

# “It’s not just windmills” STFC and Sustainable Particle Accelerators

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ASTeC Sustainable Accelerators Task Force)

Nature Physics 13<sup>th</sup> June 2023

## Editorial

<https://doi.org/10.1038/s41567-023-02117-0>

## Strive towards sustainability

 Check for updates

**Exacerbated by the impacts of climate change and the recent energy crisis, concentrated efforts towards more sustainable research have become matters of urgency, in particular for large-scale accelerator complexes and light sources.**



two accelerated particle beams after colliding them, why not recover the beam energy? The principle of an energy recovery linear accelerator was first demonstrated in 1987 – enabled by superconducting radiofrequency technology. A recent experiment at the S-DALINAC machine demonstrated saving up to 87% of the consumed beam power in its main linear accelerator<sup>4</sup>.

In the design of large-scale facilities, perfor-

...owards the end of 2022, several

<https://doi.org/10.1038/s41567-023-02117-0>

# The Need for Sustainability

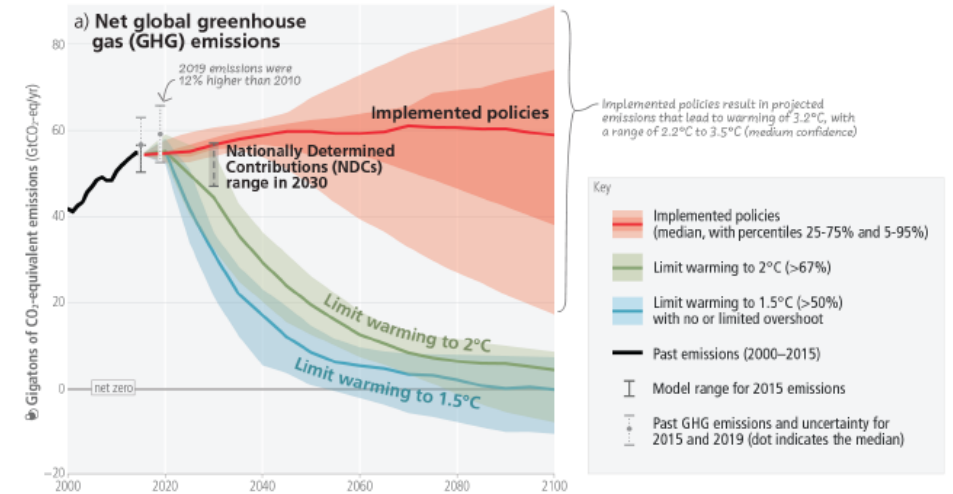
- 1994 - UNFCCC (UN Framework Convention on Climate Change)
- 1997 – Kyoto Protocol (in force 2005)
- COP21 Paris Agreement – economy-wide **GHG reduction of 68% by 2030** (cf. 1990)
- UK Nationally Determined Contribution – not only CO<sub>2</sub>, but also GHGs such as CH<sub>4</sub>; UK BEIS responsible for climate policy

<https://unfccc.int/sites/default/files/NDC/2022-09/UK%20NDC%20ICTU%202022.pdf>

- 2008 UK Climate Change Act – **legally binding 80% by 2050** (Climate Change Committee)
- 2019 Net Zero legislation (UK first)
- 2021 Net Zero strategy – how to deliver on Carbon Budgets 4,5,6 (but Ukraine war effect)
- Industrial Decarbonisation Strategy; <https://www.gov.uk/government/publications/industrial-decarbonisation-strategy>
- Ten Point Plan for a Green Industrial Revolution; <https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution>

Carbon Budgets 1,2 met  
 Carbon Budget 3 on track  
 Carbon Budget 4 not on track (2023-2027)

<https://www.ipcc.ch/report/ar6/wg3/>



## Atmospheric CO<sub>2</sub> concentration

Global average long-term atmospheric concentration of carbon dioxide (CO<sub>2</sub>), measured in parts per million (ppm). Long-term trends in CO<sub>2</sub> concentrations can be measured at high-resolution using preserved air samples from ice cores.



Source: EPICA Dome C CO<sub>2</sub> record (2015) & NOAA (2018)

OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

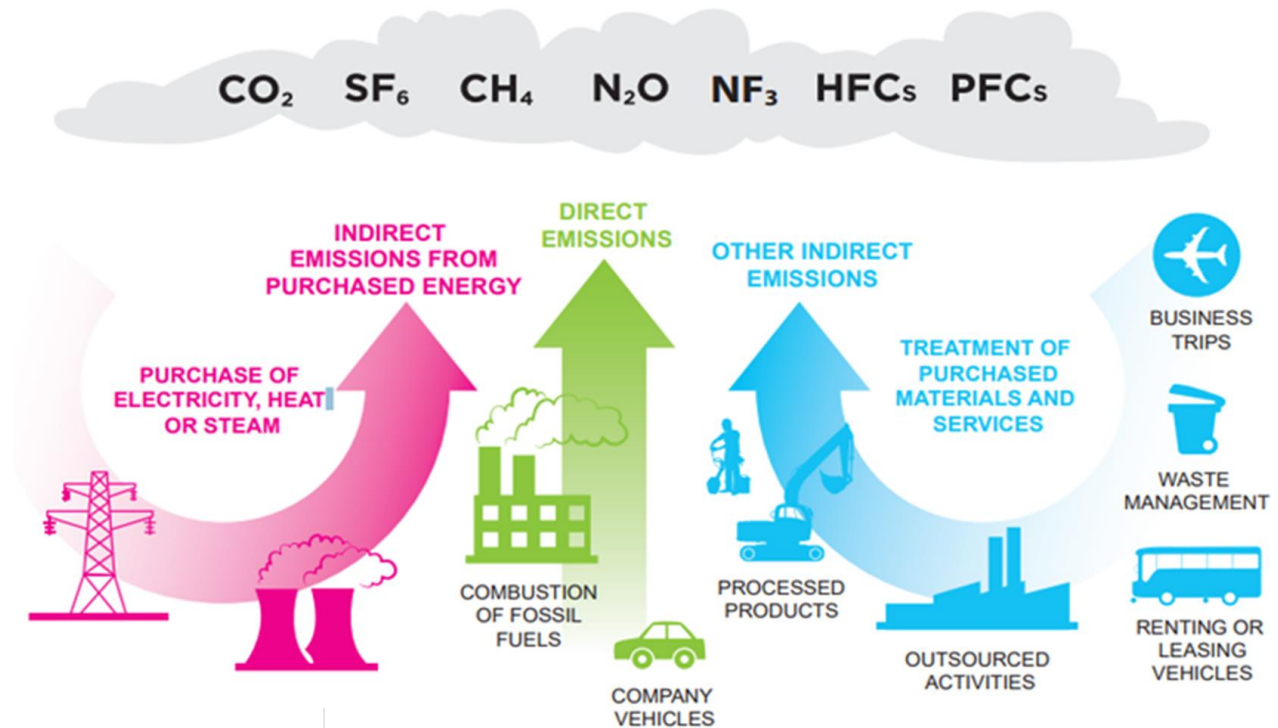
# Lots of People are Thinking About This

- Relevant Sectors:
  - Particle Physics
  - Astronomy (e.g. land-based)
  - HPC
- Relevant Initiatives/Studies
  - HECAP:  
[https://sustainable-hecap.github.io/Sustainability\\_in\\_HECAP.pdf](https://sustainable-hecap.github.io/Sustainability_in_HECAP.pdf)
  - ALLEA Working Group  
<https://allea.org/wg-climate-sustainability-in-the-academic-system/>
  - Snowmass 2021  
<https://arxiv.org/abs/2209.07684>
  - UCL LEAF <https://www.ucl.ac.uk/sustainable/leaf-laboratory-efficiency-assessment-framework>
  - iFAST WP11  
<https://ifast-project.eu/wp11-sustainable-concepts-and-technologies>
- A few points:
  - ‘CO2 is not the only greenhouse gas (note SF6)’
  - ‘Science labs don’t have special status’
  - ‘Greenwashing is not allowed’
  - ‘Research should not reward hypermobility’
  - ‘Better software can be more important than efficient IT’
  - COVID has prompted a rethink in the need for travel – hub conferences, travelling conferences etc.
  - Researcher travel can be a significant part of a project’s environmental impact
- ‘Separation of concerns’
- Standardisation of accounting tools – be careful of local conditions for energy usage and impact

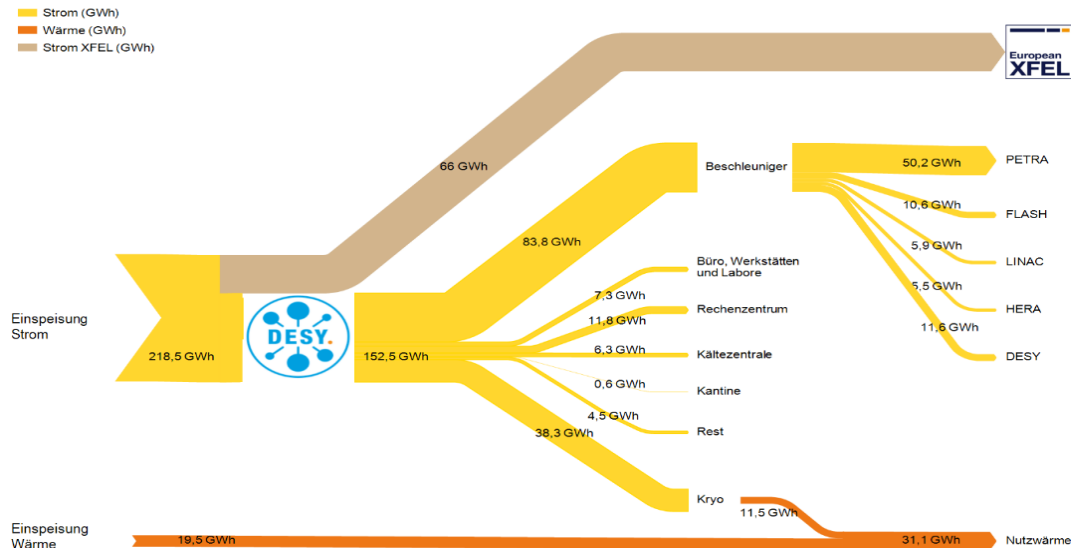
**Big Science  
=  
Big Carbon Footprint**



**You Are Here**



**Energieverbräuche DESY 2021**



SCOPE 2      SCOPE 1      SCOPE 3

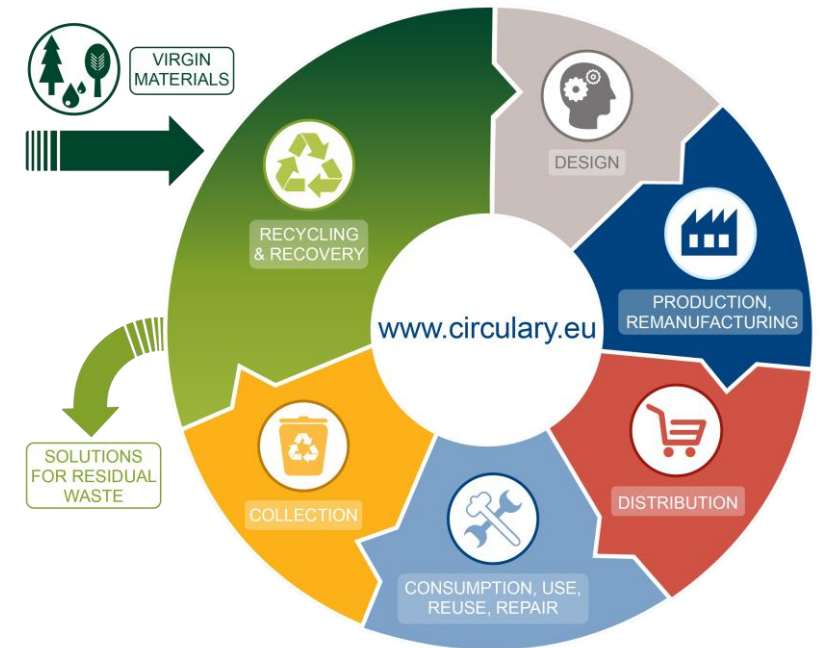
- Large scientific facilities will create significant carbon footprints during all phases of their lifecycle.

**Design, Construct, Operate, Decommission**

- All emissions scope will be applicable, and the dominance will depend on the lifecycle of the facility.

# UKRI, STFC and Sustainability

- 2023 UKRI Sustainability Strategy – ‘embed by 2025’;  
<https://beta.ukri.org/publications/ukri-environmental-sustainability-strategy/>
- ‘Greening Government Commitments’;  
<https://www.gov.uk/government/publications/greening-government-commitments-2021-to-2025/greening-government-commitments-2021-to-2025>
- STFC Framework for Accelerator Development:  
<https://www.ukri.org/publications/stfc-strategic-framework-for-future-accelerator-science-and-technology-development/>
- STFC – net zero by 2040**



## STFC Hierarchy

- Energy reduction
- Improving processes and efficiency
- Energy substitution
- Compensation and offsetting



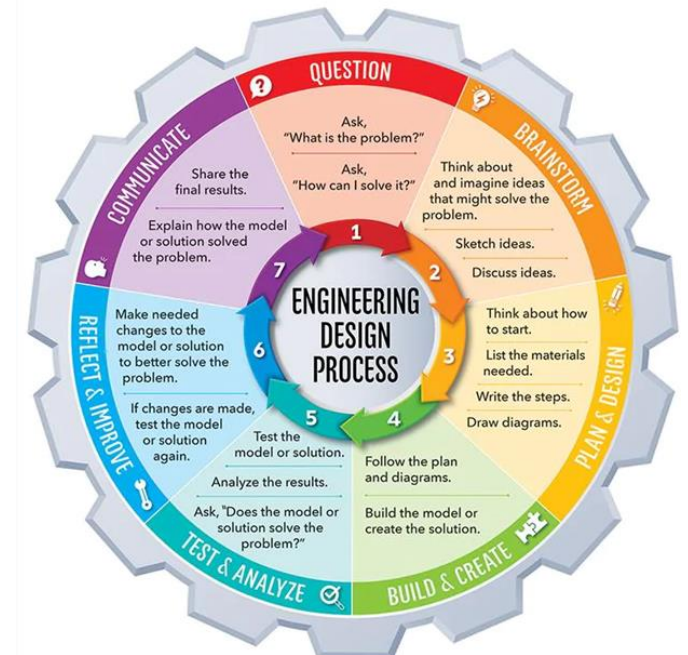
## SUSTAINABLE DEVELOPMENT GOALS



9: Sustainable Industrialisation and Innovation

12: Sustainable Consumption and Production

13: Action to Combat Climate Change

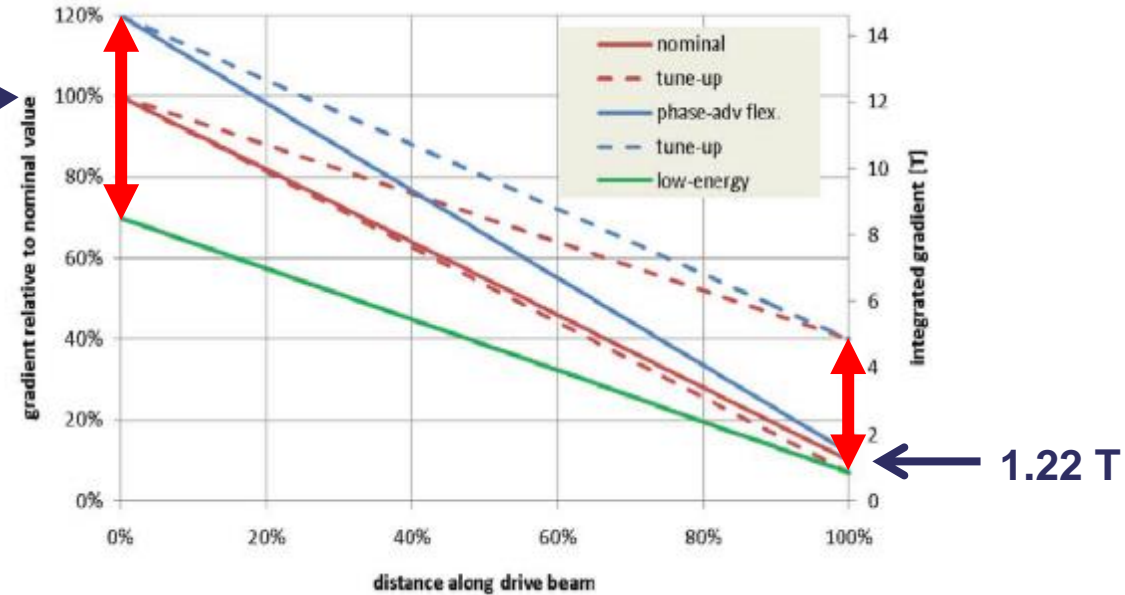


# ASTeC Green Projects: ZEPTO



- **Zero-Power Tunable Optics**
- Initially, collaboration between ASTeC and CERN to develop tunable PM quadrupole magnets for CLIC's drive beam
- Nominal **0.24-2.4 GeV**, with some tuning range at each point
- **41,400** quadrupoles required for CLIC drive beam
  - Projected **13.5 MW** of electricity demand
  - Permanent magnet option as an alternative
- Two prototypes built at STFC Daresbury Laboratory
  - **27 mm** aperture
  - **230 mm** length
  - **15-60 T/m**, **4-35 T/m** ranges
  - Fixed poles, movable PMs
  - Simple control system with one motor

12.2 T →



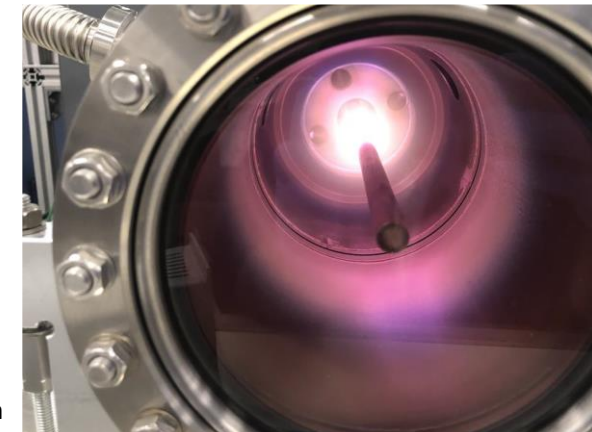
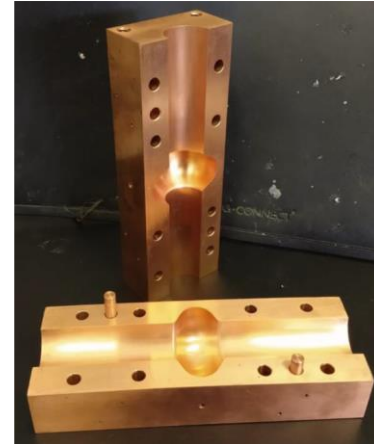
# Thin Films at Daresbury

- **Bulk niobium cavities** have been the choice for SRF for the last 50 years
- Use a considerable amount of natural material
- Performance limit of niobium has been reached
- Costly to produce
- Run at a temperature of 2 K
  - A considerable cryogenic demand and energy load
- Thin films open up the possibilities to
  - Use a copper supporting cavity
    - better thermal properties, cheaper material and production
  - Using different superconducting materials (e.g.  $\text{Nb}_3\text{Sn}$ ,  $\text{NbN}$  and  $\text{MgB}_2$ )
  - Higher operation temperature of new alloys
  - Theoretical higher accelerating gradients

1.3 GHz cavity for STF deposition



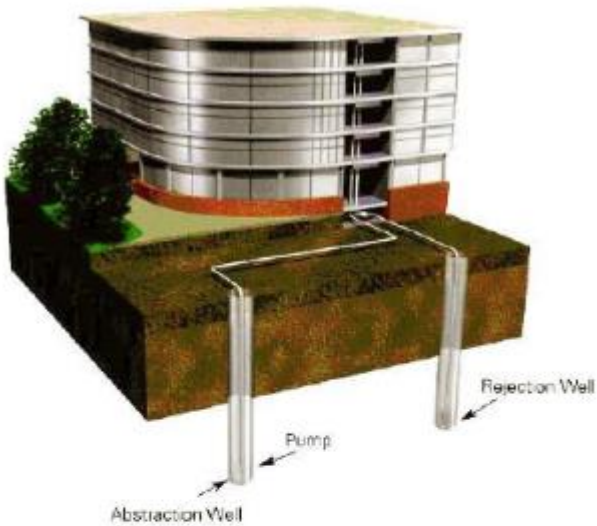
6 GHz split cavity



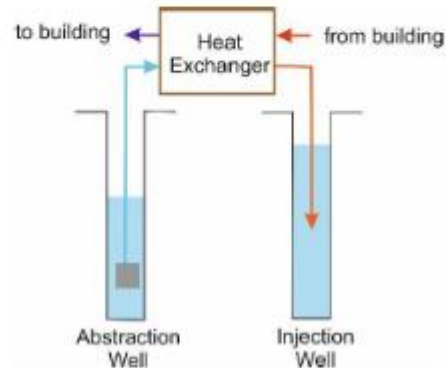
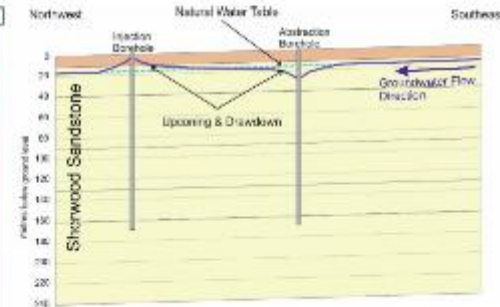
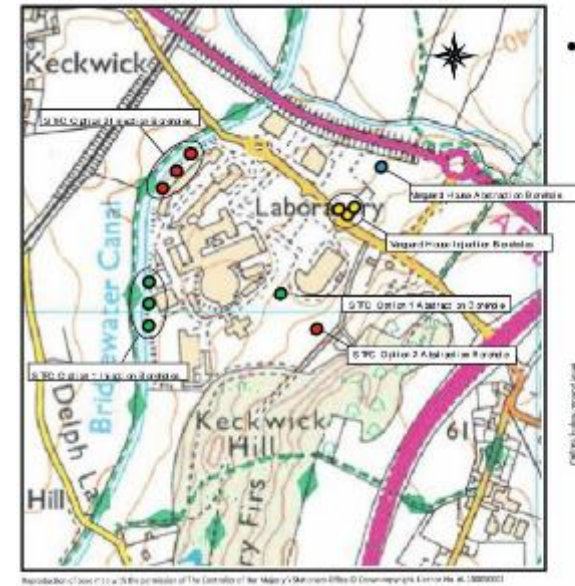
Cylindrical magnetron

# Ground Water Cooling

- Minimise thermal feedback



- Feasibility and modelling study
- Envireau Water, 2017
- Potential **2 MW** cooling scheme
- Support the cooling of ASTeC's suite of particle accelerator test facilities
- Would reduce electricity consumption by **4000 MWh** (> £600k / year\*)



Feasibility Study and Numerical Modelling showed positive results:

- **48 L/s** abstraction
- Fixed temperature differential of **10°C**
- STFC Abstraction temperature rise of **2.3°C**
- Delivering **2 MW** of cooling

- Minimal impact on Vanguard House scheme
- Environment Agency have reviewed proposed scheme and modelling and have no objections subject to final design

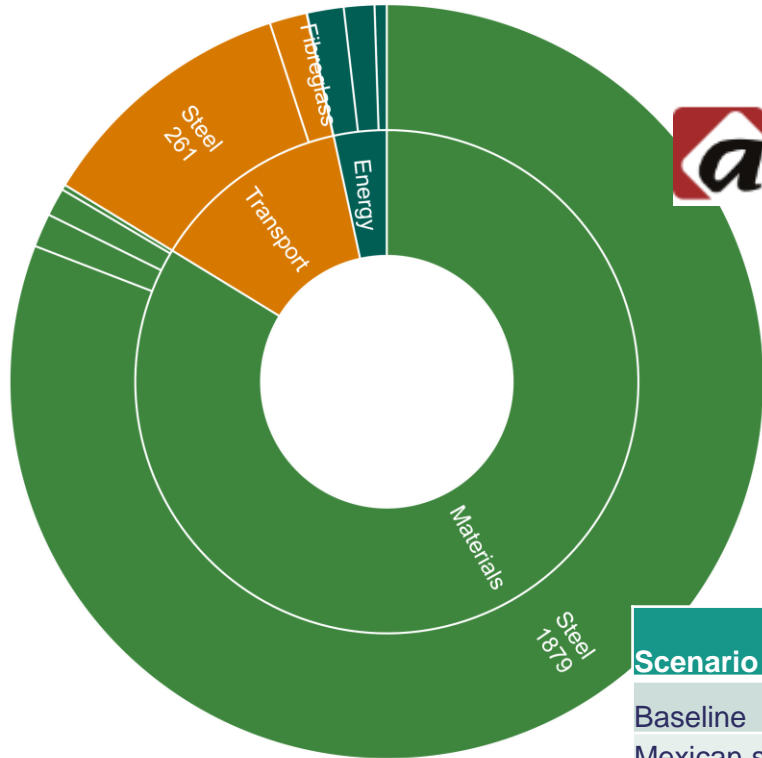
\*2019 prices, 16p/kWh: likely saving in '22 is much more!



# Magnet Carbon Footprints

Magnet LCA from Antec

Transport Materials Energy



Scenario	kgCO <sub>2</sub> e	% change
Baseline	2324	0%
Mexican steel	1449	-38%
Rail freight for steel	2091	-10%
EU-average for copper	2393	+3%

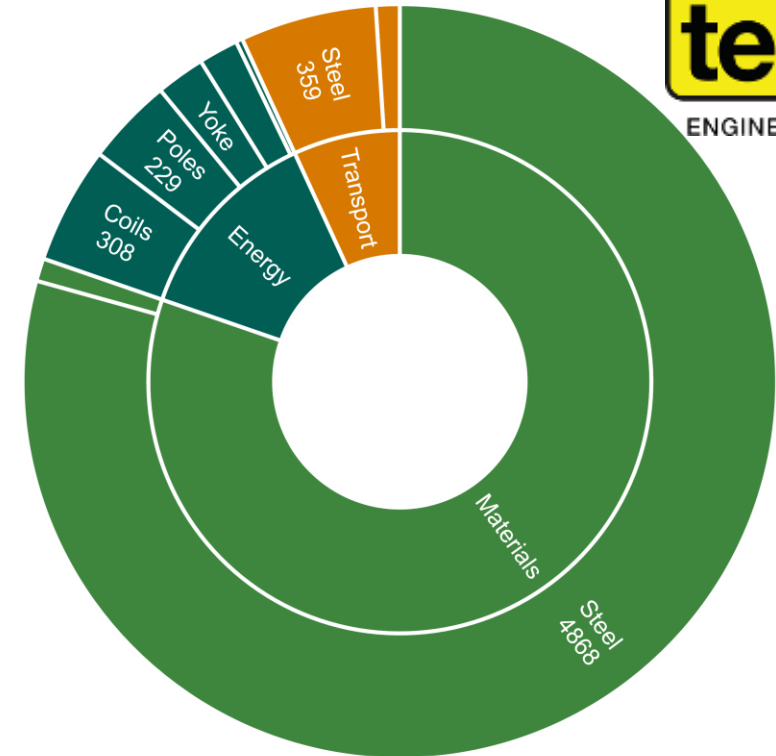
Total **2.3 tCO<sub>2</sub>e**  
(3 kgCO<sub>2</sub>e / kg of finished product)



Daresbury Laboratory

Magnet LCA from Tesla

Transport Materials Energy



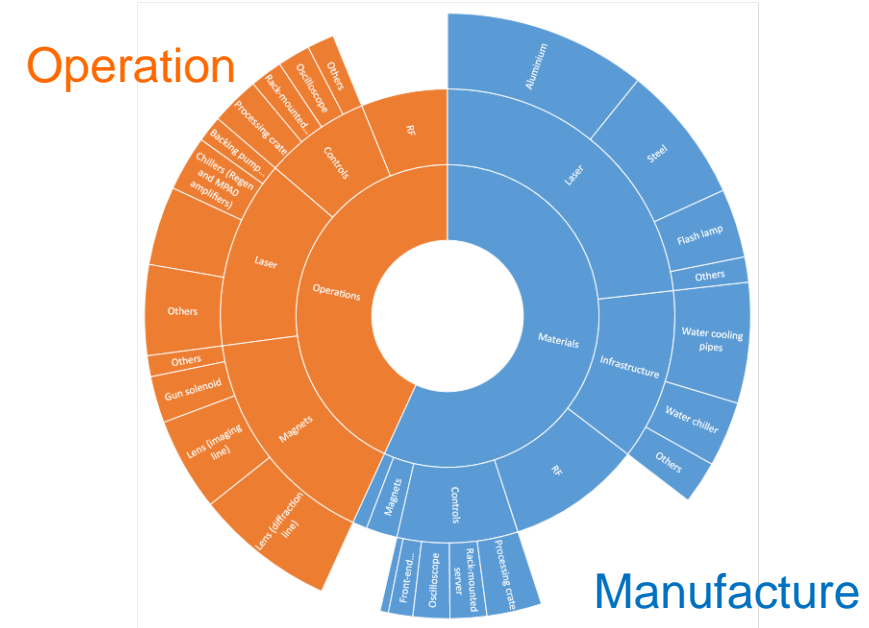
Total **6.2 tCO<sub>2</sub>e**  
(2.9 kgCO<sub>2</sub>e / kg of finished product)

# Future UKRI Infrastructures

- Future UKRI Infrastructures will need to demonstrate sustainability through their lifecycle
- UKRI Infrastructure Fund and Carbon Forecasting
  - Burning Fuels
  - Process and fugitive emissions (e.g. SF6)
  - Process removals
  - Water use
  - On-site renewables
  - UK and overseas Grid use
  - Travel of people
  - Travel of goods and equipment (e.g. samples)
  - Emissions elsewhere caused by infrastructure

# STFC Life Cycle Analysis and Report

- ASTeC Sustainable Accelerators Task Force
- LCA using RUEDI project/facility as a model
  - 1. Inventory of key components and primary materials
  - 2. Supplier sourcing and energy use
  - 3. Literature comparison for energy use
  - 4. Power and resource estimate
- Some points:
  - Embed sustainability into engineering component design – modularity, materials, energy impact
  - Lifespan estimates and component re-use
  - Critical materials (e.g. Nb, NdFeB, SF6)
  - Energy source (renewable or not)
  - Concrete CO2 can dominate – modular shielding and other methods
  - Activated materials can have a big environmental burden
- Publication later in 2023



Example breakdown of relative kgCO2e emissions in a project

## 5.2 Building a Green Future

Our multidisciplinary facilities play a nationally significant role in developing green technologies by supporting a programme of targeted Net Zero research and delivering against the UKRI Building a Green Future strategic theme, the UK's Net Zero Research & Innovation Framework and the British Energy Security Strategy.

### We will:

- Leverage the capability of our National Laboratories to deliver a new Net Zero research and innovation demonstrator programme in conjunction with UK industry
- Complete the business case for a new centre of excellence in 'Sustainable Accelerators'.