

IMPROVING HELIUM SUSTAINABILITY: CURRENT PERFORMANCE AND UPGRADE OF THE ALBA HELIUM LIQUEFACTION FACILITY

M. Quispe[†], J. Casas, C. Colldelram, G. Peña Calurano, M. Sánchez Hidalgo
B. de Abreu Francisco, ALBA Synchrotron, Cerdanyola del Vallès, Spain

Abstract

Efficient use of gaseous and liquid helium, a non-renewable resource essential for accelerator-based experiments, is a key priority at ALBA Synchrotron Light Source. This work presents the operational status of ALBA’s helium liquefaction plant and the liquid-helium production achieved in recent years, based on recovery from its use in the BOREAS, LOREA, CLAESS and MSPD beamlines. The helium liquefaction plant’s operating mode is discussed, with emphasis on its main limitation: the system can only process recovered gas with an average helium purity of 99.5%. To overcome this constraint, the plant was upgraded during 2025–2026 with the installation of a gas purifier capable of treating gas helium with purities as low as 90%. The first operational results and performance of the helium liquefaction plant with the integrated purifier are presented.

BACKGROUND

Helium, in both its liquid and gaseous states, plays a fundamental role in the operation of the ALBA Synchrotron owing to its cryogenic properties and chemically inert nature. Currently, four of ALBA’s experimental beamlines – BOREAS, LOREA, MSPD, and CLAESS – use liquid helium in the execution of their experiments.

In the case of BOREAS, a beamline specialized in advanced X-ray spectroscopy techniques for studying materials, liquid helium is used to cool superconducting magnets (enabling magnetic field generation) and to maintain samples at cryogenic temperatures, thereby allowing the investigation of magnetic and quantum materials using advanced X-ray techniques. For LOREA, primarily dedicated to photoemission spectroscopy using VUV and soft X-ray radiation, helium is used to reach cryogenic temperatures to study low temperature phase transitions, to have better ultra-high vacuum conditions, and get (a factor 10) better spectroscopic resolution.

At CLAESS (Core Level Absorption and Emission Spectroscopies), helium gas at room temperature is used for routine operations in the ionization chambers, as it allows data collection, and in experiments both as an inert gas to purge the line and test for leaks, and in mixtures to dilute reactive gases (this is related, for example, to heterogeneous catalysis and CO₂ conversion). Liquid helium is also used for the Dynaflow cryostat to access low temperatures, enabling two main functions: exploring the temperature range from approximately 10 K to 300 K, also allowing transferring samples from cold storage (80 K) to the cold data collection environment. In addition to enabling temperature-dependent experiments (typically, but not

exclusively, on superconductors, magneto-electronic, spintronic, multiferroic, and strongly electron-correlated systems), it helps to reduce the risk of radiation damage in sensitive samples (typically soft matter).

In the case of MSPD (Materials Science Powder Diffraction), beside marginal need of helium in gas form for specific scientific applications (chemical reactions under pure or mixed helium), it is essentially helium in liquid form which is required by so called Dynaflow LHe cryostat to collect data down to 5K. Such studies generally relate to highly correlated electron system for which transport properties, magnetic and crystal structures interplay.

Table 1 summarizes the liquid helium purchases made by ALBA during the last three years for the operation of these beamlines, together with the associated costs. In terms of consumption distribution in 2025, liquid helium usage was allocated as follows: BOREAS (74%), LOREA (22%), MSPD (2%), and CLAESS (2%). The cost data also illustrate the progressive increase in the price of liquid helium, from €38/L in 2023 to €41.7/L in 2024 and €43.5/L in 2025.

Table 1: Liquid Helium Purchases at ALBA

| Year | Liquid Helium purchased [L] | Cost [k€] |
|------|-----------------------------|-----------|
| 2023 | 5220 | 198 |
| 2024 | 9060 | 376 |
| 2025 | 10050 | 437 |

At present, the use of helium presents a structural challenge, as it is a non-renewable resource on a human timescale and its global availability is limited, with a supply chain subject to geopolitical and economic volatility [1]. In this context, helium recovery and reuse have become a strategic priority for the international scientific community.

During operation in cryostats and superconducting systems, liquid helium inevitably evaporates due to thermal loads, transitioning into the gaseous phase. Traditionally, this gas was vented to the atmosphere, resulting in the irreversible loss of a critical resource. However, advances in recovery infrastructure have demonstrated that evaporated helium can be effectively captured, purified, and reliquefied. At synchrotron facilities such as ALBA, these systems comprise low-pressure piping networks that convey helium gas to compressors, purification units, and liquefaction plants, thereby closing the helium usage cycle [2]. Table 2 summarizes the amount of liquid helium recovered at the ALBA facility over the past three years, as well as the corresponding market value of the recovered helium.

[†]mquispe@cells.es

Table 2: Liquid Helium Recovered at ALBA

| Year | Liquid Helium recovered [L] | Market value [k€] |
|------|-----------------------------|-------------------|
| 2023 | 14930 | 567 |
| 2024 | 11400 | 475 |
| 2025 | 7050 | 306 |

HELIUM PLANT OPTIMIZATION

Figure 1 presents a simplified PID (Piping and Instrumentation Diagram) of the main components involved in the helium recovery plant. The black lines represent the operating configuration in place until the end of 2025, while the red lines and components indicate the modifications implemented at the beginning of 2026.

Although the recovery results presented in Table 2 are encouraging, production has been constrained to the processing of recovered helium gas with a purity above 99.5%, a threshold required for proper operation of the liquefier. This purity level is typically achieved in the BOREAS and LOREA beamlines; however, it is not consistently reached in MSPD and CLAESS due to differences in experimental procedures, which increase the likelihood of air contamination in the helium stream in these latter cases. Given these operational constraints, ALBA implemented an upgrade in 2025 consisting of the integration of a helium gas purifier into the facility, enabling the system to process recovered helium gas with purity levels as low as 90%.

As shown in Fig. 1, the purifier was installed upstream of the liquefier. Between the purifier and the liquefier, a bank of 24 cylinders, each with a capacity of 50 L, has been installed to store purified helium gas at pressures of up to 200 bar. This configuration enables two operating modes for the liquefier. The first mode consists of supplying gas directly from the 24-cylinder bank while the purifier is bypassed. The second mode consists of supplying gas directly from the operating purifier, in which case the 24-cylinder bank acts as a buffer, storing excess purified gas that cannot be immediately processed by the liquefier. At present, the system is operating in the second mode.

In the PID, the three main operational stages (recovery, purification, and liquefaction) are highlighted. Vaporized impure helium is transported from the 400 m perimeter recovery ring to two 20 m³ gas storage bags. The recovery compressors then compress the stored helium to pressures of up to 200 bar, reducing volume and preventing collapse of the gas bags. The compressed gas is subsequently stored in 70 cylinders (each with a capacity of 50 L), after which it is purified and then liquefied for reuse.

Figure 2 shows a current image of the ALBA helium plant, highlighting its main components.

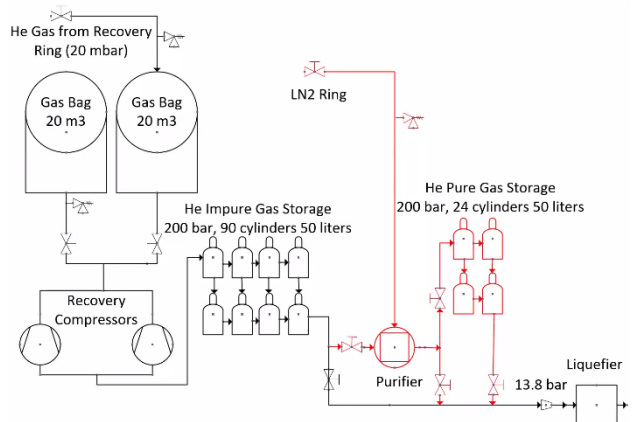


Figure 1: Simplified PID diagram of the ALBA helium plant, with the implemented modifications highlighted in red, including the integration of a helium gas purifier into the system.

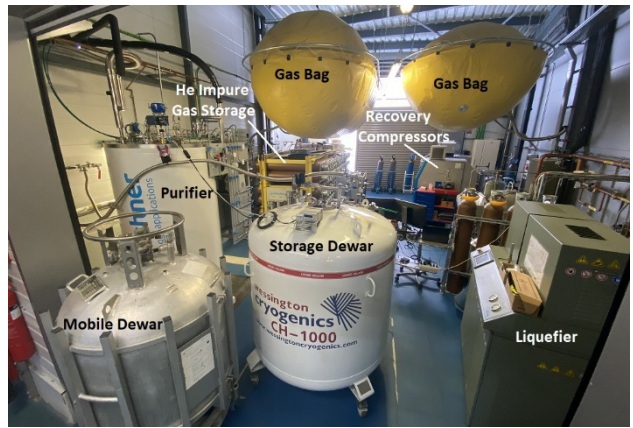


Figure 2: Current image of the ALBA helium recovery plant.

Purifier

Figure 3 shows the purifier model installed at ALBA, which operates under the following technical conditions:

- Continuous helium purification is possible with up to 10% air contamination.
- The helium output achieves a purity of 99.996%, with minor concentrations of N₂, O₂, and H₂O.
- Helium grade 5.0 can be obtained with an inlet purity of 99%.
- Nominal production rate: 8.35 kg/h.
- Inlet pressure range: 30 – 200 bar.

The performance of the purifier was tested in terms of both production and operation, yielding satisfactory results. When operated at a flow rate of 10 bar/h, the purifier produced helium with an outlet purity of approximately 99.998% (corresponding to an analyser reading of 6.84 ppm of nitrogen). For this test, helium gas with an initial purity of 95% was supplied to the purifier inlet.



Figure 3: Purifier installed in the ALBA helium recovery plant.

Improvements in the Liquefier

At present, ALBA targets a production of 600 L of liquid helium per week. This production primarily covers the demand of the BOREAS beamline, which requires 450 L per week, while the remaining 150 L are stored as a reserve to supplement the following week's production. It should be noted that this reserve is subject to boil-off losses of approximately 5 L per day in the 1000 L capacity dewar (for smaller dewars of 250 and 450 L, the losses are higher, in the range of 5 – 10 L per day). In addition, to meet the requirements of the LOREA beamline, ALBA must purchase 250 L of liquid helium per month.

Before the installation of the purifier, the production target was not consistently achieved. Historically, the average production was 500 L per week (ranging from 600 L in the best weeks to 300 L in the worst), which required unplanned purchases of liquid helium to ensure beamline operation. This variability was attributed to the presence of relatively high and uncontrolled levels of contamination in the helium gas supplied to the liquefier.

Following the installation of the purifier and after six weeks of operation, the average production has increased and is now consistently maintained at 600 L per week. Moreover, the production has become significantly more stable: peak values have risen to 700 L per week, while production has not dropped below 550 L per week.

Another aspect to highlight is that, prior to the installation of the purifier, unexpected process shutdowns occurred due to contamination-induced saturation of the

liquefier. With the purifier in operation, the process now only stops when there is either no available gas supply or no storage capacity for liquid helium.

Figure 4 compares two production scenarios over 20 hours of operation, with and without the purifier. Regarding the filling level of the 1000 L dewar, the case without the purifier reaches a maximum of 55.5% at 20 hours, with the curve approaching an asymptotic value. In contrast, with the purifier in operation, a filling level of 71.5% is achieved after 18 hours, and the curve still exhibits an increasing trend. The same figure also shows the production rate in litres per hour: without the purifier, the rate is highly variable and decreases to approximately 7 L/h, whereas with the purifier, the production rate remains stable at around 40 L/h.

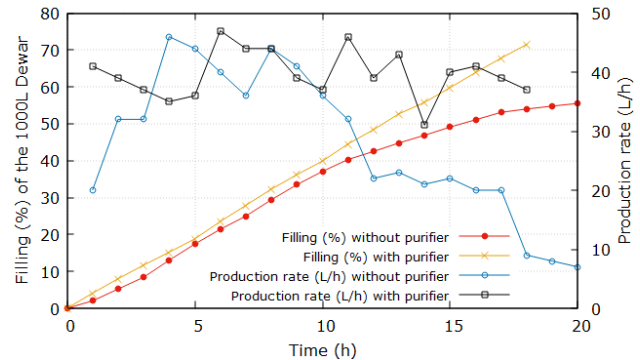


Figure 4: Comparison of two helium production processes over 20 hours of operation, with and without the purifier installed.

CONCLUSIONS

During 2025, a helium gas purification unit was installed in the ALBA helium liquefaction plant. The purifier is capable of processing helium gas recovered from consumption with purities as low as 90%, representing a significant improvement over the previous configuration, which was limited to processing recovered helium gas with a purity higher than 99.5%, the level required for proper operation of the liquefier. The operational performance of the purifier has been demonstrated during testing, achieving purified helium with a purity of approximately 99.998% when inlet gas with a purity of 95% was supplied to the purifier.

After the first six weeks of operation in 2026 with the purifier in service, the plant has shown clear operational improvements: (i) an increase in liquefier production capacity, (ii) a highly stable production rate during operation, and (iii) the elimination of unexpected process shutdowns previously caused by contamination-induced saturation of the liquefier. These improvements enable ALBA to accurately plan the annual liquid helium procurement and to reduce purchase volumes as a result of the increased production capacity.

REFERENCES

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