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How to Develop and Assemble a Sustainable ULT Freezer?

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Whenever the topic of sustainability comes up in the scientific community, there is a broad range of matters to be considered. Besides bags with biological, chemical, or radioactive waste, ULT freezers in use 24/7 are on top of the list. The sustainability of a ULT freezer is not limited to energy consumption. The environmental footprint of a product is a multi-faceted story. This includes aspects about development, production, logistics, usage in the lab, and, finally, disposal. This White Paper shows the points of action by Eppendorf to improve our ULT freezers from the perspectives of R&D and production.

Figure 1: Production of ULT freezers is completed with a 24h test run

Introduction

The importance and impact of sustainability on our lives increases every day. Wherever we interact in our personal lives, the topic of sustainability appears more and more often. The same holds true for the life in laboratories worldwide. Compared to a few years ago, talk of lab equipment is no longer limited to performance and price. The topics of sustainability and the overall environmental impact of a product play an increasing role in the decision-making process. Scientists, technicians, students, sustainability officers, and also purchasing departments and procurement systems, request information. At Eppendorf, we see a growing interest in our company's commitments and approach to sustainability for all our products. This interest is split into two subtopics:

> What is Eppendorf as a production facility/supplier doing to improve the sustainability of its freezers?
> What can I do as a user in the lab to improve the sustainability footprint of my ULT freezer?

Progress and continuous improvements with respect to sustainability require open communication about product performance and measures taken. In parallel, there are official third-party certification processes like the ISO 9001 and ISO 14001 for the Eppendorf Group, as well as ACT® and ENERGY STAR® certifications specific to ULT freezers.

In this White Paper, we focus on the first subtopic: What has been improved at Eppendorf, what is in progress, and where do we still see open tasks. The second subtopic is addressed in the separate White Paper 74.
Though a detailed life cycle analysis based on Scope 3 (Scope 3 emissions describe greenhouse gas emissions along a company's value chain) is still challenging, there are certain elements that can be examined in the life cycle of a freezer, especially its life before the unit is shipped to the laboratory. These include the sourcing of and type of material, the location of and conditions in production, improvements for new freezer generations, waste, power consumption, etc.

When it comes to energy consumption in the laboratory, ULT freezers at -80 °C are at top of the list. For the last decade, freezers were the very rare group of instruments where power consumption has always been important. Many suppliers publish the power consumption values of their ULT freezers.

The second major topic for freezers are the cooling liquids. Several years ago, ozone-depleting CFC (chlorofluorocarbon)-based cooling liquids were phased out (based on the Montreal Protocol).

The cooling was and partly is replaced by alternative compounds known as hydrofluorocarbons (HFCs), particularly R508b and R404a. Due to the high Global Warming Potential (GWP) of HFCs, hydrocarbons (HC), also known as green or natural coolants, are the better choice (GWP is equivalent to CO_2). Since Eppendorf launched its first freezer using hydrocarbon coolants in 2008, many modern ULT freezers now utilize these more eco-friendly refrigerants.

Local sourcing and material

Although the design of a freezer is relatively simple compared to lab automation systems or complex analytical instrumentation, a lot of different parts are needed. In our global world, we are accustomed to acquiring parts and products from all over the globe. For Eppendorf, all our suppliers need to act in accordance to our Code of Conduct.

Our freezer manufacturing facilities, located in the Southern parts of the UK, receive a relevant share of all parts from local suppliers in the UK, as well as from Western Europe, within a 800 km/ 500 miles radius.
Major parts of the freezer are made of metal, such as steel, stainless steel, and copper. Based on EuRic data (https://www.euric-aisbl.eu/facts-figures/euric-brochures), the recycled content of European metal production is (on average) 44% for copper and 55% for steel in 2020 (https://www.eurofer.eu/issues/environment/circular-economy/). Recycling of steel saves more than 70% of the energy needed for primary production and is related to significantly reduced CO_2 emissions.

Plastic components of the freezer with a weight above 25 g are labeled to follow EN ISO 11469. In professional recycling agencies, this marking ensures fast identification of the material and the application of correct, material specific recycling methods.

The insulation of ULT freezers is based on Vacuum Insulation Panels (VIP) and/ or polyurethane (PU)-based foam. This foam enfolds the inner freezer chamber as well as the copper-made cooling pipes. This set-up is used by almost all large-scale freezer manufacturers. Although this design provides an optimal cooling/insulation set-up, it is difficult to recover the copper for recycling at the end of the freezer life cycle. Improvements are needed to optimize recycling processes of the copper.

The packaging of the ULT freezer contains different materials. This includes a wooden pallet, cardboard, a plastic dust cover, and some foam parts. Our freezer packaging cardboard material consists of ca. 70% recycled material. The plastic parts are made of LD-PE (low density Polyethylene) with ca. 15% recycled origin. The wooden pallet is based on ca. 70% recycled content due to usage of chipboard material. PET (polyethylene terephthalate) parts are based on a ca. 30% recycled ratio. In the mid-term perspective, the recycled origin of parts and packaging will be further increased.

Design & production

Our freezers are developed and assembled based on high UK (and formerly EU) regulations regarding social and environmental standards. Safety in production is supported by strict guidelines and regular safety trainings of all employees. Where required, personal safety equipment is worn. All critical components are documented and related material safety data sheets are available.

Important factors for energy consumption

When designing a new ULT freezer, several characteristics need to be considered to optimize energy consumption in combination with temperature performance. All these parts are areas for improvements.

> Thickness of insulation
> Type of insulation
> Type of cooling liquid
> Efficiency of compressors
> Control of compressors
> Pressure in the cooling system
> Style of cooling loops (diameter, length, density, etc.)
> Seals of outer door
> Seals of inner doors
> Insulation of outer door
> Insulation of inner doors
> Airflow of heated air
> Construction and position of filter
> Sealing of access ports and vent ports

Eppendorf testing procedure

Performance data of freezers should be reliable, as they may act as factors in the decision-making process. The technical performance of a new ULT freezer is optimized in the R&D process. Finally, these data need to be validated. During the development phase of a new Eppendorf freezer, on-going checks are performed in-house, by standard. These numerous tests are performed in dedicated environmental chambers in the R&D departments to understand and optimize the performance of our freezer prototypes. Changes in seals, wall insulation, or the location of the cooling coils can have an impact on the performance.

For the final tests, we at Eppendorf believe in an independent, external counter control. To fulfill this request, we co-operate with an external European testing body with highly-trained engineers. As there can be slight performance differences between single units, three units of ULT freezers of the same kind (serial production level) are sent over to the testing body. The external testing of these instruments is performed with defined and standardized conditions, following a dedicated standard operating procedure (SOP). This means, for example, adherence to specific room temperature, controlled humidity, validated & certificated testing instruments, and exact positioning of temperature probes. All conditions and results are documented and signed. The resulting external test data, like power consumption, temperature performance, and pull-down times of our new freezer, are then averaged based on the data of the three units involved. These three units are the origin for all Eppendorf-published technical data about the specific freezer type as typical performance characteristics. In other words, the technical performance data of Eppendorf freezers published are measured externally by an independent third party. A more detailed description of this testing procedure is available as White Paper 75.

Generational improvements

Sustainability is based on a constant improvement of goods and products. The same is true for product development in industry. By combining the longevity and quality of our existing freezers with future-proven new concepts, we are able to improve not only the performance but also the sustainability footprint of our ULT freezers within the current generation.

	CryoCube® F740hi	CryoCube® F740h	CryoCube® F570h	CryoCube® F570n	CryoCube® F440h	CryoCube® F440n
Voltage	230 V	230 V	230 V	230 V	230 V	230 V
Precursor model power consumption per day	12.2 kWh	17.1 kWh	8.9 kWh	10.5 kWh	8.4 kWh	10.8 kWh
Power consumption per day	10.5 kWh	11.8 kWh	7.4 kWh	8.3 kWh	6.8 kWh	8.3 kWh
Reduction of power consumption in %	-14%	-31%	-17%	-21%	-19%	-23%
Saving of power consumption per year	621 kWh	1,935 kWh	548 kWh	803 kWh	584 kWh	913 kWh
Saving of power consumption per 10 years	6,210 kWh	19,350 kWh	5,480 kWh	8,030 kWh	5,840 kWh	9,130 kWh
Savings of power costs per year	130 €	406 €	115 €	168 €	123 €	192 €
Savings of power costs per 10 years	1,300 €	4,060 €	1,150 €	1,680 €	1,230 €	1,920 €
Savings of CO_2 per year	0.17 t	0.53 t	0.15 t	0.22 t	0.16 t	0.25 t
Savings of CO_2 per 10 years	1.7 t	5.3 t	1.5 t	2.2 t	1.6 t	2.5 t
GWP reduction	0	-4,453 kg	0	-4,369 kg	0	-4,211 kg

Table 1: Generational change of Eppendorf ULT freezers (230 V), comparing savings in power consumption and related costs and CO_2 based on reference data of EuroStat 2019 (0.21 €/ KWh) and the European Environment Agency 2019 (www.eea.europa.eu) (275 g CO_2/ KWh)

The improvements for power consumption (230 V) vary between the different models (shown in Table 1), depending on the development level of the former model. The data of the current models are based on external measurements of three units (serial production level) in parallel. The financial savings are based on the average costs per kWh of electric power in Europe (0.21 €/ kWh; 2019), published by EuroStat. The savings in CO_2 are based on the average CO_2 emission for European electric power production, published by the European Environment Agency (www.eea.europa.eu), which are 275 g CO_2/ kWh (2019).

Please keep in mind that these calculations are based on a model calculation. In reality, the cost savings per year will increase due to increasing costs for electric power over time. The total CO_2 savings will decrease as the average amount of CO_2 per kWh of power produced will decrease due to more and more green energy (solar power, wind, water) in the power system.

Further power savings for the next freezer generation are planned. Still, we must keep the right balance between power saving and temperature accuracy and recovery to keep your samples safe.

The display of all CryoCube® ULT freezers is attached on the surface of the outer door and not integrated within. What looks like a misalignment at first, due to the required additional space, is actually a way to optimize the insulation of the door. An integrated display reduces the thickness of the insulation behind. On the surface, the display and related electronic parts generate some heat. The CryoCube freezer solution minimizes this double negative impact on the sample temperature and therefore their safety.

Figure 2: Non-integrated freezer display at Eppendorf CryoCube freezers for optimized insulation of front door

Another topic of constant improvement is the freezer door handle (Figure 3). As the door handle is the central connection between the user and the storage location of their samples, we have continuously improved the ergonomics of the handle. The ancient stick-like handle is now a piece of high-tech equipment which combines easy and comfortable handling with haptic feedback of its closing status as well as enabling safe door locking for an accurate temperature within the freezer. Following the Eppendorf PhysioCare Concept®, the ergonomic design is an important building block for a sustainable product in respect to the interaction between the user and the product.

Figure 3: Ergonomic design of an Eppendorf freezer door handle enables comfortable and easy handling

Cooling liquids

The coolant or cooling liquid within a ULT freezer is used to regulate the temperature. Several years ago, the ozone-depleting chlorofluorocarbon (CFC)-based cooling liquids were phased out (based on the Montreal Protocol). The cooling was (and partly is) replaced by alternative compounds known as hydrofluorocarbons (HFCs), particularly R508b and R404a. Despite being better for the environment (ozone), these classic cooling liquid HFCs still have a high Global Warming Potential (GWP). The GWP is based on carbon dioxide as reference (see Kyoto protocol, 1997). CO_2 is defined to have a GWP of 1. Other gases are mathematically converted into carbon dioxide equivalents (CO_{2e} or CO_{2eq} or $CO_{2\text{-}e}$).

For example, R404a has a GWP of 3,922. This means that 100 g of this substances have the same GWP as 392 kg of CO_2-equivalent. R508b has a GWP of 13,400, resulting in a GWP of 1,340 kg CO_2 equivalent for 100 g.
To reduce global warming, there is a clear tendency towards reducing classic cooling liquids, such as these R508b and R404a. The green or natural gases (e.g. R170 (ethane), R290 (propane), Figure 4) are future proof and have a very low GWP. This is also supported by European Union Regulation (EU_517/2014; F-gas regulation) as well as the US SNAP regulations. Additionally, these hydrocarbon-based cooling gases quite often result in lower power consumption by the freezer.

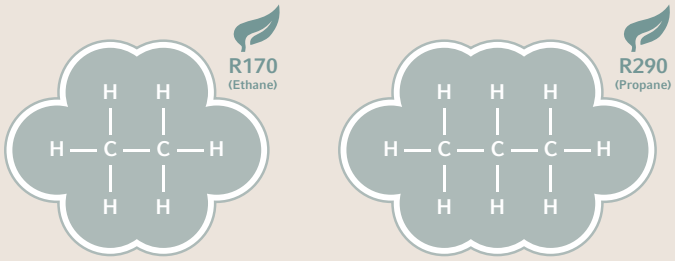

Figure 4: Chemical structures of R170 and R290 as hydrocarbon based cooling liquids

The New Brunswick Premium U570-G by Eppendorf was one of the very first commercially available ULT freezers driven by these green cooling liquids: In 2008, however, the interest was still limited.
After nearly 15 years of experience in R&D, production, logistics, and service in the field of green ULTs, we are now happy to see the concept globally confirmed: Nowadays, the majority of ULT freezers sold in Europe and America are green, energy-efficient models. There is an increasing demand of employing power-saving freezers in Asia. A growing number of users take green ULTs for granted, and more and more ULT suppliers are producing green ULT freezers.

Waste in the facility
Since 2019, there are special collection containers for cardboard, metal, and wood. This sorting of packaging materials from deliveries by suppliers significantly reduces the amount of final general waste at the facility. A further scrap reduction program was established beginning of 2022.

Assembled with green energy
The energy required by the Eppendorf group in the factories is based on renewable energy sources that meet the statutory environmental standards. Thus, the vast majority of Eppendorf facilities achieve climate neutrality in their calculated electricity consumption. The assembly of our ULT freezers in the UK is based on 100% renewable energy since 2018. The stainless steel racks are also assembled with 100% green energy. By purchasing electricity from green renewable energy sources, the CO_2 footprint of Eppendorf at the different production facilities is significantly reduced per year.

Figure 5: All Eppendorf ULT freezers are assembled by using 100% renewable energy in our facility

Re-use of heat
The Eppendorf ULT freezer manufacturing process includes several quality checks. Each ULT freezer is thoroughly inspected to meet the rigorous quality guidelines. The final inspection takes more than 24 h and is based on a real test run of the unit down to -80 °C. This process is documented by an individual Certificate of Quality, complete with serial number, provided as standard for your documentation. The compressors consume energy to cool the ULT freezer to -80 °C, but also generate heat. The freezer manufacturing facility takes advantage of this: The heat output during final individual unit testing discharges into the building heating system.

Independent certification

The level of sustainability can be stated by the supplier. For many of our ULT freezers, we also asked independent 3rd party organizations to validate our instruments. Therefore, we co-operate with the "ACT®" concept of "My Green Lab®" as well as "ENERGY STAR®". Details are listed at the dedicated products. More details about the ACT label can be found in Whitepaper 61. Keep in mind that ENERGY STAR data are based on 115 V versions and a different test protocol compared to the Eppendorf partnering test house.

Figure 4: Chemical structures of R170 and R290 as hydrocarbon based cooling liquids

Logistics

In general, Eppendorf ULT freezers are shipped by container ships from our central first hub to our global distribution subhubs. Due to several global distribution subhubs, we reduce global drop-shipments to a minimum. Our supply teams optimize the content of each container to maximize efficiency of space. On average, a 20 foot standard container can be filled with up to 11 ULT freezers.

Based on literature, the ship-based transportation of a freezer from Europe to the USA may have an impact of about 35-40 kg CO_2 (15-17 g/ t and km, depending on source; freezer gross weight ca. 400 kg; distance Rotterdam/ NL-New York/ USA ca. 5,900 km).

Due to their weight and volume, freezer shipment by plane is not recommended. Based on different sources, a cargo flight between Amsterdam/ NL and New York/ USA results in about 1,000 to 1,200 kg CO_2 for a package of 400 kg (6,000 km; www.cargolux.com). Due to their size, ULT freezers cannot be shipped in a passenger jet as belly freight, dedicated cargo planes must be used.

Local transportation is based on trucks. Many logistic companies started to use electric-driven carriers for light goods, whereas the usage of heavy e-trucks is still at the very early stage. Due to weight and size of ULT freezers, a truck with a lifting ramp is mandatory.

Summary

The sustainability of the ULT freezer and its related footprint covers more aspects than just energy consumption and the type of cooling liquids. Design and production in the factory, the shipment, independent certification as well as valid performance data, longevity, maintenance, and finally clear guidance of what to do with the instrument at end of life are relevant as well.

Eppendorf started its journey to improve the ULT freezer footprint already 15 years ago when the first R&D engineers spent their time on hydrocarbon based cooling. Many other aspects were improved, but we still need to proceed.

About Eppendorf

Since 1945, the Eppendorf brand has been synonymous with customer-oriented processes and innovative products, such as laboratory devices and consumables for liquid handling, cell handling and sample handling. Today, Eppendorf and its approximately 5,000 employees serve as experts and advisors, using their unique knowledge and experience to support laboratories and research institutions around the world. The foundation of the company's expertise is its focus on its customers. Eppendorf's exchange of ideas with its customers results in comprehensive solutions that in turn become industry standards. Eppendorf will continue on this path in the future, true to the standard set by the company's founders: that of sustainably improving people's living conditions.

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