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 (<38,000 kg/hour) and low to medium steam pressures (<50 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 & CBBL, 2020).

Technical dimensions

**Capacity**

<table>
<thead>
<tr>
<th>Year of Euro</th>
<th>Current</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment costs</td>
<td>€ / MWh</td>
<td>17.56</td>
<td>15.00</td>
</tr>
<tr>
<td>Other costs per year</td>
<td>€ / MWh</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Fixed operational costs per year (excl. fuel costs)</td>
<td>€ / MWh</td>
<td>1.82</td>
<td>Min</td>
</tr>
<tr>
<td>Variable costs per year</td>
<td>€</td>
<td>Min</td>
<td>Max</td>
</tr>
</tbody>
</table>

Investment costs are reported of 17.6 €/KWh for 1-5 MW boilers and 9.7 €/KWh for 5-25 MW boilers by Ecodesign (2014). Steam Handbook presents values around 20-25 €/KWh for 4 MW boilers and 14.9 €/KWh for 10 MW boilers. Danish Energy Agency reports 55 €/KWh 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 55€/KWh for a 8.1 MWth boiler in their calculations.

Case studies from Ecodesign (2014) report operational costs around 5000 €/per year, which are not related to the size of the boiler. These convert to operational costs of 2,813,804 €/per year for 1,720,816 MW boilers. Energy Matters (2015) uses 1 €/KWh 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).

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

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Unit</th>
<th>Current</th>
<th>2030</th>
<th>2050</th>
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<tbody>
<tr>
<td>Steam output</td>
<td>PJ</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Natural gas</td>
<td>PJ</td>
<td>1.08</td>
<td>1.06</td>
<td>1.05</td>
</tr>
<tr>
<td>PJ</td>
<td>-</td>
<td>1.25</td>
<td>1.06</td>
<td>1.05</td>
</tr>
</tbody>
</table>

#### 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 significant 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

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit</th>
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<th>2030</th>
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<tr>
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<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
</tbody>
</table>

#### Material Flows Explanation

### Emissions (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS))

#### Emissions

<table>
<thead>
<tr>
<th>Substance</th>
<th>Unit</th>
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<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
</tbody>
</table>

#### Emissions Explanation

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)

### References and Sources

- Industrial Combustion Boilers, IEA-ETSAP, 2010
- Ecodesign Preparatory Study on Steam Boilers, PwC, Fraunhofer ISI and ICCS-NTUA, 2014
- Klimaatakkoord achtergrondnotitie: De potentie van Power to Heat in de Nederlanse Industrie, 2018
- Steam Handbook: an introduction to steam generation and distribution, Endress+Hauser, 2017
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**Table:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Current</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
</tbody>
</table>

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**Explanation:**

- **Energy in- and Outputs:**
  - Steam output: 1.00 PJ
  - Natural gas: 1.08 PJ, 1.06 PJ, 1.05 PJ
  - Pj: - 1.25 PJ, 1.06 PJ, 1.05 PJ

- **Material Flows (Optional):**
  - Min: - Max: Min: Max: Min: Max: Min: Max

- **Emissions (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)):**
  - O: 0
  - Min: - Max: Min: Max: Min: Max: Min: Max

- **Other:**
  - Min: - Max: Min: Max: Min: Max: Min: Max

**References and Sources:**

- Industrial Combustion Boilers, IEA-ETSAP, 2010
- Ecodesign Preparatory Study on Steam Boilers, PwC, Fraunhofer ISI and ICCS-NTUA, 2014
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