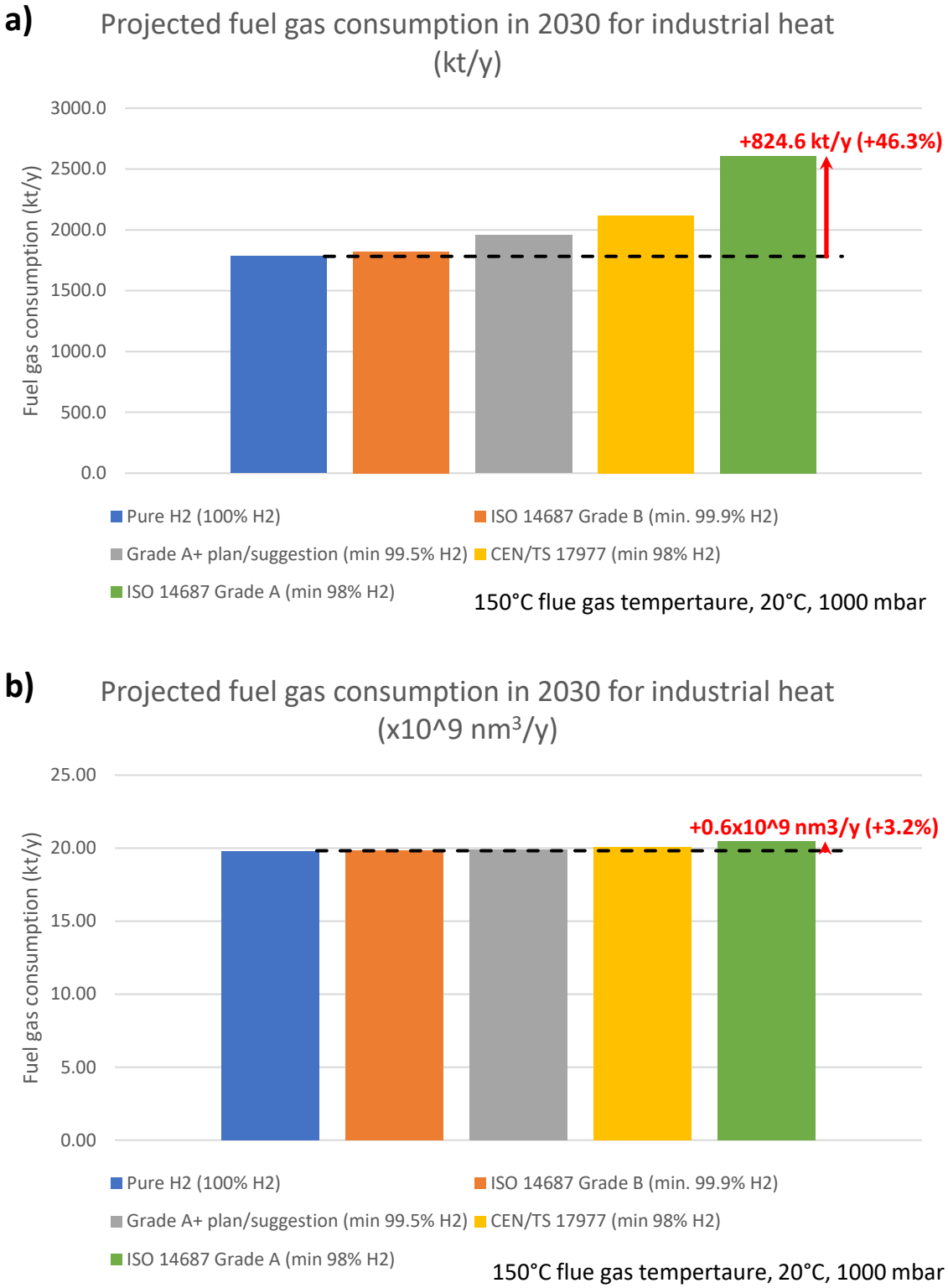
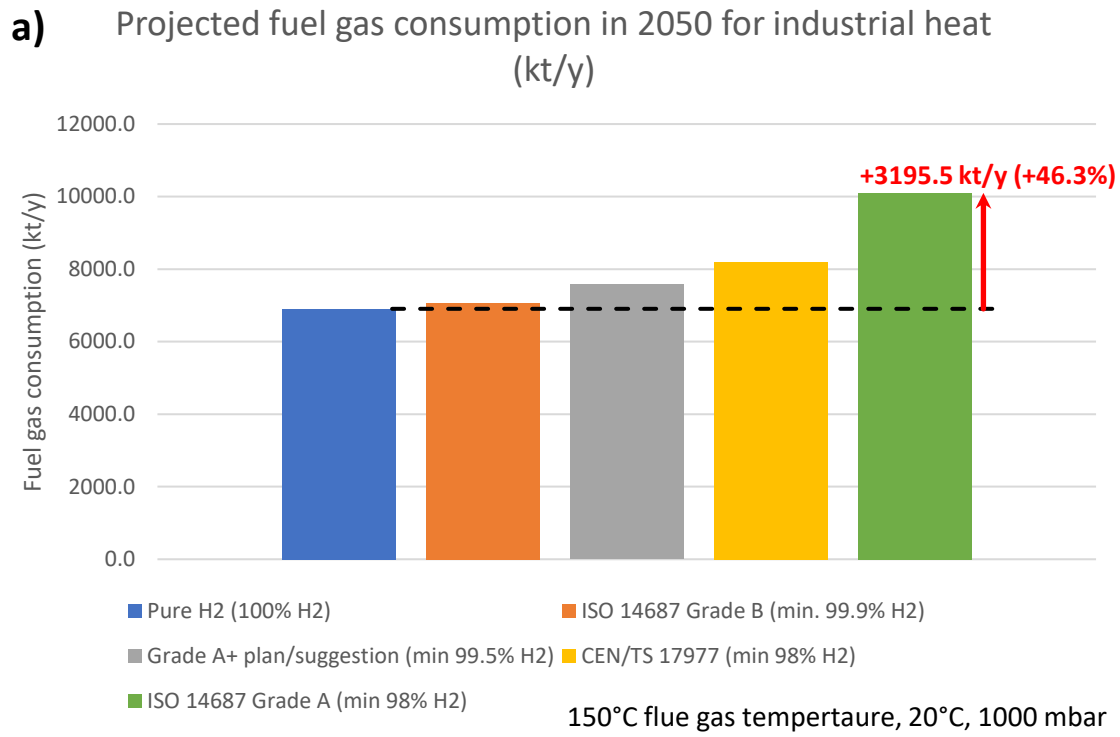


Figure 9: Projected fuel gas consumption in 2030 for industrial (high temperature) heat on mass flow (a) and volumetric flow basis (b).



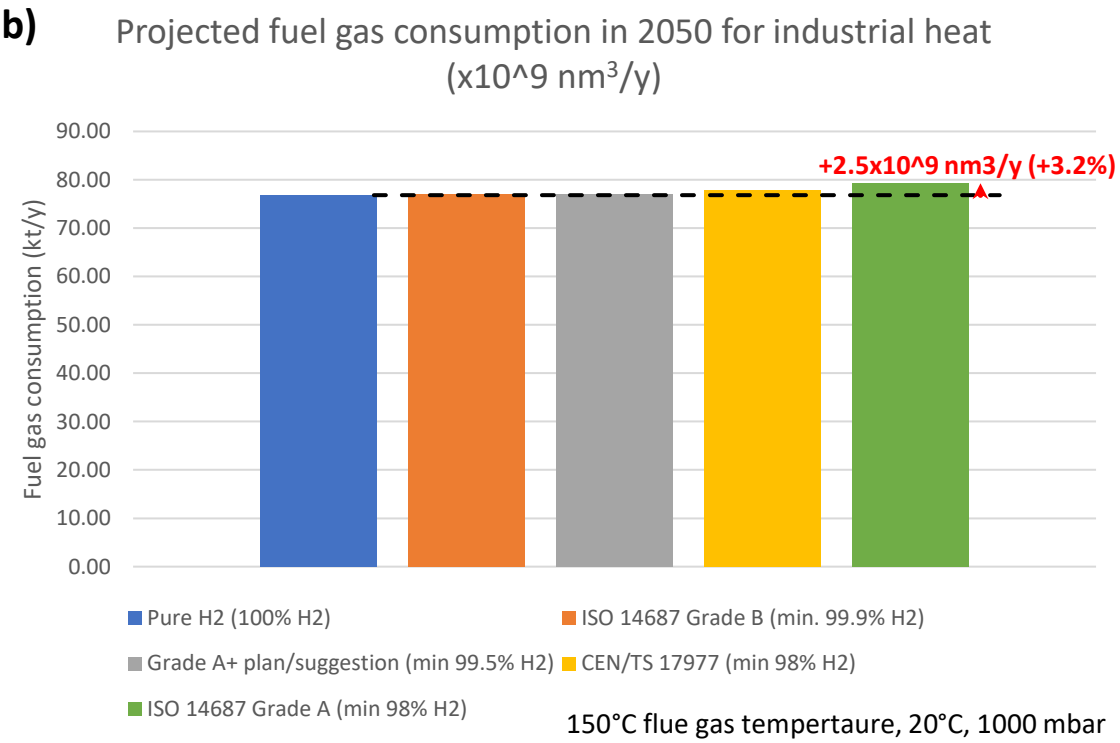


Figure 10: Projected fuel gas consumption in 2050 for industrial (high temperature) heat on mass flow (a) and volumetric flow basis (b).