

Sustainability in the UK

Efforts ongoing in relation to accelerators

Hannah Wakeling & Ben Shepherd

Laboratory Directors Group UK Meeting

14th October 2026



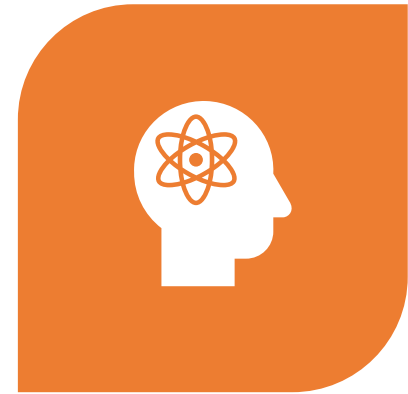
Overview



THE UK PERSPECTIVE ON
SUSTAINABILITY



EUROPEAN INPUT



NATIONAL EFFORTS



STFC and sustainability

UKRI Environmental Sustainability Strategy 2025 to 2030

UKRI



Reporting



Procurement



Climate
protection



Energy
management



Waste heat



Civil
Construction



The UK perspective

UK National Input to the ESPPU 2026

Environmental sustainability is **an underlying focus** that must be properly funded and embedded into any flagship particle physics experiment.

Europe is provided with a **unique opportunity** to develop and lead environmentally sustainable construction approaches, and this must be embraced.

R&D to accomplish long-term sustainable accelerator, detector and computing infrastructure must be funded and **we expect this to be built into future FCC plans.**

Reuse of existing experimental infrastructure may reduce negative environmental impacts as part of **comprehensive life-cycle planning.**

Maximising the environmental sustainability of future particle physics projects is **essential.**

This was particularly emphasised by ECRs.



UK participation in European projects

iSAS

EuPRAXIA

TwinRISE

EPITA

iRIS





European Input

STFC and CERN support environmentally sustainable physics

08 Apr 2024

The Science and Technology Facility Council (STFC) and CERN have signed a new agreement to support the development of more sustainable particle accelerators.

"The agreement will act as a framework to better direct CERN and STFC's funding, expertise and technological investment to minimise environmental impact.

It provides **guidance and recommendations that consider the entire lifecycle of accelerator facilities**, from design and construction to operation and decommissioning."





National Efforts

ASTeC at Daresbury Laboratory

Accelerator Science and Technology Centre

- RUEDI Environmental Impact Assessment
- ZEPTO permanent magnets
- Thin film SRF development
- CLARA
- Energy monitoring
- Ion Beam Analysis (IBA) prototype (joint with ISIS)

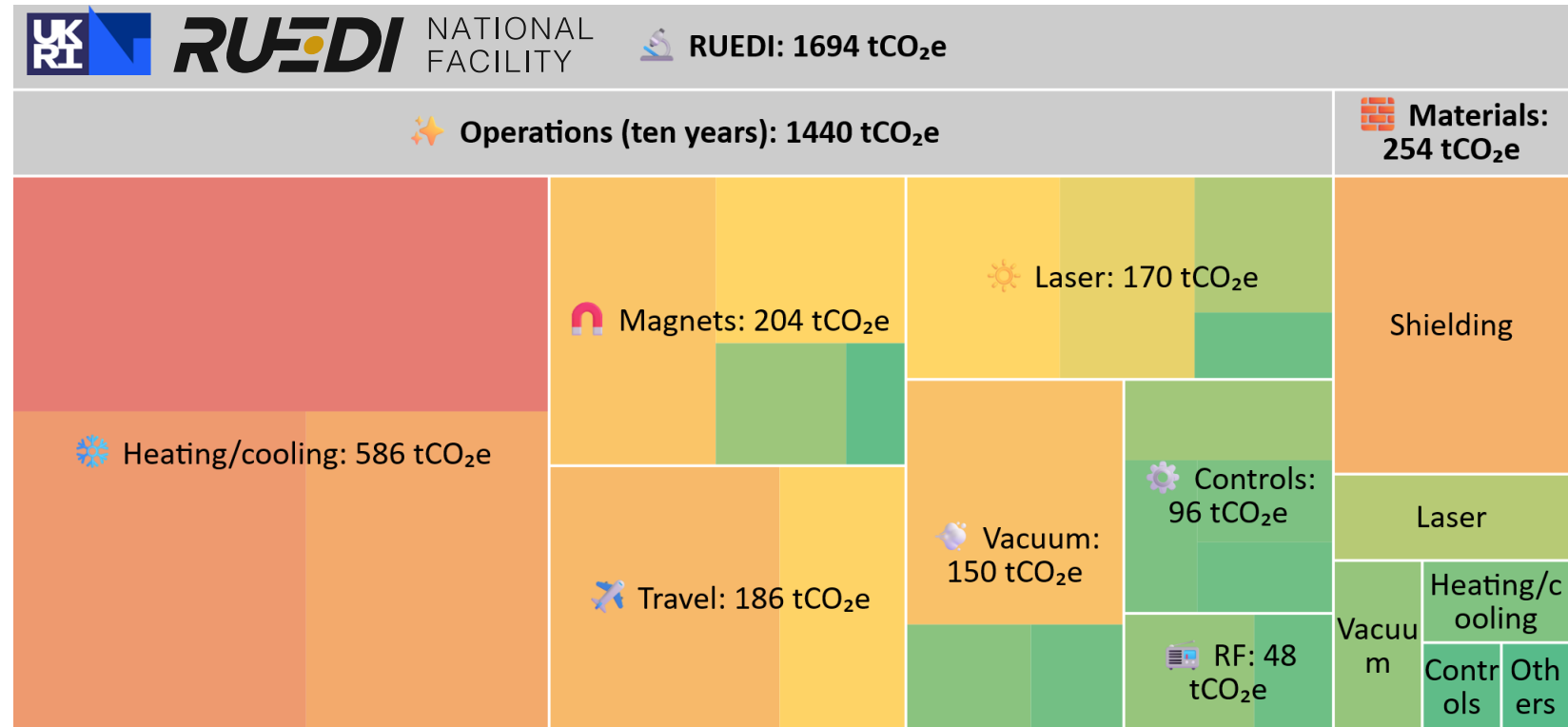




RUEDI at Daresbury Laboratory

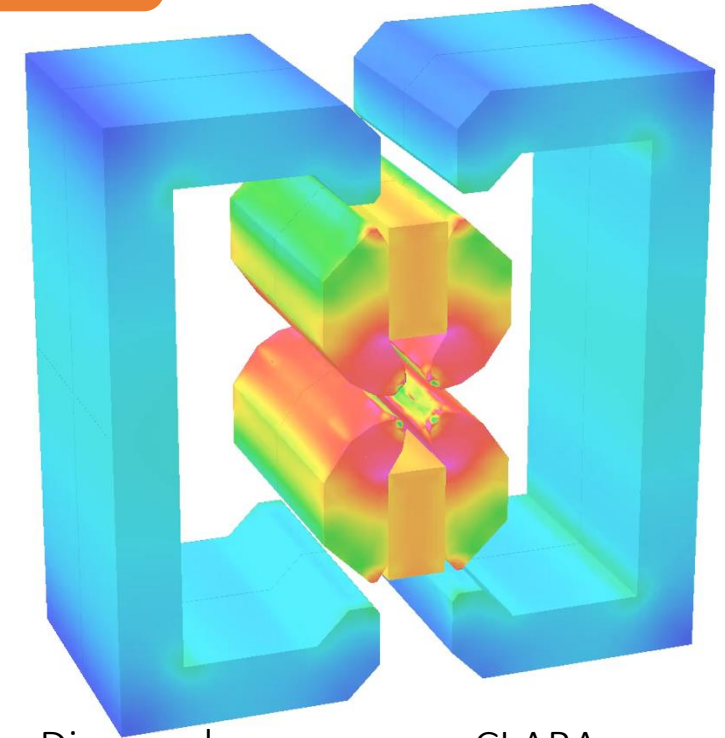
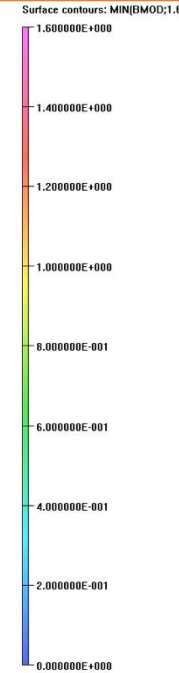
Relativistic Ultrafast Electron Diffraction & Imaging

- ASTeC's Sustainable Accelerators Task Force
- Carbon emissions produced of building and operating a small accelerator facility.
- The report uses the future RUEDI facility as a case study
- Lists:
 - biggest sources of these emissions
 - some strategies for minimising the environmental impact of future accelerators.
- [IET PAEN 2024 Recording](#)

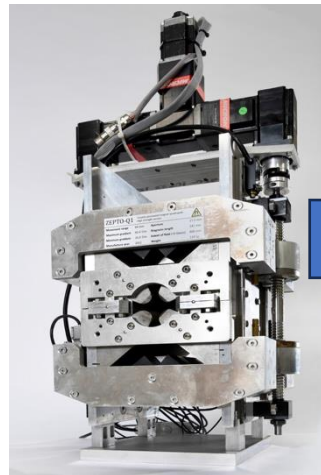


ZEPTO tuneable quadrupoles

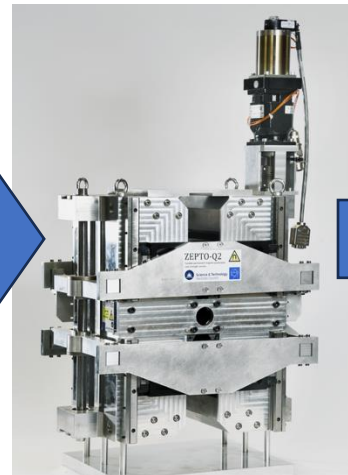
- Quasi-linear 8-100% tuning range: 3.5-43 T/m
- Tuning using outer shell as secondary flux circuit to reduce quad strength rapidly
- PMs move perpendicular to magnetic axis → low forces
- Q2 parameters:
 - 2 NdFeB blocks, each 37.2 x 70 x 190 mm
 - Pole gap 27.6 mm
 - Field quality $\pm 0.1\%$ over 23 mm
 - Length: 190 mm
- Originally developed for CLIC
- Diamond, CLARA devices similar specs



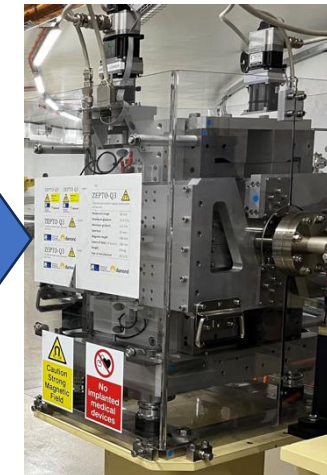
Prototype 1



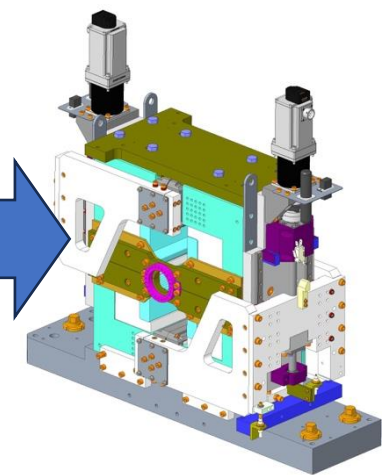
Prototype 2



Diamond



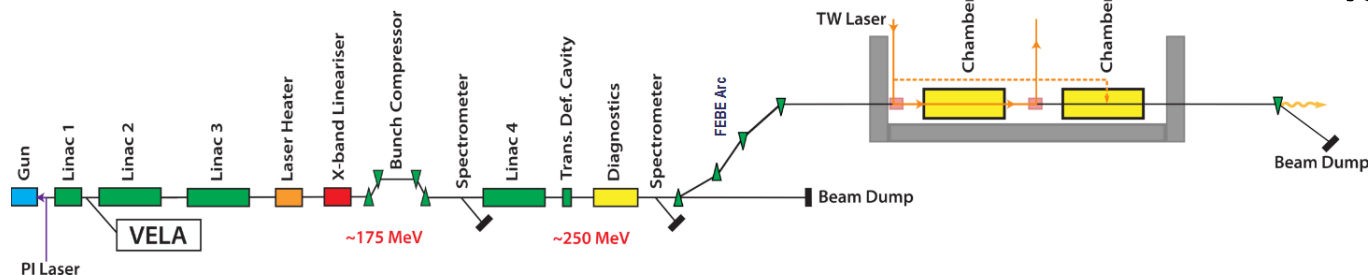
CLARA



CLARA

- Optimising the CLARA RF system
- High voltage (HV) modulator and klystron often overspecified for beam stability and redundancy
 - Currently CLARA RF operates with 5 μ s RF pulse length for 250 MeV beam
 - Propose reducing to 3 μ s
 - Reduce energy usage of RF system by 35%

- RF energy usage
 - Electrical power: 2.4 MWh per 12-hour shift
 - Water cooling: 950 kWh per shift (est)
- 120 days of beam time per year
- Annual costs:
 - £100k for RF
 - £32k for water cooling
- Estimated usage after pulse width reduction
 - 1.5 MWh electrical
 - 420 kWh water cooling
- **Total estimated savings: £48k/yr**
 - **21.6 tCO₂e/yr**



Thin film SRF development

- Bulk niobium cavities have been the choice for SRF for the last 50 years
- Require a large volume of critical raw material
- Run at a temperature of 2 K
 - A considerable cryogenic demand and energy load

Benefits of thin films

- Use a copper supporting cavity
 - Better thermal properties, cheaper material and production
 - Lower embedded carbon emissions
- Use different superconducting materials e.g. Nb_3Sn , NbN and MgB_2
 - Better performing materials than Nb that can't be formed into solid cavities
- Higher operation temperature
 - Run at 4.2 K rather than 2 K
 - Cut refrigeration power by factor of 3
 - Huge impact for new large projects e.g. FCC-ee



6 GHz split cavity with Nb coating

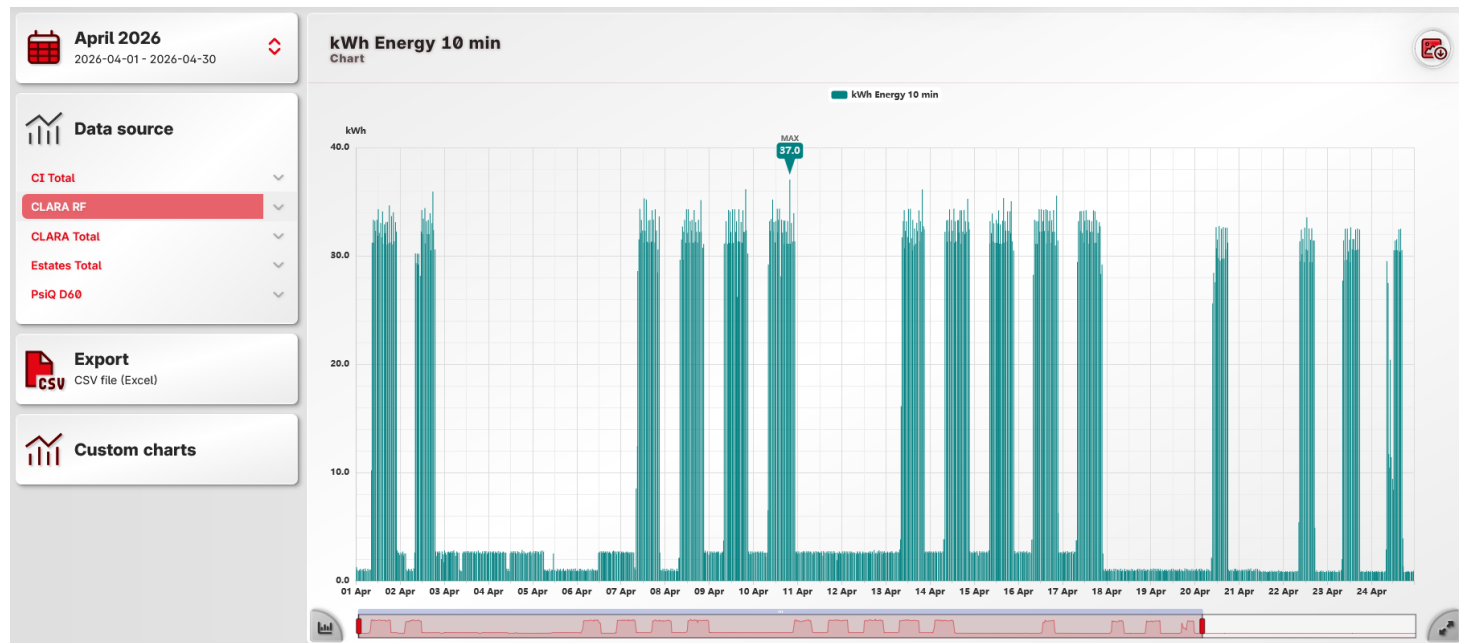
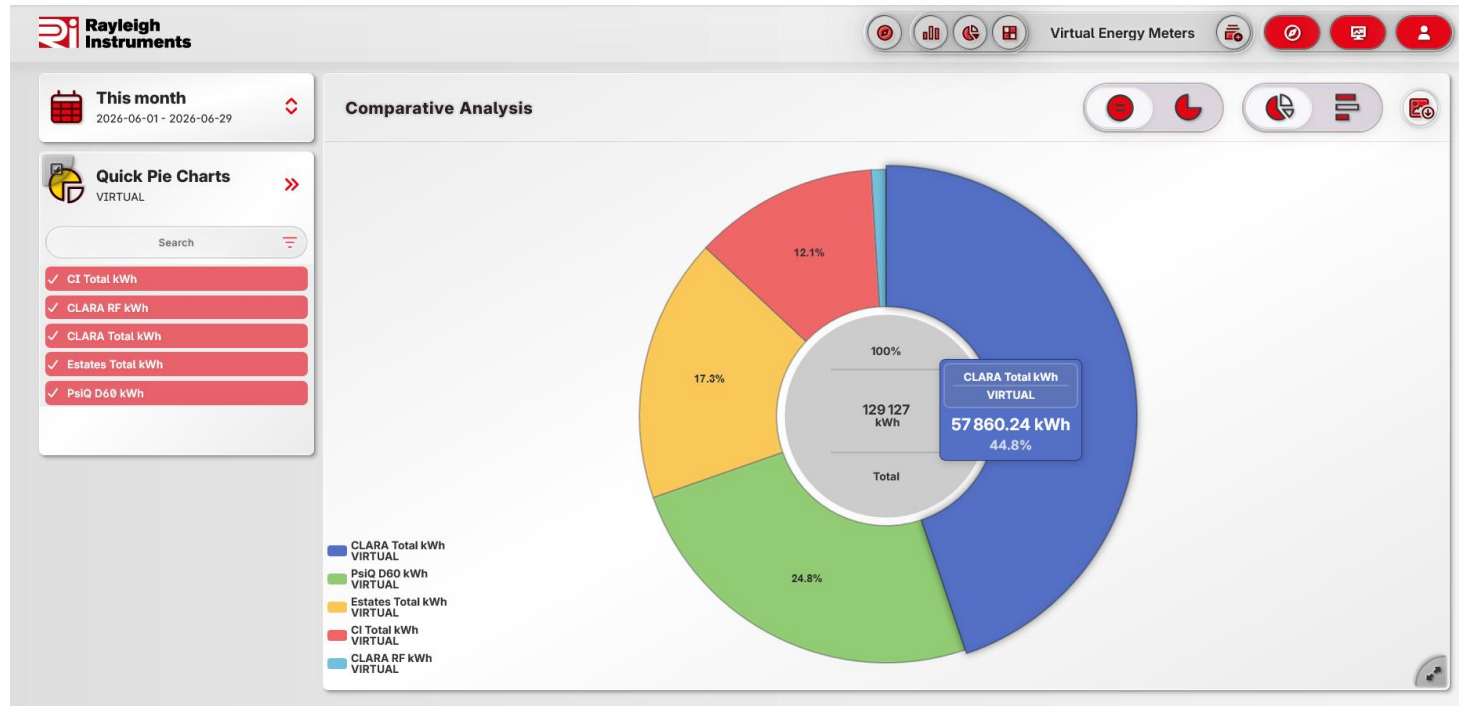
STFC VISTA laboratory: deposition facility





Energy monitoring

- Installing and understanding energy monitoring data by ASTeC
- Around 50 submeters installed on CLARA and around Daresbury site – more to be installed soon
- Data available down to 1-minute intervals
- Drill down to find usage of subsystems: RF, magnets, water, AC, ...
- Compare long-term trends and operating modes
- Understand impact of efficiency initiatives



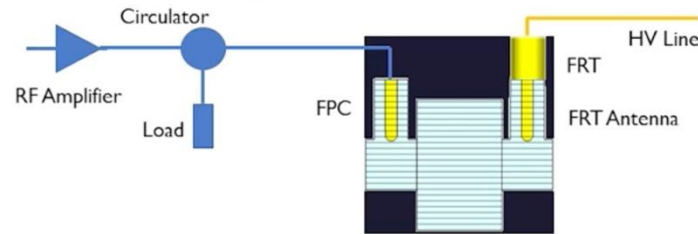


National Efforts

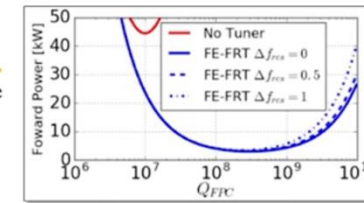
Cockcroft Institute

- More sustainable RF for Future Accelerators
 - IET PAEN 2024 recording
- E.g. development of Fast Reactive Tuners (FRT)

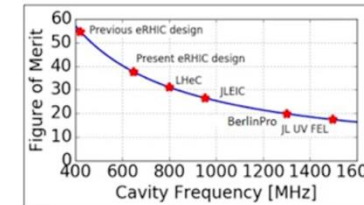
FRT Concept



- An Fast reactive Tuner (FRT) is a shorted co-axial structure containing a ferro-electric element
- RF power flows into the FRT and is reflected back to the cavity
- Voltage applied to the ferro-electric changes its permittivity
- Permittivity change $\rightarrow$ Phase change of the reflected power $\rightarrow$ Cavity frequency change
- Tuning speed measured at less than 600ns, limited by HV circuit

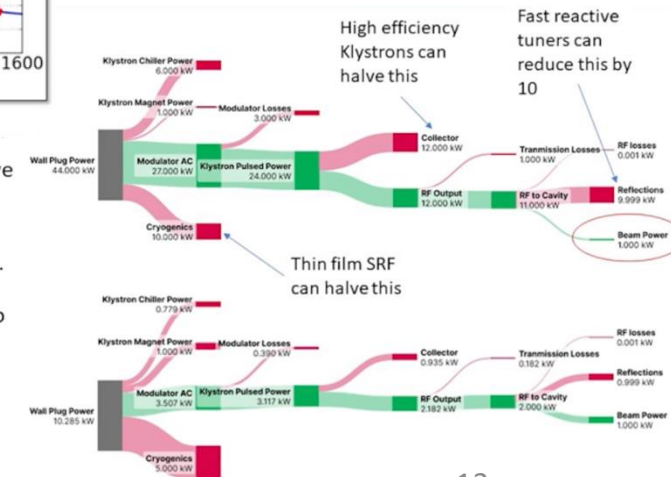


Case study: RF power for PERLE vs QL with and without FRT



Estimated FRT FoM vs RF frequency

- By going superconducting we reduce the RF power losses but we now have cryogenic losses and RF reflections
- Klystrons are still a big issue.
- Microphonics makes it difficult to transfer power to the cavity
- Carnot efficiency makes cryogenics inefficient
- Typically only 2-10% of the wall plug power ends up in the beam.





National Efforts

ISIS Neutron and Muon Source

- Sustainability projects register
- Consultancy review (Arup)
- Reliability in operation
 - Poster at PABG 2025
- LCA-lite in ISIS Design Division
- REACT – Recycling Energy from Accelerators by Capturing Thermal Waste
 - IET PAEN 2024 recording
- Ion Beam Analysis (IBA) prototype (joint with ASTeC)
- ISIS component optimisation

RIKEN solenoid

- Replacement of the muon decay channel solenoid a.k.a RIKEN beamlines
- Old system:
 - 5 m long cold bore cryomagnet with its own in-built liquid cryo-plant
 - Over the years of use (~300 days a year in operation) and many magnet quenches, the cryo-plant is now running at maximum capacity all the time, drawing 250 kW
- New system:
 - Under manufacture
 - Cryogen-free cooling system
 - Much lower power requirement of ~30 kW

Assuming current UK grid carbon intensity of 0.144 kg CO₂e / kWh:

annual carbon saving of ~220 tCO₂e/yr

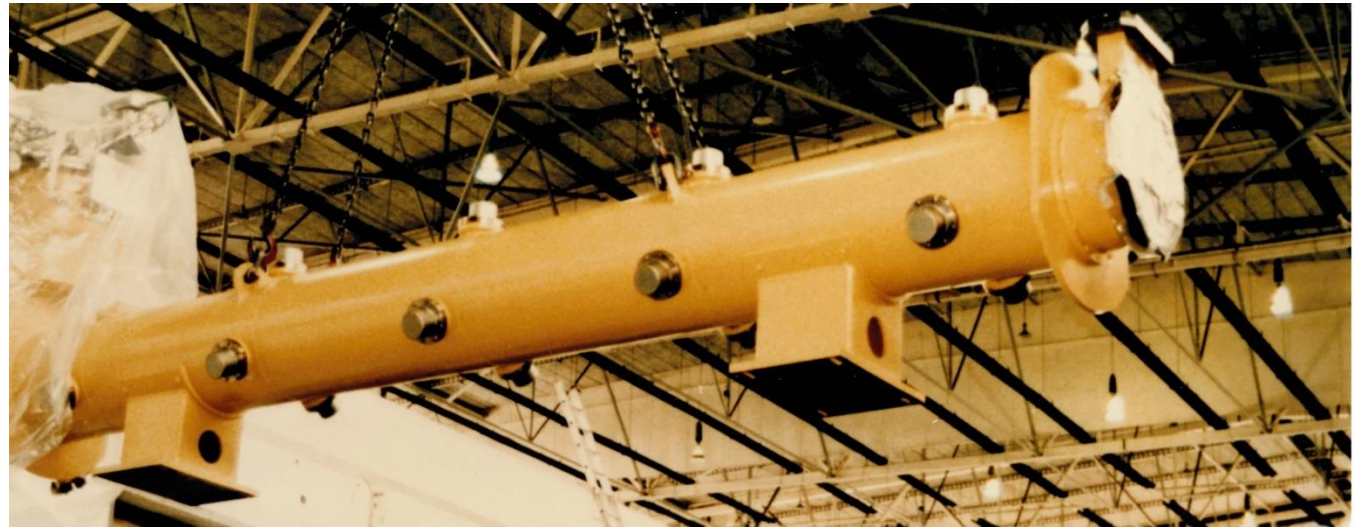


Image: installation of the original solenoid, 35 years ago

RF upgrades

2021: All six of the fundamental RF systems that drive the synchrotron acceleration were replaced.

- ~9% of the proton beam energy needed for producing neutrons and muons comes from the ion source and linear accelerator, but the rest is supplied by the six fundamental radio frequency (RF) systems in the synchrotron.
- These systems were installed when ISIS was first built. At their core are valves known as tetrodes.
- An upgrade of this scale required over a decade of planning but has brought huge efficiency savings
- 60% power savings!

2024: the second harmonic RF was also upgraded in the same way.

- **Total annual energy savings of ~2.9 GWh/yr**
- **With annual carbon savings of 360 tCO₂e/yr**



ISIS RF team

- Low power RF system: running more intelligently, including adapting when the synchrotron is supplying only one target station.
 - For each day operated in this mode, 29 MWh are saved!

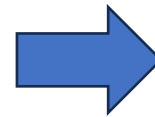


R80 chillers phase 1 – adiabatic coolers

- Replacing 5 closed-circuit cooling towers with 8 adiabatic coolers
 - provide cooling for the neutron instrument systems in ISIS Target Station 2
- Resulting in water and energy savings
- **Notably, water savings of 6500 m³ per year**



The old coolers in action



The new coolers being installed

R80 chillers phase 2 – energy efficient pumps

- Replace old chiller units with more modern ones
 - Conceptually simple project
 - Better energy efficiency
 - Aided by boost from Turbocor compressor
 - Installation due end of 2026
- **Expected energy savings of 560 MWh/yr**
- **Expected carbon savings of 80 tCO₂e/yr**



R6A blast chillers

Summer 2024: New air blast cooler

- Installed on the roof of the R6A synchrotron building.
- To be used during colder periods
 - **air cool** the water-cooling circuit for the synchrotron main magnet power supply, rather than via the existing chiller system
- **Potential energy savings of 56 MWh/yr**
- **Equating to carbon savings of 8 tonnes CO₂e/yr**





Better live monitoring

“The smart meter effect”

- Having the live energy consumption of ISIS displayed prominently in the main control room is being used to nudge behavioural changes with equipment use, especially during shutdowns and run-up / run-down periods.
- Equipment owners can now see the impact of leaving their kit running but not used, helping to optimise schedules and save energy.



Recovering scarce materials – helium and D₂O

- Helium and D₂O (heavy water) are both scarce resources but are both essential for some neutron scattering experiments
 - Helium: cryogenic cooling
 - D₂O: isotope contrast
- Although primarily cost driven, recovering and recycling these materials saves energy and the environment

Helium source	Production footprint (g CO ₂ /l He)	Transportation footprint (g CO ₂ /l He)	Boil-off losses (%)	Total footprint (g CO ₂ /l He)
ISIS helium recovery system	450	0	10	500
Gas company (excluding LNG production)	450	87.7	25	712
Gas company (including LNG production)	440,000	87.7	25	587,000

0.08% of gas company
inc. Liquid Natural
Gas (LNG) production



Radioactive waste recycling

Part 1: Improving recycling rates of radioactive material through better monitoring and appropriate decay storage.

- From 50% a few years ago to 90% now.
- Materials are mostly metal, and equate to 100 – 200 tonnes per year
- Comes from legacy waste plus material being removed to make way for upgrade works
 - E.g. magnets, shielding
 - All low-level waste
- A significant Scope 3 CO₂ saving
- Required close engagement with regulators





ISIS Radiation Protection

- "The Carbon Cost of Radiation Protection: When are we doing more harm than good?" - Chris McKay
- Developed an approach for comparing the benefit of radiation protection interventions with the indirect harm of their carbon footprint
- Shielding studies and tools



Philip Nicholson Award



The Carbon Cost of Radiation Protection: When are we doing more harm than good?

Christopher McKay¹

¹ Science and Technology Facilities Council, Harwell Campus, Oxfordshire, OX11 0QX, UK



Introduction

A key principle of radiation protection is that "Any decision that alters the radiation exposure situation should do more good than harm" ICRP103^[1].

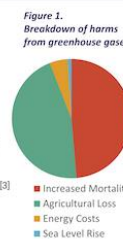
This work presents an approach for comparing the benefit of radiation protection interventions with the indirect harm of their "carbon footprint" and the integration of that into a radiation protection optimisation processes.

Harm of Greenhouse Gas Emissions

Global warming is resulting in harms such as extreme weather, disruption of food supply, increased wildfires. The **Social Cost of Carbon (SCC)** is the assessed harm from additional greenhouse gas (GHG) emissions. SCC informs setting of climate policy targets. The **Marginal Abatement Cost (MAC)** is the additional cost to achieve national emissions targets per unit GHG emissions. MAC informs decision making to achieve the targets.

$$SCC \approx £188 \text{ per tCO}_2\text{e}^{[2]} \quad MAC \approx £260 \pm 130 \text{ per tCO}_2\text{e}^{[3]}$$

Since 2009 the UK Government requires the MAC to be considered in decision making by all UK Public Bodies.



Harm of Radiation Exposure

In the low dose and dose rate range, harm is the risk of stochastic cancers

- Risk from exposure to reference person = 5.7×10^{-2} per Sv^[1]
- UK HSE valuation of death by cancer = £4,798,705 (as of 2025)^[4]

Application to ALARP or BAT

Firstly, apply regulatory obligations and relevant good practice, then...

Step 1 – Assess change in lifetime collective (or risk of) dose from a practice or intervention. *Very low individual doses, a small fraction of natural sources, should not be included in the calculation of collective dose^[1].*

Step 2 – Assess change in GHG emissions caused by change over full lifecycle

Step 3 – Compare ratio against equivalent harm value (below or figure 2), with suitable gross disproportion factor

$$\text{GHG Dose Equivalent Harm [tCO}_2\text{/Sv]} = \frac{\text{Fatality Valuation [£]} \times \text{Radiation Risk Coefficient [Sv}^{-1}\text{]}}{(\text{SCC or MAC}) [\text{£/tCO}_2\text{e}]}$$

$$= 1.1 \pm \frac{1.1}{0.4} \text{ tCO}_2\text{e/mSv} \quad (\text{based on 2025 MAC})$$

Figure 2. Variation of GHG Dose Equivalence Value with Time



Equivalent Harm

$$1 \text{ mSv} \approx 1.1 \text{ tCO}_2\text{e}$$

based on ICRP103^[1] and 2025 MAC UK Carbon Valuation^[3]

Equivalent embodied carbon:



Example – A Shielded Facility

STFC is procuring a facility to handle items equivalent to 1TBq Co-60.

- annual collective occupancy of ~2000 man-hours and a
- 30-year operating life.
- A design constraint of 7.5µSv/h set based on relevant good practice

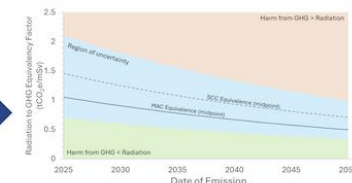
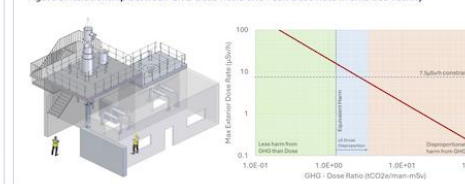
But is it ALARP to specify shielding beyond 7.5µSv/h?

Figure 3 shows the incremental change of the GHG-Dose ratio against peak dose rate for this facility as bulk shielding changes.

- ~800 tonnes of precast concrete required to achieve 7.5µSv/h
- GHG-Dose Ratio ~2.6 tCO₂e/man-mSv.
- exceeds the GHG-Dose equivalent harm level
- further shielding would quickly become grossly disproportionate.

Therefore, specifying requirements for further bulk shielding is unlikely to be appropriate, but there remains opportunity for detailed optimisation.

Figure 3. Relationship between GHG-Dose Ratio and Peak Dose Rate in Shielded Facility



^[1] ICRP Publication 103, 2007

^[2] Comprehensive evidence implies a higher social cost of CO₂, Nature V210, p687, 2022

^[3] Valuation of greenhouse gas emissions for policy appraisal and evaluation, UK Department for Energy Security and Net Zero, 2021

^[4] Cost Benefit Analysis (CBA) Checklist, Health and Safety Executive, 2003

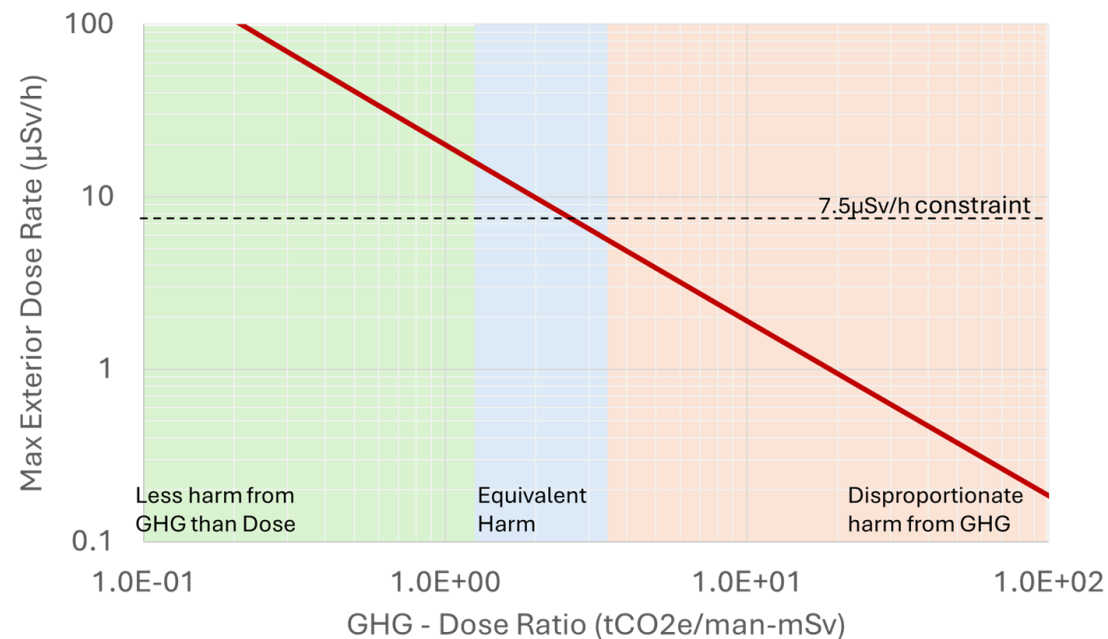
^[5] Inventory of Carbon and Energy (ICE) Database V4.0, 2024

^[6] Government conversion factors for company reporting of greenhouse gas emissions, UK Department for Energy Security and Net Zero, 2024

Radioactive waste recycling

Part 2: The carbon cost of radiation shielding

- Motivated by the idea that one might trade off the harm of low-level radiation exposure with the harm of greenhouse gas emissions from the manufacture of shielding
- Various work indicates that the cumulative harm of 1.1 tonnes CO₂e emissions is approximately 1.1 mSv of radiation exposure
- Compute at what point adding more shielding causes more harm than it protects against



Sustainability projects at RAL: wider campus

Rooftop solar

- Most of the site roof area on the RAL site that can have solar installed on it has had over the past few years
 - Over 20,000 solar panels
- Solar car ports for the main staff parking areas
- **3.4 GWh generated in 2025/26**
 - **Equating to 490 tonnes CO₂e**



Solar farm

- Proposal to build a 15 MW solar farm on land adjacent to the Harwell campus
- Planned private wire to RAL site
- **Projected yield: 15 – 16.5 GWh per year**
 - Based on southern England data
- Pre-planning process at present: goal ~2028



Sustainability projects at RAL: wider campus

Energy recovery / district heating

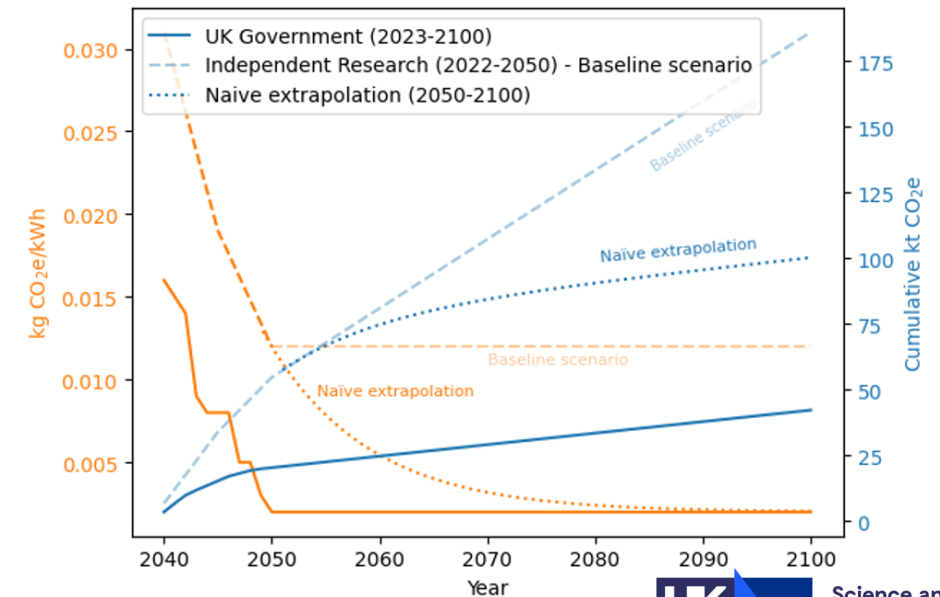
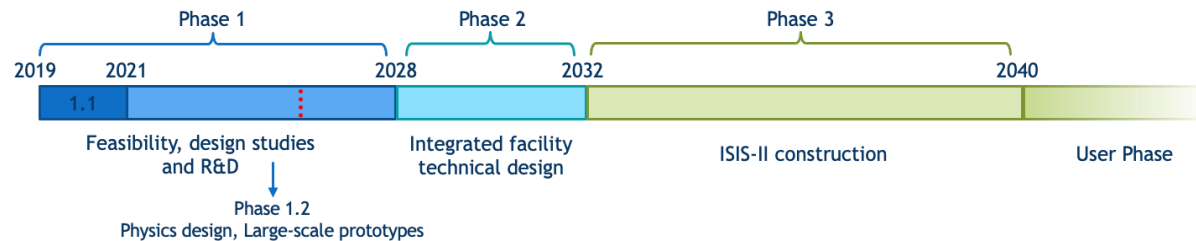
- Planning application submitted to build an energy recovery facility, AKA district heating
 - using waste heat from the machine room of the STFC Scientific Computing department
- Retrofitting a district heating system brings significant technical challenge
- New buildings over the last few years have had infrastructure put in place to benefit from this facility when built.
- Projected 60% reduction in site-wide Scope 1 emissions through replacement of gas-fired heating 2025/26 gas-use:
 - **19.8 GWh**
 - **= 3600 tonnes CO₂e**





ISIS-II Neutron and Muon Source

- Sustainability Strategy
- (Simplified) Life Cycle Assessment of whole facility
 - Examining various grid decarbonisation scenarios and dependency on this
- Sharing of methodology





Other National Efforts



SPADE at STFC

Sustainability Principles and Advice for Design and Engineering

Design tips for
cryogenics

Design designing for
manufacturing

Electrical
engineering

Firmware

Sustainable shielding

Vacuum engineering

Produced databases
for the embodied
carbon of common
engineering
materials

Supports a single
floating licence of a
lifecycle analysis
software ANSYS Eco
Audit.

Launched a material
and equipment
exchange internally
to STFC

Developing tutorials
for STFC

[Link to talk](#)



Detectors and sustainability

- Highest global warming potential [kgCO_2e] of our detector systems are direct gas emissions (Scope 1)
- ~80% from LHC detectors
 - Dominated by ATLAS/CMS RPCs
 - ~100,000 $\text{tCO}_2\text{e}/\text{annum}$
or a fully occupied A340 ✈️ London → New York per day for a year

Life Cycle Assessment Methodology for LHC detectors: Quantifying embodied CO_2e from Full Simulation

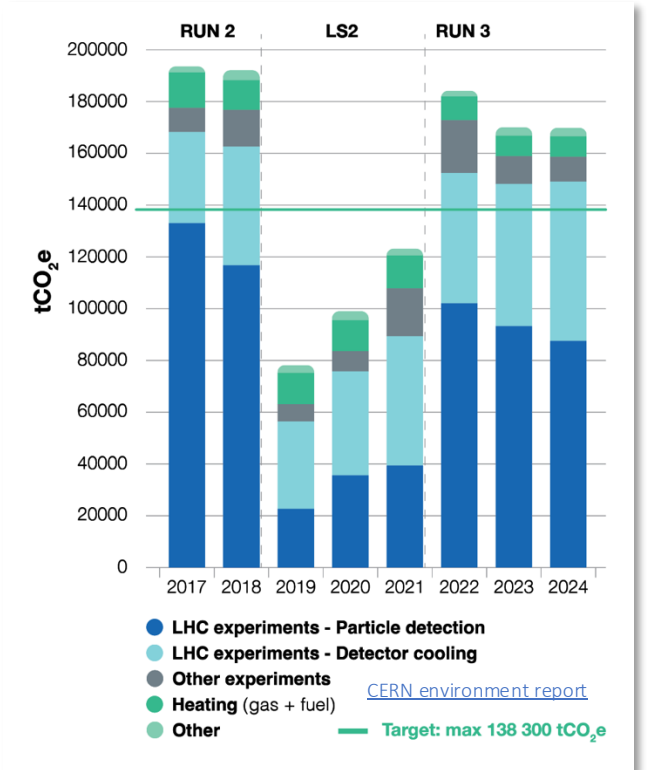
Dominic Graham, Chris Parkes, Silvia Borghi

- Scope 3 (corporate value chain e.g. procurement) emissions excluded in previous CERN environmental impact reports
- Propose simulation as a solution
 - Akin to digital twins
- Inventory extraction to Life Cycle Assessment

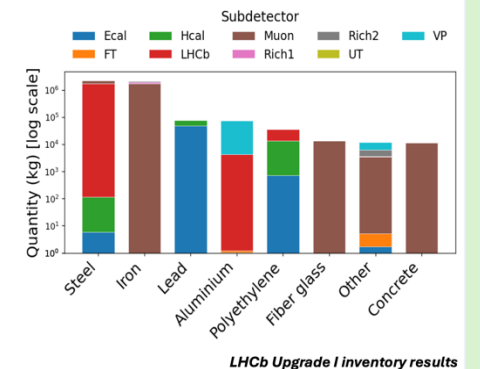
Overviews of efforts:

[Prof. Chris Parkes - Environmental Issues in high energy physics detectors](#)

[Prof. Archana Sharma - Sustainability for Gaseous HEP Detectors](#)



- Inventory analysis is a key challenge in large-scale LCAs, requiring detailed input/output tracking.
- By parsing GDML geometry with ROOT, we reconstructed material quantities from LHCb simulations.
- This yielded a 4,600-tonne inventory—82% of the expected total for LHCb I. Can analyse further at sub-detector level.





Digital Research Infrastructure

NetDRIVE

NetZero Digital Research Infrastructure Vision and Expertise



- E.g. SustTrain

Sustainable Training Initiative for NetDRIVE



- Produce training material
- Contribution to SPARKHub + other catalogues available to international DRIs
- E.g. Green scheduling
- Many more: [link to poster](#)

GridPP

- Environmental sustainability as a strategic priority [[link](#)] and has established a forum to follow up on it.

- ENSURE



- Database with environmental metrics from DRIs
- Enables environmental sustainability certifications
- Measure and monitor prior to mitigation



High-Level Environmental Sustainability Guidelines for Large Accelerator Facilities

- Started as a UK initiative
- Grown/growing to include more experts
- Living document
- Version 3
 - Aims to include detector recommendations
 - (Amongst other updates!)

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Hannah Wakeling [✉](#), Philip N. Burrows, Jim Clarke, Jo Colwell, Niko Neufeld, Ben Shepherd, Dwayne Spiteri & John Thomason

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Sections

Figures

References

[Abstract](#)

[Introduction](#)

<https://link.springer.com/article/10.1007/s41781-026-00163-w>



Making environmental sustainability **sustainable**

We've heard that sustainability is “not a nuisance, it's a necessity” (Mark Thomson, ESSRI 2026)

Analysis applied to FCC showed long term sustainability to be a **worthwhile investment** (ESSRI 2026)

The question is: *HOW* can we embody sustainability into accelerators in a sustainable way?

- i.e. what options do we have to incorporate sustainability?



Projects should implement environmental impact evaluation throughout

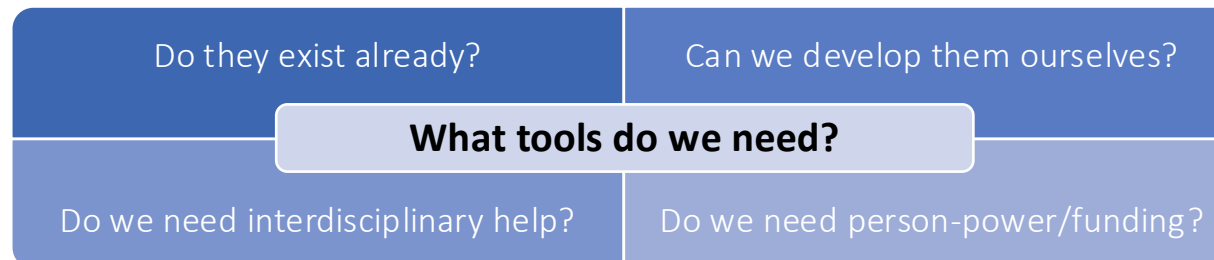


Quantify **to** minimise environmental impact



Continue and intensify our efforts to develop and adopt sustainable solutions

To successfully embed environmental sustainability into our facilities, it needs to be feasible.





Summary

- The focus on sustainability with accelerators and particle physics within the UK has grown in recent years
- National and international efforts exhibit broad level of expertise
- Efforts to be more sustainable align with reducing power consumption and financial costs too
- UK efforts:

RF

Magnets

Radiation
protection

Detectors

DRI

Life-cycle
thinking

- To successfully incorporate environmental sustainability into our facilities, it needs to be sustainable itself
 - Culture change
 - Affordable
 - Efficient
 - Simple

Thank you





Back-up slides

Detectors and sustainability

HEP community already has [considerable effort](#) in this direction:

- Activities aimed at more sustainable gas mixtures, detector cooling, air conditioning systems, and gas recirculation and recuperation systems
- Sustainable Gas Mixtures for Future Detectors (DRD1)
 - Sealing
 - Recirculating and recuperating
 - Alternative gases
(to PFCs, HFCs, SF₆, NF₃, HFOs and CO₂ etc.)
- EcoGas at GIF++ (RPC)

Overviews of efforts:

[Prof. Chris Parkes - Environmental Issues in high energy physics detectors](#)

[Prof. Archana Sharma - Sustainability for Gaseous HEP Detectors](#)