vgbe position paper

Factsheet
H2-readiness for gas turbine plants

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Factsheet: H_2 readiness for gas turbine plants

vgbe energy e.V. represents operators of plants for the energetic use of hydrogen. With its H_2 ready position paper published in September 2022, the association has contributed the views of its member companies to the current debate on the definition of H_2 readiness. The factsheet at hand provides further information on the use of hydrogen in gas turbine plants.

Contents

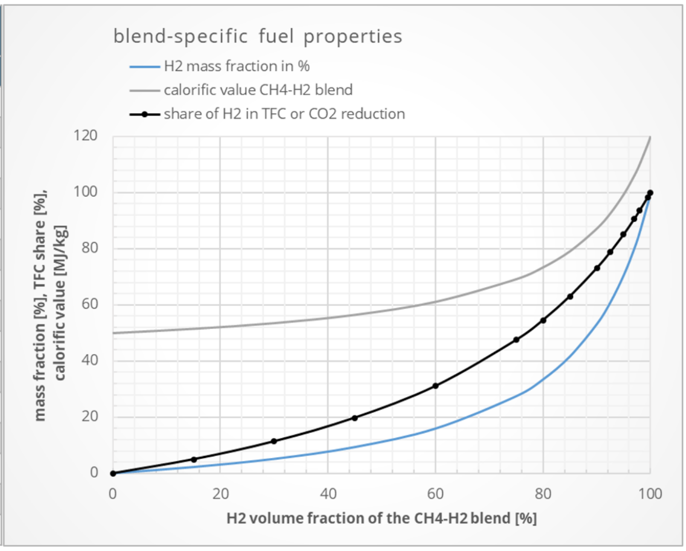
1 General requirements for H_2 readiness

Load- and fuel-flexible gas turbines with low-pollution combustion will also play an important role in the energy system of the future, as they provide the necessary stability and flexibility in the power grid. Hydrogen and H_2-based energy carriers, such as ammonia, will be the important fuels in a CO_2-free energy system.
Gas turbines have to be able to burn blends of natural gas and hydrogen in a wide range between 100 % natural gas and 100 % hydrogen and also tolerate rapid changes in the composition of such gas blends. Especially due to the still unclear supply situation, the safe combustion of varying mixtures is indispensable.
This requirement applies equally to both new and existing systems. Consequently, manufacturers are to develop and offer conversion options for existing plants in addition to new plants in order to be able to implement cost-optimised, low-CO_2 energy supply in a timely manner. Important impetus to initiate the necessary technical developments is to be provided by politics through appropriate funding opportunities.

2 Fraction of hydrogen in the thermal firing capacity in the gas mixture

A plant is considered “H_2-ready” if it can be operated at 100 % with hydrogen during its service life. On the way to 100 % hydrogen combustion, several intermediate steps are conceivable. In order to take into account, the different levels of H_2 readiness and the portion of decarbonisation associated with the use of H_2, it is necessary to classify the plants according to the H_2 fraction of the thermal firing capacity (TFC). These classifications represent technological development stages, especially in combustion technology.
Particularly the differences between natural gas and hydrogen in terms of density and calorific value, do not allow drawing a direct conclusion about CO_2 reduction from the hydrogen content in vol.%. This relationship is illustrated in Figure 1. It can be seen that a hydrogen fraction of less than 60 % by volume only has a relatively small influence of approx. 31 % on CO_2 reduction compared to 100 % natural gas combustion.

H_2 volume fraction	H_2 mass fraction	Share of H2 in TFC* or CO_2 reduction
[%]	[%]	[%]
0	0.0	0.0
15	2.2	5.0
30	5.1	11.4
45	9.3	19.8
60	15.9	31.1
75	27.4	47.5
80	33.4	54.6
85	41.6	63.1
90	53.1	73.1
92,5	60.8	78.8
95	70.5	85.1
97	80.2	90.7
98	86.0	93.7
99,5	96.2	98.4
100	100.0	100.0



*thermal firing capacity (TFC) is the heat supplied to a heat engine (e.g. a gas turbine or a gas engine) per unit of time.

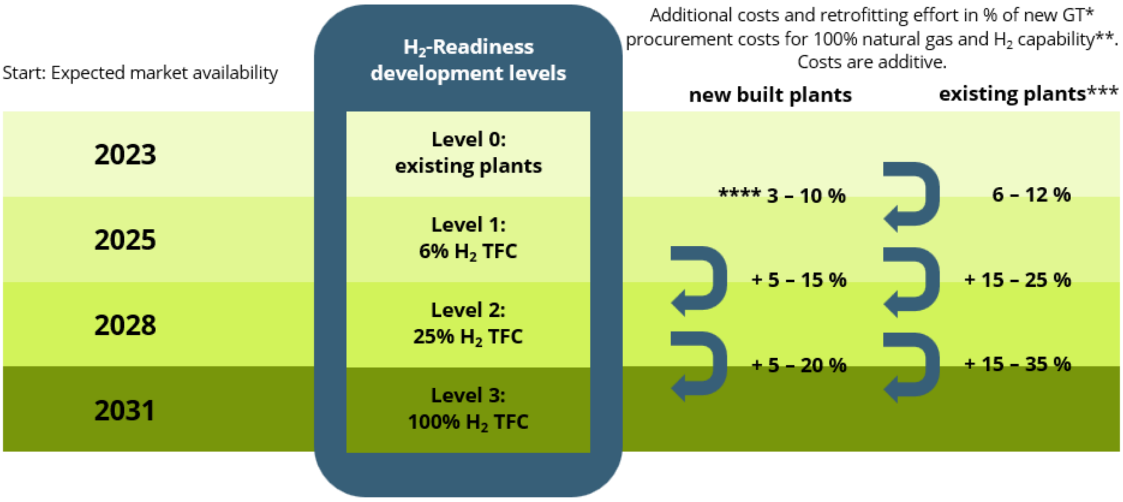
The H_2 share of the TFC corresponds to the share of CO_2 reduction.

Figure 1: CO_2 reduction as a function of H_2 volume and H_2 mass fraction in the natural gas-hydrogen mixture, source: Freimark, M.; Gampe, U.; Buchheim, G.: Considerations on H_2 co-combustion in gas turbines, vgbe, 2022 .

With regard to the use of hydrogen in gas turbines or in turbomachinery in general, it has to be noted that generally applicable regulations for design, selection of materials, etc. are almost not available in Europe. These documents are to be prepared in the not-too-distant future.

3 Classification of the gas turbine plant on the way to H_2 readiness

The following figure shows various intermediate stages (Level 1 and 2) on the way to H_2 readiness (Level 3) and the associated costs for new and existing plants. A gas turbine plant (GTP) is defined as plant that includes fuel supply, gas turbine as well as flue gas cleaning and flue gas removal. For existing plants, the data refer to plants with a standard natural gas design.



* The scope of retrofitting refers to the retrofitting of all components necessary for operation, but the cost reference is the gas turbine as core component

** A pre-planned modular design of the ancillary systems can significantly reduce retrofitting costs for new plants (H_2 capability)

*** In many cases, retrofitting existing systems can make much more economic sense, even if measures to extend the service life, etc. still have to be carried out on the GTP

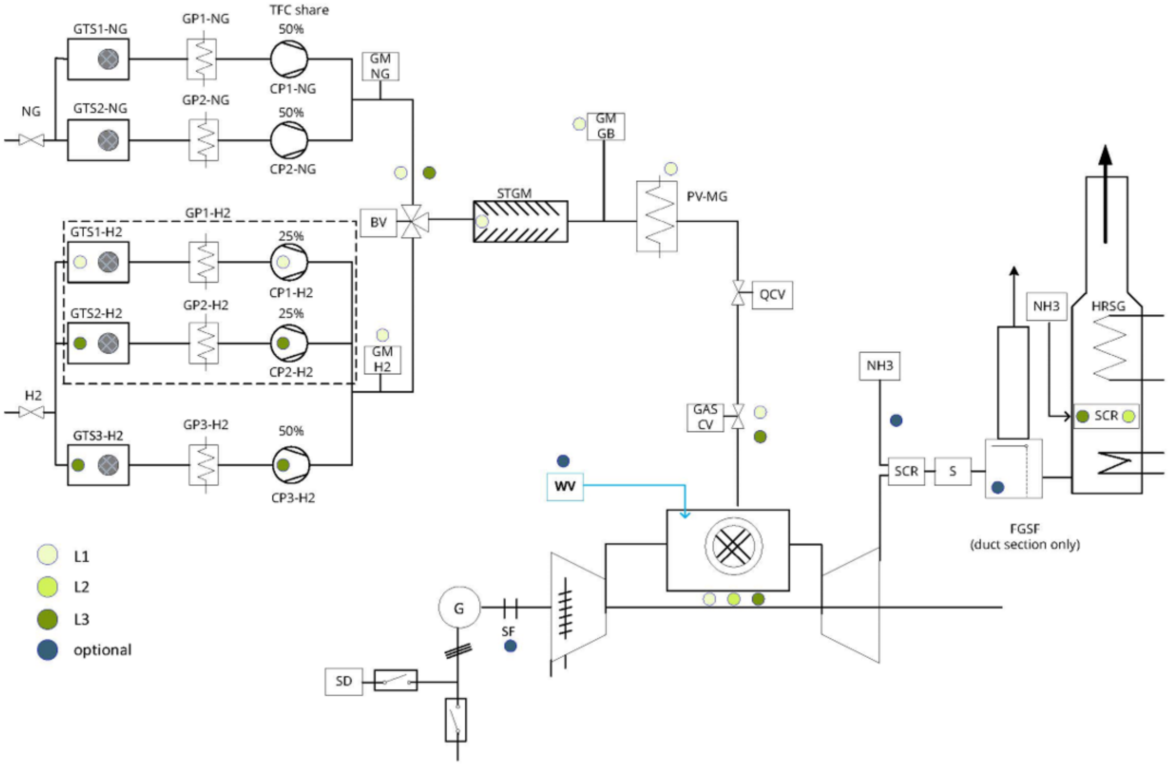
**** Additional costs for H_2 capability

Figure 2: Development levels of H_2 readiness for gas turbine plants.

The following further boundary conditions apply to the figure:

- The availability of H_2 in the GTP influences costs (e.g. in the case of supply via a separate H_2 line of the new hydrogen network to the power plant boundary or possible supply of a gas mixture of CH_4 with H_2 up to 6 % TFC) – the costs are lower if natural gas-H_2 blend is available at the plant boundary.
- Accompanying and supporting costs for operation and maintenance, service life extension, upgrades, etc. are not taken into account when considering measures for H_2 readiness of existing plants.
- If correctly designed and manufactured, e.g. according to API 617 and 941, material problems are unknown regarding increased hydrogen embrittlement in high-pressure applications (experiences from the chemical industry).

Parts affected by respective upgrades are identified in the following diagram:



GAS CV	Gas control valve upstream of combustion chamber
GM H2	Gas measuring station hydrogen
GM GB	Gas measuring station gas blend natural gas/hydrogen
GM-NG	Gas measuring station natural gas
GTS1-H2	Gas transfer station hydrogen
GTS1-NG	Gas transfer station natural gas
GP MG	Gas preheater gas blend natural gas/hydrogen
GP1-H2	Gas preheater hydrogen
GP1-NG	Gas preheater natural gas
HRSG	Heat recovery steam generator (HRSG)
BV	Gas blending valve natural gas/hydrogen
NG	Natural gas
NH3	Ammonia storage for DeNOX
FGSF	Flue gas switching flap or duct for later bypass
S	Silencer
SCR	DeNOX catalyst (Selective Catalytic Reduction)
QCV	Gas quick-closing valve upstream of combustion chamber
STGM	Static gas mixing device
SD	Start device
CP 1-H2	Gas compressor hydrogen
CP 1-NG	Gas compressor natural gas
WV	Water or Water vapour (injection)
SF	Shaft fitting for later retrofit of clutch needed for single generator operation

Figure 3: Overview sketch of a gas turbine plant with corresponding measures to achieve H_2 readiness.

4 Criteria for assessing H_2 readiness

The following sub-systems are considered in the assessment of H_2 readiness:

- Gas supply

- Fuel gas system between gas in-feed, compressor, mixing device, fuel gas block up to fuel gas tripping valve (SSV)
- Combustion system and gas turbine
- Waste gas system including HRSG
- Control technology and turbine protection
- Fire and explosion protection
- Retrofit of existing plants
- Commissioning procedures, emissions etc.

Criteria and design requirements for the respective sub-systems	Remarks/special requirements
Gas supply	
▪ The admixture of H_2 into the existing natural gas grid is not to exceed 3 % H_2 in a first step and 6 % in a second step in order to enable continued operation of as many existing plants as possible. ▪ In the future H_2 network, all major consumers are to meet at sufficiently high pressure to operate gas turbines without additional fuel gas compressors (50 to 60 bar). ▪ The gas purity (in terms of gas composition) of H_2 is rather uncritical for gas turbines compared to other consumers such as fuel cells.	Requirements to be met by gas grid operators
Fuel gas system between gas feed-in, compressor, mixing device, fuel gas block up to fuel tripping valve	
▪ International regulations such as ISO 21789 have to be complied with and national standards have to be taken into account.	Design for:
▪ Gas transfer stations for natural gas, incl. measurement and analysis technology	100 % natural gas

Criteria and design requirements for the respective sub-systems	Remarks/special requirements
▪ Gas compressor station for natural gas, incl. pipe system up to connection section (blending of H_2 with natural gas is to be possible within the current scope of the gas grids.)	100 % natural gas approx. 5% H_2- TFC
▪ Gas transfer stations for H_2, incl. measurement- and analysis technology	100 % H_2
▪ Gas compressor stations for H_2, incl. pipe system up to connection section	100 % H_2
▪ Connection section including fittings and adapter-section for insertion of blending station, note: for TFC, p_{Gas}= constant is $V_{H2} = 3.3 \times V_{CH4}$	100 % H_2
▪ Blending station with measurement and analysing technology for gas blend at GT entrance Fuel gas preheating downstream of blending station 100 % natural gas up to 100 % H_2 (Attention with preheating: not absolutely necessary with H_2 due to heating by Joule-Thompson effect) H_2 pre-heating > 200 °C results in increased H_2 diffusion, whether or not still sensible has to be clarified individually on a project-specific basis.	100 % H_2
▪ Dimensioning suited for fuel gas block, material selection, connection engineering and fittings for 100 % natural gas up to 100 % H_2 operation (e.g. API 617 and API 941)	100 % H_2 Commissioning with dispersion calculation
▪ Installation and commissioning of pressure relief lines of tripping valve groups (natural gas and H_2) of the fuel gas block and other gas safety valves for 100 % H_2 and 100 % natural gas operation as well as mixed operation (see also ISO 21789).)	

Criteria and design requirements for the respective sub-systems	Remarks/special requirements
▪ Emission approval of GTP operation for rated thermal firing capacity in 100 % H_2 and 100 % natural gas operation as well as mixed operation (according to ISO Standard). This also includes emission limit values for NO_x, CO and soot with regard to defined GT power ranges between idling operation and nominal load.	TFC legal licensing-basis for site, if necessary partial license for Level 1, 2, 3) BImSchV (Ordinance of the German Immision Control Act)
Combustion system and gas turbine	
▪ Depending on the combustion chamber concept – silo or can/ring combustion chamber – different requirements have to be met in the structural concept for the area compressor-exit-turbine-inlet.	
▪ For Level 1 (mixture of natural gas with H_2 fraction with TFC of up to 6 %), burners are to be provided which can be replaced by a new generation of burners within the scope of an upgrade for Level 2 (approx. 6 % to approx. 25% H_2 fraction with TFC) without any significant change to the combustion chamber (can, ring or silo combustion chamber).	
▪ Level 3 (from approx. 25 % H_2 TFC) probably requires an extended radial installation space due to expected new burner technology for enlarged combustion chamber cans or ring combustion chamber to be replaced.	100 % H_2
▪ For Level 3, replacement of burners with new combustion technology, if necessary, replacement of combustion chamber with enlarged version of combustion chamber with adapted cooling concept.	100 % H_2
▪ Device technology (fittings, pipelines, filters) for 100 % natural gas – 100% H_2 operation	100 % H_2

Criteria and design requirements for the respective sub-systems	Remarks/special requirements
▪ Flame detector suitable for 100 % natural gas – 100 % H_2 (depending on level of readiness) ▪ Operation from 100 % natural gas to 100 % H_2 possible without any load restrictions compared to load range with natural gas, especially in the increasingly important lower load range. ▪ The hot gas components for H_2 operation have to be designed in such a way that service life is not impaired compared to operation with natural gas. **Optional only:** ▪ Preparation of primary emission control (CO, NO_x) ▪ Water or steam injection incl. process engineering infrastructure as possible intermediate step in Level range 3 up to dry low NO_x (DLN) combustion technology with a high fraction of H_2 of up to 100 %. ▪ Possibility to retrofit an engageable clutch between gas turbine and generator if supplementary grid stabilisation without gas turbine operation is required; this concept is affecting shaft length and bearing.	
Flue gas system including HRSG	
▪ Arrangement of a catalyst in the optimum temperature range of the HRSG, preferably downstream of turbine, including its process engineering infrastructure ▪ Sufficiently dimensioning of NH_3 storage (also ammonia water or urea solution) for possible increased NO_x concentration in stages of Level 2 and 3 and acquiring approval for maximum capacity.	Approval by authority for stages of L2 and L3, if necessary, with accident analysis

Criteria and design requirements for the respective sub-systems	Remarks/special requirements
▪ Structural/spatial requirements for expansion of catalyst in the event of increased NO_x concentration in stages of Level 2 and 3 ▪ Design of heat exchanger surfaces and the water/steam circuit for 100 % H_2 and 100 % natural gas operation without operating restrictions. **Optional only:** ▪ Bypass at HRSG for low part load operation or only a duct section in the flue gas duct for subsequent installation of switching flap for bypass, which can significantly reduce the start-up times of GT. ▪ Consideration of the suitability/performance of non-metallic materials for increased water vapour in the flue gas in connection with load-flexible operation (e.g. compensators). ▪ Consideration of increased water vapour especially at the cold end (acid dew point of flue gas).	
Control technology and turbine protection	
▪ Suitable gas turbine setting (constant thermal firing capacity (TFC) and constant compressor nominal mass flow with regard to operating licence). Adapted monitoring of temperature non-uniformity in gas turbine meridian flow Suitable purging concept for HRSG for start-up of GTP (inert gas) for 100 % natural gas to 100 % H_2. ▪ Fluctuations in fraction of H_2 in the fuel gas have to be detected and GT control has to automatically adjust control behaviour.	Protection against over-firing and local thermal-mechanical overload in gas turbines TFC is the basis for approval (BImSchV)
Fire and explosion protection	

Criteria and design requirements for the respective sub-systems	Remarks/special requirements
▪ Gas-tight shut-off/shut-off capability at all operating states of the GTP (prevention of H_2 slip) ▪ All connections in the H_2 system have to be designed technically tight ▪ Purging of HRSG when starting the GTP (inert gas) ▪ Sensor and actuator systems in line with explosion protection concept ▪ Adaptation of building ventilation technology ▪ Adaptation of the entire explosion protection concept General note: Due to the significantly lower density of H_2 compared to natural gas, considerations of gas distribution in case of leakage must be re-evaluated; see also ISOTR15916:2000 Basic Considerations for the Safety of Hydrogen Systems	
Conversion of existing plants	
▪ In many cases, up to approx. 3 % H_2 TFC, only marginal or no conversion at all is necessary.	Attention: Modification of authority license may be needed
▪ Up to 6 % H_2 TFC, conversion is normally possible without any problems: - Apart from a few exceptions, current burners can burn fuels with a fraction of H_2 of up to max. 6 % TFC. - CO emissions can most likely be met by tuning, since even a low fraction of H_2 is positively influencing combustion characteristics.	Attention: Modification of authority license may be needed

Criteria and design requirements for the respective sub-systems	Remarks/special requirements
→ However, the specific plant configuration is always decisive and has to be checked individually (this note is particularly important towards politics). ▪ In most cases, conversion is technically possible from 6 – 25 % H_2 TFC. ▪ From 25 % H_2 FWL, conversion may only be possible at great expense; new burner technology has to be employed. ▪ Retrofitting of devices for monitoring combustion pulsations and an automatic control concept for combustion stability is considered necessary. ▪ Explosion protection concept has to be checked when blending H_2 to the fuel gas. ▪ HRSG has to be examined for gas traps in the upper area and has to be optimised if necessary. ▪ Installation of a suitably large SCR (Selective Catalytic Reaction) catalyst places great demands on the structural boundary conditions and a corresponding conversion of the entire HRSG; alternative possibilities for NO_x reduction may be used, e.g. proven water/steam injection. ▪ ***When setting the NO_x limit values for H_2 combustion, the technical feasibility has to be taken into account when retrofitting existing plants.***	
Licensing procedures, emissions etc.	
▪ At 100 % H_2 combustion, increased water vapour in the flue gas is to be expected. Due to this higher water vapour content, normalisation to dry NO_x leads to a disadvantage with H_2 combustion – this	

Criteria and design requirements for the respective sub-systems	Remarks/special requirements
fact has to be taken into account when setting the emission limit values. ▪ The market model has to be adapted to the expected operating regime of the H_2 gas turbines. Investment incentives are required in a timely manner in order to have sufficient H_2-fired GT available in due time as back-up capacity in a future energy system.	

5 Summary

The current state of knowledge on the realisation of H_2 readiness in new and existing gas turbine plants can be summarised as follows:

- The design of gas turbine plants capable of firing H_2 can mostly be based on existing gas turbine technology.
- It is not necessary to design and manufacture completely new gas turbines for H_2 firing.
- However, special attention has to be paid to the modification of the combustion system and several auxiliary devices for partial and, in particular, complete H_2 combustion The focus is on burner, combustion chamber, materials, seals, fire protection, explosion protection, monitoring and control equipment for combustion, etc.
- Upgrading of proven design concepts is not only suitable to avoid extensive capital expenditure in the transformation period, but also to save a lot of time in the conversion of large fleets of existing gas turbines to H_2 operation.

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vgbe energy e.V. is the technical association of energy plant operators and the international competence centre for the generation and storage of electricity, heat, hydrogen and energy carriers based on them as well as sector coupling. vgbe energy coordinates and supports its members in issues of standardisation, research and development, the exchange and preservation of know-how, access to expertise as well as basic and advanced training. vgbe's current 436 member companies from 34 countries operate an installed plant capacity of more than 300,000 MW.

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