

# Facility Sustainability

JAI AB | Royal Holloway University of London | April 2025

Dr. Hannah Wakeling

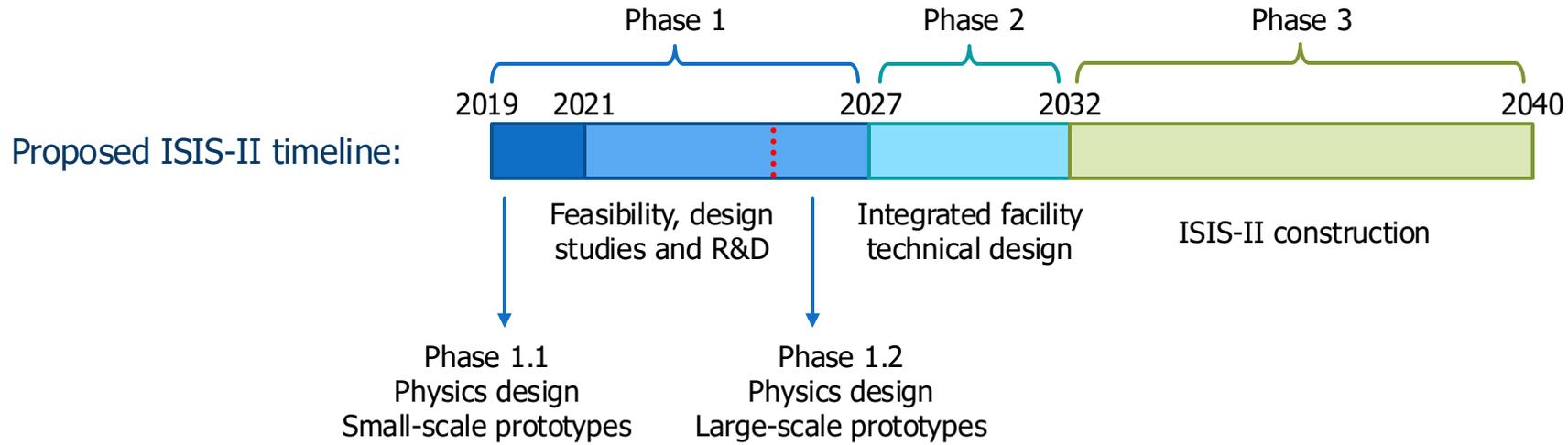


# Overview

- ISIS-II
  - Life Cycle Assessment (**LCA**)
  - Sustainability Strategy
- Accelerator sustainability studies
- High-level environmental sustainability guidelines for large accelerator facilities
- Communication, collaboration and education
- Future

# ISIS-II Neutron & Muon Source

- Identified as a potential UKRI multi-stage mega-project
- Rutherford Appleton Laboratory, STFC, UK
- 2.4 MW beam facility



- Developing our sustainability strategy by performing a (simplified) LCA of the conceptual design options
- LCA ongoing; preliminary findings

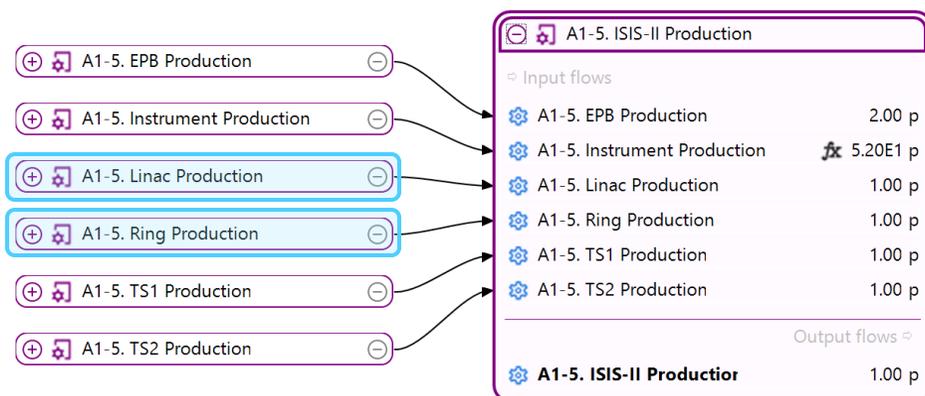
# (Simplified) Life Cycle Analysis

- **Goal & Scope:** To identify the lowest lifetime environmental impact between a Rapid Cycling Synchrotron (RCS) and Accumulator Ring (AR) and the corresponding linear accelerator (Linac) designs necessary to deliver a beam of protons at an energy of 1.2 GeV to the neutron and muon community over a period of 60 years.
- **Functional Unit:** ISIS-II facility delivering nominal baseline of beam power over 60 years of operational lifetime → will develop.
- **Life Cycle Inventory:** OpenLCA, ecoinvent allocation cut-off by classification model and unit process database, Using BS EN 17472 standard as guidance.
- **Life Cycle Impact Assessment:** ReCiPE 2016 midpoint (H)
  - with a focus on Climate Change impact factor [kg CO<sub>2</sub>e] referred to as Global Warming Potential (GWP) or Global Warming Impact (GWI)
- Utilise the *iterative* nature of LCAs to continually improve the understanding of the environmental impact of ISIS-II as designs evolve, and as LCA inventories, databases etc. develop.

**Construction, operation + decommissioning**

# Life Cycle Inventory of an accelerator facility that doesn't exist yet

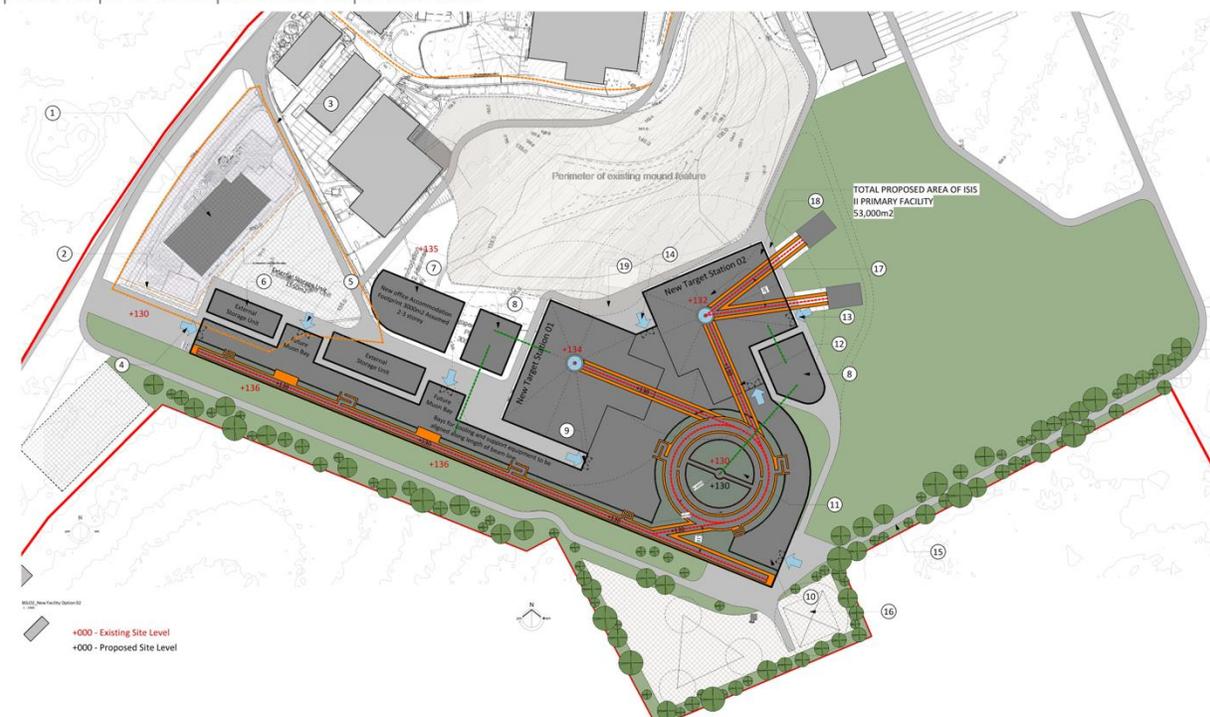
- How do you model a state-of-the-art mega-project?
- 2 major proposed design options
  - Comparison of two rings: Rapid Cycling Synchrotron and an Accumulator Ring
- Hundreds of design options to take into account
  - Emerging technology that may be incorporated



### 3.3

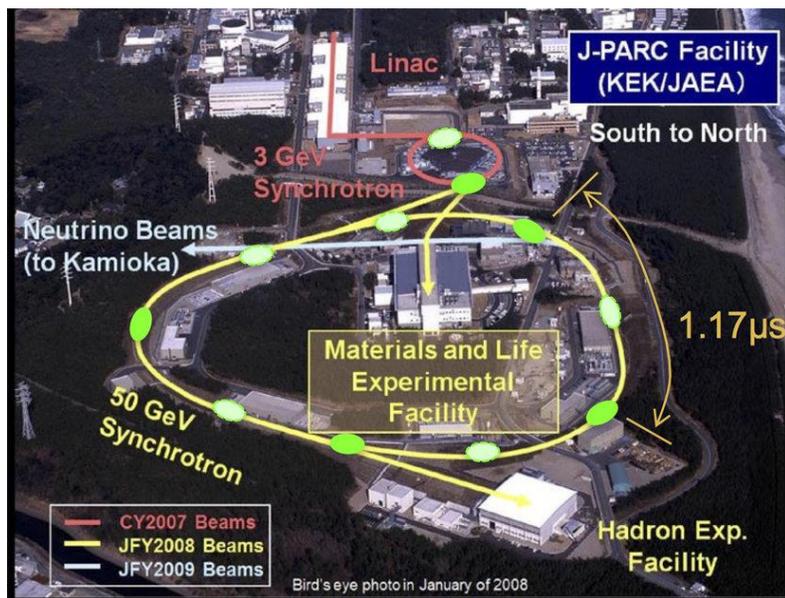
#### BIG SCIENCE LAND - OPTION 02 DEVELOPMENT SCOPE

Proposed scope of development and major interfaces.



# Modelling using existing facilities

- Modelling performed using existing facilities such as SNS and J-PARC, where ISIS-II designs not yet available.
  - Some similar areas/components which may be used as a basic model
  - ISIS-II will be built decades after; change in techniques, material and policy



[J-PARC facility - photo source](#)

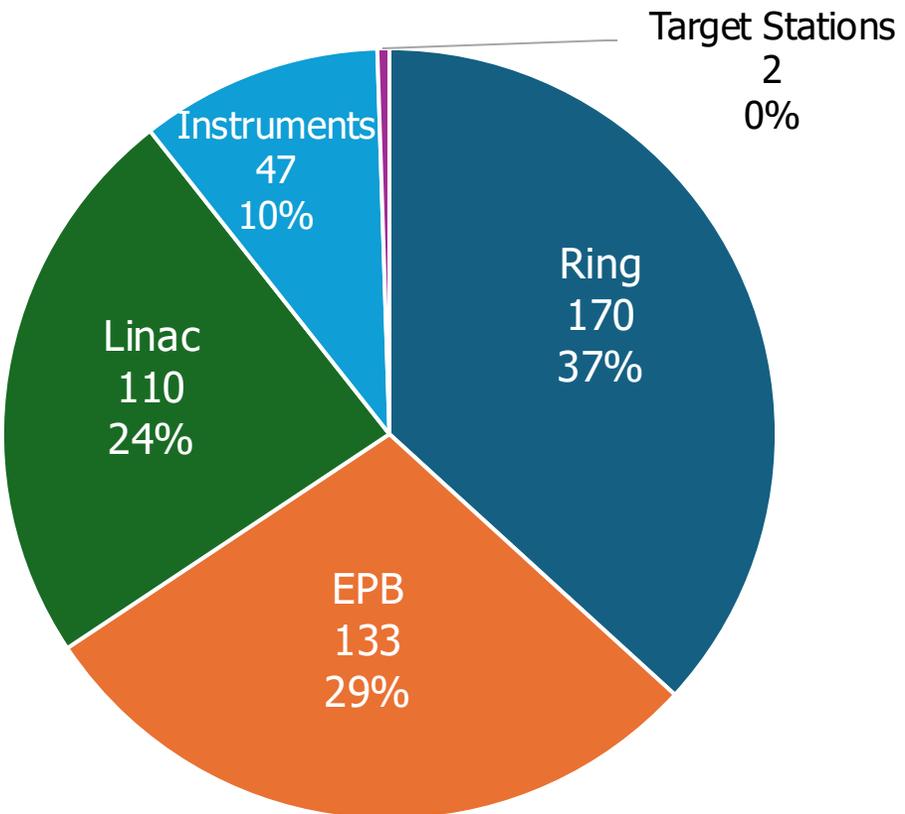


[Spallation Neutron Source - photo source](#)

# ISIS-II Construction (Embodied) Impacts

Updated estimations of the embodied CO<sub>2</sub>e emissions due to embodied impacts (construction) for various designs of ISIS-II:

Global Warming Impact (**GWI**) will be a minimum of **462±52 kt CO<sub>2</sub>e** under Business As Usual (**BAU**) actions.



Largest impacts:

- ~176,000 t concrete (various types)
- ~92,000 t steel (various types)

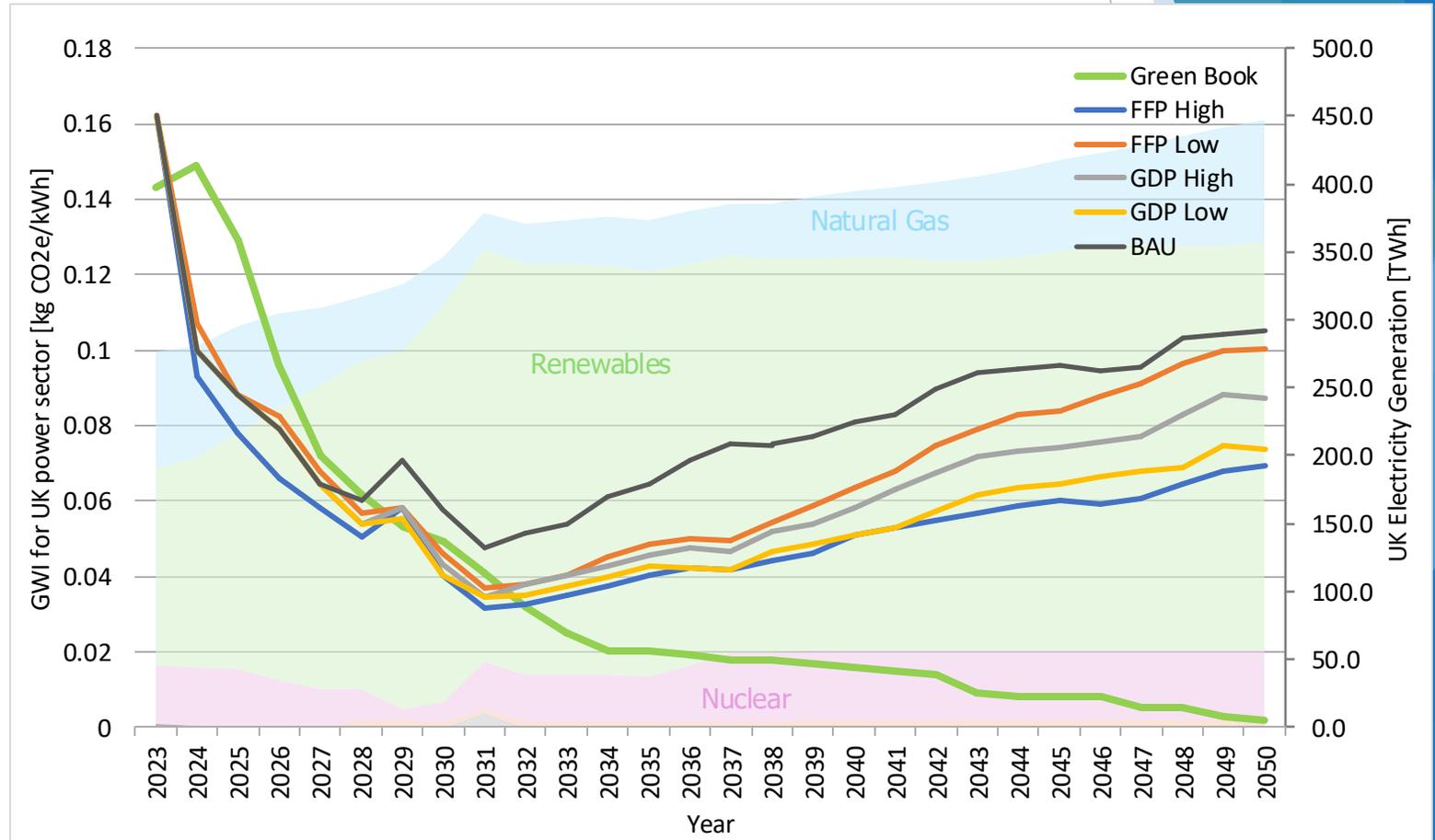
Note, modelling is still incomplete. These numbers are expected to change, and impact is expected to increase!

Embodied (Construction) GWI [kt CO<sub>2</sub>-Eq]

# ISIS-II Operational Impacts

With the net-zero goals of UK grid power generation, construction of ISIS-II is naturally the largest proportion of the carbon impact of the facility, however, depending on energy scenarios of the UK, this varies between models.

How does one model electricity supply from 2040-2100?



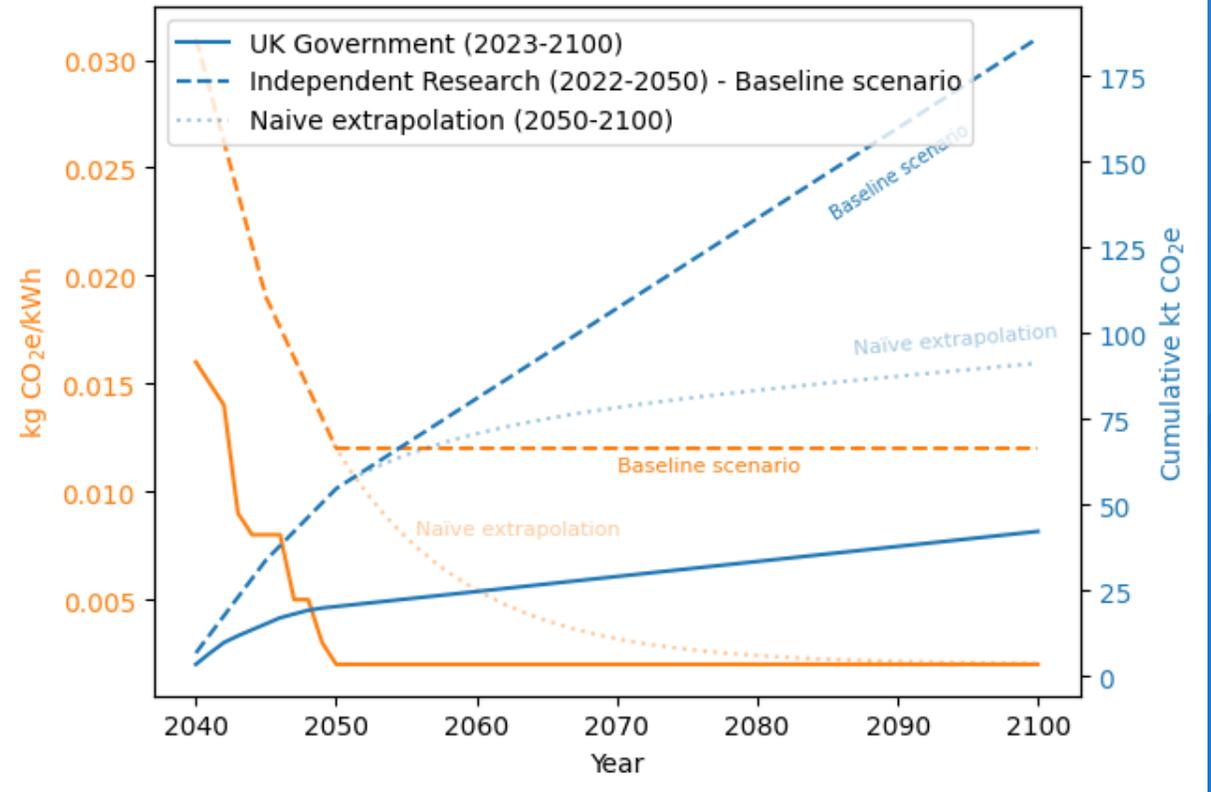
# ISIS-II Operational Impacts

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Assuming a 25 MW wall-plug power facility (219 GWh/yr) running for 60 years (from 2040-2100) = ~9-13 TWh. (with beam-time, planned maintenance, and unplanned downtime)

Total operational power impacts can range from 26 kt CO<sub>2</sub>e – 1612 kt CO<sub>2</sub>e (6% to 350% GWI of construction)

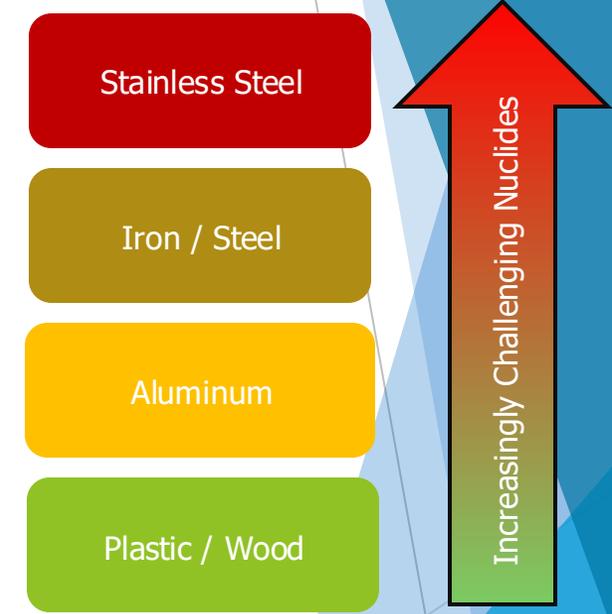
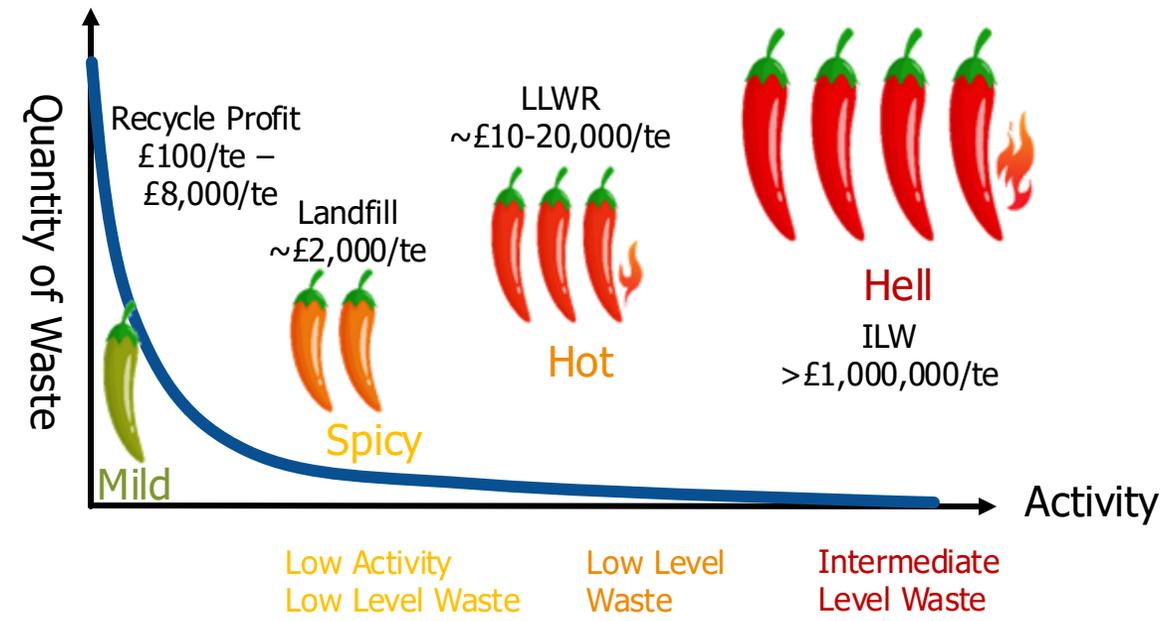
Operations model	% of facility lifetime GWI
UK net-zero grid	5%
BAU	74%
Naïve extrapolation	16%



438 tCO<sub>2</sub>e per year of operation from 2050

# ISIS-II Decommissioning Impacts

- ▶ Decommissioning is highly dependent on the construction materials, beam power (radiation, maintenance), decommissioning procedure, etc. etc.
- ▶ Assuming the facility components will be recycled (where possible).
- ▶ Current estimates show decommissioning to range between 5 and 10% of the total facility GWI.
- ▶ Modelling and data collection is still underway.

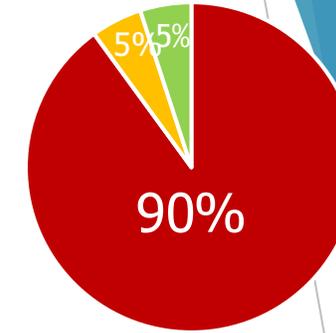


# ISIS-II Lifetime Global Warming Impact

- ▶ The LCA for the ISIS-II facility has strong dependencies on external and internal factors
- ▶ At the current stage of the study, the lifetime GWI of the facility ranges between **~500 to 2200 kt CO<sub>2</sub>e**
- ▶ Best- and worst-case scenarios indicate potential areas of environmental impact reduction, through optimisation of bulk shielding materials to reducing and improving the efficiency of power consumption.

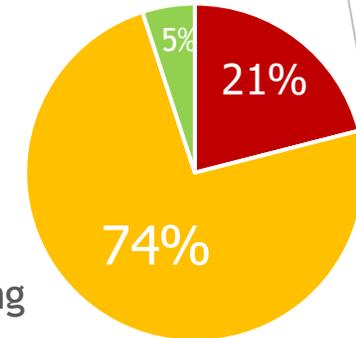
ISIS-II Facility Stage	GWI [kt CO <sub>2</sub> e]
Construction	462
Operation	26 - 1612
Decommissioning	24 - 103
<b>Total</b> (naïve extrapolation)	<b>~580</b>

ISIS-II GWI

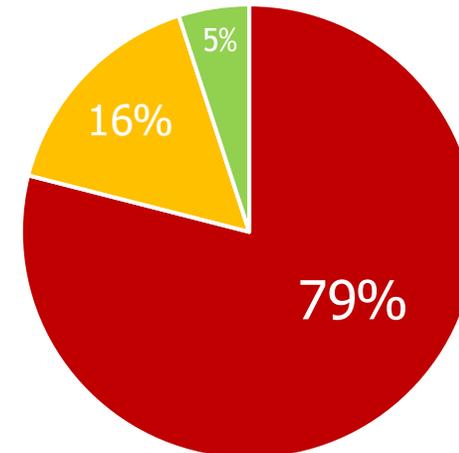


UK net-zero grid  
512 kt CO<sub>2</sub>e

- Construction
- Operation
- Decommissioning



BAU  
2178 kt CO<sub>2</sub>e



Naïve extrapolation  
579.6 kt CO<sub>2</sub>e

# ISIS-II sustainability strategy

The ISIS-II facility will set **SMART** goals as part of its sustainability strategy.

Two specific overarching objectives and prioritise them based on feasibility and environmental impact, namely GWI.

- 1) Design the world-leading ISIS-II Neutron and Muon Source facility with state-of-the-art technology, fully optimised for environmental sustainability by 2032.
- 2) Contribute significantly to the UKRI's 'net-zero' target by 2040 by minimising operational greenhouse gas (GHG) emissions, strive to meet net zero GHG emissions of operational power consumption and reduce construction impacts by X%\* from the ISIS-II LCA baseline value.

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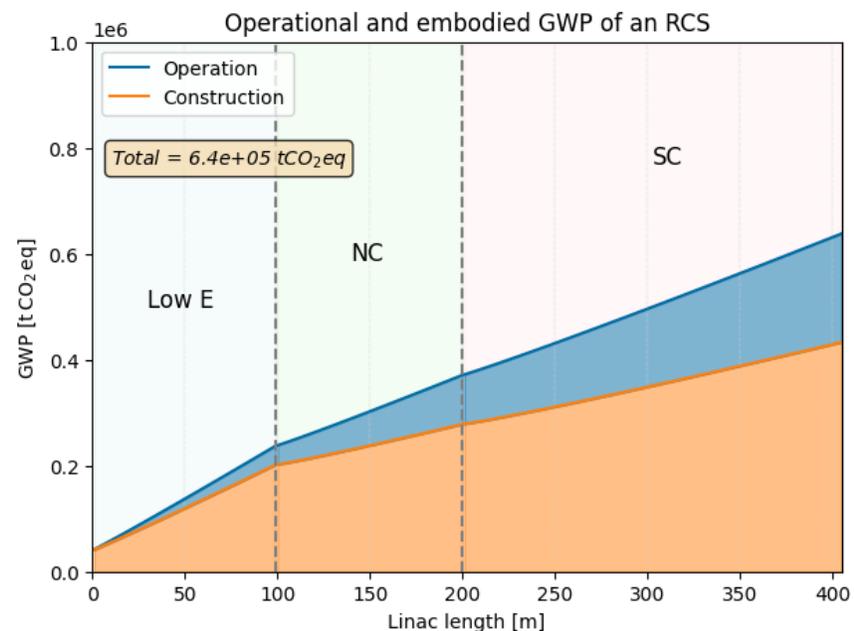
**SMART:** Specific, measurable, achievable, relevant, and time bound.

\*Where X is a percentage to be determined in upcoming studies.

# Ongoing accelerator sustainability studies

Multiple studies ongoing aiming to answer questions like:

- Is a normal conducting (NC) or superconducting (SC) linear accelerator more environmentally sustainable?
- What are the optimal lengths of NC vs. SC linac for an AR and RCS?
- How much can we reduce GWI with failure/downtime prevention?



RCS ring design option for ISIS-II

Under development,  
but here is an example  
output!

# High-level environmental sustainability guidelines for large accelerator facilities

- ▶ Generic sustainability guidelines, recommendations and opportunities exist.
- ▶ Yet a common issue is that specific recommendations are not available for bespoke and niche areas, such as PP.
- ▶ Living document created (<https://arxiv.org/abs/2501.14979>).
- ▶ Nature Reviews Physics Comment (Underway).
- ▶ Version 2 about to start.
- ▶ Invited to IPAC'25 to give talk.

## High-level environmental sustainability guidelines for large accelerator facilities

Version 1

Hannah Wakeling<sup>\*1</sup>, Philip Burrows<sup>1</sup>, Jim Clarke<sup>2</sup>, Jo Colwell<sup>3</sup>, Ben Shepherd<sup>2</sup>, and John Thomason<sup>4</sup>

<sup>1</sup>John Adams Institute for Accelerator Science, University of Oxford, UK

<sup>2</sup>ASTeC, Daresbury Laboratory, Science and Technology Facilities Council, UK

<sup>3</sup>Science and Technology Facilities Council, UK

<sup>4</sup>ISIS Neutron and Muon Source, Rutherford Appleton Laboratory, STFC, UK

January 28, 2025

Please refrain from printing this document where possible.

### Abstract

The proposed construction of new particle accelerator-based facilities in the coming decades – and upgrades to existing facilities – provides the unique opportunity to embed innovative environmental impact reduction techniques into their design. This living document provides high-level guidelines to improve environmental sustainability in the planning, construction, operational and decommissioning stages of large accelerator facilities. A collection of various resources is provided, with examples of some existing and suggested practices.

**Keywords** — Accelerator, physics, environment, impact, greenhouse gas, carbon, life cycle assessment, sustainable.

# Communication, collaboration, education

- ▶ ESPPU 2025 contributions
  - ▶ For sustainability efforts to have maximal success, sustainability needs to be embedded within facilities, policy and practice.
  - ▶ This year the European Strategy for Particle Physics Update (ESPPU) submissions included many inputs which called for and highlighted the need for sustainability within PP
    - ▶ Laboratory Directors Group Sustainability Working Group submission
    - ▶ Independent (<https://arxiv.org/abs/2504.03012>)
    - ▶ EPPSU ECR submission (<https://arxiv.org/pdf/2503.19862>)
    - ▶ UK submission

# Communication, collaboration, education

- ▶ ESPPU 2025 contributions
- ▶ Sustainable Accelerator Design Group (ISIS)
- ▶ HECAP+ ([Environmental Sustainability in Basic Research](#))
- ▶ Sustainable HEP conference
  - ▶ May 12<sup>th</sup>-15<sup>th</sup> <https://indico.global/e/susthep25>

# Communication, collaboration, education

- ▶ ESPPU 2025 contributions
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- ▶ Sustainable HEP conference
- ▶ JAI Graduate Lecture Course: incorporation of sustainability into final project
  - ▶ 2<sup>nd</sup> year of sustainable accelerators lecture
  - ▶ 1<sup>st</sup> iteration of problem set (in the style of a thought exercise)
  - ▶ Goal: To encourage students to think about their environmental impact throughout the project and to exhibit the importance of evaluating and reducing their environmental impact in the design stages of the project.
  - ▶ Students presented estimated electricity consumption in final presentation

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- ▶ Sustainable HEP conference
- ▶ JAI Graduate Lecture Course: incorporation of sustainability into final project
- ▶ Summer intern: Sustainability R&D in accelerators, focusing on optimisation of shielding for various accelerator scenarios

# Future

- ▶ LCA (can always and iteratively be improved)
  - ▶ Many variables/parameters to include, improve and refine e.g., radioactive materials
  - ▶ ISIS-II-based ring design comparison; AR vs RCS
- ▶ Sustainability Strategy
  - ▶ Determine % of realistic and potential sustainability scenarios and the financial costs/savings of embedding environmental sustainability.
- ▶ “Lift the bonnet” on the ESPPU accelerator proposals environmental sustainability reporting



Thank you

Sustainable HEP Conference 2025  
May 12<sup>th</sup>-15<sup>th</sup>  
<https://indico.global/e/susthep25>



# Backup slides

# Uncertainty analysis

- Input variable uncertainty based on “Bilan Carbone” uncertainties defined as:

Data	Uncertainty
Emission factor from a direct measurement	0-5%
Reliable non-measured data	15%
Calculated data	30%
Approximated data (statistical data)	50%
Order of magnitude estimate	80%

- Database quality entry: Ecoinvent Data Quality System with base uncertainty of Bilan Carbone uncertainty
- Uncertainties then evaluated using Monte Carlo standard deviation (under re-evaluation)

# Example: LCI of an ISIS-II instrument/experiment



- Most accurate area of the Life Cycle Inventory (LCI) at this point in time is for an ISIS-II instrument
- Usual lifetime of 30 years before upgrade/replacement
- Modelled using 1 “generic” instrument
- However, ISIS-II would likely have 26 varying instruments
  - E.g., 1 in 10 instruments will have a Beryllium filter