ATES installations generally have a capacity of 0.2 to 10 MW (Wesselink, 2016). A review-report focussed on the UK gives examples of projects with heating capacities ranging from 250kWth (excl. fuel costs) Other costs per year

<table>
<thead>
<tr>
<th>Investment costs</th>
<th>Euro per Functional Unit</th>
<th>Current</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>€ / kWth</td>
<td>529</td>
<td>2,975</td>
<td>476</td>
<td>2,978</td>
</tr>
<tr>
<td>Other costs per year</td>
<td>€ / kWh</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>€ / kWh</td>
<td>16</td>
<td>96</td>
<td>14</td>
<td>90</td>
</tr>
</tbody>
</table>

**Costs explanation**

In the table above, a cost range is shown based on average cost data from multiple sources (see referencing). The investment (capital) costs consist of the storage system, heat pump and heat exchangers (including transport) pipes. Note that for ATES we refer to capacity in terms of kWth, for aquifers the size is usually expressed as the (maximum) rate at which heat can be extracted from a well at a single time.

According to Nationaal Warmtepunt Trendrapport (2018) the potential of water/water heat pumps (i.e. ATES) is 7 GWth (National Warmtepomp Trendrapport, 2018).

Worldwide, there are more than 2,800 ATES systems in operation at present, with 95% of them low-temperature-systems (storage temperatures of < 25 °C). 95% of all systems are located in the Netherlands, and a further 10% are found in Sweden, Denmark, and Belgium (Briant et al., 2018).

The number of heating full load hours of the ATES (and the peak demand heating system) depends on the heat supply profile of the ATES and the heat demand profile of the heat consumer. Similar distribution rule is also valid for space cooling. In different countries around the world the ATES technology has a 1,000 – 2,000 full load hours per year for heating (IEA, 2007). Depending on country ATES has 400 - 1,000 full load hours per year for cooling (IEA, 2007). Range obtained depends on the different climate conditions in the investigated countries. ATES have 1,000 full load hours in the U.S. for Northern Europe and Canada and for cooling an average of 1,500 full load hours per year is given by DWA. Valves for the Netherlands (heating 180°C; cooling 80°C) are taken from the VESTA model from FIB (Far, 2007). Generally, the cooling demand is lower than heating demand.

In order to exchange the excess demand in the system the heat/cold demand has to be supplied with auxiliary heating (e.g. gas-fired boiler or electric boiler).

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In order to exchange the excess demand in the system the heat/cold demand has to be supplied with auxiliary heating (e.g. gas-fired boiler or electric boiler).
In the table above we show the average annual energy in- and outputs associated to space heating. The energy in- and outputs of the entire ATES system, from heat source to end consumer, depends on a number of assumptions regarding heat losses and the SPF (seasonal average COP) of the heat pump. These assumptions are as follows:

- Total heat losses associated to heat extraction and seasonal storage of heat in an aquifer is assumed 20% per year.
- The coefficient of performance (COP) of the heat pump is the ratio between electricity input and heat output. The COP depends on the temperature difference between the heat source and heat sink. The annual average COP is called seasonal performance factor (SPF). At a temperature difference of 4-8 °C (between extraction and infiltration), the COP of a heat pump ranges between 3 and 5 (Bisemendal et al., 2017). According to Schüppler et al. (2013), the estimated seasonal performance factor (SPF) of the ATES system for heating is 4 (Schüppler et al., 2013). We assume COP=SPF=4 since the source temperature is almost constant over the year.
- Furthermore, there is pump energy involved. Typically, one uses between 17 and 20 kWhe of pump energy per GJ thermal energy output (Koornneef t., 2019). We assume 20 kWhe/GJth, which converts to 0.07 GJe/GJth.
- With this, the in- and outputs of the system are calculated. The typical (average) system efficiency is 79%.

For comparison:
- REN21 indicates a 50 - 90% ATES system efficiency for heating (IRENA, 2013).
- Department for Business, Energy and Industrial Strategy (2016) reports 70-90% ATES system efficiency for heating (efficiency is higher for cold storage) (Department for Business, Energy and Industrial Strategy, 2016).

For transition:
- Only a significant increase in performance of heat pumps can be expected. We base our heat pump COP projections for 2030 and 2050 on improvement percentages from an IEA factsheet (IEA, 2013b). The performances of heat pumps in 2030 are projected to be 30-50% higher compared to 2013 (for cooling 20-40%). In 2050, the performance increased by 40-60% compared to 2013 (for cooling 50-60%). Since the IEA projection is compared to 2013 (and for the purpose of this factsheet it needs to be compared to 2020) we take the minimum percentage in each case (as 30% in 2019 and 46% in 2050 for heating with heat pump).