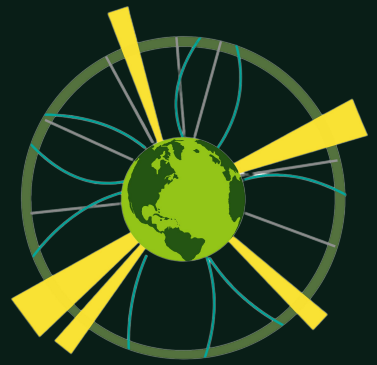


Sustainable HEP 2026: From Ambition to Action

How can we maintain fundamental scientific excellence while drastically lowering the environmental footprint of research?

Kristin Lohwasser & Hannah Wakeling

University of Sheffield

John Adams Institute for Accelerator Science

The 2026 International Workshop on the High Energy Circular Electron Positron Collider • 21–26 OCTOBER 2026

Core Mission
Measurable environmental accountability.

Technical Scope
Accelerators, detectors, and computing.

Community Goal
Shared methods and systemic roadmaps.

Institutional Responsibility

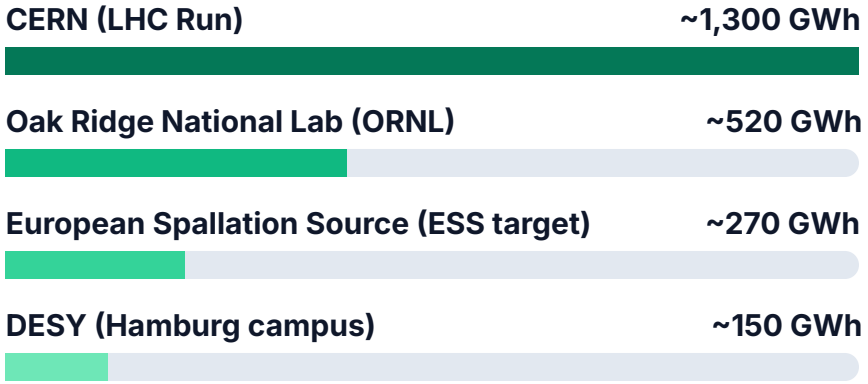
Why Sustainability Matters in Particle Physics

Science is not exempt from Responsibility

Large scientific facilities depend heavily on substantial amounts of energy, cryogens, specialised materials, and significant computing requirements.

Environmental sustainability and scientific ambition are symbiotic imperatives, not opposing constraints.

Major Lab Annual Electricity Benchmark (GWh/yr)



Source: Falastine Abusaif (2026).

Future frontier accelerators should systematically incorporate environmental sustainability into their lifetime plans.

A Forum to discuss

Sustainable HEP Workshop History & Statistics

5 Editions
2021 – 2026 Series

1,000+
Global Participants

100+
Talks & Panel Sessions

>100x
less Carbon Footprint (Virtual)

2021
1st Edition
June 28–30, 2021

- Inaugural virtual workshop on basic research footprint
- Nearly Carbon-Neutral (NCN) conference framework
- Sparked HECAP+ sustainability perspective

2022
2nd Edition
Sept 5–7, 2022

- **254** registered participants
- Aligned with IPCC reports & UN SDGs
- Publishing & INSPIRE HEP sustainability

2024
3rd Edition
Online Conference

- Broadened lab & university best practices
- Published video recording archives
- Cross-experiment working groups

2025
4th Edition
May 12–15, 2025

- **235+** registered participants
- Focus on future collider carbon footprints
- Physics-inspired economics & climate keynotes



Detailed program & archives: **https://indico.global/event/16058/overview**

Policy Progression

Institutional Strategy: Awareness to Action

What has happened since the first Sustainable HEP conference?

2020

European Strategy

Explicit sustainability integration into long-term particle physics planning.

2024

LDG Working Group

Harmonised guidelines developed across European lab directorates.

2026

Accountable Targets

Standardisation of environmental sustainability criteria to upcoming projects.

2026

European Strategy Update

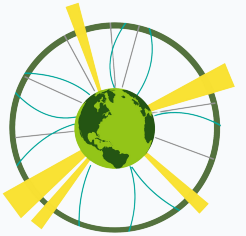
Recent update recommended more of a focus on sustainability!

⚠ **The Central Hurdle:** Transitioning top-level institutional roadmaps into enforceable funding contingencies and audited milestones.

So what have been presenters discussion about in this year's edition?

Life Cycle Assessment

Measuring Infrastructure Impacts: Research Facility 2.0



Raw Materials
Extraction impacts

Manufacture
Supply chain footprint

Construction
Civil embodied carbon

Operation
Power, gas, cooling

End-of-Life
Decommissioning/reuse

22 Indicators

Spanning 9 distinct environmental subdomains including carbon, rare materials, and water.

EIC & LHCb Hotspots

Highlighting that embodied hardware emissions rival operational energy over decadal horizons.

References: EIC LCA & LHCb data centres

We cannot effectively reduce environmental impacts we do not rigorously model and quantify.

Frontier Engineering

Sustainable Accelerator Infrastructure

Fast Reactive Tuners

Eliminates RF power overheating.

Nb_3Sn Cavities

Higher-temperature cryogenic operation.

Energy Recovery (ERL)

Decelerating beams recycles power.

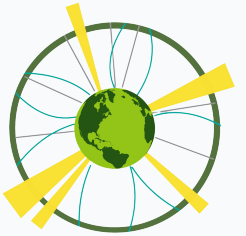
Grid-to-Beam Efficiency: The greatest leverage exists during early conceptual design before civil and magnet lock-in.

iSAS Consortium

Reference: ISAS presentation

Circular Operations

Recovering Operational Energy & Resources



THERMAL STORAGE PROPOSAL

ULISSE Seasonal Storage

Harnesses high-volume low-grade waste heat from accelerator cooling towers to supply regional district heating networks across seasonal cycles.

Reference: ULISSE

Feasibility design for large-scale heat recycling

DEMONSTRATED CAPTURE

Helium Reliquefaction

Univ. of New Hampshire closed-loop recovery demonstrates over 85% recapture efficiency, mitigating global supply shocks and cryogenic loss.

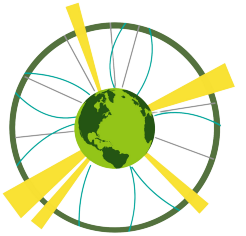
Reference: Sustainable Cryogenics

>85% Recapture efficiency achieved in practice

Resource recovery delivers operational resilience, cost stability, and direct emissions mitigation.

Greenhouse Gas Mitigation

Greener Detectors: The 4R Framework



01. Reduce

Operational Flow

Active leak remediation and flow reductions.

02. Recover

Recirculation

Closed-loop recuperation of heavy F-gases.

03. Replace

Eco-Gases

CO_2 and low-GWP hydrofluoroolefins.

04. Redesign

Next-Gen R&D

Novel architectures without greenhouse mixtures.

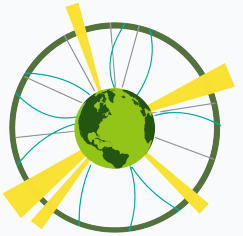
Large number of talks on investigations into green gaseous detectors

ATLAS Experiment Milestone: Implemented revised gas mixtures in January 2025, yielding an immediate ~27% reduction in global warming potential.

-27% GWP

Operational Reliability

The Detector Longevity Challenge



Low-GWP Is Not Automatically Sustainable

Irradiation tests at CERN's GIF++ facility revealed dark currents and electrode surface fluorination in Resistive Plate Chambers using eco-gas mixtures.

Premature chamber replacement introduces heavy embodied manufacturing emissions that easily eclipse gas savings.

Timing & Efficiency
Sub-nanosecond resolution must be preserved.

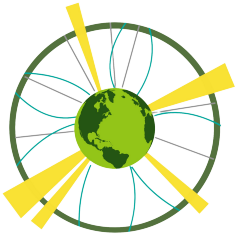
Electrode Degradation
HF byproduct deposits cause localised damage.

Full-Lifecycle Accounting
Emissions balance must incorporate chamber lifetime.

Detector sustainability requires validating resilience over 10+ year high-luminosity operational lifespans.

Distributed Infrastructure

The Environmental Footprint of Scientific Computing



~200
Tier Sites Worldwide
Across 42 partner countries

>85%
Off-Site Compute
Processing happens outside CERN

50%+
Embodied Footprint
Hardware manufacturing share (LHCb LCA)

> **The Embodied vs. Operational Reality:** In low-carbon electricity grids, semiconductor silicon fabrication and server replacements dominate lifetime emissions – making server lifetime extension critical.

Common telemetry and power benchmarking are needed to guide procurement decisions.

Algorithmic & Architectural Solutions

Making Scientific Computing More Efficient

GPU Efficiency

Workload tuning for trigger pipelines.

J. Zhuo et al.

Event Biasing

Optimised sampling in rare searches.

L. Milligan

ML Fast Sim

Surrogate models replacing Geant4 cycles.

H. Day-Hall

Shared MC

Open event samples prevent duplicate jobs.

J. Hogan et al.

Parallel Code

Vectorised software boosts hardware duty.

SC4RC 2026

The Jevons Paradox: Higher computational efficiency often triggers larger simulation demands. Efficiency gains must translate into absolute resource ceilings.

Civil Engineering & Metallurgy

Sustainable Materials and Construction

The SuShi Project

Rammed Earth Shielding

Investigating compressed earth blocks and excavated soil as carbon-neutral photon radiation shielding, replacing high-embodied-carbon portland cement.

Reference: SuShi

Trade-off: Requires increased spatial thickness while dramatically lowering civil carbon emissions.

Detector Metallurgy

Ultra-Pure Copper Alloys

Developing high-strength, radiopure copper alloys to minimise overall material consumption in rare-event cryostats while boosting structural safety factors.

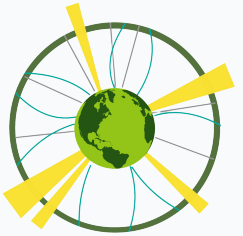
Reference: Ultrapure Copper

Impact: Enhances detector sensitivity while cutting raw mass extraction requirements.

Civil construction accounts for massive upfront carbon expenditure in future underground tunnels and caverns.

Broader Impact

Physics Expertise Applied Beyond HEP



CH4rLiE Methane R&D

Adapting detector gas recuperation technologies to capture point-source methane in livestock facilities.

Reference: CH4rLIE

Agrifood Modeling

Applying reproducible high-energy software workflows to national and global food system resilience.

Reference: Agrifood

Climate Analytics

Leveraging massive data handling and uncertainty modeling for precision environmental forecasting.

Reference: Modelling

Dual Mandate: The responsibility of physics involves cutting internal footprints while directly deploying analytical competence to external planetary crises.

Professional Pathways

Careers: From Physics to Sustainability



Laura Bianchi

United Machining

Industrial sustainability.



Raluca Cruceru

UNEP

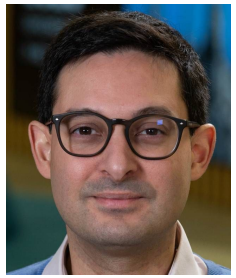
Environmental information.



Lia Formenti

GHGSat

Satellite methane mapping.



James Robinson

Turing Institute

Environmental forecasting.



André Schneider

World Climate Found.

Climate policy leadership.

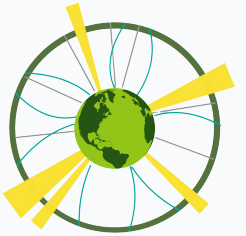
Panel Summary & Key Takeaways

- **Motivation & Transition:** Panelists pivoted from fundamental physics to sustainability driven by direct societal impact and climate urgency, applying analytical rigor to real-world challenges.
- **Mindset & Skill Shifts:** Success requires adapting to corporate and policy frameworks, translating complex technical ideas for non-technical stakeholders, and valuing pragmatic execution over academic perfection.
- **Broad Sector Impact:** Meaningful environmental contributions occur both in dedicated climate roles and by embedding green practices—such as sustainable computing and efficient algorithms—into existing operations.

Core Transferable Skills: Complex problem-solving, data analysis, systems architecture, and cross-disciplinary collaboration.

Synthesis & Insights

Five Takeaway Lessons



1
Measure
Implement impact evaluation e.g. LCA.

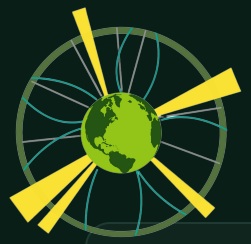
2
Scientific Return
Evaluate science output.

3
Full Lifetime
Account for construction, operation and decommissioning.

4
Standardise
Simplify comparison and reduction efforts through common goals and metrics.

5
Collaboration
E.g. open software and shared toolkits.

Strategic Maturation: Particle physics is actively crossing from ethical awareness to validated technical methodologies with verifiable impact metrics.



Near-Term Priorities (2026–2028)

- **Uniform Baselines: Standardise facility carbon accounting.**
- **Proven Deployments: Scale gas recovery and low-grade heat capture.**
- **Open Methodologies: Share carbon tools and data openly.**

Decadal Horizons (2028+)

- **Design: Embed impact measurement and reduction into facility design, operation and decommissioning.**
- **Eco-Technology Validation: Certify multi-decade detector longevity.**
- **Impact Reduction Metrics: Exhibit tangible environmental impact reduction efforts e.g. in grant proposals and awards.**

Environmentallly Sustainable HEP is not about doing less science.
It is about enabling discovery with fewer environmental impacts.

Measure Innovate Implement

Environmentally Sustainable HEP is not about doing less science.
It is about enabling discovery with fewer environmental impacts.

MEASURE **INNOVATE** **IMPLEMENT**

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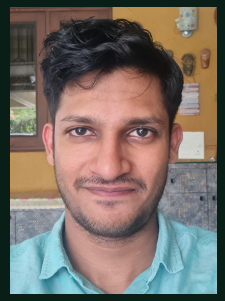
ROYAL HOLLOWAY UNIVERSITY OF LONDON

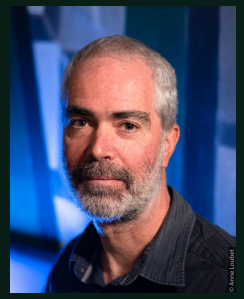
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Thanks to our sponsors for enabling the hosting of Sustainable HEP,
and thanks to the volunteers that organised and ran it!


Shreyasi Acharya


Chandramauli Agrawal


Yann Coadou


Kristin Lohwasser


Hannah Wakeling

Interested in organising the next Sustainable HEP?
Email: susthep26 “at” physics “dot” ox “dot” ac “dot” uk

Kristin Lohwasser & Hannah Wakeling

University of Sheffield

John Adams Institute for Accelerator Science