ENERGY STORAGE
A KEY TO LOW CARBON COMMUNITIES
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THE INTEGRATED ENERGY SYSTEM – A VIRTUAL BATTERY

Most energy is consumed in cities, but cities have, due to economy of scale, the potential for an efficient energy infrastructure, including:

- electricity
- gas
- district heating (hot water)
- district cooling (cold water).

The grids are interconnected via conversion technologies:

- **CHP plants** generating heat and electricity from gas and biofuels
- **Electric heat pumps** generating heat and cold from electricity
- **Absorption heat pumps** generating cold and low temperature heat from high temperature heat
- **Electric boilers** generating heat from electricity
- **Power-to-gas plants** generating renewable gas and heat from electricity.

Due to the conversion technologies and the integrated networks, we can e.g. store electric energy not as electricity, but as hot water, cold water or gas in case this is the end-use demand. Thereby, a city with this infrastructure can react on the electricity market and use a lot of electricity at low prices and even generate electricity at peak prices.

Seen from the power system the city reacts as if there was a huge electricity storage installed – we call it the **virtual battery**. In case there is no infrastructure for district heating and cooling it is possible to take into account the benefits of storing energy in the energy planning of this infrastructure.

**01 EXPERIENCE**
Ramboll has been involved in a wide range of projects for planning and design of all components of the integrated energy system in cities and campuses, e.g. The Greater Copenhagen District Heating system.
Heat storage tanks have for decades played an important role in the hot water district heating for optimising the production of combined heat and power.

**Economy of scale**

The costs of storing the hot water depends on the size of the storage. The larger the cheaper. The pressure less tank can store heat up to 95°C, but a slightly pressurised tank can store heat up to 130°C.

The most common integration in the network is a direct connection at the main production plant in such a way that the tank maintains the pressure in the network and furthermore can offer storage capacity for make-up water. The flow difference between the distribution and the production pump simply defines the operation of the storage.

**At CHP plants** which can generate power without heat, the heat storage allows the plant use its maximal power capacity and still deliver heat at a very low cost. A steam extraction plant can stop the heat production and generate maximal power capacity at power peak prices and later generate more heat in an optimal operation.

**At CHP plants** which generate heat and power in a fixed mode, e.g. gas engines or back-pressure plants, the operation can be optimized to maximize the revenues from sold electric energy and capacity and thereby reducing the cost of the heat.

**At district heating plants** in general, the heat stores can optimize the heat production from boilers, surplus heat and solar heat and level the production taking into account the weekly fluctuations of the heat demand.

Finally, by leveling the daily fluctuation on the coldest days, the store can offer peak capacity to the district heating.

**Heat storage pit**

The heat storage pit is a further development of the heat storage tank to lower construction costs and heat losses in order to increase the share of solar heating. The storage is a combination of a landfill pit with a 100 % water tight plastic liner, a tower for out- and inlet of water similar to the one in the heat storage tank and an insulated floating cover. The insulation in the cover is protected against water from the pit and from rain water by two water tight liners. The water in the pit cannot be completely free of oxygen and is therefore connected to the district heating via a heat exchanger.

There is only insulation in the cover, as the dry soil during a couple of years has a stable temperature and takes part in the storage. The heat losses in stable operation is around 20 % of the energy content, for a typical 200,000 m$^3$ storage.

**Ramboll has been involved in the planning, design and supervision of almost all heat storage tanks in Denmark and a number of international projects. That includes a 75,000 m$^3$ pressureless storage tank at Fynsværket CHP plant and a 2 x 24,000 m$^3$ pressurised heat storage tanks designed for a maximal temperature of 120°C at Avedøre CHP plant, which is a part of the Greater Copenhagen district heating system.**

In case there is a pressure difference between the tank and the network, a pressure sectioning can be installed, which is more cost-effective than heat exchangers and can operate without temperature loss. Pressure difference: 10 Bar. Maximal capacity for loading and unloading 300 MW.
A WIDE RANGE OF OTHER ENERGY STORAGE FACILITIES

**Cold storage tanks**
The cold storage has an important role in district cooling due to the daily fluctuations from comfort cooling. The storage can be loaded in low load hours and unloaded in peak hours and save expensive cooling capacity. Like the heat storage tank, the tank can maintain the pressure in the network and store make-up water, and it opens for optimal operation taking into account fluctuating electricity prices. Ramboll has been involved in planning and design of several cold storage tanks.

**Natural gas storage**
Huge seasonal gas storages compensate for the fluctuations of the consumption and increase the security of supply. There are three types: depleted gas/oil reservoirs, aquifer reservoirs and salt caverns. We expect that gas storages in the longer-term will play an important role storing surplus wind energy in the form of methane for later use to generate back-up capacity for power and heat.

**Compressed air in caverns**
The gas storage technology in caverns can be reused for compressed air storage facilities. Ramboll has been involved in feasibility studies, which indicate that storing electricity this way can compete with pump hydro stores and batteries.

**Electric batteries**
Electric batteries are more expensive than gas and thermal stores for storing energy. However, they are booming in the transport sector services which cannot be delivered by gas and thermal storage, as they can offer large capacities in a concentrated volume.

Ramboll has been involved in battery storage projects and in urban planning for infrastructure and automatization which will improve the short-term demand response of battery driven facilities, e.g. to ensure that loading of electric cars do not overload the grid in peak hours.

**Frequency stabilization**
In the transformation from traditional power plants to wind and solar, the power grid needs inertia to stabilize the frequency, voltage and instantaneously power demand response. The load can change from plus to minus within milliseconds. There are several solutions, which compete in this market, e.g. synchronous condensers, electric boilers, high-speed flywheels and batteries.

Ramboll has offered consultancy services for a wide range of competitive projects to solve this problem, mainly synchronous condensers and electric boilers up to 80 MW.

**GAS STORAGE**
Ramboll has been involved in large-scale gas storage facility projects in all three types of gas storages covering all services. Ramboll are currently involved in feasibility studies for power2gas.

**STEAM STORAGE**
Ramboll has designed two 170 m³ tanks to store the steam from two 12 bar boilers at a pharmaceutical industry.

**HYDRO POWER**
Ramboll has through our strong position in Norway and Sweden been involved in all services within hydro power, in particular refurbishment of old plants.

**Hydro power and pump stores**
Hydro power is a fluctuating energy source depending on the rain fall. However, hydro power dams have for more than a century been a cost-effective way of storing electricity.

The potential for more hydro power, including pump storage facilities, can be further explored, but the remaining cost-effective resources are limited for environmental reasons.

**Steam storage tank**
Steam is widely used for industrial processes. In case the load gradient of the demand exceeds the capability of the supply source, a steam storage tank can solve the problem and improve the operation. However, the storage volume is limited due to the construction cost of the tank.
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Cost effective energy storage facilities

The UN Sustainable Development Goals and COP21 are recognised landmarks for our energy policy.

The challenge will be, not only to increase the market share of surplus energy and fluctuating energy from wind, solar and hydro, but rather to use it and meet the objectives in a cost-effective way.

Therefore, there will be an increasing need for energy storage facilities and energy demand-response. To solve the problem, we have to consider both the supply and the demand side. The thermal demand can e.g. be supplied with hot and cold water which can be generated by renewables and stored at very low cost compared to steam and electricity.

Moreover, hot- and cold- water systems can be integrated into district heating and district cooling in cities and benefit from economy of scale.

Seen from the power system, district heating and cooling is a smart consumer, which can offer huge demand respond.

To identify the smartest solutions for the society it is a good idea to analyze the energy infrastructure and its energy carriers for electricity, gas and thermal energy and take into account quality and time – ranging from seasonal storage to frequency stabilization.

ABOUT RAMBOLL

SIZE
With 14,000 experts across 35 countries and more than 300 offices, Ramboll is one of Europe’s largest consultancies.

OWNERSHIP
The Ramboll Foundation is the main owner (98%) of Ramboll Group A/S. The remainder of the company is owned by Ramboll employees.

HEAD OFFICE
Ramboll’s Group Management and head office are located in Copenhagen, Denmark.

GEOGRAPHICAL SPREAD
Our presence is global with especially strong representation in the Nordics, the UK, North America, Continental Europe, Middle East and Asia Pacific.

Cover page: Vojens solar heating plant and heat storage pit.
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