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DECARBONIZING ASPHALT MIXING PLANTS WITH ELECTRIFICATION AND ENERGY STORAGE

Summary

Asphalt mixing plants in Germany are dominated by fossil-fired aggregate drying and heating. This study uses minute-resolved annual simulations and techno-economic optimization to assess how far direct electrification, high-temperature thermal energy storage (TES), battery energy storage (BESS), warm material storage (WS) and modest process adaptations can decarbonize a large batch plant under long-term electricity, gas and hydrogen price scenarios. Hybrid layouts with electric resistance heaters, different storage options and a fuel-fired backup are controlled based on day-ahead prices and storage state of charge. With natural gas as back-up fuel, they reach electric heat shares of roughly 30-40% without storage and up to about 80 % with large storage, while keeping levelized cost of heat close to or below a solely gas or hydrogen-fired references and cutting CO_2 emissions by more than 50 %. Compared to a hydrogen-fired reference, electrification and storage is even more competitive and electric heat shares beyond 90% are reached. Process-side moisture/air-flow reduction further lower demand and storage needs.

Keywords: asphalt plants, industrial process heat, electrification, thermal energy storage, warm material storage, hydrogen, techno-economics, decarbonization,

Field of application for the findings: Industrial high-temperature drying/heating, asphalt production.

Addressed audience: Researchers and practitioners in renewable process heat, thermal storage, industrial electrification and energy systems; equipment suppliers, plant operators and policy makers.

1. Introduction

Asphalt production requires high-temperature drying and heating of mineral aggregates and reclaimed asphalt in rotary drums, typically supplied by large natural gas, oil or even coal burners, implying high CO_2 emissions. As the asphalt demand profile in Germany is strongly seasonal and concentrated in daytime hours, there is a natural match with cheap electricity from solar PV. In a future energy system, gas becomes significantly more expensive with higher CO_2 costs, while electricity prices show larger intra-day spreads with frequent low-price hours, and hydrogen remains costly.

This work explores how a combination of direct electrification and flexibilization options with storage (TES – see Figure 1, BESS, WS) can exploit these evolving price structures. For a typical German large batch plant with 20 MW nominal thermal power, we quantify the techno-economic performance of various hybrid electrification concepts with and without storage, in different economic scenarios (energy prices, CAPEX funding rates, backup fuel type and costs) and compare to combustion-only reference systems.

2. Methodology

2.1 Concepts and modelling framework

Starting from a combustion-only reference, we integrated electrified concepts that combine resistance heaters, high-temperature packed-bed TES (air as heat transfer fluid), warm material storage, battery storage and fuel-fired backup (gas or hydrogen). Low-temperature pre-drying is implemented as a reduced moisture content. All concepts must satisfy an identical annual production profile.

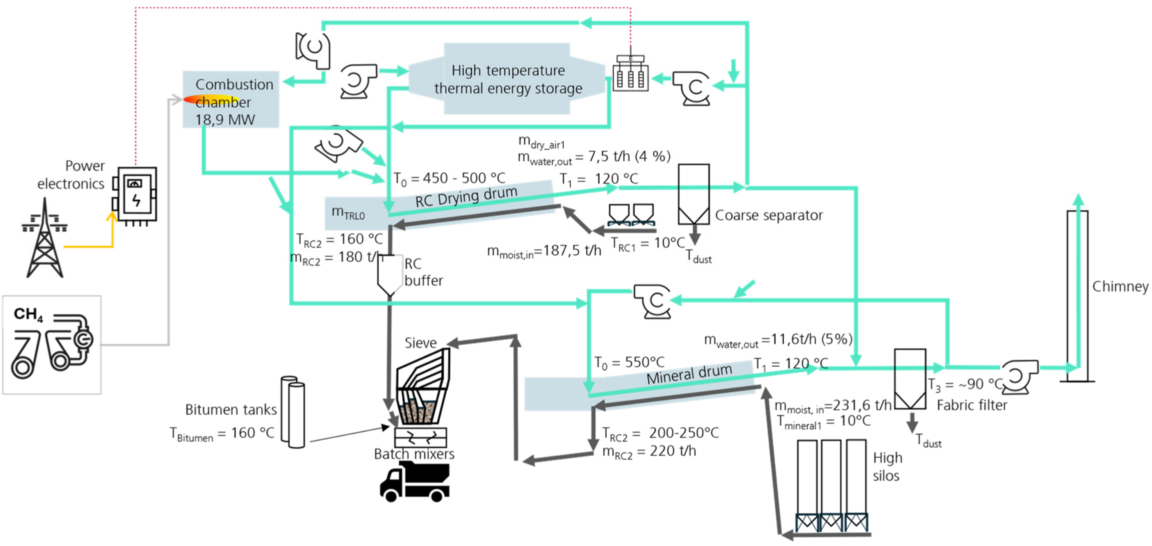

Figure 1: Schematic layout of an electrified asphalt plant with resistance heaters and thermal energy storage

2.2 Dynamic simulation and control

The plant and energy supply are simulated in the Fraunhofer ISE in-house software ColSim (Rohani et al., 2025) with a 60 s time step for selected years up to 2044. The dynamic model represents material flows (mineral, moisture, air), aggregate and reclaimed asphalt drying drums, material buffers, the mixing process on one hand and the heat supply system with gas/hydrogen/electrical heaters, TES, batteries and auxiliaries on the other hand. Dynamic rule-based control strategies use day-ahead electricity prices, TES/BESS/WS state of charge and current production to decide whether heat is provided by direct electric heating, storage discharge or backup burners. Hourly electricity, gas and hydrogen prices for several long-term scenarios, including sensitivities in absolute price level and price spread, are derived from national energy-system projections and applied consistently across all concepts (REMod, Thelen et al., 2024).

2.3 Techno-economic assessment

For each configuration, discounted cash-flow analysis over 20 years covers CAPEX including replacement of major components and OPEX including annual expenditures for electricity and fuels. TES size and key control parameters (mainly price thresholds for charging and dispatch) are varied to minimize levelized cost of heat for the asphalt production. From the simulations we derive – for each concept – the discounted cost, cumulative CO_2 emissions and the electric heat share (directly or via TES).

3. Results

Hybrid concepts with direct electrification already reach substantial electric heat shares without storage: with resistance heaters and dynamic operation against day-ahead prices, electric shares around 30–40 % are achievable at lifetime costs comparable to a fully gas-fired reference (see Figure 2). Adding storage options can improve economics and further decrease CO_2 emissions. Among the storage variants, warm material storage is most cost-competitive due to its low CAPEX. In the gas-based hybrid reference, techno-economic optimization yields an optimal warm material storage of about 32 MWh, which already enables a noticeable shift of drying and heating into low-price hours (electric heat share > 50%). TES is also economically attractive and, as a clearly separated component, easier to integrate in many layouts. With appropriately sized TES, hybrid concepts reach electric heat shares on the order of 60-80 % while keeping levelized heat costs close to the gas-only reference.

Battery storage and hydrogen play more specialized roles. Large BESS used only to shift electricity for process heat are not competitive at current CAPEX, although batteries can be attractive if they also participate in ancillary services or intraday markets, or when limited to non-thermal plant loads. Hydrogen enables complete fuel-side decarbonization, but the hydrogen-only reference system is significantly more expensive than the electrified concepts (and the gas-only reference). In the hydrogen price scenario, optimization of a hybrid layout with electrical heaters, TES and a hydrogen burner as backup leads to an optimal TES size of around

60 MWh and electric heat shares exceeding 90%. Hydrogen is then used only in a small number of high-price hours, so that such hybrids remain clearly cheaper than a hydrogen-only reference.

Process-side measures complement these options across all scenarios. Pre-drying and moisture/air-flow reduction can cut the thermal demand of the drums by 10-25% for realistic parameter ranges. If implemented mainly with internal waste heat or low-cost heat pumps, these measures reduce operating costs.

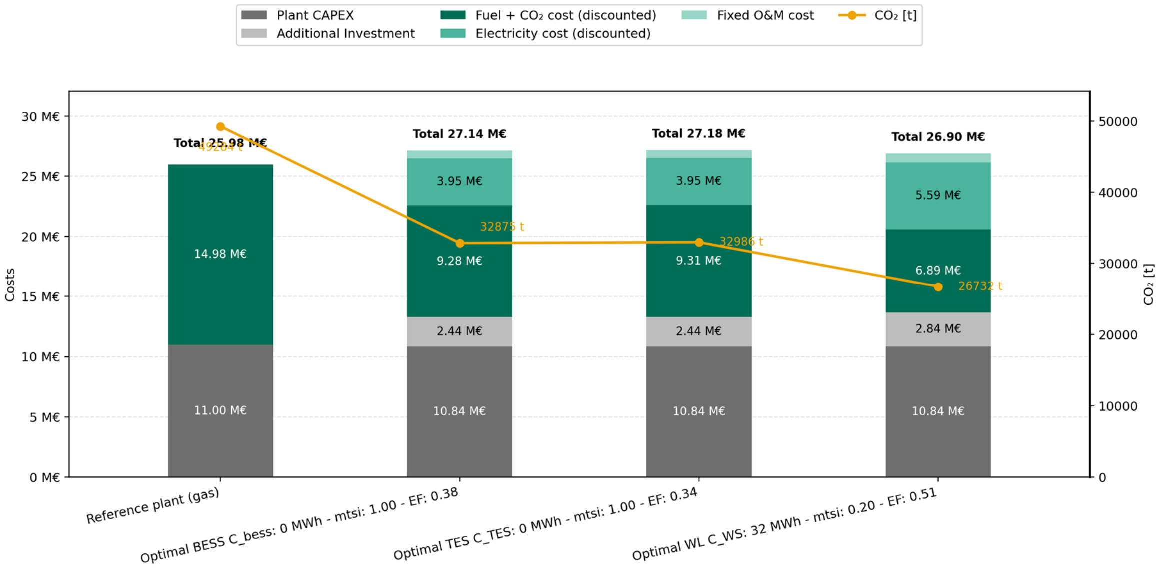

Figure 2: Indicative comparison of natural gas-only reference, BESS, TES and warm material storage hybrid concepts: discounted 20-year cost, electric heat share and CO_2 emissions. Electrification (electric fraction EF) and storage components ("Additional Investment") are assumed to get CAPEX funding of 50%.

4. Conclusions

Minute-resolved simulations with dynamic control and techno-economic optimization show that asphalt plants can be deeply decarbonized by combining moderate process efficiency measures with direct electrification and suitable storage. Hybrid concepts with resistance heaters and either warm material storage or high-temperature TES reach high electric heat shares at lifetime costs similar to, or in some cases lower than, a future gas-fired reference, while hydrogen-only and large battery options remain significantly more expensive for process heat. Warm material storage is the most economical storage option (costs per kWh) but is more process-specific; TES offers comparable overall economics with simpler integration. Because CAPEX dominates for these low-utilization plants (annual full-load hours < 2000 h), public funding and other investment support are key to accelerate implementation of these decarbonization pathways.

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