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Eco-design of an innovative cleaning device inspired by NASA research to clean fragile surfaces and preserve cultural heritage

MOXY PROJECT – Green Atmospheric Plasma Generated Monoatomic Oxygen Technology for Restoration of the Works of Art – Funded by the European Union – Horizon Europe

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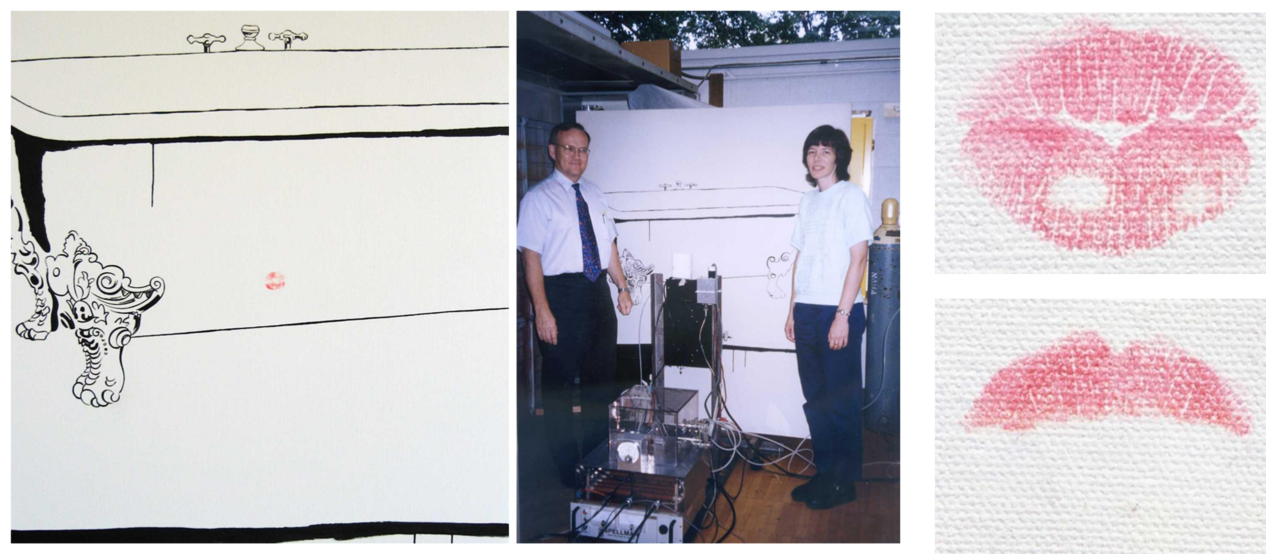
CONTEXT

- The climate crisis and unsustainable activities increasingly threaten **tangible cultural heritage** worldwide through the deposition of various carbon-based contaminants from **pollution, transport, fires, wildfires, and vandalism**, among others.
- Many sensitive and fragile materials, which constitute works of art and other cultural heritage assets, often cannot tolerate mechanical "wet" or "dry" cleaning using organic chemicals and contact cleaning in general.
- MOXY aims to develop a sustainable non-contact technology for the **preservation of tangible cultural heritage**, which is an irreplaceable resource of humanity and its safeguarding is among the UN's Sustainable Development Goals (SGD).

OBJECTIVES OF THE MOXY PROJECT

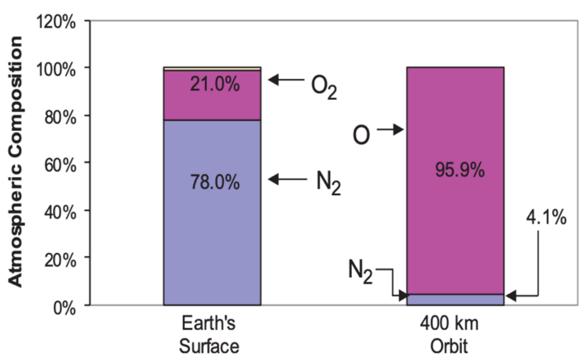


NASA scientists Bruce Banks and Sharon Miller during A. Warhol's "Bathtub" (1961) treatment in 1977. Cleaning tests on mock-ups using the atmospheric atomic oxygen device by Banks and Miller. Images: NASA

The MOXY project, which in 2022 was funded with a grant of over €4 million under the Horizon Europe call for "Green Technologies and Materials for Cultural Heritage", takes a radically different sustainable approach to cleaning based on technology developed by NASA, based on a **cold plasma-generated effluent of atomic oxygen (AO)** to remove various carbon-based contaminants, such as soot, dust, grease from fingerprints, smoking deposits, adhesives, biological matter, hydrocarbons and other organic compounds, with an incremental precision and non-contact cleaning process free of harmful chemicals, compared to the traditional cleaning methods using contact methods and organic solvents. Experts from plasma physics, green chemistry, heritage science, and conservation from **Ghent University, University of Amsterdam, University of Antwerp, National Gallery of Denmark, University of Pisa, Eindhoven University of Technology, KPV, Moderna Museet, ICOMOS-Lithuania, and WeLOOP** have joined forces to develop and test the new atomic oxygen technology, and to ensure that the technology is sustainable via a Life Cycle Assessment.

WHAT IS ATOMIC OXYGEN?

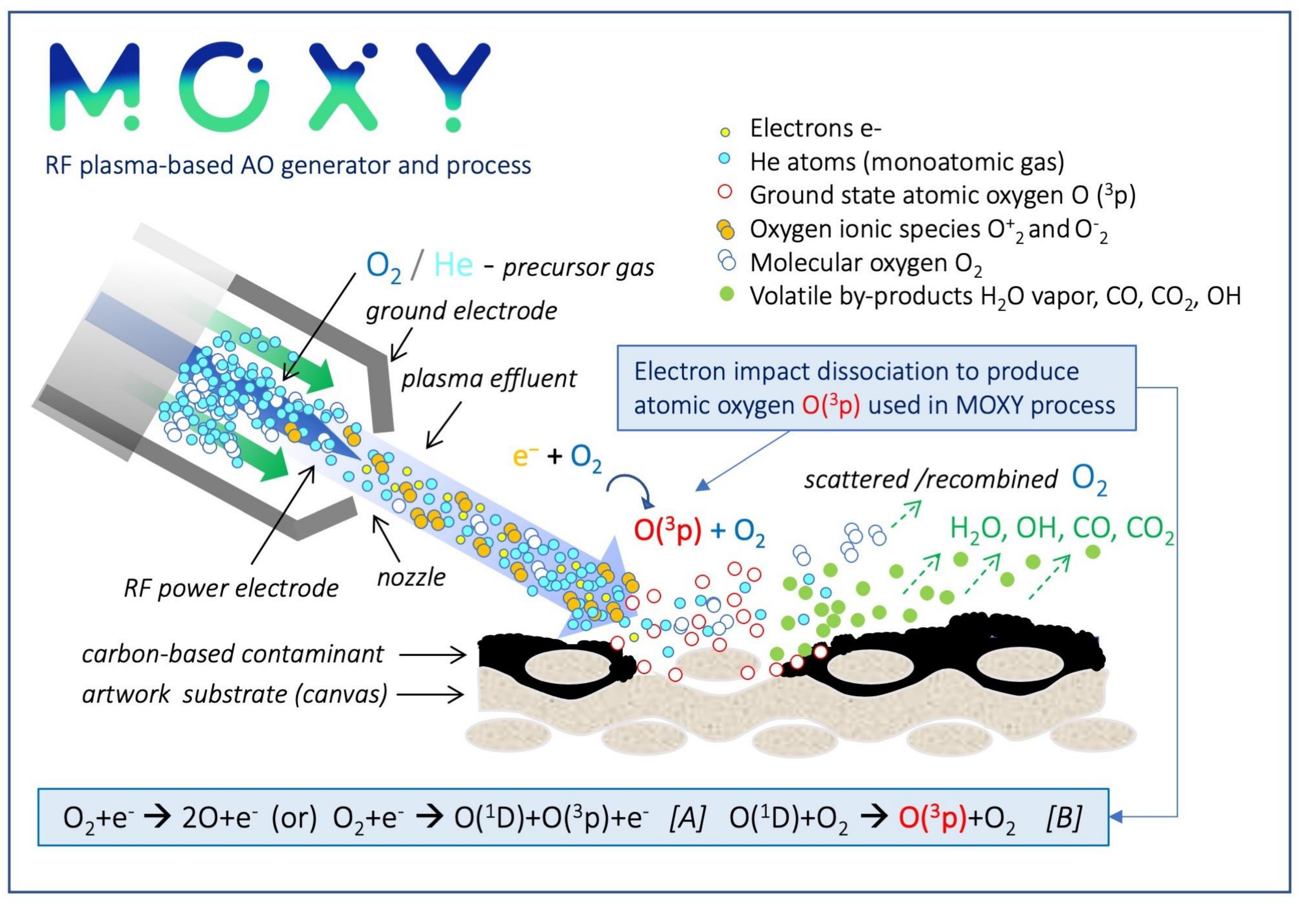
Atomic oxygen (AO) at ground state O (^{3}p), investigated by the MOXY project is a space environment element, present in the region known as LEO: low Earth orbit (80 - 1000 km) and is extremely short-lived on the ground (a few milliseconds).



The ratio of O2 and atomic oxygen O in space and close to Earth's surface Image: Sharon Miller, NASA

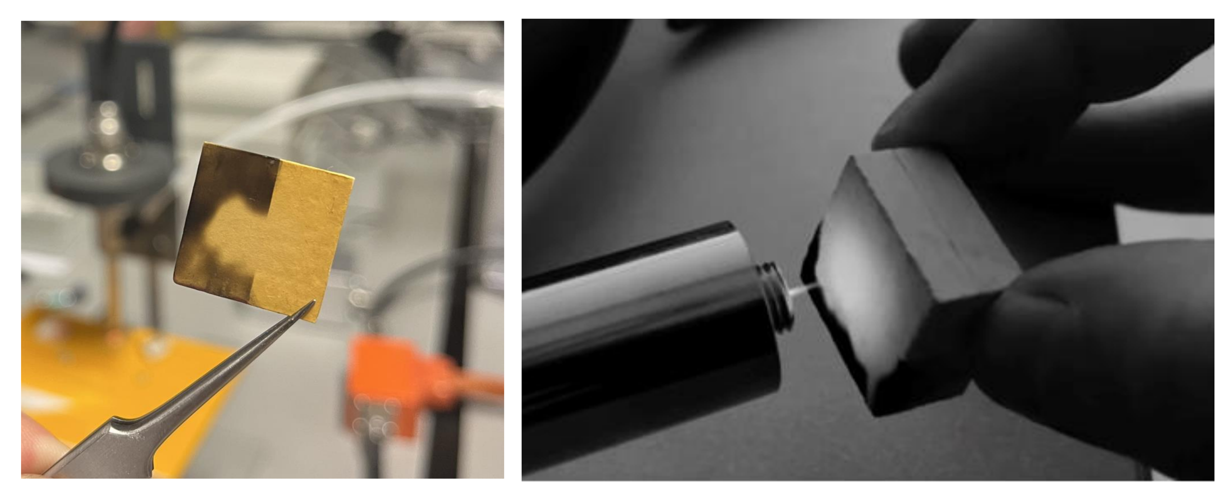
In space, AO is produced by the dissociation of O_2 by UV radiation. AO is highly unstable and reactive, and in space exists without recombination since only about 10^9 atoms are found in 1 cm^3. However, opportunities for reacting with other atoms are abundant on the ground, which is a challenge to apply AO for conservation treatments in atmospheric, rather than low-pressure conditions.

HOW THE AO DEVICE WORKS



AO generation and cleaning principle. Image: RUPT, Ghent University

- Cold plasma is generated by radiofrequency (RF) field
- Cold RF plasma splits O2 molecules: O2 + e- > 2O + e- into atomic oxygen (AO) through impact dissociation.
- Helium is used to transport O atoms to the surface and prevent rapid recombination of AO into O2
- AO reacts with organic contaminants, removing them in a non-contact way, the by-products are mainly CO_2 and H_2O vapours



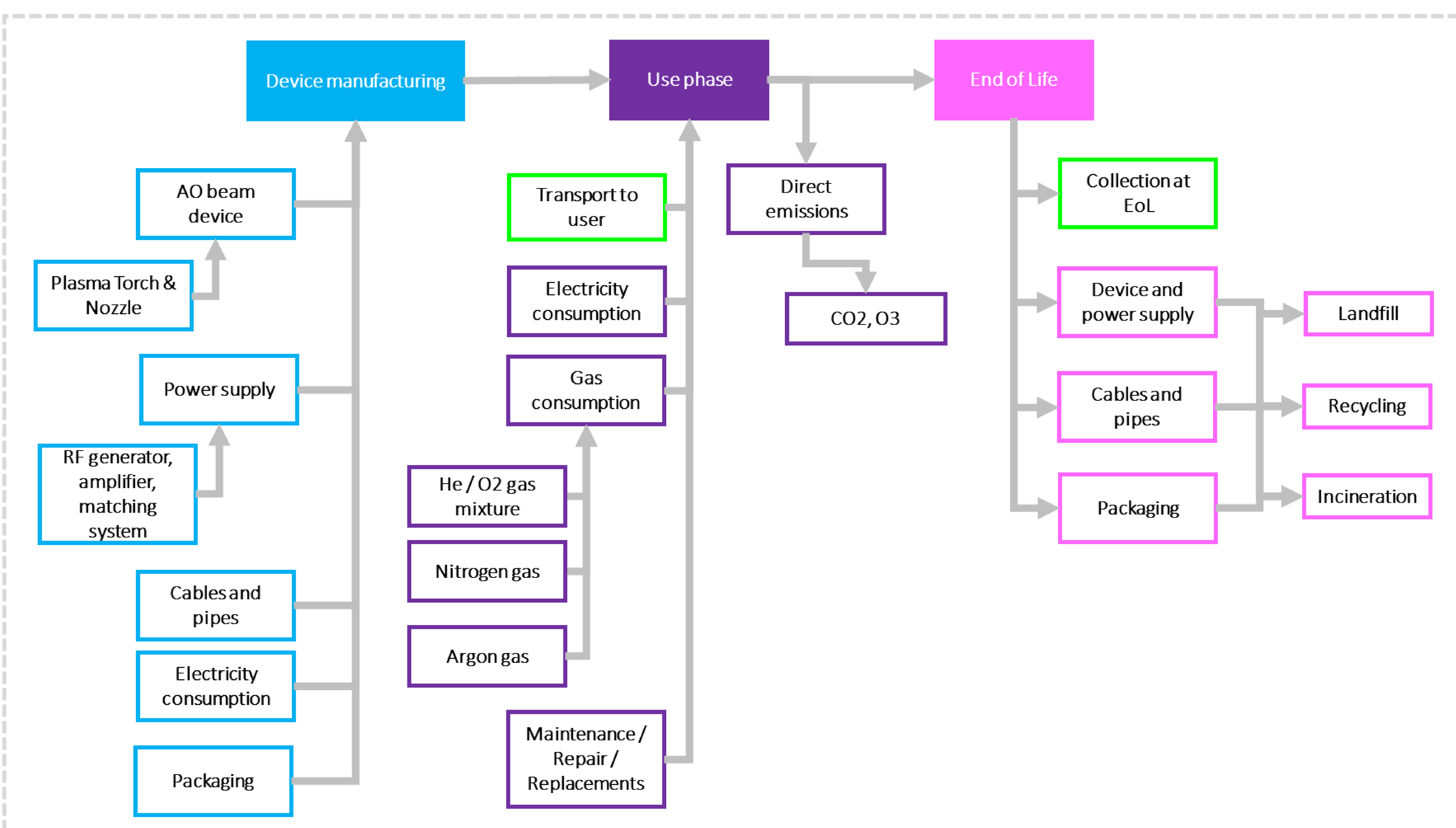
Experimenting AO cleaning at Ghent University. Image: RUPT, Ghent University

LCA GOAL AND SCOPE DEFINITION

The environmental performance of the AO device is evaluated and optimized via an attributional LCA in different steps:

- An **environmental hotspot analysis** to identify main contributors to impacts (presented here)
- An **eco-design approach** to optimize the environmental performance (upcoming)
- A **comparison** with alternative cleaning approaches (upcoming)

The device technology is still in its development phase. A close collaboration between the technology engineers and the sustainability assessors enables the identification of hotspots and their optimisation during the design phase.



Functional Unit:
"Removing organic contaminants from a cultural heritage object during one cleaning session"

1 cleaning session ≈ 2 minutes

Research ongoing regarding:

- Carbon removal rate
- Compatible contaminants
- Suitable substrates
- Operation modes (manual, robotic arm, etc.)
- Business model (purchase, rental)

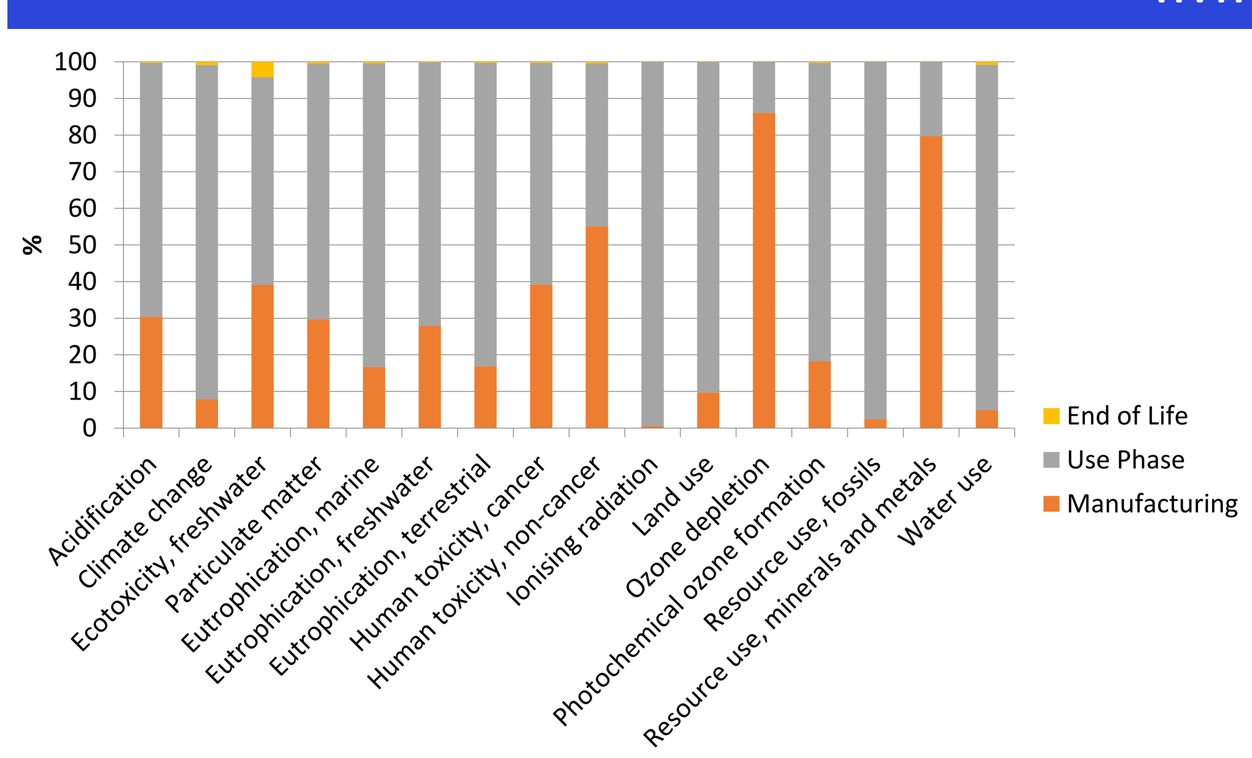
INVENTORY ANALYSIS

- Data collection from U-Gent (device designers)
- Ecoinvent 3.9 Cut-off system model

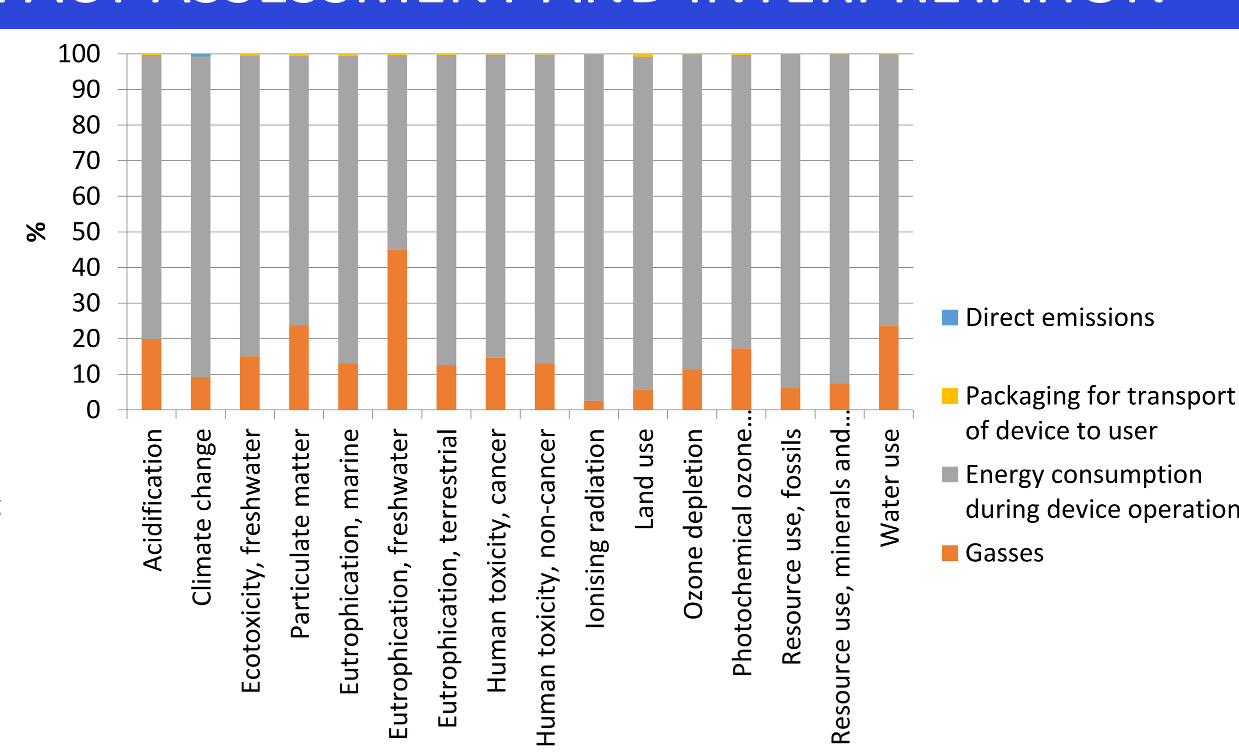
Key challenges of the inventory analysis:

- Lab-scale vs. commercial RF generator
- Complex supply chain of gasses
- Establishing EoL scenarios

IMPACT ASSESSMENT AND INTERPRETATION



Analyzing 1 p 'Life Cycle'; Method: Environmental Footprint 3.1 (adapted) V1.00 / EF 3.1 normalization and weighting set / Damage assessment / Excluding long-term emissions



Analyzing 1 p 'Use Phase'; Method: Environmental Footprint 3.1 (adapted) V1.00 / EF 3.1 normalization and weighting set / Damage assessment / Excluding long-term emissions

Hotspots Use phase	Hotspots Manufacturing
• Electricity consumption during device operation • Production of liquified Argon	• Production of power supply unit • Production of AO beam device

NEXT STEPS

- Eco-design workshop to identify opportunities to decrease impacts
- Comparative LCA via a refined functional unit
- Economic and social sustainability screening

Contact https://www.moxyproject.eu/ d.schrijvers@weloop.org

MOXY – GHENT UNIVERSITY – Universiteit Antwerpen – TU/e – Università di Pisa – Moderna Museet – ICOMOS Lietuva – WeLOOP – SMK – KPV – Funded by the European Union