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# Real-Time Digital Twin for High-Strength Co-Digestion: Model-Based Decision Support in a Large Biogas Facility

Manel Garrido-Baserba*, Jose Jimenez**

*Brown and Caldwell, Coral Gables, FL, USA, mgarrido@brwncald.com

**Brown and Caldwell, Orlando, FL, USA, jjimenez@brwncald.com

**Abstract:** New developments in remote control, data analytics, and anaerobic models (e.g., co-digestion) are pushing toward a new way to operate biogas facilities. A real-time model-based digital twin (DT) with prediction capabilities was established as a monitoring and decision support platform in a large biogas facility to enhance the operations of the high-strength waste co-digestion of more than 20 different feedstocks. A similar but more straightforward approach was also followed for the manure operations side. The digital twin was deployed to support plant operations, optimize the feeding regime to the digesters, and improve storage and feed synergies while providing predictive capabilities to better monetize newer feeds and business opportunities. The DT is connected to all key elements of the operations, from internal databases and operating software (e.g., Scada, meters, etc.) to lab data, truck scales, gas injection ports, and reporting software. The DT enabled the expansion of the monitoring capabilities by maximizing plant operational efficiency while facilitating operators and personal facility insight and supporting daily decisions.

**Keywords**: Digital Twin; Co-digestion; Automation; Real-time modelling.

## Introduction

The growing interest in maximizing biogas production through co-digestion of organic wastes has led to the development and implementation of a digital twin (DT) to enhance digester operations and prepare for upcoming feedstock diversification challenges. The DT not only captures current optimization potential with existing equipment and infrastructure but also prepares for future scenarios by evaluating various co-digestion feedstock combinations.

Increasing feedstock availability, varying waste characteristics, and complex interactions between different organic streams require facilities to continuously improve their co-digestion management strategies. This necessitates a reliable tool that not only maintains peak digester performance under existing conditions but also plans ahead for various feedstock scenarios while actively engaging operators, process engineers, and managers in making informed decisions about co-digestion opportunities.

An ambitious project to advance digester automation and feedstock analytics was developed to address these challenges. The implementation of a digital twin with automated data processing, advanced process control, live process modeling, and forecast capabilities provides a comprehensive and accessible environment to monitor co-digestion operations in real-time and perform what-if scenarios based on both historical and forecast data, equipping the operations staff with better tools and insights to identify optimal feedstock combinations and support better decisions as new co-digestion opportunities arise.

**Figure 1.** Digital twin interface showing: (top) real-time comparison between measured and SIMBA#-predicted biogas production, (middle) operational trends and performance indicators, and (bottom) detailed visualization of both the PowerBI data model architecture integrating 150+ signals and the ADM1-based process model implemented in SIMBA# for co-digestion simulation.

## Methodology

The Co-digestion Digital Twin continuously captures all operational insights by collecting and processing raw data from the plant's incoming truck scale system, laboratory information management system (LIMS), and various financial tracking interfaces. A continuous data pipeline into SQL databases was developed to provide preprocessing and reconciliation functionalities specific to co-digestion feedstock characterization (e.g., outliers, data gaps, feed variations, etc.). This pipeline generates compatible, high-quality datasets through Python-based analytics for real-time model simulations, with results visualized through PowerBI dashboards for operational decision support.

A detailed process model of the co-digestion system was developed using SIMBA# simulation software. The model incorporates a tailored version of ADM1 (Batstone, 2002; Derbal, 2009) with enhanced pH sensitivity and improved capture of co-substrate characteristics (ifak, 2024). A custom-built influent generator tool was developed to transform Weender analysis properties of any feedstock into SIMBA#-compatible model inputs. Real-time integration with the facility's scale system enables immediate characterization and simulation as trucks arrive, leveraging an extensive feedstock database. The model accounts for all critical operational and financial parameters, including water consumption, biogas monetization based on composition, liquid CO2 production for commercial sale, and carbon credit opportunities. This comprehensive approach, combining real-time data acquisition, advanced process modeling, and financial tracking, ensures that the Digital Twin can reliably identify optimization opportunities while providing accurate predictive capabilities for both operational and business decision-making.

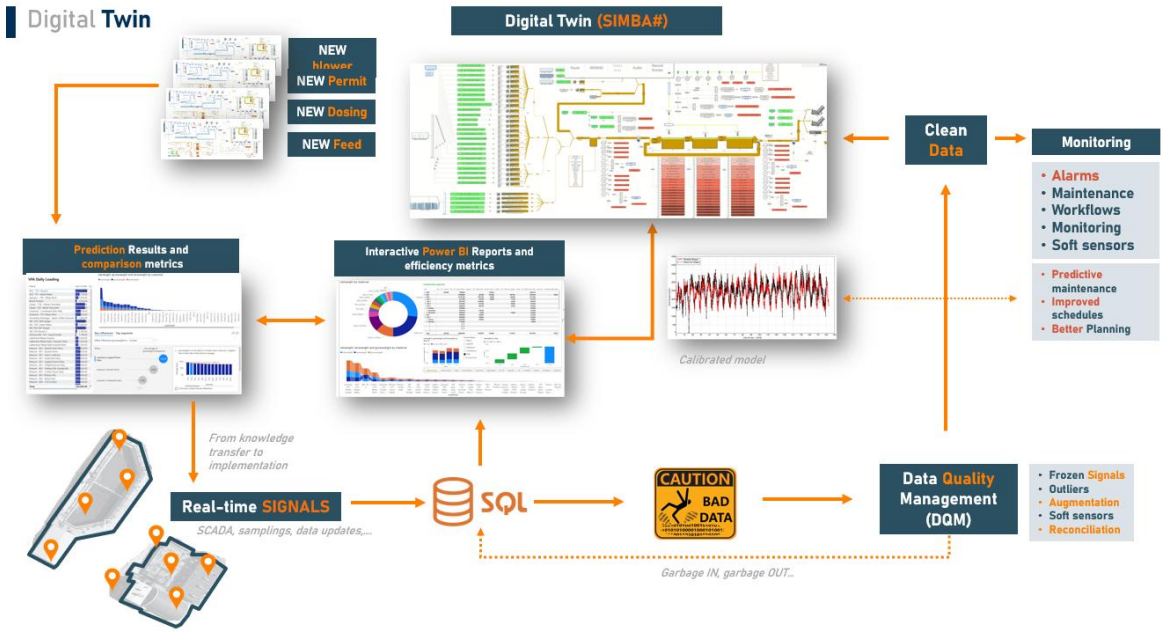


**Figure 2.** Conceptual architecture of the digital twin implementation showing the complete workflow: from real-time signal acquisition through SQL-based data cleaning and validation, to SIMBA# model integration and predictive analytics, providing interactive dashboards for monitoring, reporting, and operational decision support.

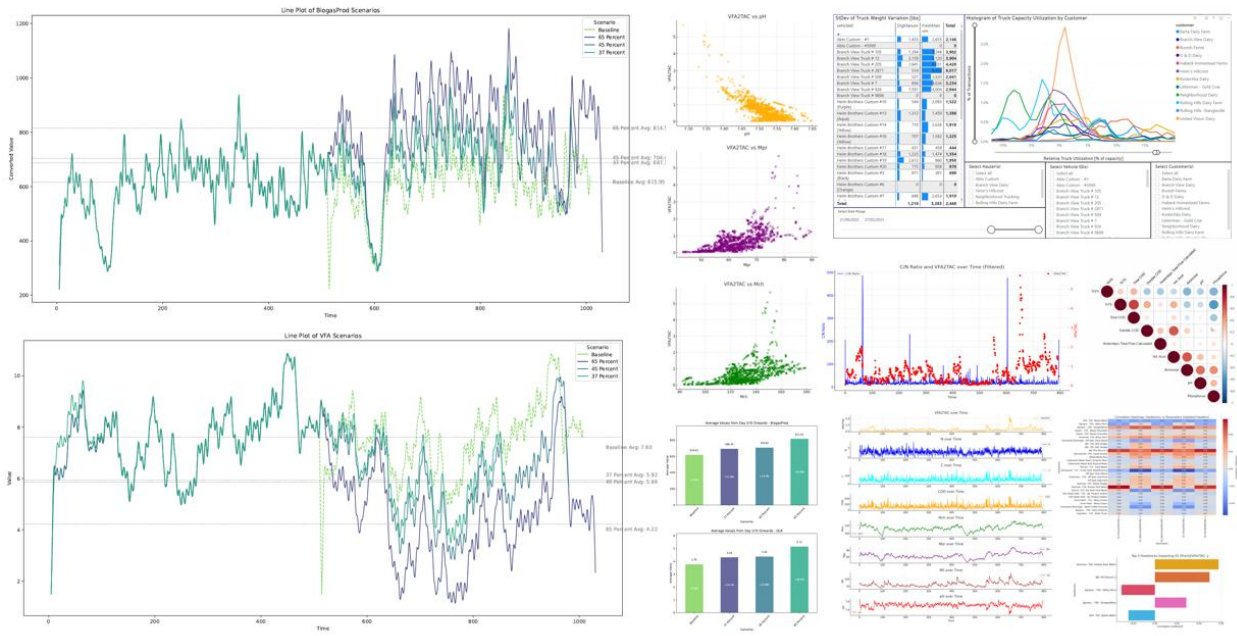

**Figure 3.** Python-based analytics outputs showcasing sensitivity studies, correlation matrices, soft sensor development for VFA and alkalinity prediction, and statistical analysis of operational parameters to support process optimization.

**Results**

The digital twin achieves over 95% accuracy in biogas prediction during normal operations, enabling reliable forecasting of energy production, liquid $CO_2$ production, and digestate quality. While feed material tracking in storage tanks shows some deviations (Figure 1), improvements are underway to close this gap. Real-time VFA and alkalinity monitoring has been enhanced through soft sensors, combining multiple data sources with machine learning to improve process stability prediction.

Successful quantification of the digestate quality ensures nitrogen content remains below application permit limits while maximizing biogas production. The digital twin leverages Python-based analytics to rapidly evaluate multiple feedstock scenarios, predicting microbial synergies and analyzing how carbohydrate-protein-lipid ratios impact methane production while providing deeper insights into feed interactions. This full-scale implementation demonstrates how integrating real-time monitoring with process modelling advances operational stability and feed management strategies while providing all facility personnel with clear visibility into plant status and the rationale behind operational decisions.

**REFERENCES**

Batstone, D. J. et al. The IWA anaerobic digestion model no 1 (ADM1). Water Sci. Technol. 45, 65–73 (2002).

Derbal, K., Bencheikh-lehocine, M., Cecchi, F., Meniai, A. H. & Pavan, P. Application of the IWA ADM1 model to simulate anaerobic co-digestion of organic waste with waste activated sludge in mesophilic condition. Bioresour. Technol. 100, 1539–1543 (2009).

SIMBA# The Wastewater Treatment Simulation Platform v.5 (ifak, 2024); https://www.ifak.eu/en/produkte/simba