

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

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Particular thanks to Ben Shepherd (lead researcher,
ASTeC Sustainable Accelerators Task Force)

Nature Physics 13th 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 accelerator⁴.

⁴In 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

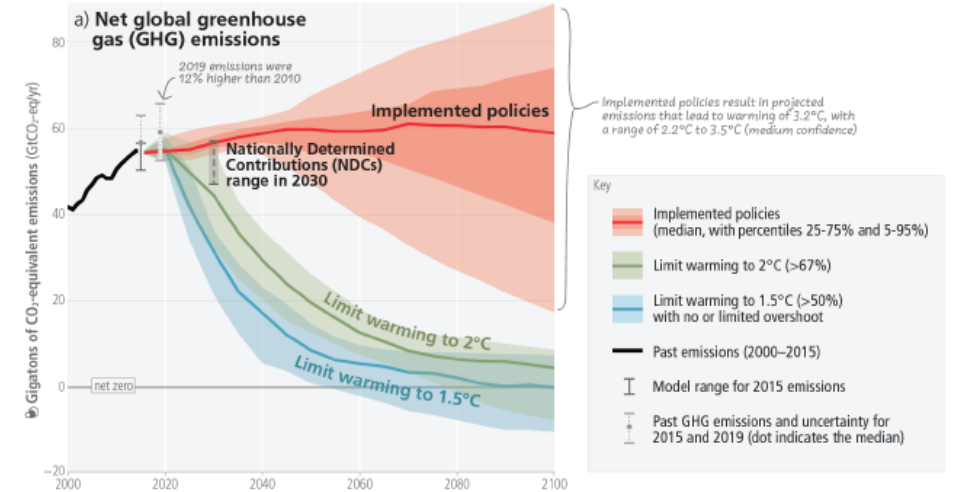
- 1994 - UNFCCC (UN Framework Convention on Climate Change)
- 1997 – Kyoto Protocol (in force 2005)
- COP21 Paris Agreement – economy-wide **GHG reduction of 68% by 2030** (cf. 1990)
- UK Nationally Determined Contribution – not only CO₂, but also GHGs such as CH₄; UK BEIS responsible for climate policy

<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 CO₂ concentration

Global average long-term atmospheric concentration of carbon dioxide (CO₂), measured in parts per million (ppm). Long-term trends in CO₂ concentrations can be measured at high-resolution using preserved air samples from ice cores.



Source: EPICA Dome C CO₂ record (2015) & NOAA (2018)

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

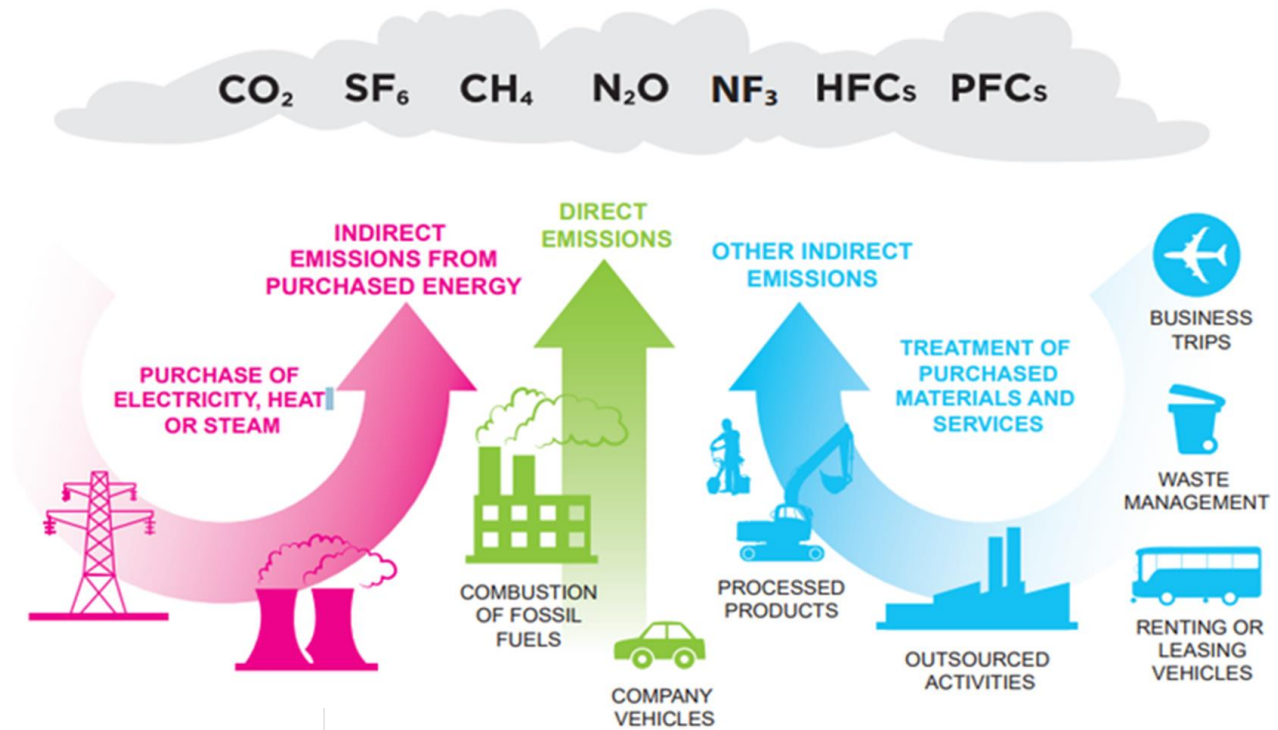
Lots of People are Thinking About This

- Relevant Sectors:
 - Particle Physics
 - Astronomy (e.g. land-based)
 - HPC
- Relevant Initiatives/Studies
 - HECAP:
https://sustainable-hecap.github.io/Sustainability_in_HECAP.pdf
 - 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

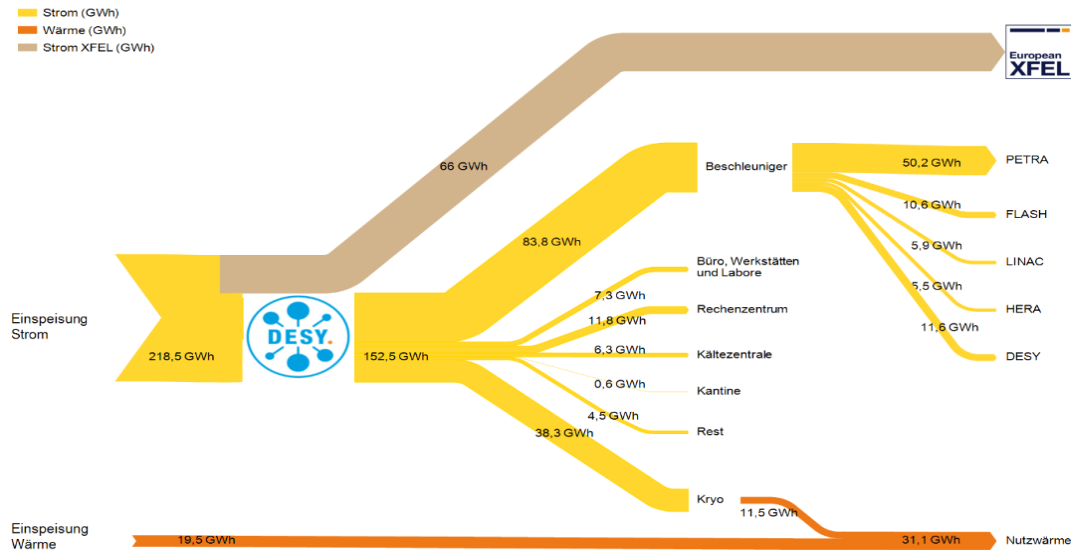
**Big Science
=
Big Carbon Footprint**



You Are Here



Energieverbräuche DESY 2021



SCOPE 2 SCOPE 1 SCOPE 3

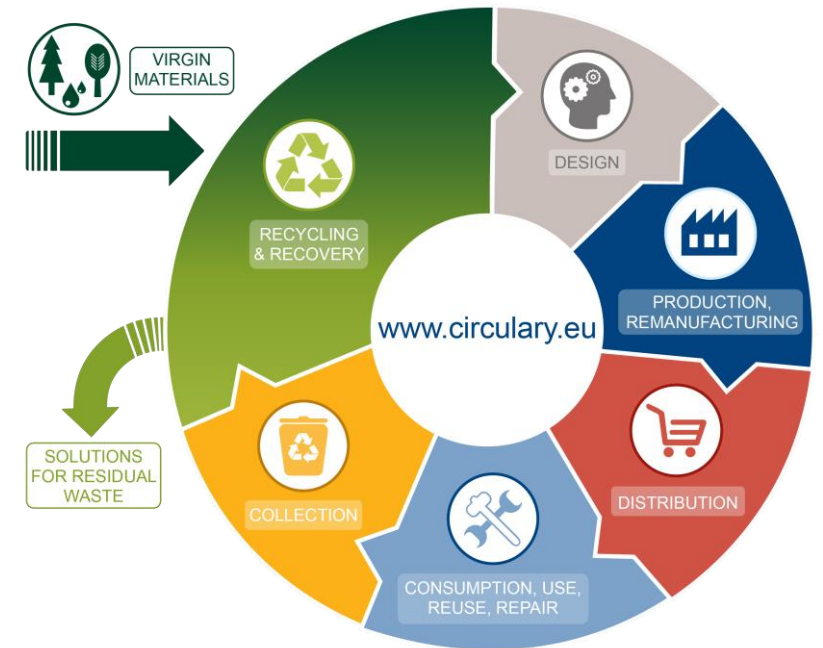
- **Large scientific facilities will create significant carbon footprints during all phases of their lifecycle.**

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



United Nations

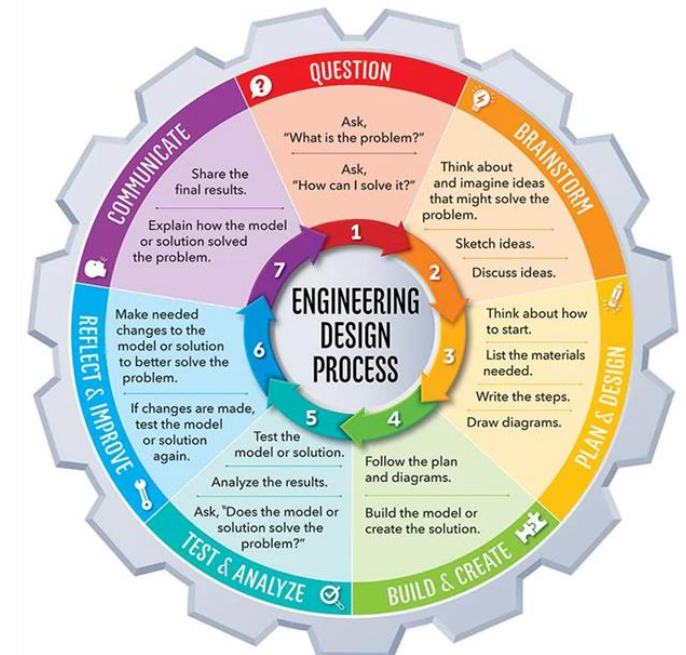
SUSTAINABLE DEVELOPMENT GOALS



9: Sustainable Industrialisation and Innovation

12: Sustainable Consumption and Production

13: Action to Combat Climate Change

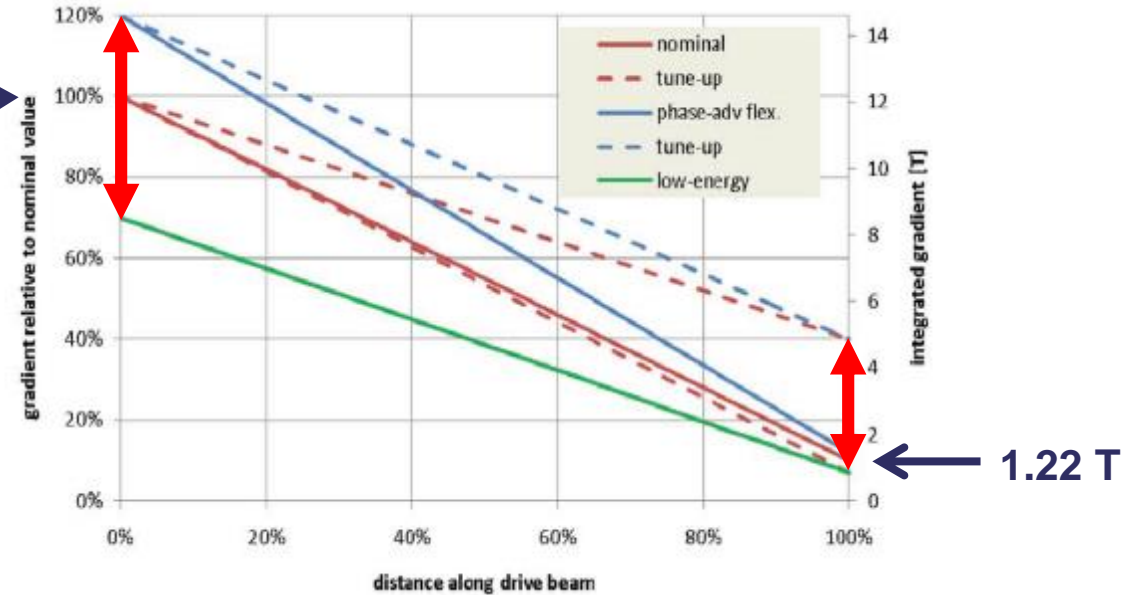


ASTeC Green Projects: ZEPTO

- 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



1.22 T



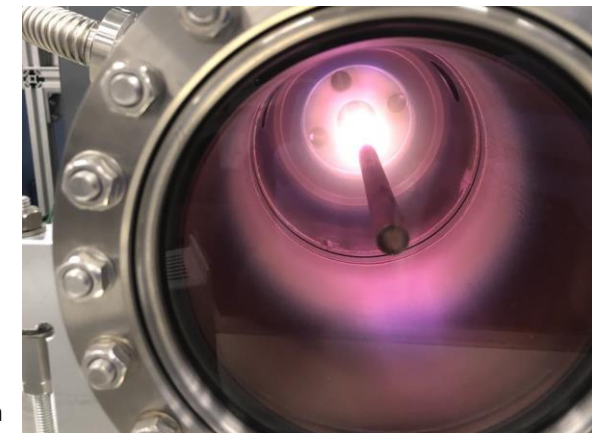
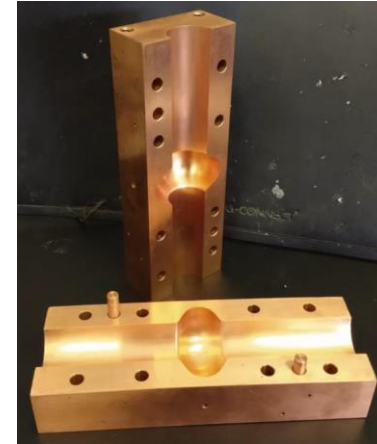
Thin Films at Daresbury

- **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. Nb_3Sn , NbN and MgB_2)
 - Higher operation temperature of new alloys
 - Theoretical higher accelerating gradients

1.3 GHz cavity for STF deposition



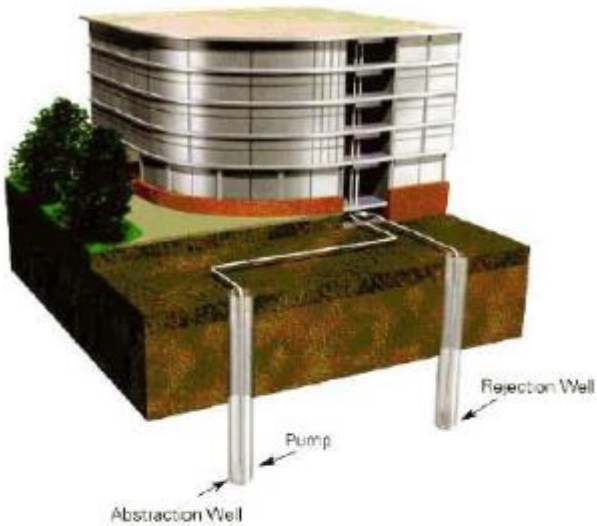
6 GHz split cavity



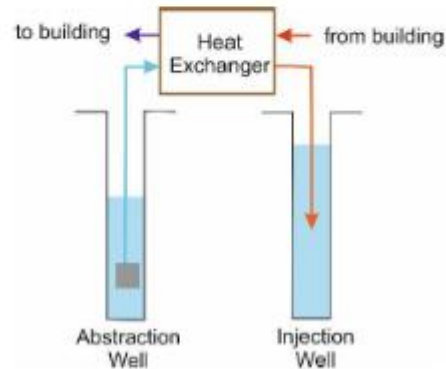
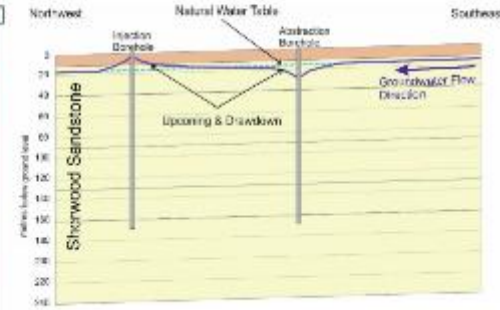
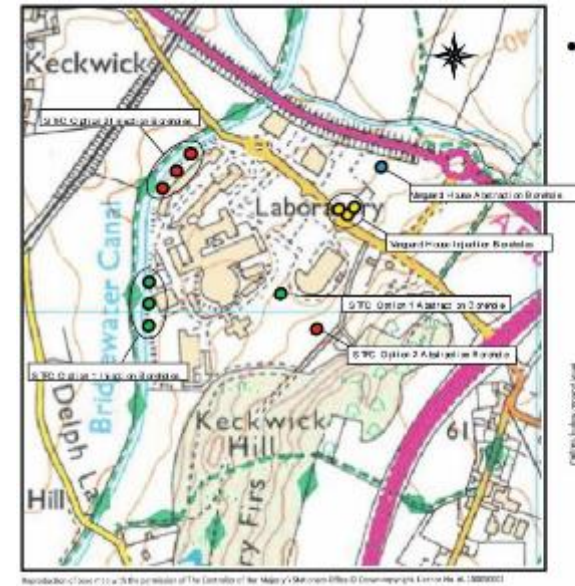
Cylindrical magnetron

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

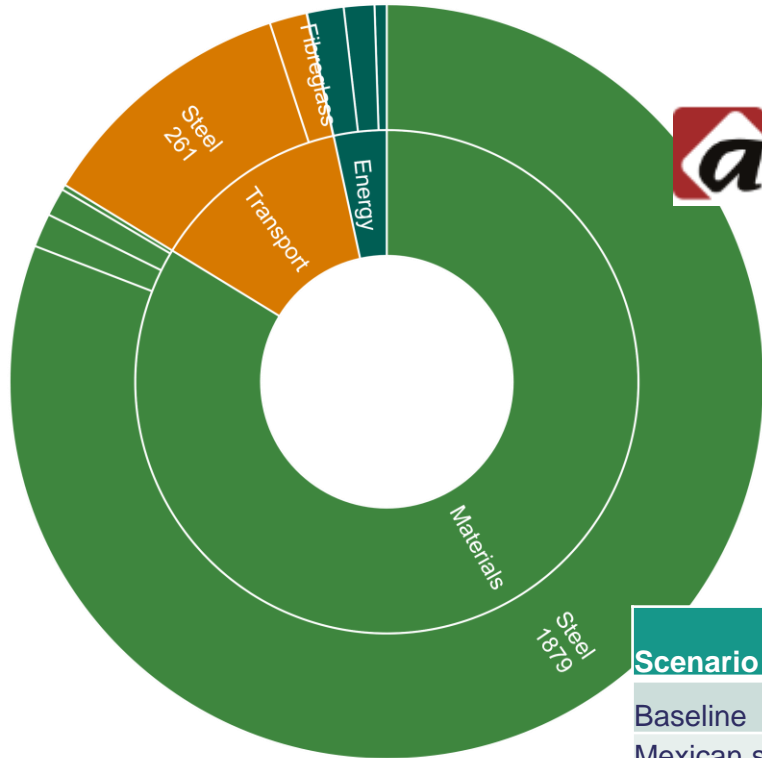
- Minimal impact on Vanguard House scheme
- Environment Agency have reviewed proposed scheme and modelling and have no objections subject to final design

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

Magnet Carbon Footprints

Magnet LCA from Antec

Transport Materials Energy



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

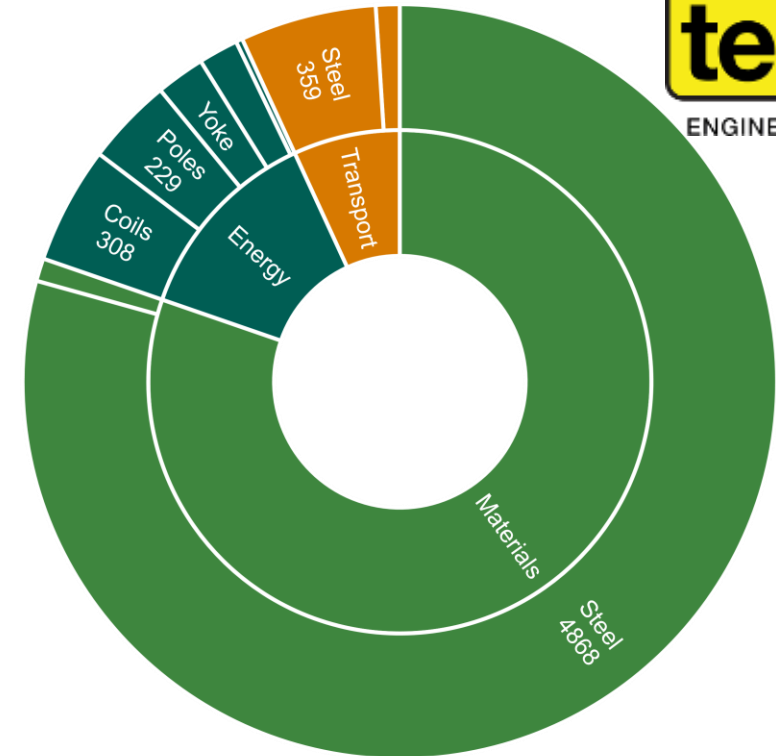
Total **2.3 tCO₂e**
(3 kgCO₂e / kg of finished product)



Daresbury Laboratory

Magnet LCA from Tesla

Transport Materials Energy



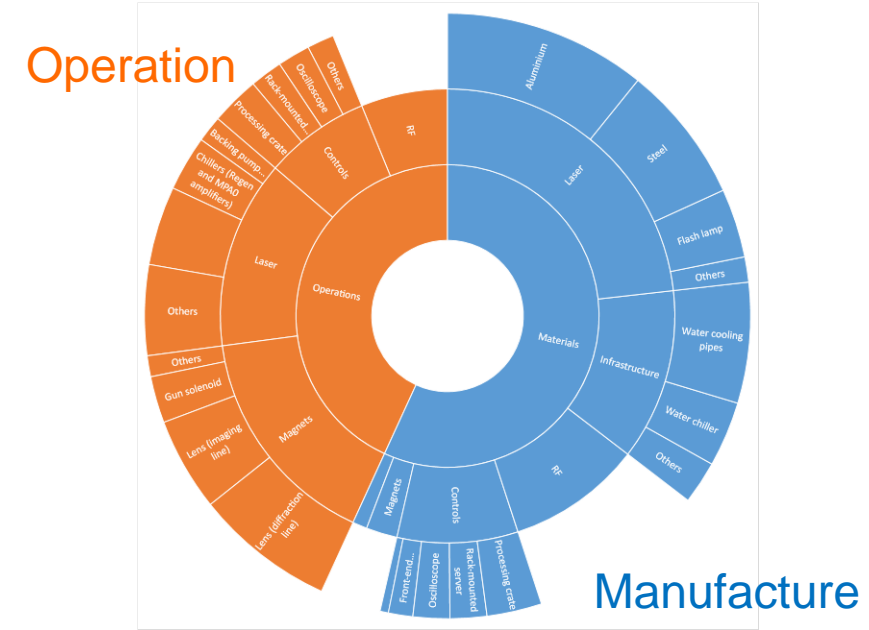
Total **6.2 tCO₂e**
(2.9 kgCO₂e / kg of finished product)

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'.