

# Novel process for the recovery of food-grade CO<sub>2</sub> and aromas from wine fermentation off-gas

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Keywords: CCU, fermentation off-gas, membrane contactors, pervaporation

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## Introduction

The CERNET project aims to develop integrated carbon capture and utilisation (CCU) solutions for biogenic gaseous emissions generated in bio-based industries. The project targets multiple sources of biogenic carbon, including winery fermentation and anaerobic digestion, with the objective of converting CO<sub>2</sub> and CH<sub>4</sub> emissions into value-added bio-based products. The overall approach combines gas capture and purification, biological conversion and downstream processing, targeting demonstration at pilot scale under real industrial conditions.

Winery fermentation represents a particularly relevant source of biogenic CO<sub>2</sub> due to its relatively high concentration and seasonal intensity. During alcoholic fermentation, approximately 35.3 L of CO<sub>2</sub> per kg of grapes are generated, indicating a relevant biogenic CO<sub>2</sub> stream that is often vented despite its suitability for upgrading and reuse. In addition to CO<sub>2</sub>, fermentation off-gases contain volatile organic compounds associated with wine aroma, which are currently not recovered. Their simultaneous capture together with CO<sub>2</sub> offers an opportunity to increase resource efficiency and circularity in the beverage sector.

## CERNET technological concept for CO<sub>2</sub> capture and aroma recovery

The proposed system (Figure 1) focuses on the upgrading of fermentation off-gases to produce food-grade CO<sub>2</sub> and a separate aroma-rich stream suitable for beverage applications. The system is designed as a modular and mobile unit, enabling integration into existing winery infrastructures with minimal process modifications.

Fermentation gas is collected directly from fermentation tanks, compressed to moderate pressures (typically 1–3 bar) and temporarily stored prior to treatment. The upgrading process integrates three main separation steps:

- Selective adsorption, primarily aimed at the removal of sulfur-containing compounds (e.g. H<sub>2</sub>S at trace levels, typically <10 ppm), using advanced adsorption media such as modified zeolites, which are well-established in food and biomaterials processing applications (Sharma et al., 2023).
- Absorption–pervaporation coupling, where volatile organic compounds present in the gas phase are transferred to a liquid absorbent and subsequently concentrated via pervaporation. Pervaporation is particularly suited for the selective concentration of aroma compounds from dilute streams and agro-food matrices (Castro-Muñoz et al., 2023).
- Membrane contactors, applied for CO<sub>2</sub> purification under mild operating conditions, enabling high mass transfer rates and low energy consumption compared to conventional absorption systems. Membrane-based gas–liquid contactors allow the production of CO<sub>2</sub> meeting industrial and food-grade specifications (Lee et al. 2023).

This integrated configuration enables the generation of two distinct product streams: purified CO<sub>2</sub> and a concentrated aroma fraction, both intended for reuse in beverage manufacturing.

## 3. Materials and methods

As the project is at an early stage, initial experimental work has focused on the characterisation of fermentation off-gases, with particular attention to aroma-relevant volatile compounds. Gas samples were collected during alcoholic fermentation and analysed using proton-transfer-reaction time-of-flight mass spectrometry (PTR-TOF-MS, PTR-TOF 1000, Ionicon Analytik GmbH, Austria). This technique enables real-time detection of volatile organic compounds at concentrations ranging from low ppbv to ppmv, without prior sample preparation. PTR-TOF-MS is therefore especially suitable for monitoring complex fermentation-derived gas streams and identifying compound families relevant for aroma recovery.

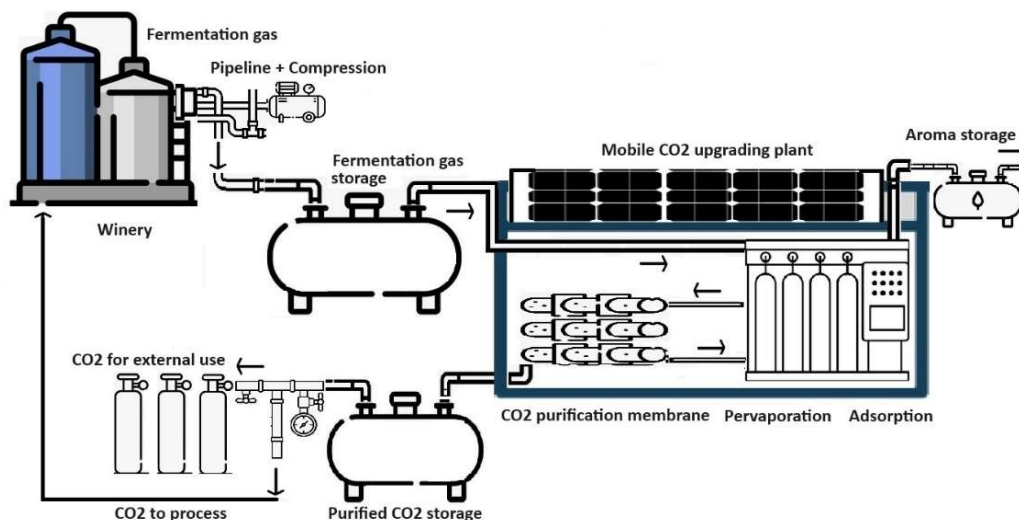
In parallel, initial CO<sub>2</sub> capture trials are being conducted using real winery fermentation off-gas in a laboratory-scale upgrading rig based on a hollow fiber membrane contactor (HFMC). The off-gas is a CO<sub>2</sub>-rich stream,

typically containing 85–99% (v/v) CO<sub>2</sub> depending on the fermentation stage, with minor fractions of N<sub>2</sub> and O<sub>2</sub> and trace levels of aroma-relevant volatile organic compounds. The fermentation gas is fed to the shell side of a Liqui-Cel® 1.7 × 5.5 MiniModule® membrane contactor. The inlet gas flow rate is controlled and monitored using a flow meter (Bronkhorst F–201CV Series), while the outlet gas flow is measured using a rotameter (Tecfluid 2000 Series) installed upstream of the vent line.

The liquid absorbent is stored in a 30 L PVC tank and maintained at 19–21 °C by room temperature control. The solvent is circulated through the fiber lumen in counter-current mode using a dosing pump (max. 10 L·h<sup>-1</sup>, 3.5 bar), and the liquid line includes a pulsation damper (0.65 L) to minimize pressure fluctuations. Liquid flow is additionally monitored using an in-line flow meter (Bürkert Type 8031; 20–250 L·h<sup>-1</sup>, ±2%). The HFMC contains 7400 fibers (X50® polypropylene/polyurethane blend), with a fiber length of 0.113 m and a membrane surface area of 0.58 m<sup>2</sup>. The fibers exhibit a nominal pore size of 0.03 μm and porosity of 40%. A valve configuration enables operation with one module or two membrane contactors arranged in series, allowing flexible assessment of capture performance.

#### 4. Preliminary results

PTR-TOF-MS analysis confirmed that fermentation off-gases contain a complex mixture of volatile organic compounds typically associated with wine aroma. Detected VOC families were dominated by light alcohols (notably ethanol and methanol), fermentative esters (e.g., ethyl acetate and related compounds), and other oxygenated species, together with aldehydes (e.g., acetaldehyde) and organic acids (with acetic acid as a key contributor). Ketones (e.g., acetone and diketones such as butanedione) and higher alcohols (e.g., butanol and isobutanol) were also detected, while sulfur-containing compounds appeared at lower relative abundance but remain relevant due to their high sensory impact and implications for achieving food-grade CO<sub>2</sub>. In parallel, the purification of CO<sub>2</sub> to industrial and food-grade specifications is being addressed through selective removal of trace contaminants and volatile compounds using adsorption and membrane-based separation. The data obtained provide a basis for the subsequent optimisation of adsorption, membrane contactor and pervaporation units in terms of selectivity, recovery yield and energy demand.



#### Acknowledgements

This work has been carried out within the framework of the CERNET project, funded by the Circular Bio-based Europe Joint Undertaking and its members and by the European Union under Grant Agreement No. 101214604.

#### References

- Castro-Muñoz, R., Ahmad, M. Z., & Cassano, A. (2023). Pervaporation-aided processes for the selective separation of aromas, fragrances and essential (AFE) solutes from agro-food products and wastes. *Food Reviews International*, 39(3), 1499-1525.
- Lee, Y., Park, Y. J., Lee, J., & Bae, T. H. (2023). Recent advances and emerging applications of membrane contactors. *Chemical Engineering Journal*, 461, 141948.
- Sharma, P., Sutar, P. P., Xiao, H., & Zhang, Q. (2023). The untapped potential of zeolites in techno-augmentation of the biomaterials and food industrial processing operations: A review. *Journal of Future Foods*, 3(2), 127-141.