Updated results of a Life Cycle Assessment of the ISIS-II Neutron & Muon Source

Dr. Hannah Wakeling

ICHEP 2024

19th July 2024

John Adams Institute for Accelerator Science

University of Oxford

Science and Technology Facilities Council

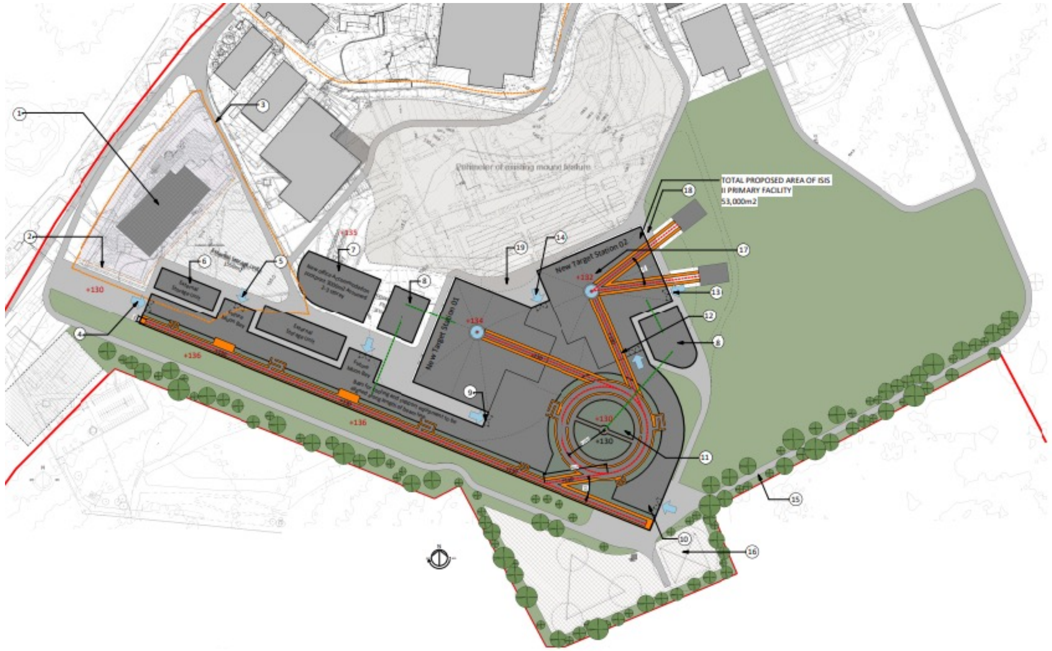
ISIS Neutron and Muon Source

Overview

1) The ISIS-II Neutron and Muon Source
2) Environmental Impact & Life Cycle Assessment of ISIS-II
   - Motivation
   - Methodology
   - Recent results

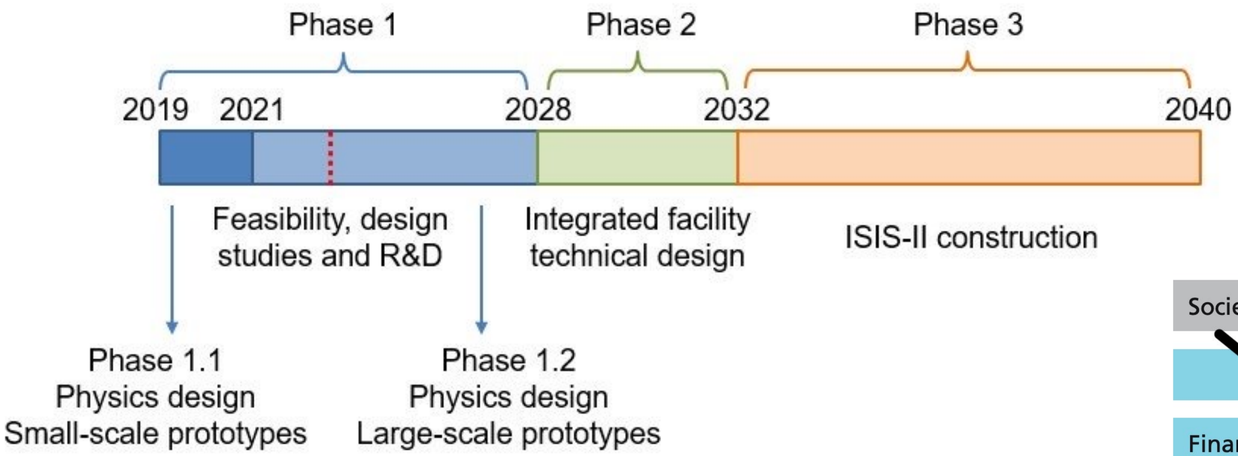
The ISIS-II Neutron and Muon Source

- The proposed 1.2 GeV beam upgrade to the ISIS Neutron and Muon Source (a two target, pulsed spallation source).
- Based at the STFC Rutherford Appleton Laboratory (RAL), Oxfordshire, UK.
- Overall power around 2.4 MW, dependent on target technology.



One proposed design option for ISIS-II.

Timeline



Proposed ISIS-II timeline.

Now is the ideal time to consider and reduce environmental impacts!

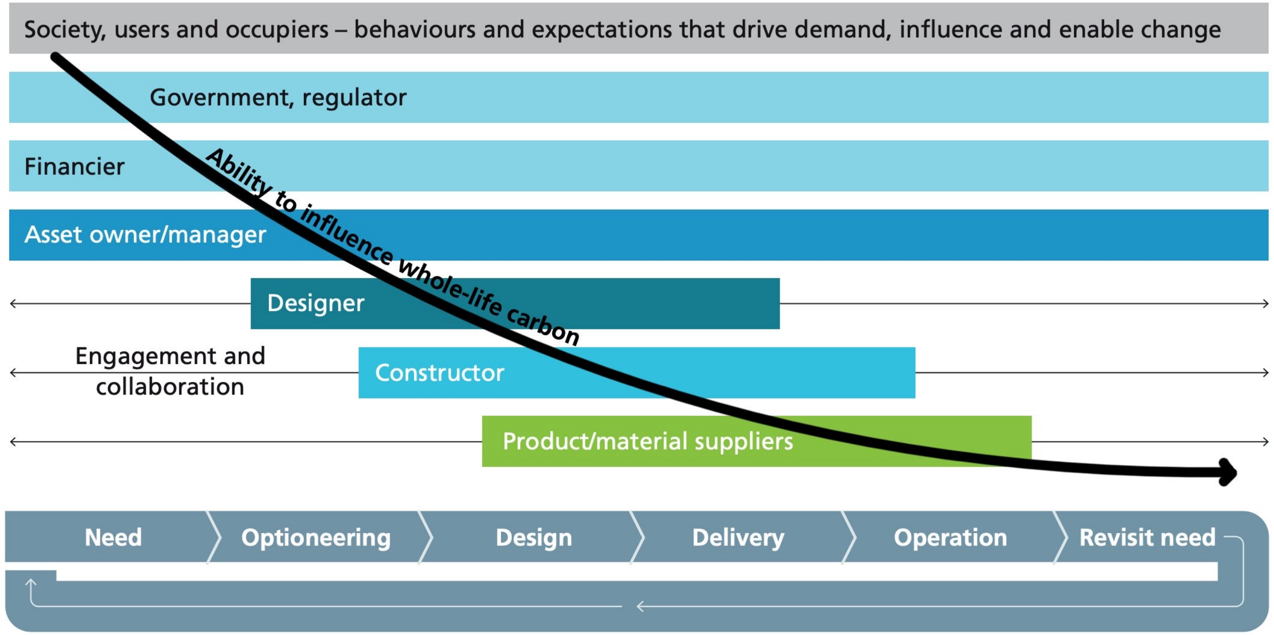
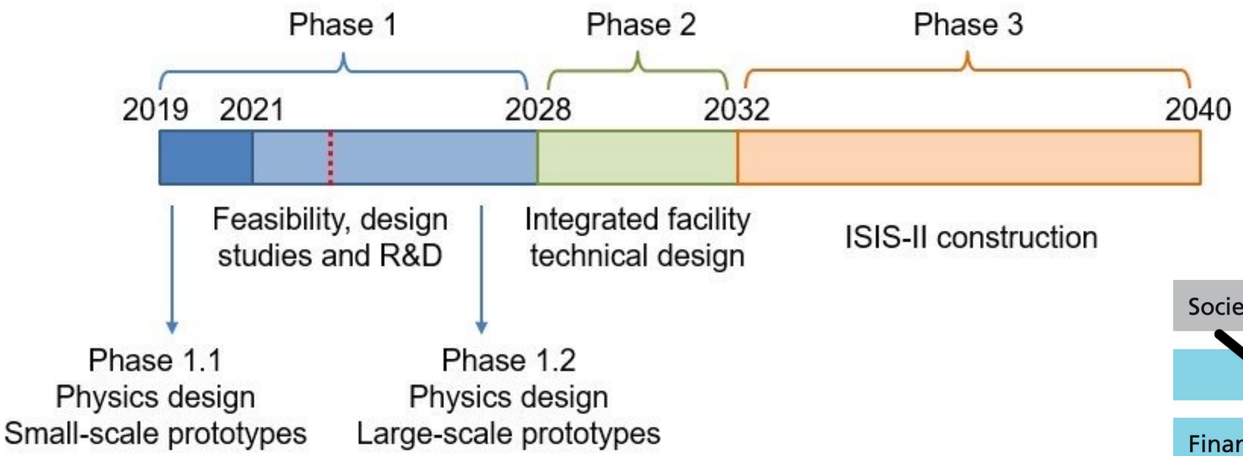


Fig 2.1: Value-chain members' ability to accelerate decarbonisation throughout the delivery process

PAS 2080 guidance document: Practical actions and examples to accelerate the decarbonisation of buildings and infrastructure

Progress on Design Studies for the ISIS II Upgrade (2019)

Timeline



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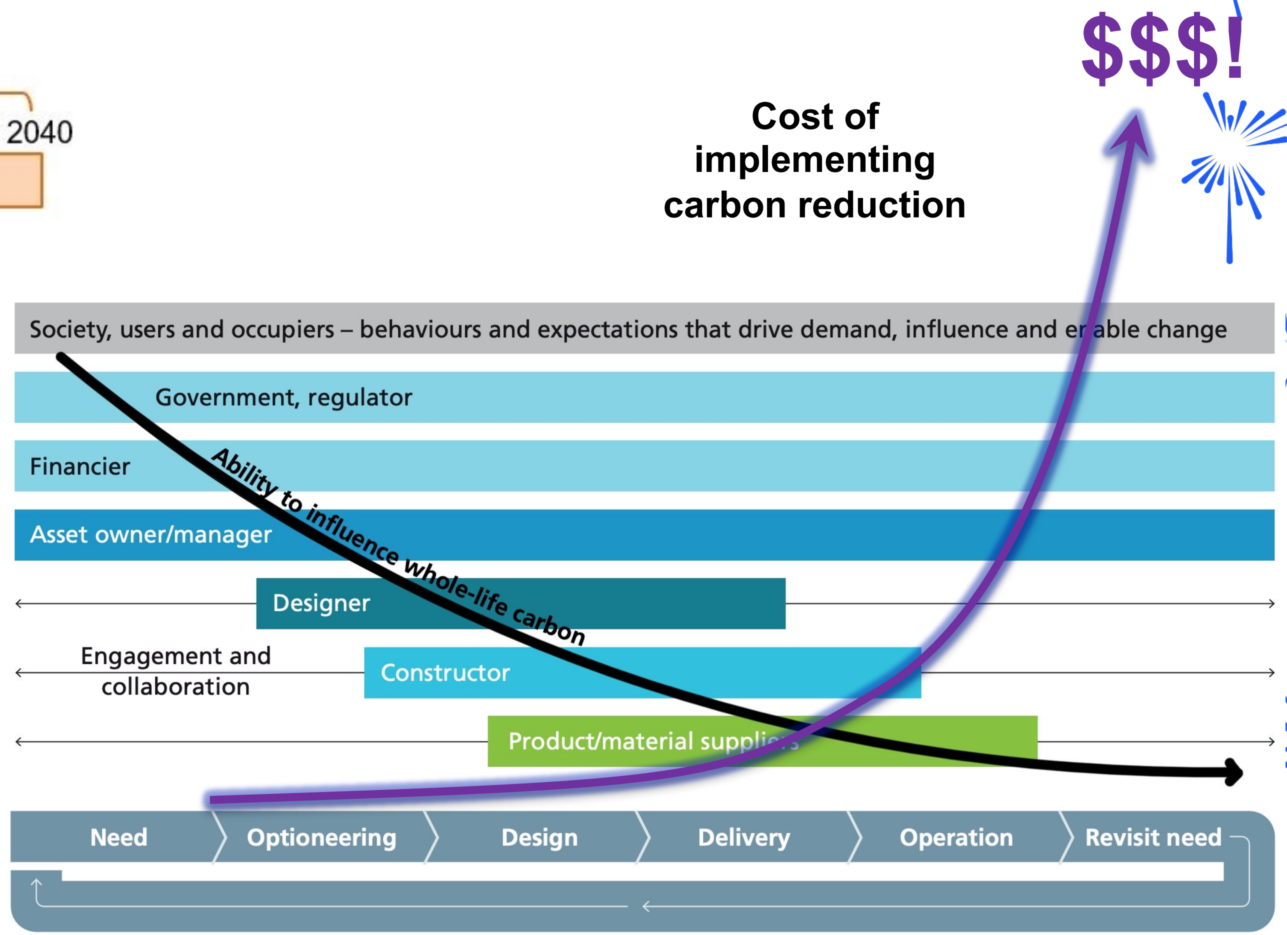


Fig 2.1: Value-chain members' ability to accelerate decarbonisation throughout the delivery process

PAS 2080 guidance document: Practical actions and examples to accelerate the decarbonisation of buildings and infrastructure

Progress on Design Studies for the ISIS II Upgrade (2019)

Motivation

Wish to evaluate the environmental impact of the proposed facility to:

- report on the full lifetime environmental impact expected at ISIS-II,
- inform ISIS-II design options,
- identify hotspots of environmental impact to allow focus to reduce these impacts, and
- help develop a methodology and resources that can be used by other future facilities.

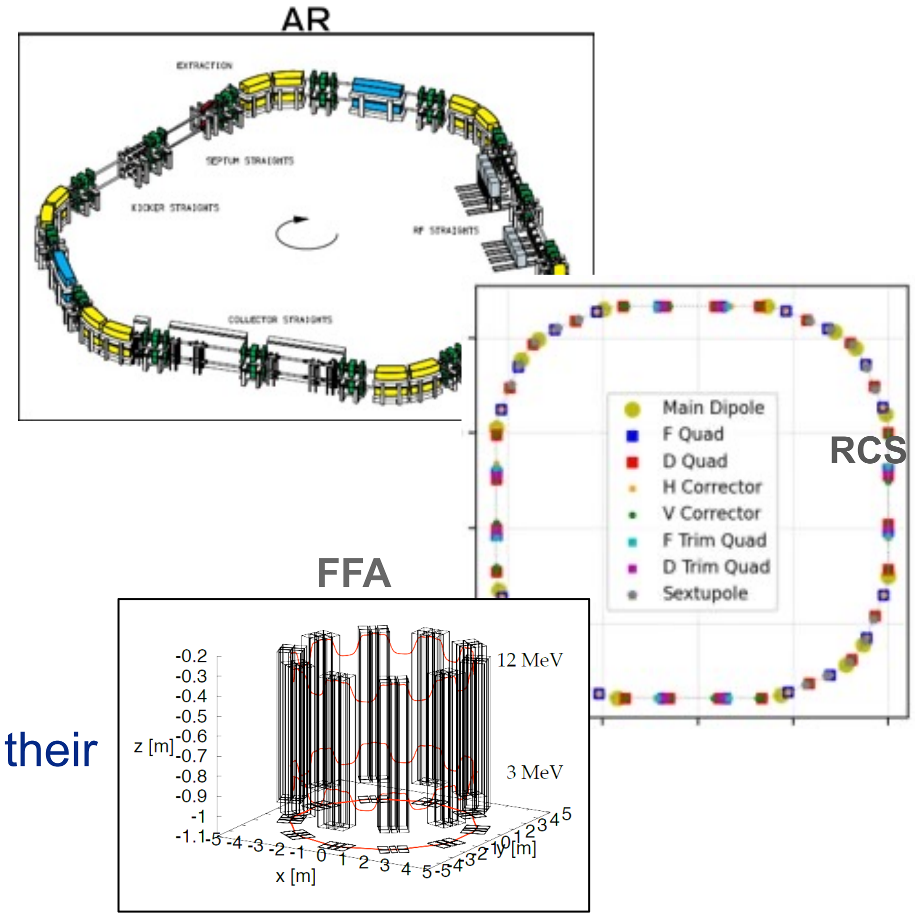
Methodology

Three major design considerations:

- Accumulator Ring (AR)
- Rapid Cycling Synchrotron (RCS)
- Fixed Field Alternating Gradient Ring (FFA)
- Fall back option: 180 MeV LINAC upgrade to ISIS

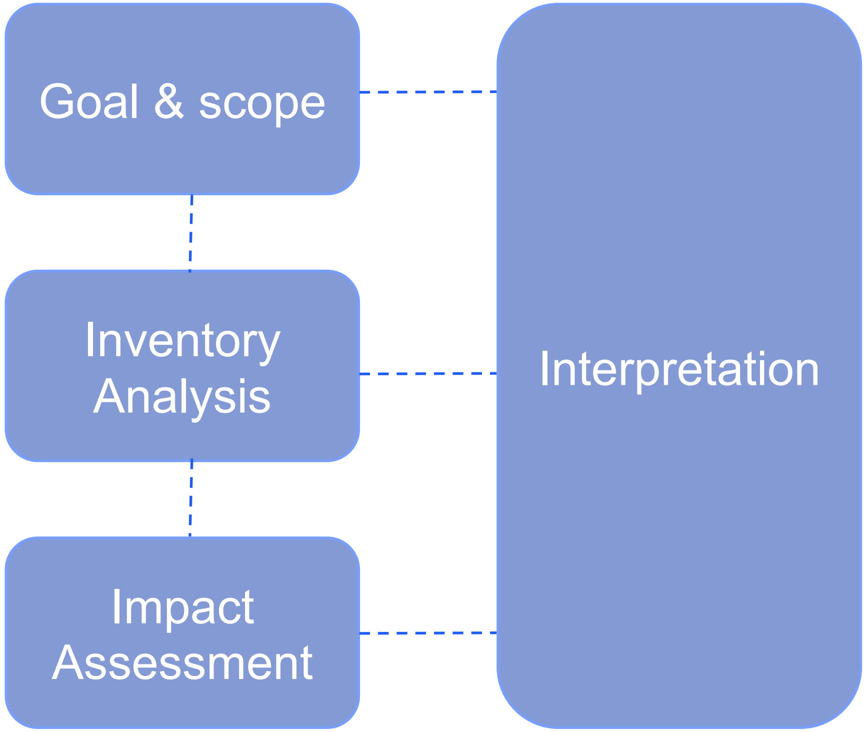
Two key stages to this analysis:

1. Core components of ISIS-II and performing estimation of their environmental impact through modelling and simulation.
2. (Simplified) **Life Cycle Assessment** (LCA)



3 ring options for ISIS-II.

Life Cycle Assessment (LCA)



LCA steps.

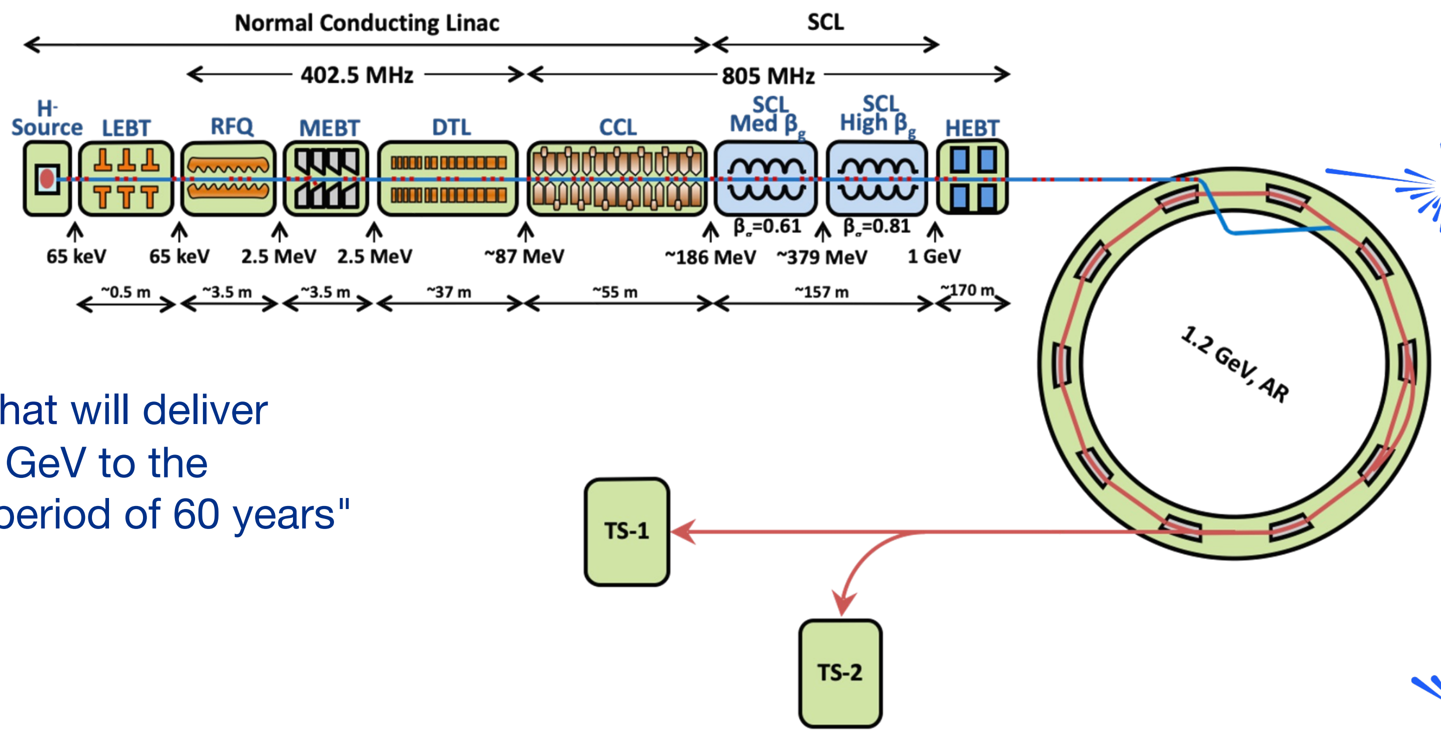
Goal & Scope

Goal

- 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 2.4 MW beam of protons to the neutron and muon community over a period of 60 years.

Scope

- RCS (low energy LINAC)
- AR (full energy LINAC)



- Functional unit is: "one ISIS-II facility that will deliver a beam of protons at an energy of 1.2 GeV to the neutron and muon community over a period of 60 years"

Inventory Analysis

Construction (2032 – 2040)

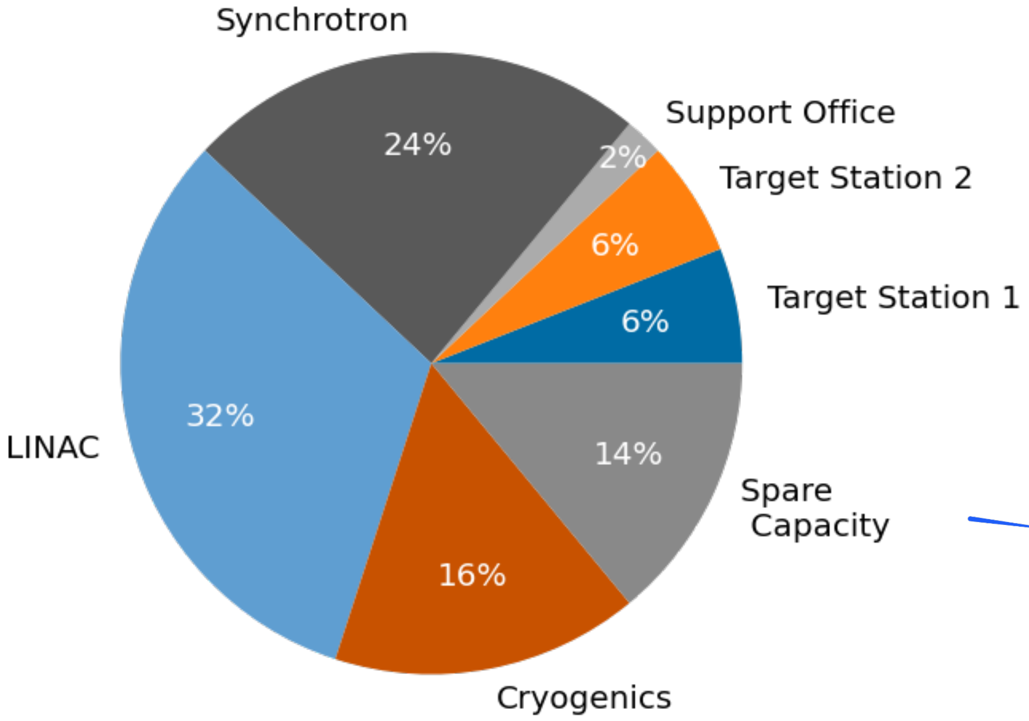
- Facility (Buildings, Tunnelling, Location)
- Machine (Accelerator Components, Ancillaries)
- Shielding
- Computing

Operation/Active life (2040 – 2100)

- Energy consumption
- Resource consumption inc. leakage
- Failure likelihoods/risks inc. replacement/repair
- Staff and user travel
- Radioactive waste

Decommissioning (2100 – 2170)

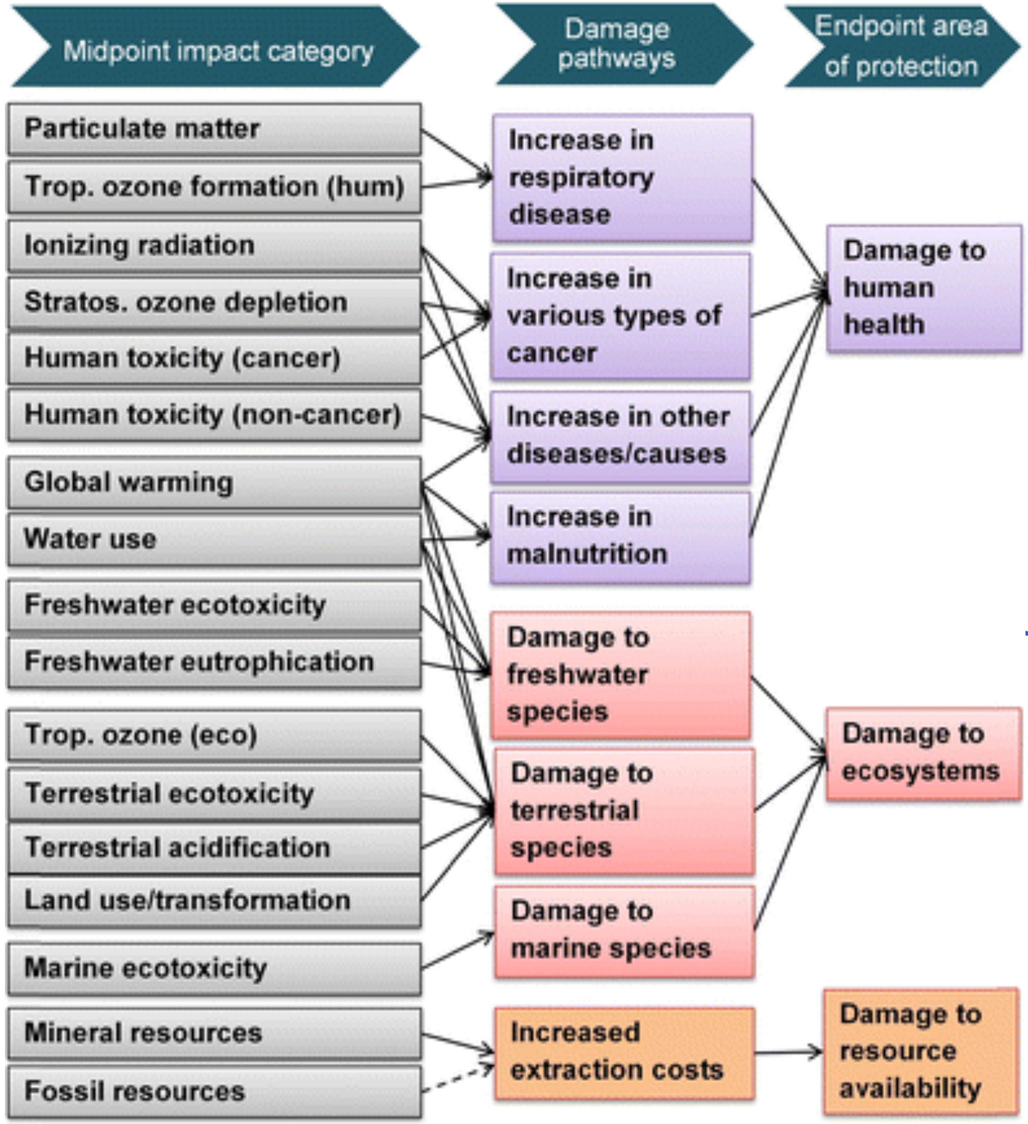
- Recycling/re-use of components/materials
- Storage of radioactive materials



Estimated ISIS-II electricity requirements for a 25MW Facility (Big Science Scheme)

Impact Assessment

- Following the EN 17472:2022 standard as a basis.
- Many impact assessment methods exist, no standard yet set within our field.
- Using the ReCiPE:2016 Midpoint (H) Life Cycle Impact Assessment Method.
- Using openLCA with the Idemat database (currently, fluid, incomplete database for study)
    - One good outcome of this: naturally creates a database with key particle accelerator components such as magnets, klystrons, cryomodules etc.



Impact Assessment thus far

Note: results highly dependent on database, design, material availability, quality of data, etc.

Evaluation of the ISIS-II facility with an AR (and corresponding LINAC)

Construction

- Machine (LINAC, Ring, EPBs, Targets, Instruments, etc.)
- Shielding and buildings

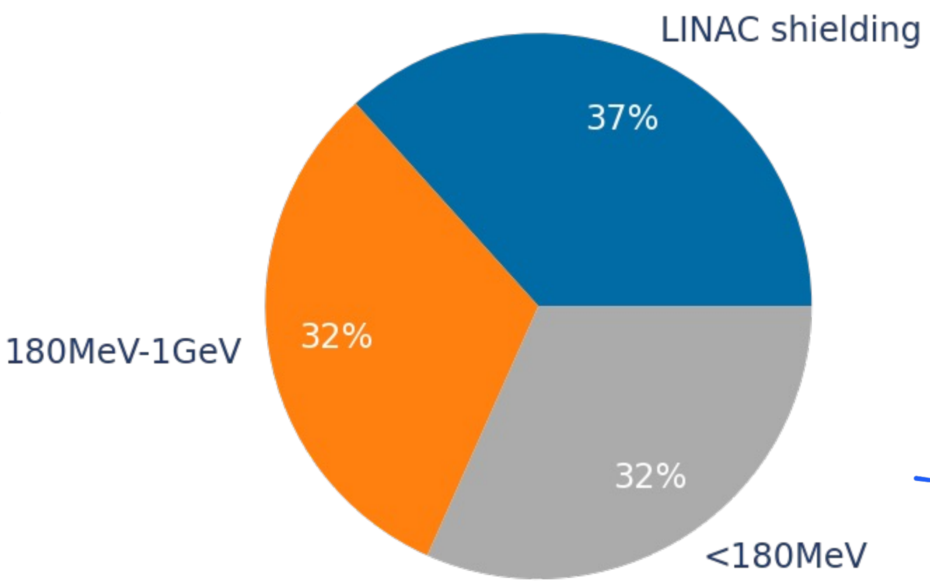
Operation/Active life

- Energy consumption
- Failure likelihoods/risks inc. replacement/repair

Life Cycle Information	Global Warming [kt CO_2 eq]
A. Construction	$\mathcal{O}(300)$
B. Operation	$\mathcal{O}(100-500)$
C. Decommissioning	TBC

ReCiPE:2016 Midpoint (H) Global Warming Impact Factor of the ISIS-II with an AR design shows construction and operation to be of the same order of magnitude.

Variation in calculation of operational impacts depends on UK net-zero power grid.



Example: Estimated CO_2e impacts of the construction of the ISIS-II LINAC required for an AR design are $\mathcal{O}(14)$kt CO_2 eq

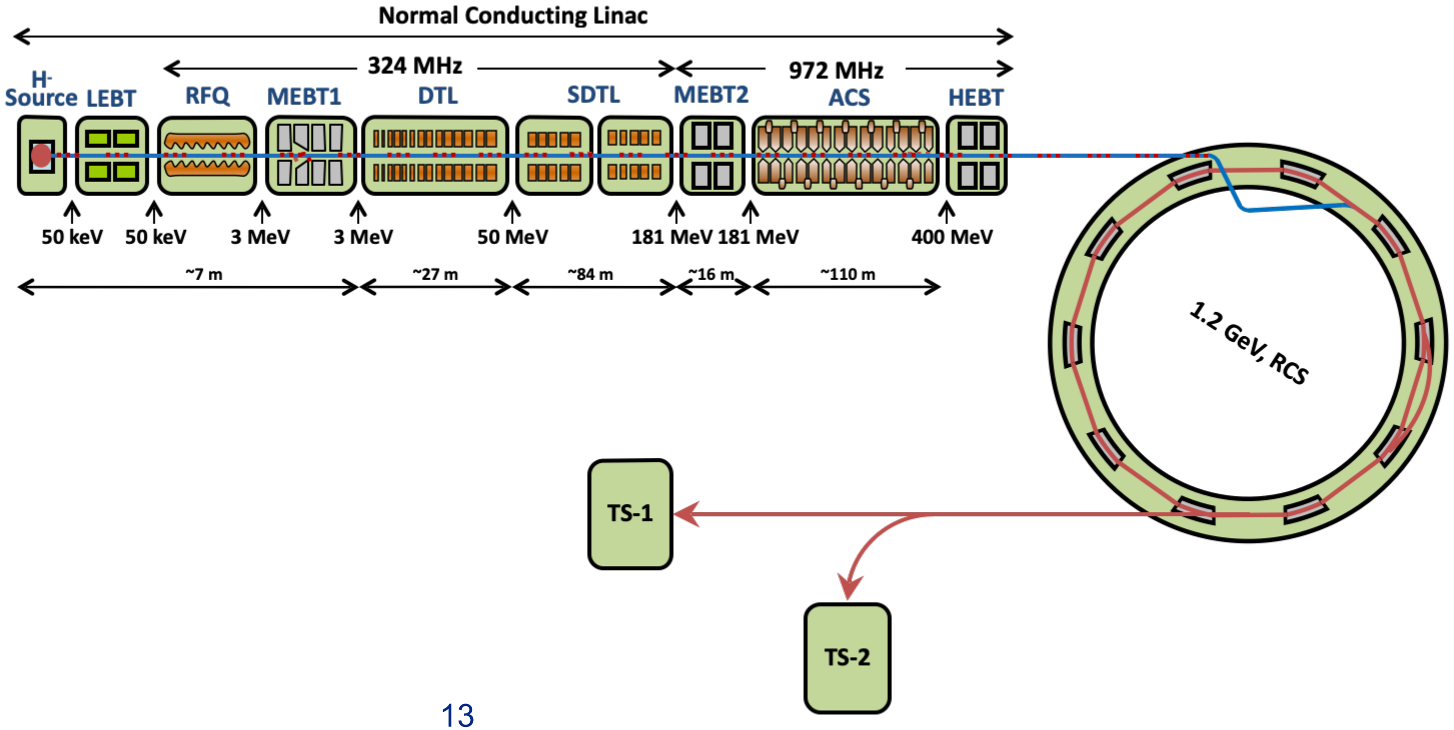
Next steps

Evaluation of the ISIS-II facility with an RCS and corresponding LINAC is nearly complete

- J-Parc 3GeV RCS used as a model (too high an energy for true comparison)

Shift to EcoInvent Database

Fine-tuning of LCA (an iterative process)



Summary and Conclusion

- Understanding and reducing the environmental impact of *all aspects* of research is necessary.
- To inform the design options for ISIS-II and evaluate its environmental impact, a simplified Life Cycle Assessment is underway.
- First estimations of the entire ISIS-II facility show that construction and operational carbon emissions are of the same order of magnitude.
  - With the UK's shift to net-zeo energy generation by 2050, it is expected that (without any efforts for reduction in carbon emissions) construction will be 2-3x that of the full lifetime operations of ISIS-II.
- As a result, ISIS-II is examining options to reduce the carbon emissions from construction.

Back-up slides

Science and Technology Facilities Council

ISIS Neutron and Muon Source

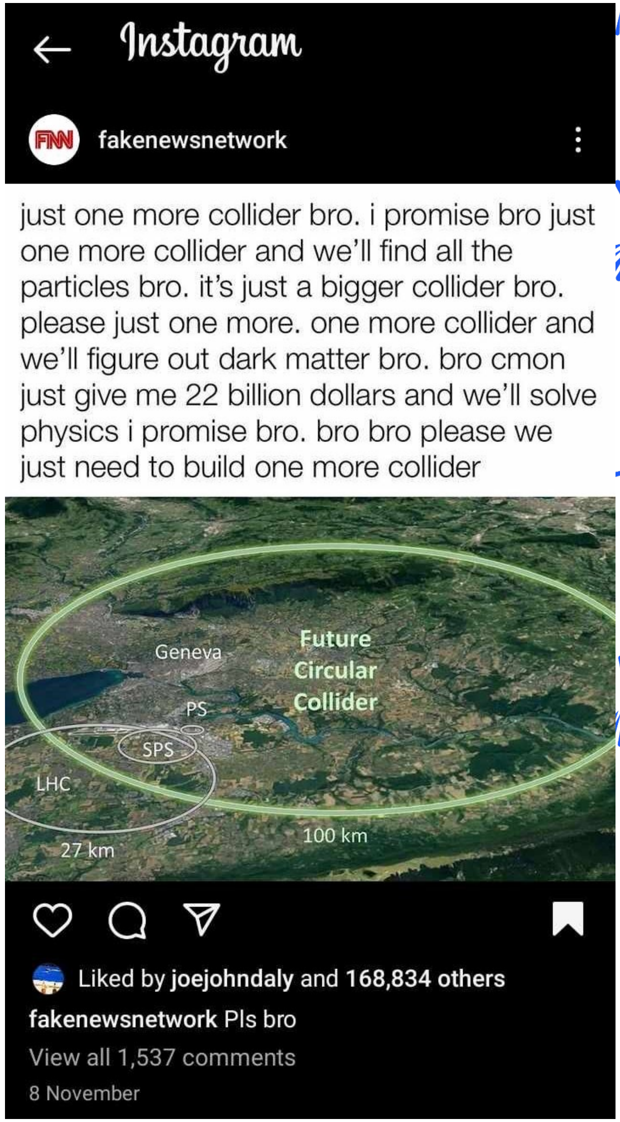
The Climate Crisis

Why do we need to care?

- GHG impacts are cumulative.
- Moral and social duty to lead by example.
- Publicly funded.

How does this *actually* relate to the field of HEP?

- HEP uses accelerators and other facilities (supercomputers)
- Large accelerator facilities are generally <u>unsustainable</u>:
    - resource consumptive, and
    - next generations aim to grow in size and/or power, and therefore (generally) consumption.

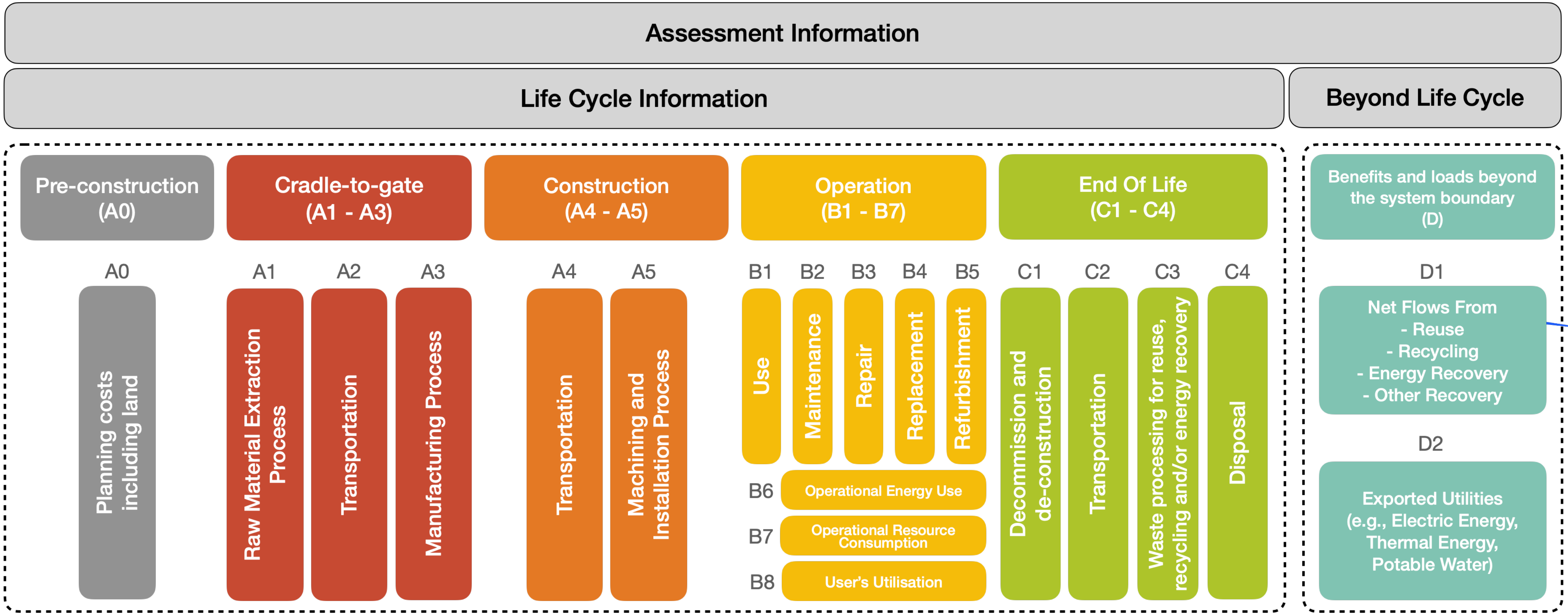


Instagram: @fakenewsnetwork

[The climate issue | Nature Astronomy]

Impact Assessment

- Following the EN 17472:2022 standard as a basis.



BS EN 17472:2022

A. Construction
B. Operation
C. Decommissioning

Complexity

- Must meet ISO requirements to publish a LCA
  - Due to strong standards to follow there is a steep beginners learning curve (time)
  - Specialists/experts required (time and/or $$)
  - May need external consulting ($$$)
- Comprehensiveness and level of detail
  - High level of detail required
    - Easy to fall into a rabbit hole
  - Information needs to be qualified
  - Not easy to get all necessary data for a full life cycle assessment
    - Much information necessary is proprietary or just simply not available
  - Requires simplifications and generalisations that prevent knowledge of actual impacts
- Average of impacts, does not consider rarely occurring risks i.e. poisonous gas leak
- Cannot quantify whether your calculated impact is ”good enough” for the environment, i.e. only comparative

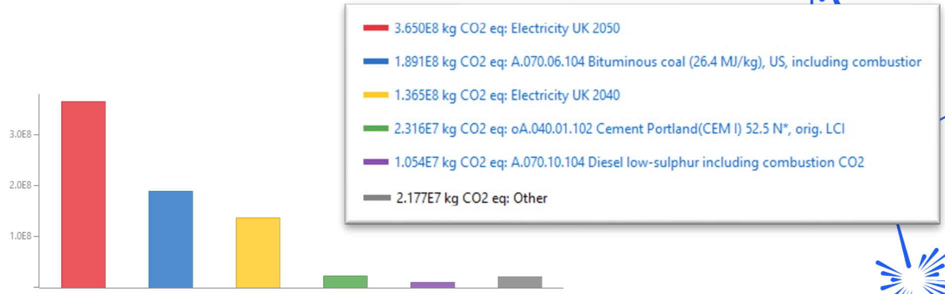
Complexity

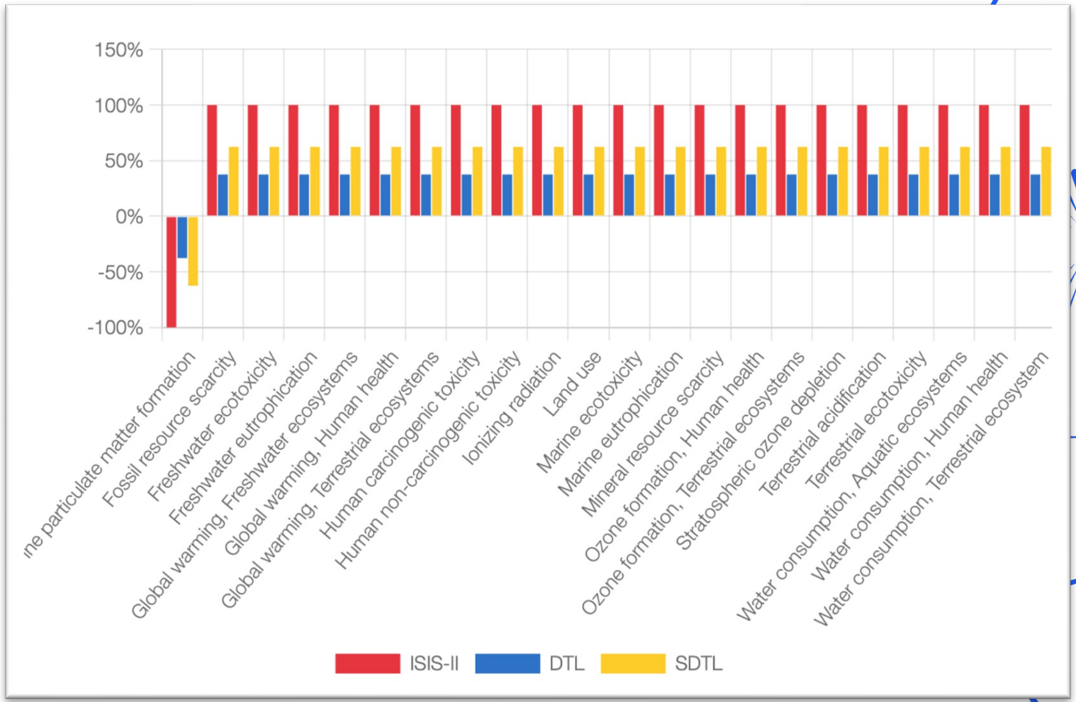
- Realistically, ISO standards to follow may be too rigid for all accelerators (and tests, components etc.) designs to have a full LCA performed on them.
- Other options that should be considered
  - ‘simplified’ LCAs
    - Bulk material LCA (e.g. show that 95% materials make up 99% of impact)
  - Carbon impact study only
    - Scope 1, 2 and 3

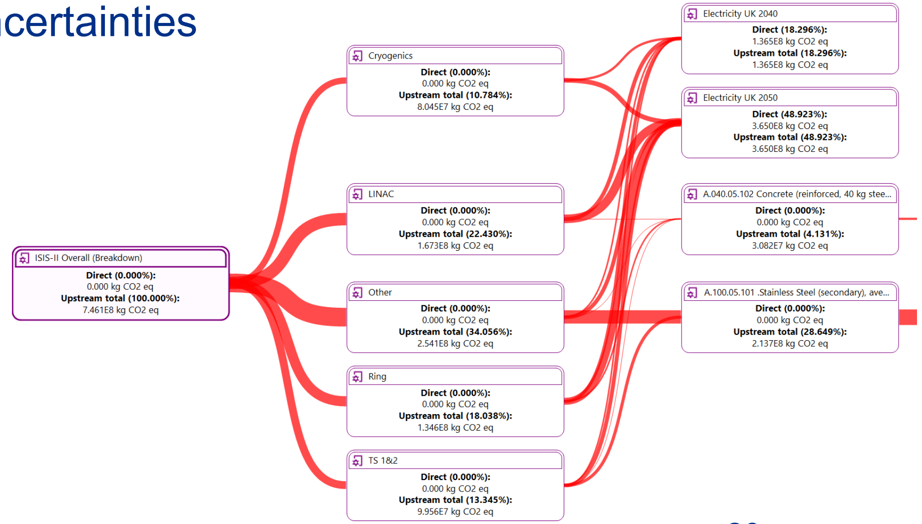
Tools available: LCA Software

- Many software options available (GaBi, Simapro, OpenLCA)
  - Many cost *$$$*
- Different software *can* create differing results through different handling of data, end of life, etc.
- LCA software not necessarily as straightforward as it may seem
- OpenLCA
  - Open Source
  - Compatible with Python
  - Enables fast calculation of component lifetime impacts
  - Enables comparison of components, different designs etc.
  - Monte Carlo uncertainties

Contribution	Process	Total result [kg C...
100.00%	ISIS-II Overall (Breakdown)	7.46052E8
34.06%	Other	2.54073E8
22.43%	LINAC	1.67336E8
18.04%	Ring	1.34572E8
13.35%	TS 1&2	9.95621E7
10.78%	Cryogenics	8.04518E7
01.35%	Support Buildings	1.00565E7







Tools available: Databases

- Global versus local
  - One of the most impactful factors in an LCA
- Age of database
  - When comparing free to paid, this is a big difference between the age/quality of data
- Particle physics has non-standard materials, often not available in a database
  - Sometimes new materials/uncommon materials not available in any database are used. To accurately represent them without performing an LCA on the material itself would add complexity. Can use similar/multiple material contributions which add uncertainty.

Example

Ecoinvent:

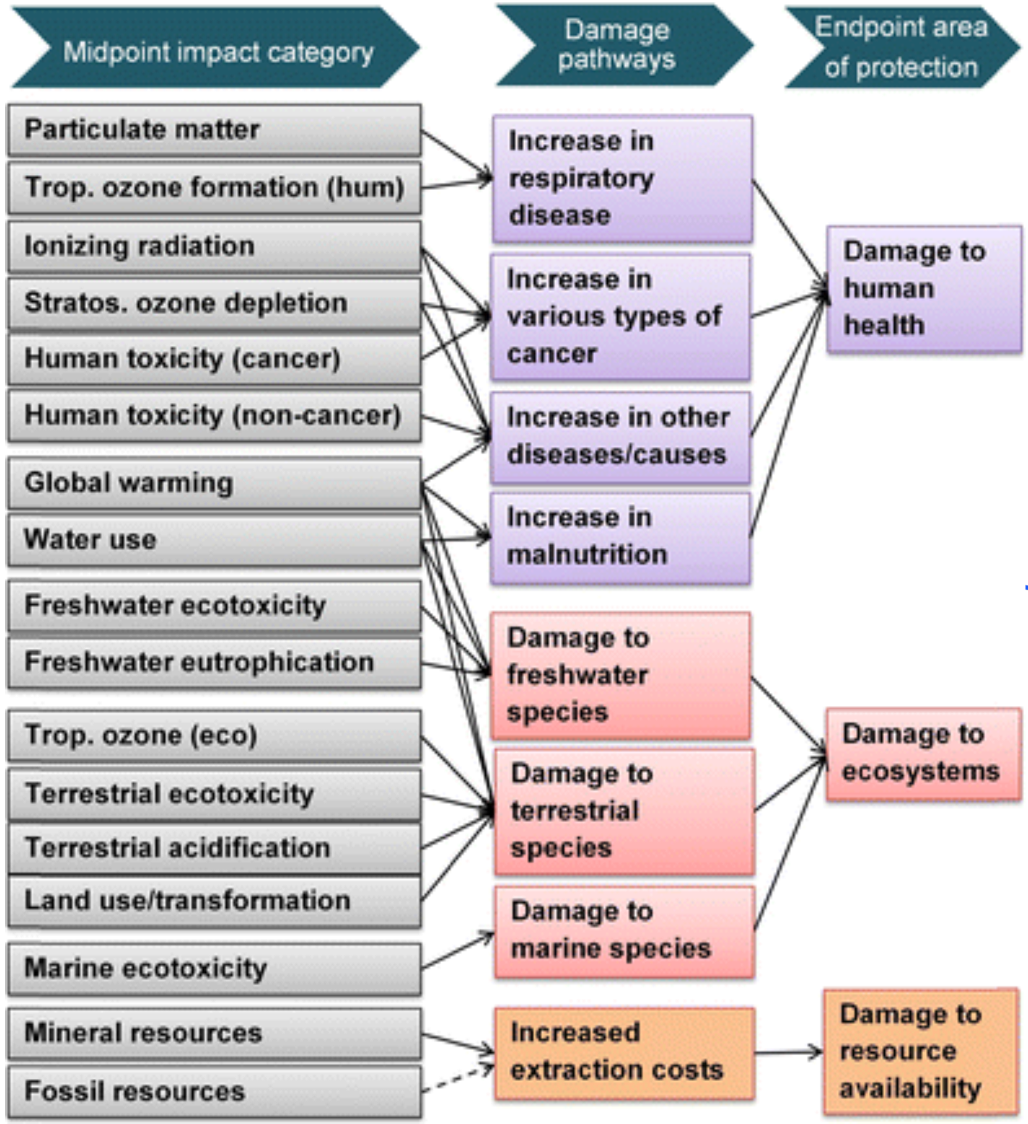
- Arguably very comprehensive dataset
- €1500/year for an individual commercial license, which is potentially a prohibitive price

Idemat:

- Academic license is free.

Tools available: Impact Assessment Methods

- Many impact assessment methods exist, no standard yet set within our field
- One example (and more common) assessment method is the ReCiPE:2016 Life Cycle Impact Assessment Method.
  - Midpoint: Groups of substance flows for detailed assessment (Climate change, …)
  - Endpoint: further down the cause-effect chain "Areas of Protection (Human health,…)



Tools available: Impact Assessment Methods

- ReCiPE:2016 Life Cycle Impact Assessment Method:
  - Midpoint: Groups of substance flows for detailed assessment (Climate change,, …)
  - Endpoint: further down the cause-effect chain "Areas of Protection (Human health,…)
  - Individualist (I): Short term (~20 years)
  - Hierarchist (H): most common policy principles (~100 years)
  - Egalitarian (E): most precautionary perspective, impact types not yet fully established (~1000 years)
- **Difficulty particularly with radiation (solid waste)**

ILCD Handbook: Analysing of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment First edition

Table 1 Pre-selection of characterisation models for further analysis [3]

	Climate change	Ozone depletion	Respiratory inorganics	Human toxicity4	Ionising radiation	Ecotoxicity	Ozone formation	Acidification	Terrest. Eutrophication	Aquatic Eutrophication.	Land use	Resource Consumption	Others
CML2002	O	o		M	o5	o	M	M	M	M	o	M	
Eco-indicator 99	E	E	E	o	o		E	E	E		E	E	
EDIP 2003/EDIP97[6]	O	M	o	M	o	M	M	M	M	M		M	Work environ-ment Road noise
EPS 2000	E	E	E	E	o	E	E	o	o	o	E	E	
Impact 2002+	O	o	E	M E	o	M E	E	M E		M E	o	E	
LIME	E	E	M	E		o	M E	M E	o	E	E	E	Indoor air
LUCAS	O	o		o		o	o	o	o	o	o	o	
MEEuP	O	o	M	M		M	M	M	M	M		water	
ReCiPe	M E	E	M E	M E	o	M E	M E	M E	o	M E	M E	E	
Swiss Ecoscarcity 07	O	o	o	o	M E	M	o	o	o	o	M E	water	Endo-crine disrupt-tors
TRACI	O	o	M	M		M	M	M	o	M		o	
Specific methods to be evaluated	Ecological footprint		7	USETox		USETox		Seppälä		Payet	Ecological footprint	deWulf et al.	Noise Müller Wenk
Specific methods of potential interest (not to be evaluated)				Watson (Bachmann)	Ecotoxicity of radiation (Laplace et al.)		EcoSense (Krewitt et al.)	EcoSense (Krewitt et al.)		Kärrman & Jönsson	8		Meijer indoor air UNEP Indoor air (Bruzzi et al., 2007)

o: Available in the methodology, but not further investigated
M: Midpoint model available and further analysed;
E: Endpoint model available and further analysed