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Acids Unlocking CO_2-Based Biomanufacturing: Multi-Omics-Driven Optimization of Gas Fermentation Coupled to Acetate-Based Production of Proteins and Omega-3 Fatty Acids

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Industrial carbon emissions remain a major barrier to achieving climate neutrality, yet CO_2-derived feedstocks offer new avenues for sustainable biomanufacturing. As part of the Research Council of Norway–funded Centre for Research and Innovation "SFI Industrial Biotechnology" and the collaborative research project "CO_2Value", we present an integrated value chain that transforms industrial CO_2 into high-value proteins and omega-3 fatty acids through gas fermentation and acetate-driven microbial bioprocesses.

At the core of this work is a thermophilic gas-fermenting bacterium capable of converting CO_2 and H_2 into acetate with high carbon efficiency. We combine a curated genome-scale metabolic model with quantitative multi-omics (proteomics and metabolomics), to unravel metabolic regulation under autotrophic and mixotrophic growth. This systems-level understanding provides the foundation for rational strain improvement and process optimisation, identifying metabolic bottlenecks and energy-flux constraints in thermophilic CO_2 fixation.

The acetate generated from gas fermentation is concentrated and directly deployed as the sole carbon source in two parallel biomanufacturing routes. First, filamentous fungi are used to produce protein-rich biomass for sustainable feed applications, achieving high yields and favourable amino-acid profiles. Second, marine protists are cultivated to synthesize omega-3 fatty acids, reaching lipid contents of up to 80% of dry cell weight under optimised fed-batch conditions. In both pathways, we demonstrate complete process chains from CO_2 to final product, including fermentation optimisation and downstream processing.

Together, these results highlight a scalable and circular CCU concept that couples thermophilic gas fermentation with acetate-based microbial production platforms. By integrating system biology, bioprocess engineering, and downstream valorisation, this work advances the technological readiness of CO_2-derived proteins and lipids for feed and food sectors, therefore contributing to a more resilient and sustainable bio-based economy.