



Wastewater treatment plants are evolving into multifunctional systems that combine water purification, energy production, and resource recovery cycles

Source: 2G Energy

The Role of CHP Systems in Wastewater Treatment Plants – Focus on the Middle East

Combined Heat and Power (CHP) systems play a central role in the energy optimisation of modern wastewater treatment plants. By utilising biogas from anaerobic sludge digestion, decentralised electricity and heat generation becomes possible, thereby reducing operating costs, emissions, and dependence on external power grids. Particularly in the Middle East, CHP systems offer significant strategic advantages due to high operational demands on energy and water infrastructure, enabling more resilient and sustainable facility concepts.

Over the past decades, wastewater treatment has undergone a fundamental transformation. What was once a purely infrastructural necessity has evolved into a complex resource management system operating at the intersection of water management, energy supply, and climate policy. This development has gained particular momentum in water-scarce regions such as the Middle East. There, wastewater treatment plants are no longer

merely disposal facilities but have become key components of national water and infrastructure strategies.

At the same time, expectations placed on these facilities have changed significantly. In addition to compliance with effluent quality standards, topics such as energy self-sufficiency, CO₂ reduction, resilience against supply fluctuations, and integration into broader smart infrastructure concepts are in-

creasingly coming into focus. Wastewater treatment plants are thus evolving into multifunctional systems that combine water purification, energy production, and resource recovery cycles.

In parallel with this functional upgrade, the energy demands of modern wastewater treatment plants continue to increase. Processes such as aeration, sludge treatment, recirculation, and pumping make municipal treatment

plants among the largest single electricity consumers in the public sector. In many cases, a substantial share of operating costs is attributed to energy consumption. This structural dependency makes it clear that energy efficiency must not be treated as a simple optimisation parameter but as an integral part of plant design.

Energy challenges in the Middle East

These conditions are further intensified in the Middle East. Rapid population growth, accelerated urbanisation, and the development of new industrial hubs and megacities are placing increasing pressure on water infrastructure. At the same time, high ambient temperatures, limited freshwater resources, and partially decentralised supply structures create specific challenges for operational reliability and resilience. National transformation programs, particularly in the context of long-term strategies such as Saudi Arabia's Vision 2030, are reinforcing the focus on sustainable and energy-efficient infrastructure solutions.

In addition, many projects in the region are implemented under highly dynamic planning conditions. Capacity expansions, phased commissioning, and strongly fluctuating inflow rates are the rule rather than the exception. This places increased demands on the flexibility of both process engineering and energy systems within wastewater treatment plants.

Functional principle and role of CHP in wastewater treatment plants

Within this context, CHP systems play a pivotal role. They enable the energetic utilisation of existing biological material flows in wastewater

treatment plants, transforming what is traditionally a disposal system into a decentralised energy production unit. The foundation of this technology is anaerobic sludge digestion, in which organic matter in sewage sludge is converted into a methane-carbon dioxide gas mixture under oxygen-free conditions. This biogas represents a continuously available energy carrier that can be utilised directly on-site.

Energy utilisation takes place in gas engines that generate electrical power while simultaneously producing thermal energy. The electrical output supports plant operations directly, while the heat has a multitude of possible uses – from temperature control at the digesters, over to sludge drying, or even providing the energy to convert sludge into fertiliser. This combined approach significantly increases the overall efficiency of the energy carrier compared to separate generation systems. In practice, this means that a waste stream is converted into a predictable energy resource within plant operations.

System benefits and energy integration

The key strength of CHP systems in wastewater treatment plants lies not only in energy production itself but in their systemic impact. Local utilisation of biogas reduces dependence on the public electricity grid, which is particularly important in regions with unstable grid conditions (reliance on diesel-based backup systems) or where the public electricity grid is not at all available. At the same time, operating costs become significantly more stable as energy production is partially decoupled from external energy markets.

Another important aspect is the possibility of load shifting within the plant. Through intelligent oper-

ational control, CHP units can be operated during periods of high grid load or elevated electricity prices, while in other operating modes the focus remains on process stability. Certain CHP units can also blend biogas with additional fuels or switch to alternative fuels such as natural gas, allowing them to match elevated electrical loads even in periods when the available biogas may not be sufficient or at all available. This flexibility is becoming increasingly relevant as many Middle Eastern countries move towards more market-oriented energy pricing structures.

Furthermore, CHP systems contribute significantly to emission reduction – in two ways. Methane that would otherwise escape from wastewater processes is instead converted into usable energy, thereby reducing greenhouse gas impact. Since methane has a substantially higher global warming potential than carbon dioxide, this effect is particularly significant. At the same time, the generated energy mostly displaces fossil-based power generation, further enhancing the climate benefits.

Relevance for energy and water strategies in the Middle East

In the Middle East, this interconnection is particularly important as water and energy infrastructure are increasingly planned in an integrated manner. Wastewater treatment plants are often part of larger water reuse systems, where treated effluent is used for irrigation, industrial applications, or urban reuse. The energy self-sufficiency of such facilities is therefore a key factor in their long-term economic viability and independence.

In addition, international financing and operating models (e.g., Public Private Partnership (PPP)

structures, energy-as-a-service, water-as-a-service) are becoming more prevalent. In such frameworks, lifecycle performance plays a decisive role. Energy efficiency and on-site energy generation are therefore not only technical parameters but also critical financial evaluation criteria.

Technical challenges in design and operation

One major challenge lies in correct system sizing. Designs are often based on theoretical biogas yield projections or future expansion scenarios, which in practice can lead to oversized CHP systems. Equally critical is the underestimation of real operating conditions, particularly high ambient temperatures and their impact on engine performance and cooling system design, which can in turn lead to undersized CHP systems.

Another key issue is biogas quality. Sewage gas is not a homogeneous fuel but varies in methane content and composition depending on influent characteristics, industrial discharges, and biological process conditions. These fluctuations can significantly affect the operational stability and lifetime of gas engines if appropriate control and protection systems are not implemented. In practice, sulfur and siloxane compounds are among the most critical factors impacting gas quality, together with varying methane content in the biogas.

In many projects, economic decisions are still strongly driven by capital expenditure, while lifecycle costs are insufficiently considered. This often results in technical solutions that incur higher maintenance costs and lower availability during operation, or in equipment that may have been cheaper by a few percentage points but may have a substantially shorter lifetime, sometimes even

one-fourth of more expensive counterparts. Particularly in municipal environments with long-term project lifetimes and operating contracts, this can lead to significant economic disadvantages.

Engineering approach for robust and flexible systems

Successful CHP implementations increasingly rely on a holistic engineering approach. Modular system designs with multiple units enable flexible adaptation to real gas availability and load profiles. At the same time, adaptive operational strategies are gaining importance, allowing CHP operation to be dynamically adjusted to current process conditions.

Integration into higher-level energy and process control systems is also becoming standard practice, ensuring optimal coordination between wastewater treatment and energy generation. The focus is therefore shifting from pure energy production towards systemic optimisation of the entire plant. In modern concepts, the CHP unit is no longer viewed as an isolated component but as an integral part of the plant's overall energy system.

International project experience and operational practice

Experience from international projects shows that particularly in hot climates, robust and well-integrated CHP systems can achieve significant efficiency gains. In several facilities in the Middle East, the use of biogas CHP systems has substantially reduced diesel consumption in hybrid energy systems and increased overall energy self-sufficiency.

At the same time, it has been demonstrated that modern systems can operate reliably even under

high ambient temperatures, provided that appropriate design concepts are implemented from the onset of project evaluation. In practice, the combination of adequate design, preventive maintenance and condition-based monitoring is crucial for achieving high plant availability.

Practical project example: CHP implementation in Saudi Arabia

A representative example of CHP integration under real operating conditions can be found in a large-scale wastewater treatment plant in Saudi Arabia. The facility, designed for a treatment capacity of approximately 270,000 m³ per day, is located in a remote area roughly 1.5 hours from Mecca. The project is among the early wastewater infrastructure developments implemented under Saudi Arabia's new PPP and BOOT (Build – Own – Operate – Transfer) frameworks, reflecting the increasing adoption of water-as-a-service models in the region.

Two CHP units of the type 2G Avus 500-plus, each with an electrical output of 600 kW, were commissioned in 2022. Due to the absence of a public grid connection at the site, the plant relies heavily on on-site energy generation. In this context, the CHP system plays a critical role in reducing dependence on diesel-based power generation and improving overall energy efficiency.

The system design follows a modular approach, enabling stable operation even under fluctuating biogas availability, which is typical for wastewater treatment processes. In addition, the units are configured in a warm-climate version, allowing them to maintain full electrical output even under elevated ambient temperatures. This is a key requirement for reliable operation in the region and reflects broader design considerations for CHP systems in

Middle Eastern wastewater infrastructure.

The project is one of several CHP installations specifically engineered for wastewater treatment applications in the Middle East, illustrating how standardised yet adaptable system concepts can be successfully deployed under region-specific boundary conditions.

Wastewater treatment plants as integrated energy and resource systems

The evolution of wastewater management clearly shows that treatment plants are increasingly to be understood not only as consumers but as hybrid energy and resource producers. CHP systems are a key component of this transformation. However, their economic and environmental benefits are only fully realised when they are planned, designed, and operated as integral parts of the overall system.

In the Middle East in particular, a strategically relevant approach emerges: the combination of water scarcity, rising energy demand, and ambitious sustainability targets creates an environment in which energy-efficient wastewater infrastructure can directly contribute to



Figure 1. CHP improve both energy self-sufficiency and environmental performance of treatment plants

Source: 2G Energy

national development goals. CHP systems play a central role in this context by improving both energy self-sufficiency and environmental performance of treatment plants (Figure 1).

Ultimately, however, success is determined not solely by technology design but by its consistent implementation in real-world operation. Only the interaction of robust design, realistic operating assumptions, and continuous optimisation enables the full potential of these systems to be realised, transform-

ing wastewater treatment plants into sustainable, energy-positive infrastructure systems.

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