TECHNOLOGY FACTSHEET

TNO

NATURAL GAS STEAM BOILER INDUSTRY

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Sector	Industry: Generic
ETS / Non-ETS	ETS
Type of Technology	
Description	This factsheet considers steam boilers. Steam boilers are a widely used technology across all industry sectors. They generate steam, which may be used as a heat carrier, a carrier of chemicals or as a driver of a mechanical process via turbines. TNO (2019) estimates that 94% of the natural gas in the Dutch industry sector is consumed in natural gas boilers. Boilers can produce saturated steam, superheated steam or supercritical steam at increasing pressures and temperatures, depending on the requirements on the end-use side. Industrial boilers may have different purposes depending on the industries and facilities they are installed and may have a wide range of sizes. Industries with high steam demand, such as primary metals and pulp and paper, predominantly make use of large boilers, whereas more heterogeneous industries such as food processing and chemical manufacturing make use of both small and large boilers (Ecodesign, 2014). The two most commonly used boilers are fire-tube boilers and water-tube boilers, which are described in this factsheet. In fire-tube boilers, hot gases pass through tubes that heat water in a shell. This water is converted into steam. Fire-tube boilers are competitive for relatively small steam capacities (<28,000 kg/hour) and low to medium steam pressures (<30 bars) (Ecodesign, 2014). In water-tube boilers, water flows through the tubes that enter a boiler drum, where it is heated by the combustion gases and converted into steam. Water-tube boilers can reach higher steam demands and very high steam pressures. Fire-tube boilers are more commonly used than water-tube boilers. In 2019, natural gas was responsible for 188 PJ out of 420 PJ (45%) of the industrial heat demand in the Netherlands. The combustion of natural gas in boilers for own use is the main source of heat for the industry sector (ECN&CBS, 2020).
TRL level 2020	TRL 9
	Natural gas boilers are a mature technology and the standard heat supply option for the Dutch industry. As energy efficiency is the main cost driver (IEA-ETSAP, 2010), there has already been a clear incentive in the past for manufacturers to optimise the boiler system. Ecodesign (2014) concludes that efficiency can be increased in the generation system surrounding the boiler, rather than the boiler itself. It foresees that economisers, combustion control and water flow control will be included in 80 to 90% of the EU boiler population by 2030. Due to CO2 reduction targets, the heat demand of industry is subject to electrification. There is a growing interest to retrofit natural gas boilers into hybrid boilers able to use both natural gas and electricity as fuel. This would enable adapting the industry sector to an intermittent energy market based on renewable electricity generation. Although retrofitting gas boilers into hybrid systems is technically possible, TNO (2019) concluded that from an economical perspective, this currently results in a negative business case.

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range								
Capacity	MWth		50.00								
			3.00			-			73.00		
Potential	NL	PJ	Current			2030			2050		
			168.00			101.00			75.00		
			146.00	–	563.00	55.00	–	473.00	55.00	–	473.00
Market share		%	100.00			60.12			44.64		
			100.00	–	100.00	37.67	–	84.01	37.67	–	84.01
Capacity utlization factor	0.98										
Full-load running hours per year	8,600.00										
Unit of Activity											
Technical lifetime (years)	25.00										
Progress ratio											
Hourly profile											

Explanation	Capacity: There is no 'average' boiler. All boilers are tailored to the process that they are used for (Ecodesign, 2014). Ecodesign (2014) reports capacity ranges of 1-25 MW for fire-tube boilers and 25 MW or higher (beyond 50 MW for specific applications) for water-tube boilers. IEA-ETSAP reports < 3 MWth for small boilers, 3-73 MW for large boilers and >73 MW for very large boilers. Potential and market share: Natural gas steam boilers are widely available and can be used for most of the industrial heating processes. IEA-ESTAP (2010) states, however, that the boiler market is not growing in Western countries. In the Klimaatakkoord Achtergrondnotitie (2018), the total industrial steam demand (below 300 °C) is reported as 142 PJ for 2030, while total heat demand in industry amounts 416 PJ. DNV GL (2018) estimates the total heat demand in industry to be 563 PJ using a different definition. The business-as-usual scenario for the Netherlands is that natural gas boilers will remain in place in the absence of government intervention. Due to their reliability, natural gas boilers can still play a role as a back-up in a transition scenario with increasing intermittent energy sources towards the Paris Agreement. Capacity utilization factor: Danish Energy Agency (2020) reports a maximum of 2% of outage per year, leading to 98% utilization factor. Full-load running hours: Danish Energy Agency (2020) reports around 8,600 full load running hours. Taking the middle value of IEA-ETSAP's availability yields 7924 running hours per year. DNV GL reports higher running hours of 8760 hours per year. In practice, the running hours often lie lower, with Ecodesign (2014) reporting an average of 6000 hours (Ecodesign 2014) and TNO (2019) estimating an average use of 3380 hours. Technical lifetimes between 20 years (Steam Handbook 2017) and 25-40 years (IAE-ETSAP, 2010) are reported.

COSTS

	Euro per Functional Unit	Current			2030			2050		
Year of Euro	2015									
Investment costs	€ / MWth	17.56			-			-		
		9.71	–	55.00	*Min*	–	*Max*	*Min*	–	*Max*
Other costs per year	€ / MWth	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Fixed operational costs per year (excl. fuel costs)	€ / MWth	1.82			-			-		
		0.38	–	2.76	*Min*	–	*Max*	*Min*	–	*Max*
Variable costs per year	€ /	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Costs explanation	Investment costs are reported of 17,6 €/kWth for 1-5 MW boilers and 9,7 €/kWth for 5-25 MW boilers by Ecodesign (2014). Steam Handbook presents values around 20,2 €/kWth for 4 MW boilers and 14,9 €/kWth for 10 MW boilers. Danish Energy Agency reports 55 €/kWth for 20MW boilers, indicating that it might be up to 20% lower if it is a hot water boiler. Energy Matters (2015) uses significantly higher investment costs of 50€/kWth for a 8,1 MWth boiler in their calculations. Case studies from Ecodesign (2014) report operational costs around 5000 Euro per year, which are not related to the size of the boiler. These convert to operational costs of 2,8/1,8/0,4 €/kWth per year for 1,7/2,8/11,6 MW boilers. Energy Matters (2015) uses 1 €/kWth per year in their calculations. As a rule of thumb, capital costs represent around 1% (Steam Handbook, 2017) to 3% (IEA-ETSAP, 2010) of the lifetime fuel costs, while Operation and Maintenance costs are around 1% (IEA-ETSAP, 2010). Water-tube boilers have higher capital costs than other boiler types (Steam Handbook, 2017). In these studies, no projections for 2030 and 2050 are given. Due to the high maturity of the technology, no major developments leading to cost reductions are foreseen in the long term (Danish Energy Agency, 2020).

ENERGY IN- AND OUTPUTS											
Energy carriers (per unit of main output)	**Energy carrier**	**Unit**	**Current**			**2030**			**2050**		
	Main output: Steam	PJ		-1.00			-			-	
			-1.00	–	-1.00	*Min*	–	*Max*	*Min*	–	*Max*
	Natural gas	PJ		1.08			1.06			1.05	
			1.08	–	1.25	1.06	–	1.06	1.05	–	1.05
		PJ		-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
		PJ		-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Energy in- and Outputs explanation

As energy efficiency is the main cost driver (IEA-ETSAP, 2010), there has already been a clear incentive in the past for manufacturers to optimise the boiler system. Moreover, best available boilers are reaching thermodynamic limits, hence no significative efficiency improvements gains are expected in the future (Danish Energy Agency, 2020).
Ecodesign (2014) reports that the efficiency of boilers is governed by the required operating pressure. It reports a 85,7% efficiency as benchmark, but notes that boilers with a low load have lower efficiencies down to 70%. Ecodesign (2014) notes that 48% of the boilers in the EU have an efficiency of 90% and higher, and another 39% has efficiencies between 85% and 90%. The Steam Handbook (2017) notes an efficiency of natural gas fire-tube boilers of 80%, where the energy losses are due to sensible heat in dry flue gases (7%), due to ethalpy in the water vapor (12%), and 1% due to radiation, convection and conduction.
According to the market operators, the main trends in product design will focus on energy efficient technologies and waste heat recovery. Technology improvements for boilers focus on efficiency and low-cost design while giving increasingly more attention to air pollutant emissions.
Ecodesign (2014) lists possible improvements to boiler systems, including a condensate return, flue-gas isolation dampers, insulation of the generation and recovery system, preheating feedwater and vapour recompression. In summary, it concludes that efficiency can be increased in the generation system surrounding the boiler, rather than the boiler itself. It foresees that economisers, combustion control and variable speed drives will be included in 80 to 90% of the EU boiler population by 2030.

MATERIAL FLOWS (OPTIONAL)											
Material flows	**Material**	**Unit**	**Current**			**2030**			**2050**		
				-			-			-	
			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)											
Emissions	**Substance**	**Unit**	**Current**			**2030**			**2050**		
	0	0		-			-			-	
			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

In article 4.431l of the Dutch regulation 'Besluit activiteiten leefomgeving' (2020), the nitrogen oxides emission boundary value of a >400 kW natural gas boiler is defined as 70 mg/Nm3. This is more strict than the EU directive 2001/80/EC, which limited the NOx emissions of natural gas (3% O2) to 150 mg/Nm3 for 50-300 MWth and 100 mg/Nm3 for installations >300 MWth (IEA-ETSAP, 2010).
The emissions from natural gas-fired boilers include nitrogen oxides (NOx), carbon monoxide (CO), and carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), volatile organic compounds (VOCs), trace amounts of sulfur dioxide (SO2), and particulate matter (PM). Nitrogen oxides formation occurs mainly as thermal NOx. The thermal NOx mechanism occurs through the thermal dissociation and subsequent reaction of nitrogen (N2) and oxygen (O2) molecules in the combustion air and is affected by three furnace-zone factors: (1) oxygen concentration, (2) peak temperature, and (3) time of exposure at peak temperature. As these three factors increase, NOx emission levels increase. Emission levels vary considerably with the type and size of combustor and with operating conditions. (US EPA, 1995)

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										

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