TECHNOLOGY FACTSHEET

H2 INDUSTRIAL BOILER

Date of factsheet	18-5-2020
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Sector	Industry: Generic
ETS / Non-ETS	ETS
Type of Technology	Hydrogen
Description	This factsheet considers steam boilers fueled by 100% hydrogen. Hydrogen can be used as an alternative input energy carrier for boilers. To be considered as a renewable option, the hydrogen (H2) has to be produced from a renewable source, such as from electrolysis using renewable electricity. The combustion characteristics of hydrogen, such as velocity and flame heating properties, are different than from natural gas. The use of hydrogen in generic industrial boilers has proven feasible and only requires a retrofit of the burner to accommodate hydrogen gas properties (E4tech, 2015). Ricardo-AEA (2012) assumes that burner replacement is required to burning hydrogen at concentrations higher than 30%. Whereas up to a 30% blend of hydrogen with natural gas has possibly the same efficiency as natural gas, 100% hydrogen oxyfuel burners are 15 percentage points more efficient than natural gas due to flue gas condensation and recycling plus reduced volume of exhaust gas (Ricardo-AEA, 2012). Whether this includes the energy required for the production of O2 (that might be used instead of air in the combustion process) is not specified.
TRL level 2020	TRL 9
	Hydrogen burners are available and sometimes used at sites with available by-product hydrogen. They are used commercially in some industrial niches, although there is currently no wider market for intentionally pure hydrogen production as fuel. (E4tech, 2015; VNP, 2018). TKI Nieuw gas (2018) estimates that H2 boilers will be ready for a wider market introduction by 2025, and ready for the mass market by 2035. Although laws and safety regulations readily exist for the use of H2 within the industry sector, regulations are currently absent for the use of H2 in adjacent sectors, which may slow down the roll-out of H2 technologies (TKI Nieuw gas, 2018).

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range								
Capacity	MWth;out										50.00
					1.00			-			300.00
Potential	PJ/year	NL	Current			2030			2050		
					100.00			100.00			100.00
			100.00	-	101.00	100.00	-	101.00	100.00	-	101.00
Market share	%				-			0.01			0.02
			-	-	-	0.01	-	0.03	0.02	-	0.60

Capacity utlization factor	0.90
Full-load running hours per year	7,900.00
Unit of Activity	PJ/year
Technical lifetime (years)	25.00
Progress ratio	
Hourly profile	No
Explanation	Capacity: The typical size of a hydrogen boiler is not specified in literature. It is assumed that steam boilers of any size can be converted into a hydrogen boiler by retrofitting the burner. Therefore, the size of industrial H2 boilers can range anywhere from < 1 MWth to > 300 MWth (IEA-ETSAP, 2010; Ecodesign, 2014). Potential: Hydrogen boilers can be used for the same application in industry as the current gas-fired boilers. Solutions for decarbonisation in industry are also sought in electrification (Klimaatakkoord, 2018; TNO 2019; DNV GL, 2018), but H2 boilers can reach higher pressures and temperatures than electric alternatives, and therefore H2 boilers are a key to substitute the 100 PJ industrial heat demand above 250 °C, rather than the 124 PJ heat demand below 250 °C (TKI Nieuw gas, 2018). Achtergrondnotitie Klimaatakkoord (2018) yields a similar figure of 101 PJ: They describe that from the 168 PJ heat demand of the Dutch industry, 67 PJ of 142 PJ heat demand below 300 °C can be electrified by 2030. The remaining 75 PJ (<300°C) and 26 PJ (>300°C), which is 60% of the industrial heat demand, is interpreted as potential market for Hydrogen boilers in this factsheet. Market share: E4tech (2015) studies two scenarios for the UK with targeted H2 deployment (critical path) and widespread H2 deployment (full contribution) and finds that hydrogen may account for up to 50% of the industrial fuel use for high- and low-temperature heat in industry in 2050. These figures are under the assumption that sufficient hydrogen is available to fuel the hydrogen boiler. Running hours: It is assumed a hydrogen boiler can run 90% of the time (E4tech, 2015). Rounded off, this implies ~7900 running hours. Lifetime: The technical lifetime according to literature varies from 20 years (VNP, 2018; Ricardo-AEA, 2012) to 25 years (E4tech, 2015).

COSTS

Year of Euro	2015								
	Euro per Functional Unit	Current			2030			2050	
Investment costs	mln. € / MWth;out			0.12			0.12		0.12
		0.12	-	0.25	0.12	-	0.12	0.02	-	0.12
Other costs per year	mln. € / MWth;out			-			-		-
		Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
Fixed operational costs per year (excl. fuel costs)	mln. € / MWth;out			0.0040			0.0043		0.0043
		0.0040	-	0.0040	0.0043	-	0.0043	0.0043	-	0.0043
Variable costs per year	mln. € / MWth;out			-			-		-
		Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*

Costs explanation	Investment costs: There is only limited information available on the cost of hydrogen boilers. According to E4tech (2015) and VNP (2018) only retrofitting of the burners of existing boilers is required. E4tech provides a CAPEX of 98.3 GBP/kW for a low temperature heat* and drying 100% hydrogen boiler. In VNP (2018), Lux Research estimates 250 EUR/kW steam output for only retrofitting an existing 15MW boiler with a hydrogen burner. Ricardo-AEA (2012) assumes that 30% blended hydrogen with natural gas has no increase in capital costs compared to a fossil equivalent, whereas 100% hydrogen with oxyburner would incur a 30% increased capital cost to pay for condensation and flue gas recycle. Representative data for a natural gas boiler can be found in the factsheet on the industrial gas boiler (to be published). In that case, a non-conservative scenario for 2050 leads to an investment cost of 23E/kW for boilers burning 100% hydrogen, when these won't be availabe solely as a retrofit, but as a standard technology option for new boilers (TNO, 2020). Operational costs: The current OPEX is 3.2 EUR2018/kW per year and expected to go up to 4 EUR2018/kW by 2030 according to E4tech (2015). If OPEX follows the expert predictions that H2 boiler costs will approximate regular gas-fired boilers, the OPEX may reduce to 2,8 to 0,4 EUR/kW (EnergyMatters, 2015; Ecodesign, 2014). In their analysis, Ricardo-AEA (2012) make the assumption that operating costs have no net increase over their fossil equivalents, because ongoing energy costs are much more important for full lifecycle costs. * 'low temperature' refers to the definition of the UK Department of Energy and Climate Change, specifying high temperatures as above 1000°C (production of glass, cement, iron and steel), and low temperature process heat as 300-500°C (food and drink, chemicals and pulp and paper industry).

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:*	PJ			-1.00			-1.00			-1.00
	Steam		-1.00	-	-1.00	-1.00	-	-1.00	-1.00	-	-1.00
	Hydrogen	PJ			1.00			1.00			1.00
			1.00	-	1.11	1.00	-	1.11	1.00	-	1.11
		PJ			-			-			-
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
		PJ			-			-			-
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*

Energy in- and Outputs explanation	The energy efficiency is 85% based on HHV according to VNP (2018). This corresponds to an efficiency of 100% based on LHV, assuming a HHV energy content of 12,7 MJ/m3 (Bossel & Elisasson, 2002) and a LHV energy content of 10,8 (RVO, 2018). E4tech (2015) reports an efficiency of 90% but does not specify whether this is based on LHV or HHV. Ricardo-AEA (2012) reports an efficiency of 100%, LHV or HHV not specified.

MATERIAL FLOWS (OPTIONAL)											
	Material	**Unit**	**Current**			**2030**			**2050**		
Material flows			-			-			-		
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
			-			-			-		
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
Material flows explanation											

EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)											
	Substance	**Unit**	**Current**			**2030**			**2050**		
Emissions	NOx	kton	-			-			-		
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
			-			-			-		
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
			-			-			-		
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
			-			-			-		
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
Emissions explanation	According to Ilbas et al. (2005), hydrogen can be a very clean alternative to fossil fuels, as there are no CO, CO2, SOx and unburned hydrocarbons emissions from the hydrogen fuel combustion. The only pollutant from the hydrogen combustion is NOx. In their study on NOx formation in hydrogen combustion, high NOx levels were found at high temperature regions and low NOx levels at low temperature regions. For 100% H2, they predicted maximum NOx level as 1961 ppm at the maximum temperature of 2325 K. The predicted average NOx level at the combustor exit was 537 ppm at a temperature of 1372 K. The overall reduction in NO emissions was about 20% using 25% air staging compared with the NO emission from the non-staged hydrogen combustion. Mixing hydrogen with natural gas decreases the flame temperature, and thereby the NOx formation. Johansson (2005) also notes that according to literature, the NOx emission can be resolved by increasing the excess of air, resulting in a lower burning temperature. The allowed emission of hydrogen boilers is not specified in the Dutch regulation 'Besluit activiteiten leefomgeving' (2020). In article 4.431l of this regulation, the nitrogen oxides emission boundary value other types of >400 kW boilers is defined between 70 mg/Nm3 (natural gas) and 275 mg/Nm3 (biomass).										

OTHER										
Parameter	**Unit**	**Current**			**2030**			**2050**		
		-			-			-		
		Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
		-			-			-		
		Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
		-			-			-		
		Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
		-			-			-		
		Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
Explanation										

REFERENCES AND SOURCES

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