Evaluating the environmental impact of the ISIS-II Neutron and Muon Source

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ISIS Neutron and Muon Source

Overview

1) The intersection of the climate crisis and particle accelerators & particle physics
2) The ISIS-II Neutron and Muon Source
3) Environmental Impact & Life Cycle Assessment of ISIS-II
   - Motivation
   - Methodology
   - A glance at some results
4) The challenges of this effort

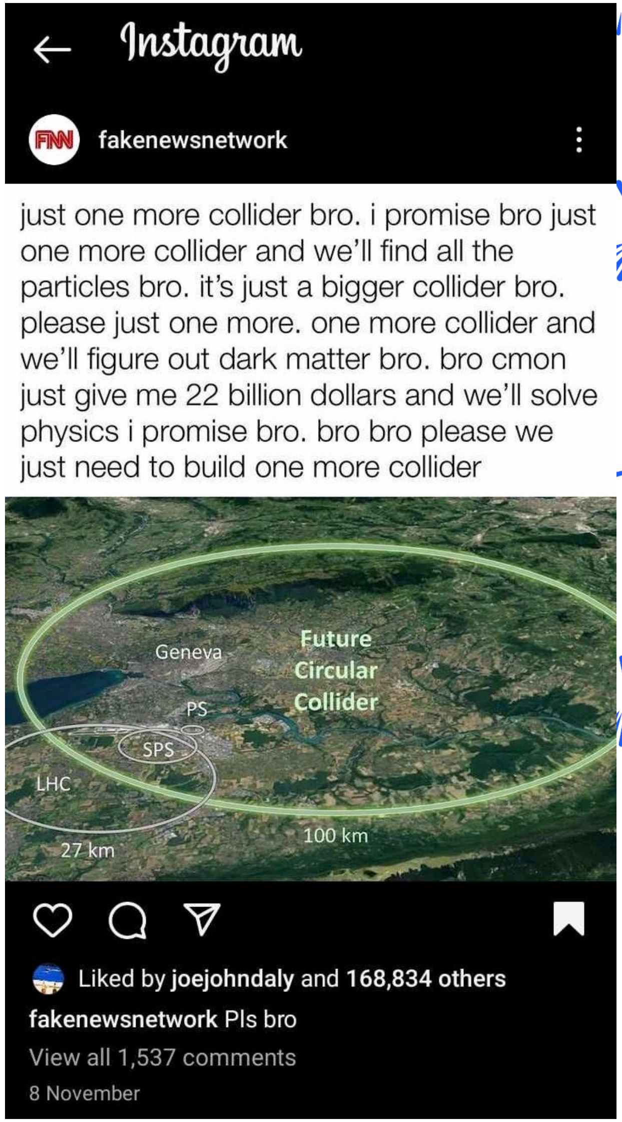
The Climate Crisis

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 accelerator science?

- 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.

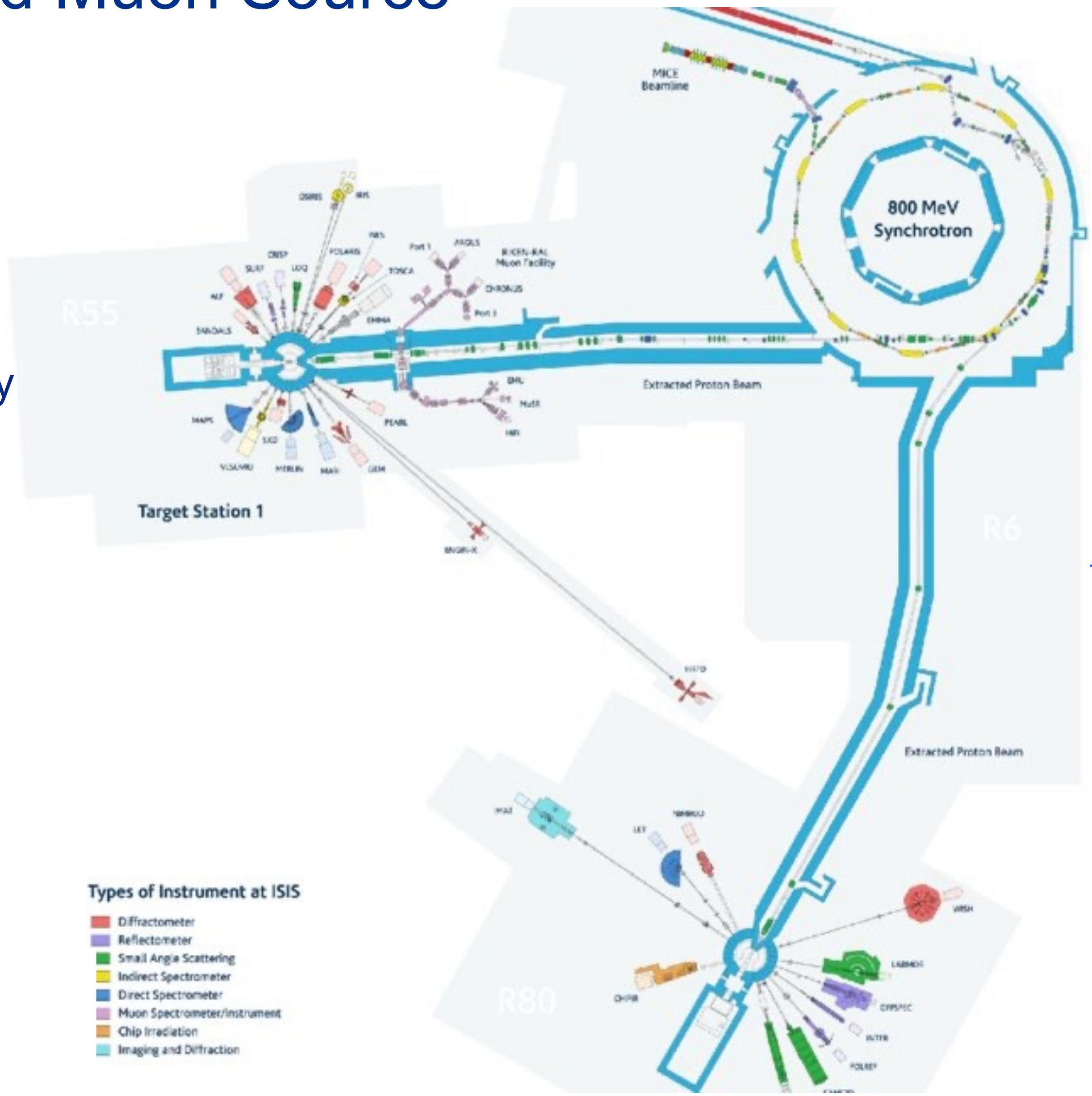


Instagram: @fakenewsnetwork

[The climate issue | Nature Astronomy]

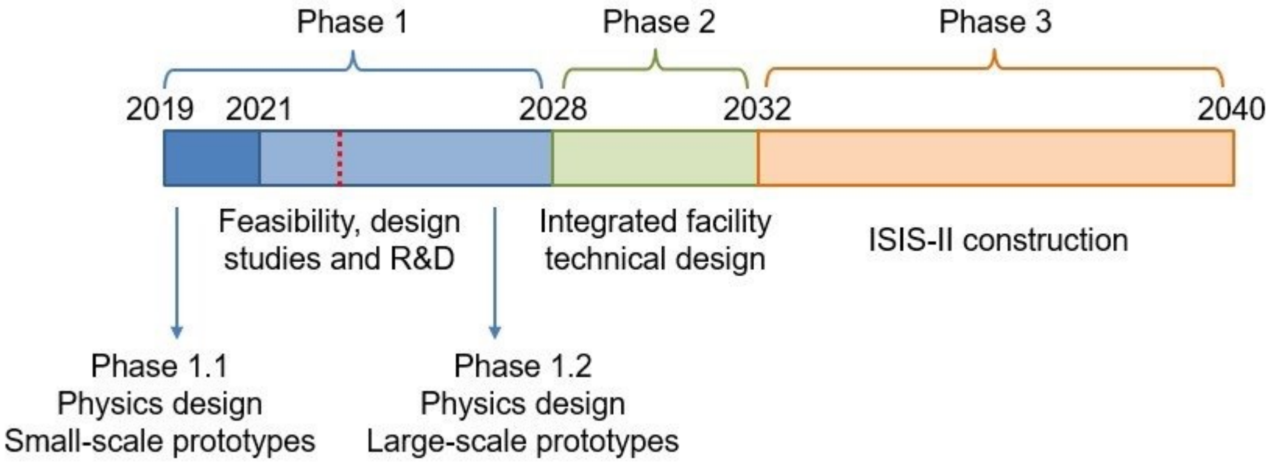
The ISIS Spallation Neutron and Muon Source

- ISIS is the UK’s two target, pulsed spallation source that produces world leading science.
- Based at the STFC Rutherford Appleton Laboratory (RAL), Oxfordshire, UK.
- This year, ISIS marks it's 40th year anniversary since neutrons!

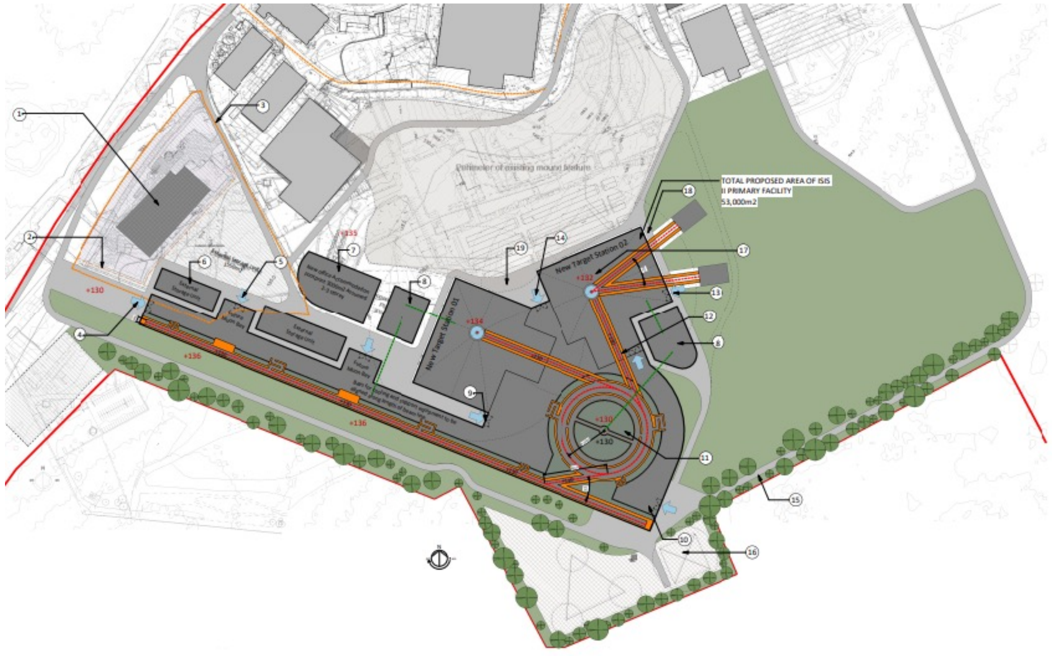


The ISIS-II Neutron and Muon Source

- The proposed 1.2 GeV beam upgrade to the ISIS Neutron and Muon Source.
- Overall power around 2.4 MW, dependent on target technology.



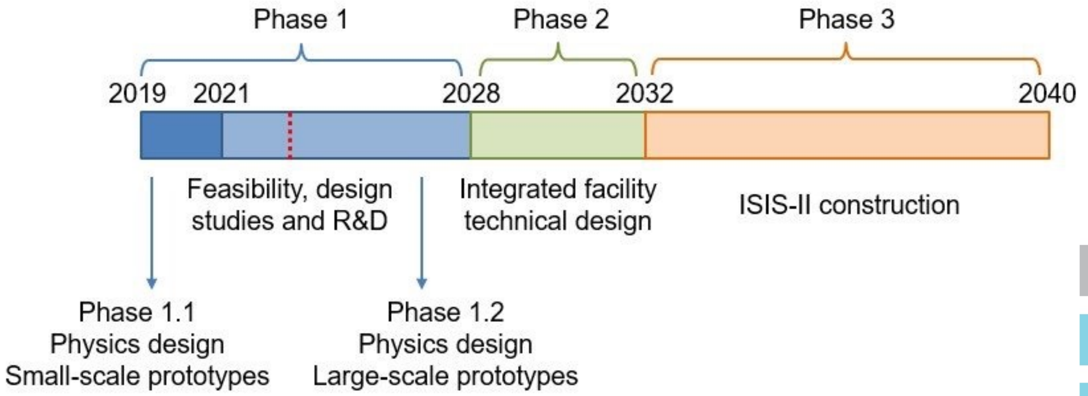
Proposed ISIS-II timeline.



One proposed design option for ISIS-II.

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

Timeline



Proposed ISIS-II timeline.

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

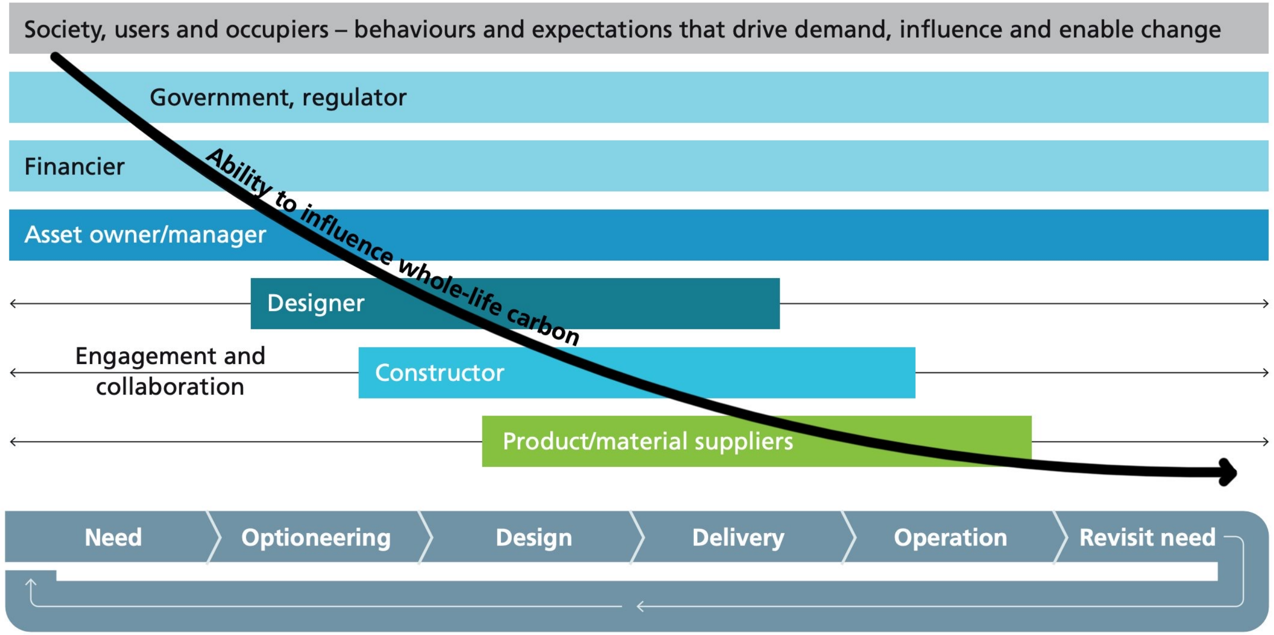
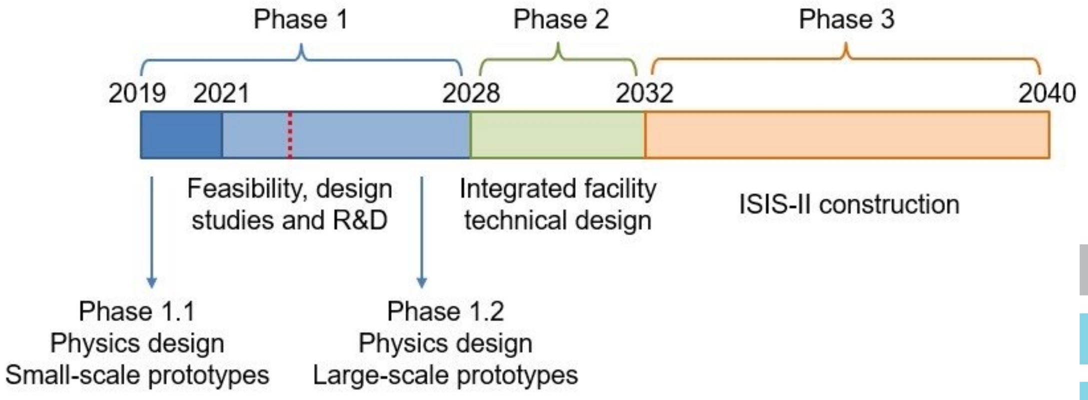


Fig 2.1: Value-chain members' ability to accelerate decarbonisation throughout the delivery process

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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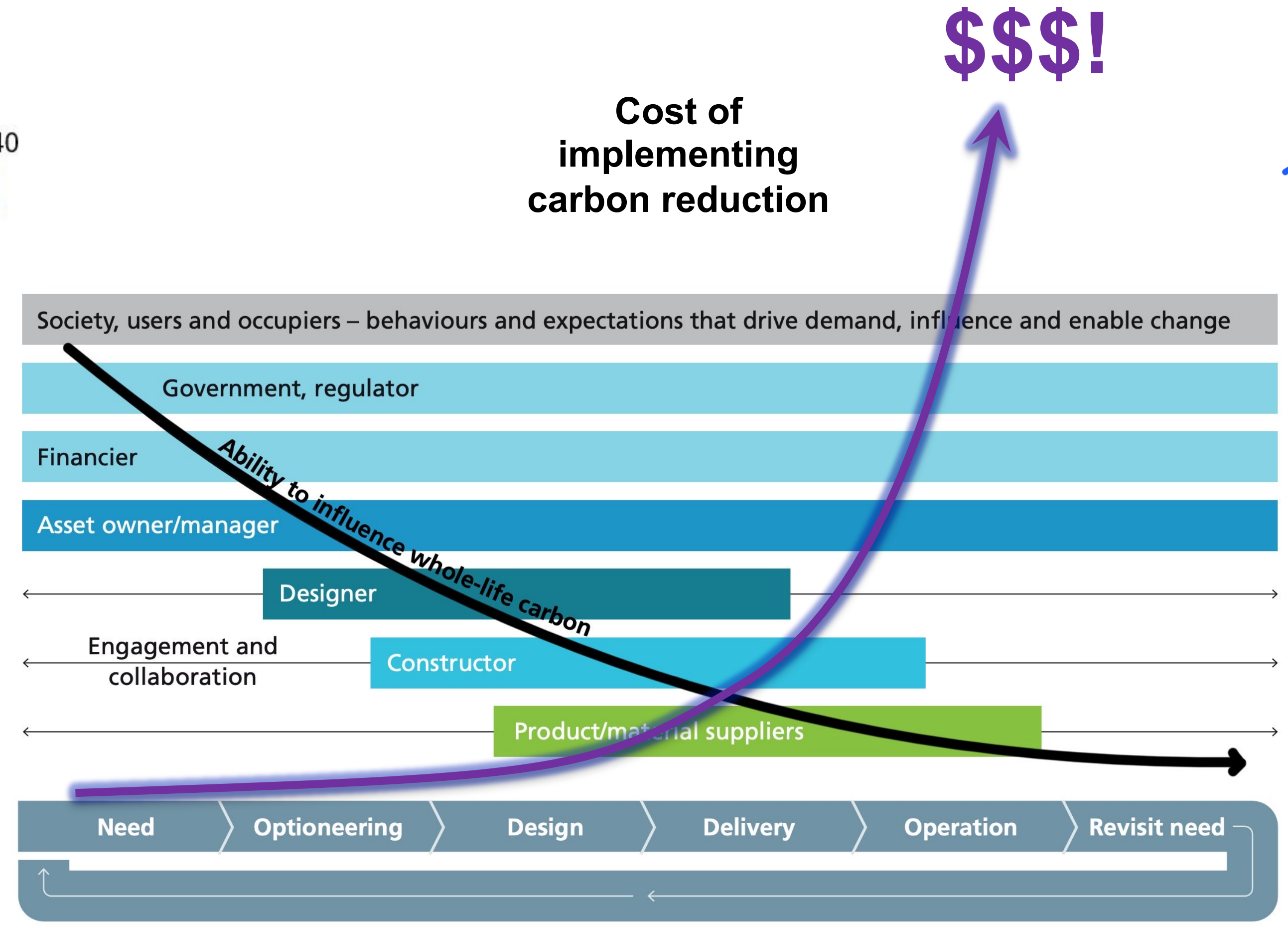


Fig 2.1: Value-chain members' ability to accelerate decarbonisation throughout the delivery process

[AS 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)]

What do we hope to achieve?

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

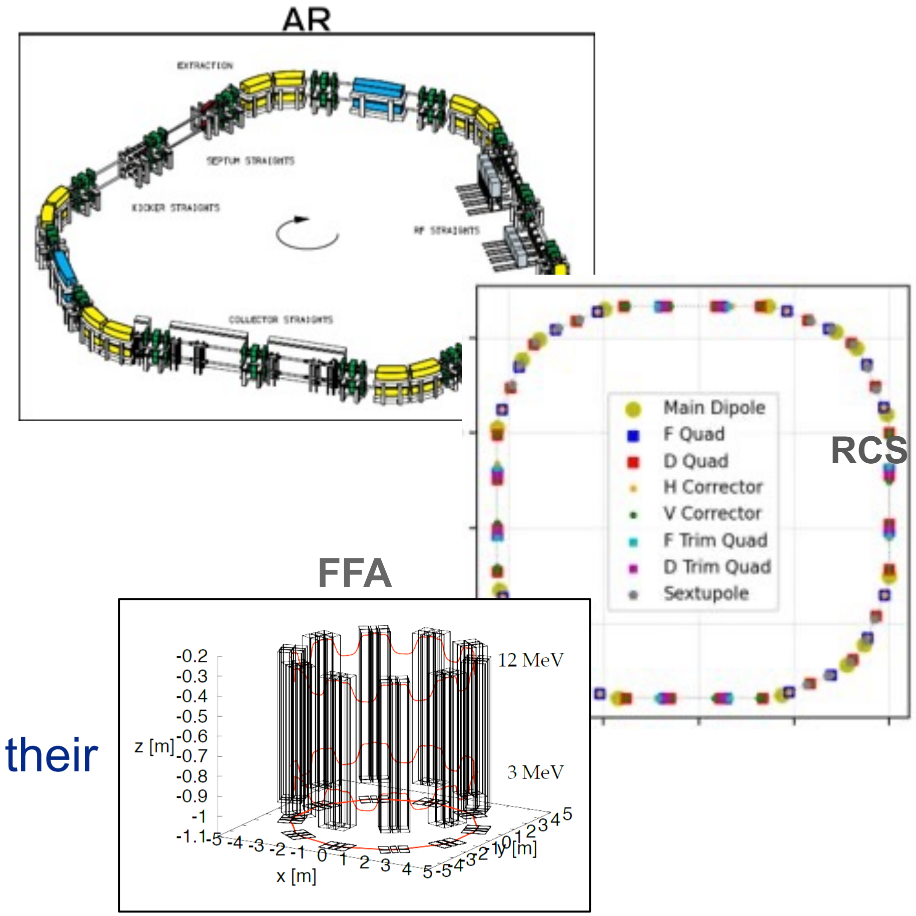
Methodology

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

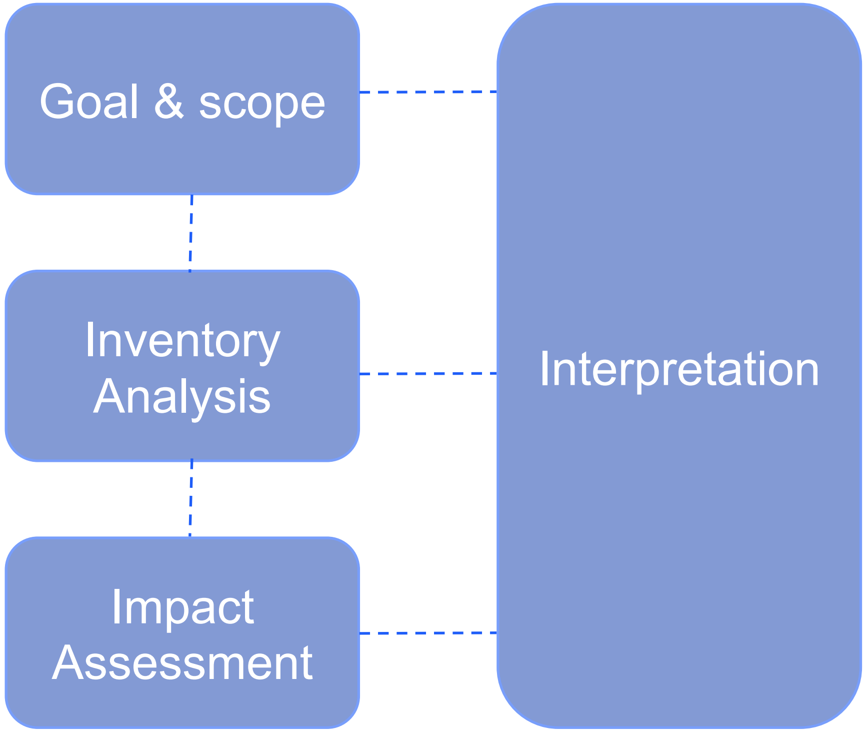
Two key stages to this analysis:

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)

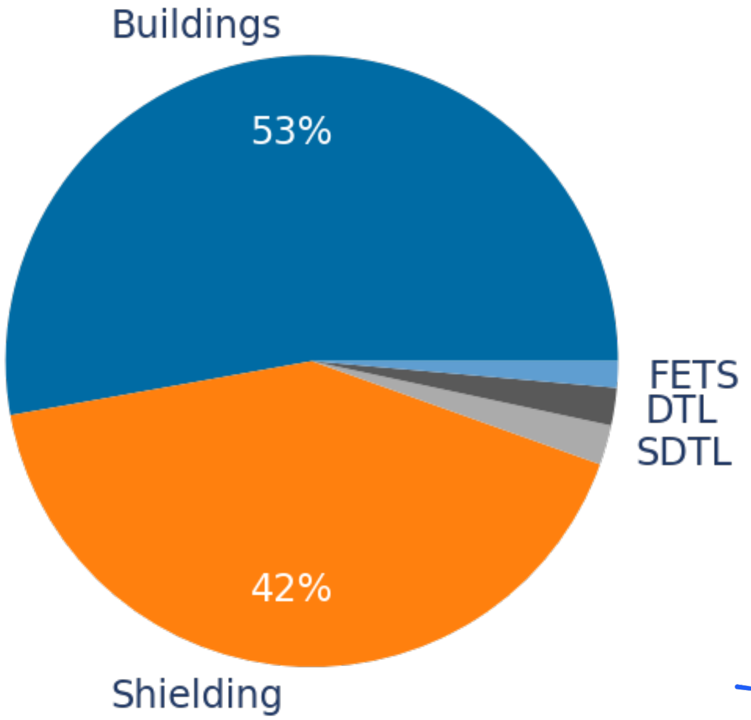


LCA steps.

Inventory Analysis

Construction

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



Estimated CO_2e impacts of various ISIS-II LINAC components for construction.

It is apparent (and unsurprising) that the largest CO_2 eq impacts in construction, at this stage in the study, originate from concrete and steel.

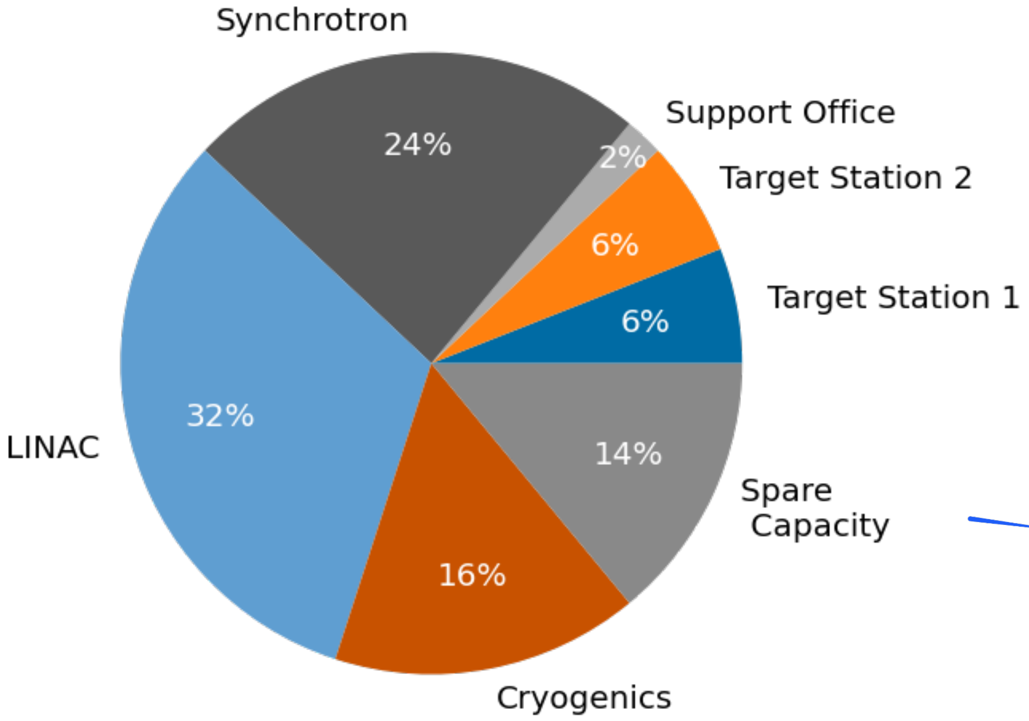
Inventory Analysis

Construction

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

Operation/Active life

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



Estimated ISIS-II electricity requirements
Big Science Scheme

Inventory Analysis

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- Computing

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Decommissioning (~2100 – 2170)

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

ISIS radioactive waste
150 – 300 tonnes of radioactive waste per year
~30,000 – 35,000 tonnes decommissioning

What would it cost to dispose ISIS current waste right now?

Waste Category	Current Volume	Disposal Cost
LA-LLW	1,140 te	~ £2.2 M
LLW	100 te	~ £1.5 M
ILW	70 te	~ £ 70 M

This is just disposal cost

Thanks to Chris McKay

Inventory Analysis

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Life Cycle Information	**Global Warming [kt CO_2 eq]**
A. Construction	$\mathcal{O}(20)$
B. Operation	$\mathcal{O}(40)$
C. Decommissioning	TBC

Global Warming Impact of defined ISIS-II LINAC components shows construction and operation to be of the same order of magnitude.

The issues that come with performing an LCA (on a full facility)

- Complexity
- Tools available
    - Software
    - Databases
    - Life Cycle Impact Assessment Methods
- (Radioactive waste)

Complexity

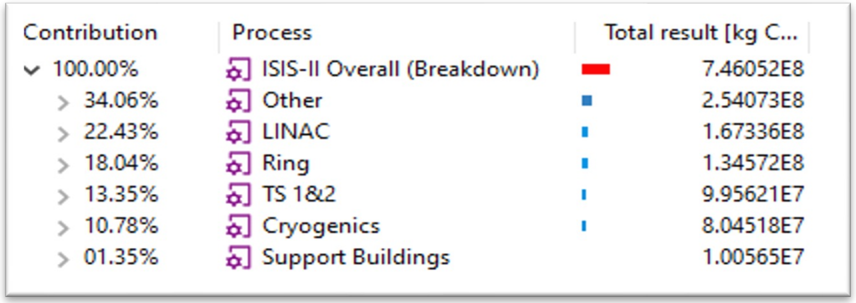
- Must meet ISO requirements to publish a LCA
    - Due to strong standards to follow there is a steep beginners learning curve (time)
    - Specialists/experts required (time and/or $$)
    - May need external consulting ($$$)
- Comprehensiveness and level of detail
    - High level of detail required
        - 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

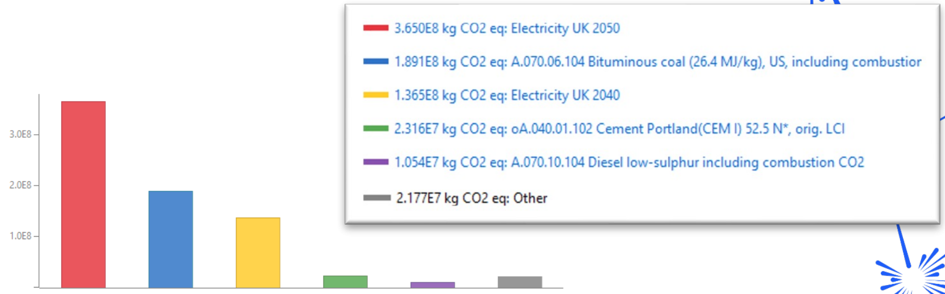
- Realistically, ISO standards to follow may be too rigid for all accelerators (and tests, components etc.) designs to have a full LCA performed on them.
- Other options that should be considered
  - ‘simplified’ LCAs
  - Bulk material LCA (e.g. show that 95% materials make up 99% of impact)
  - Carbon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

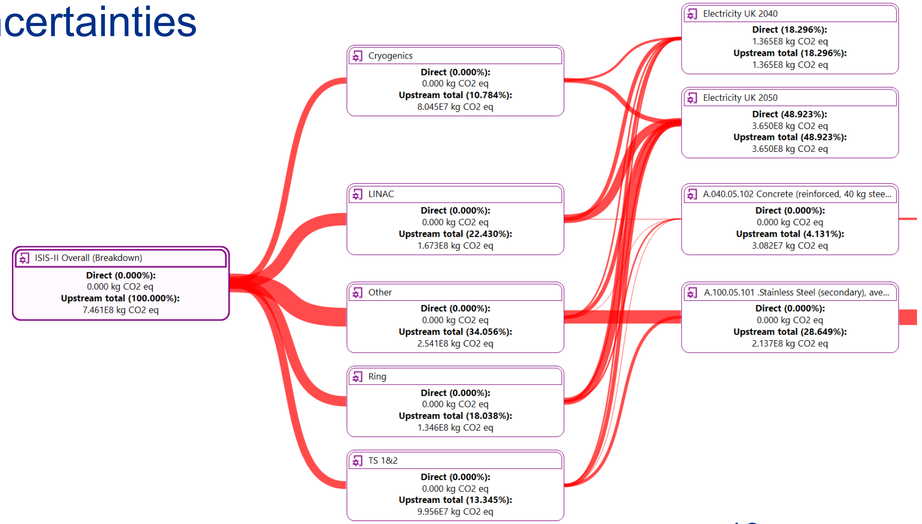
Tools available: LCA Software

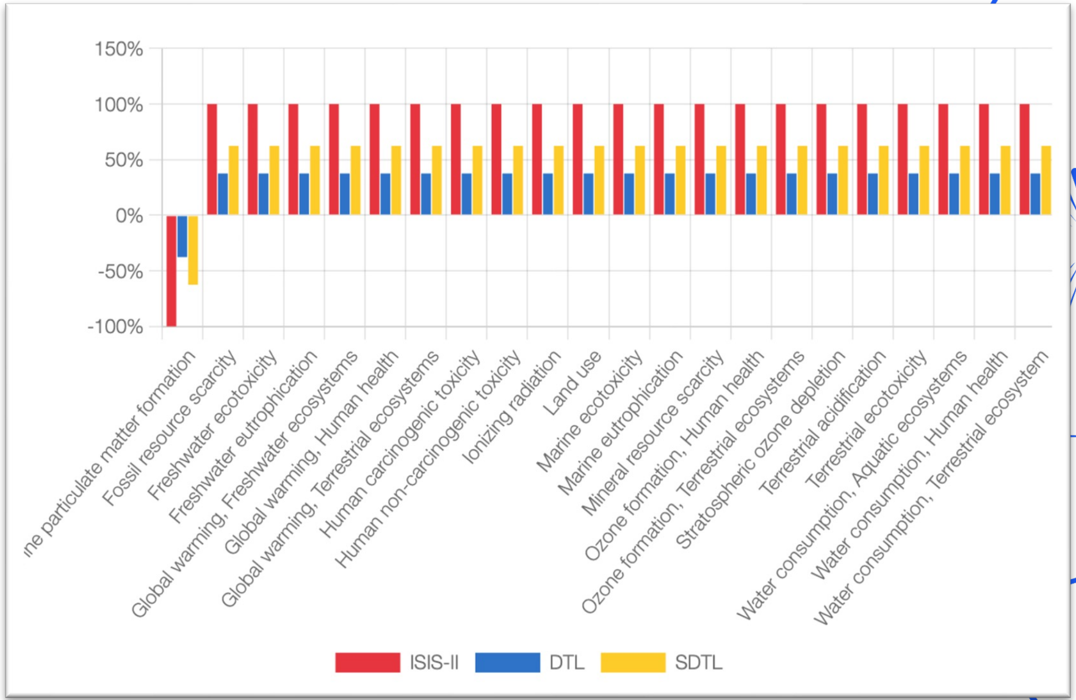
- Many software options available (GaBi, Simapro, OpenLCA)
  - Many cost *$$$*
- Different software *can* create differing results through different handling of data, end of life, etc.
- LCA software not necessarily as straightforward as it may seem
- OpenLCA
  - Open Source
  - Compatible with Python
  - 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.

<u>Example</u>

Ecoinvent:

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

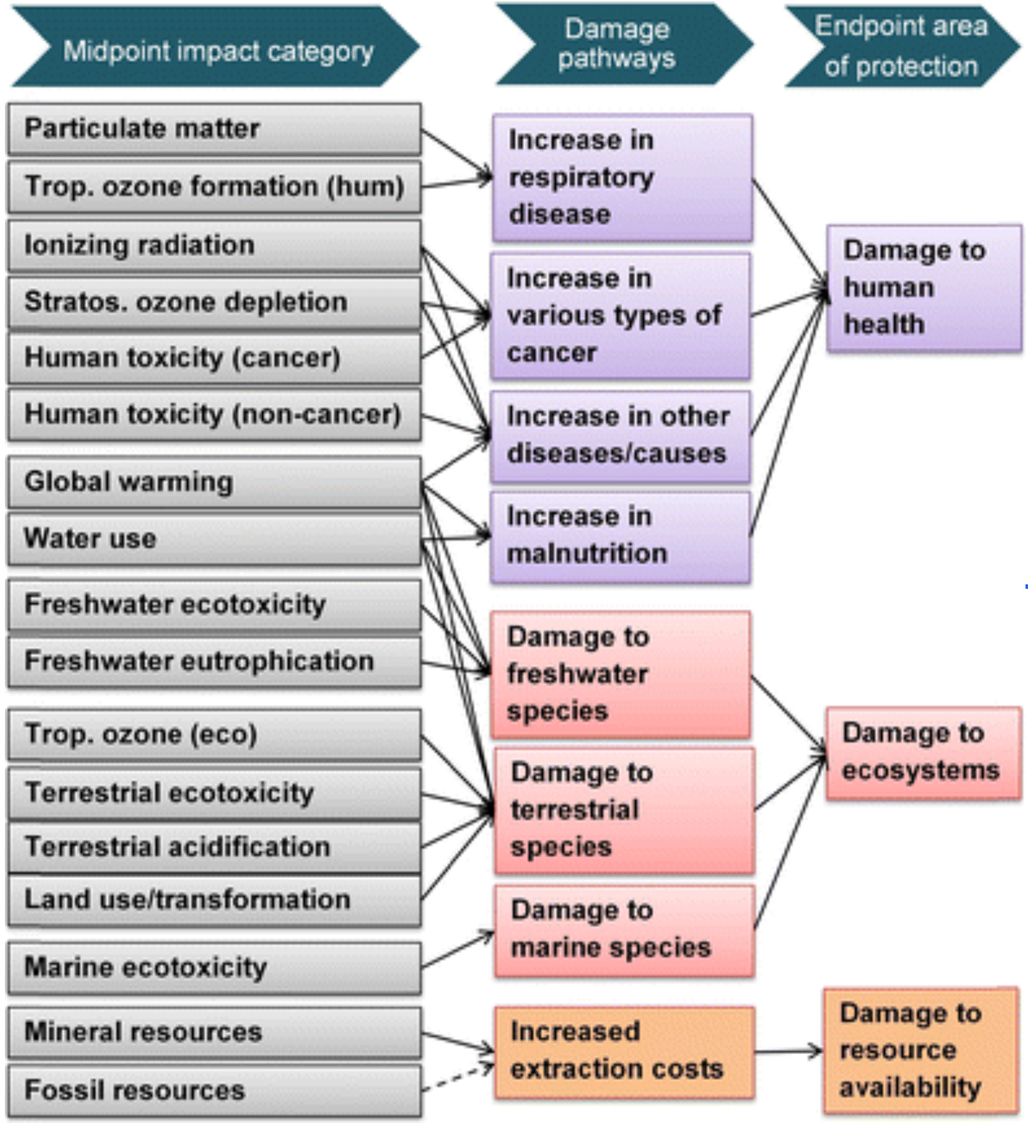
Idemat:

- Academic license is free! Paid work must use a commercial license.

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,…)

Particular difficulty with radiation (solid waste)



Summary and Conclusion

- Understanding and reducing the environmental impact of *all aspects* of research is necessary.
- To evaluate the environmental impact of ISIS-II, an impact analysis is well underway.
- To inform the design options for ISIS-II and the next funding bid, a simplified Life Cycle Assessment will be performed.
- LCA's are a very comprehensive environmental impact assessment tool
- They enable hotspot analyses, comparison of impacts of different designs, reporting of (comparative) impacts and can further efforts in reduction of impact
- There are some issues that come alongside them, e.g.
  - To perform a legitimate LCA we need time and expertise (money)
  - Tools are not (yet) standardized within physics so assessments are not (yet) entirely comparable
- With time and effort, this can only improve

Back-up slides

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"

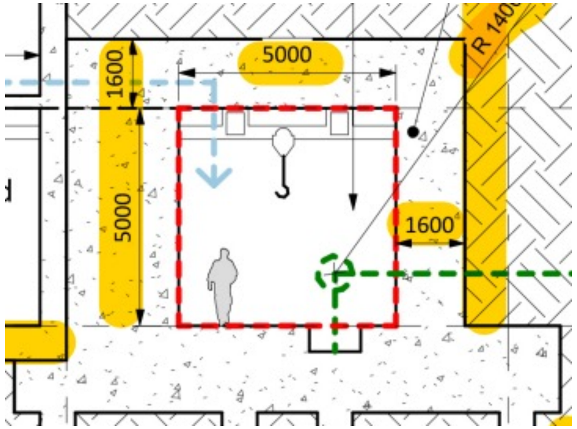
Inventory Analysis

Modelling performed using existing facilities such as SNS and J-PARC, where ISIS-II designs not yet available

Construction

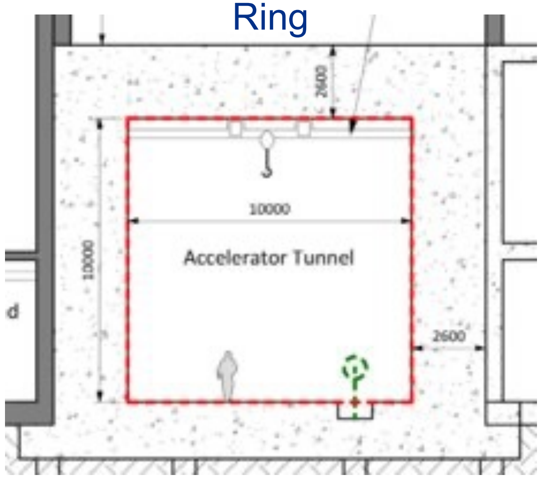
- Facility (Buildings, Tunnelling, Location)
- Machine (Accelerator Components, Ancillaries)
- Shielding
- Computing

LINAC



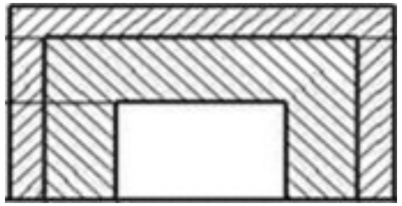
$10s\ ktCO_2$

Ring



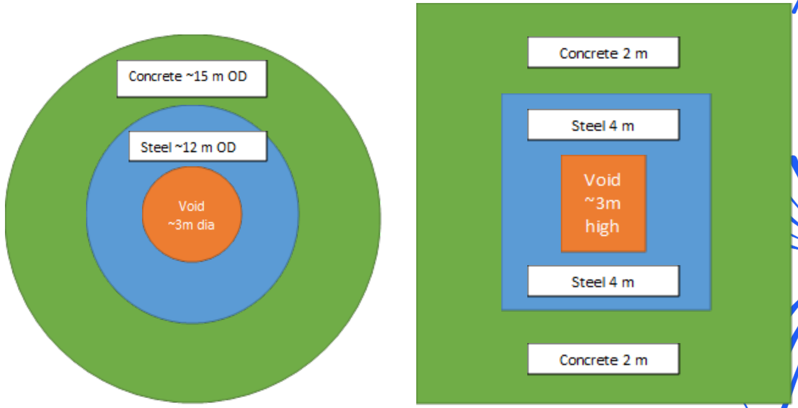
$10s\ ktCO_2$

EPB



$100s\ ktCO_2$

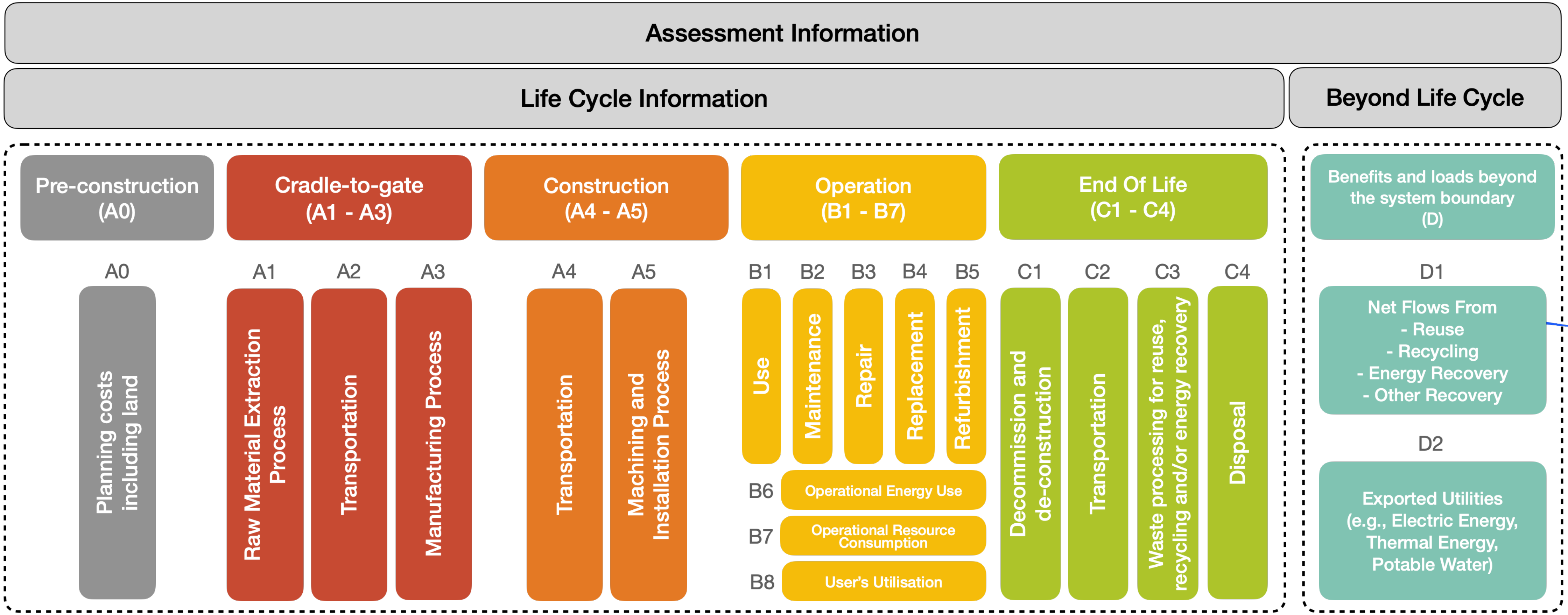
Targets



$10s\ ktCO_2$

Impact Assessment

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

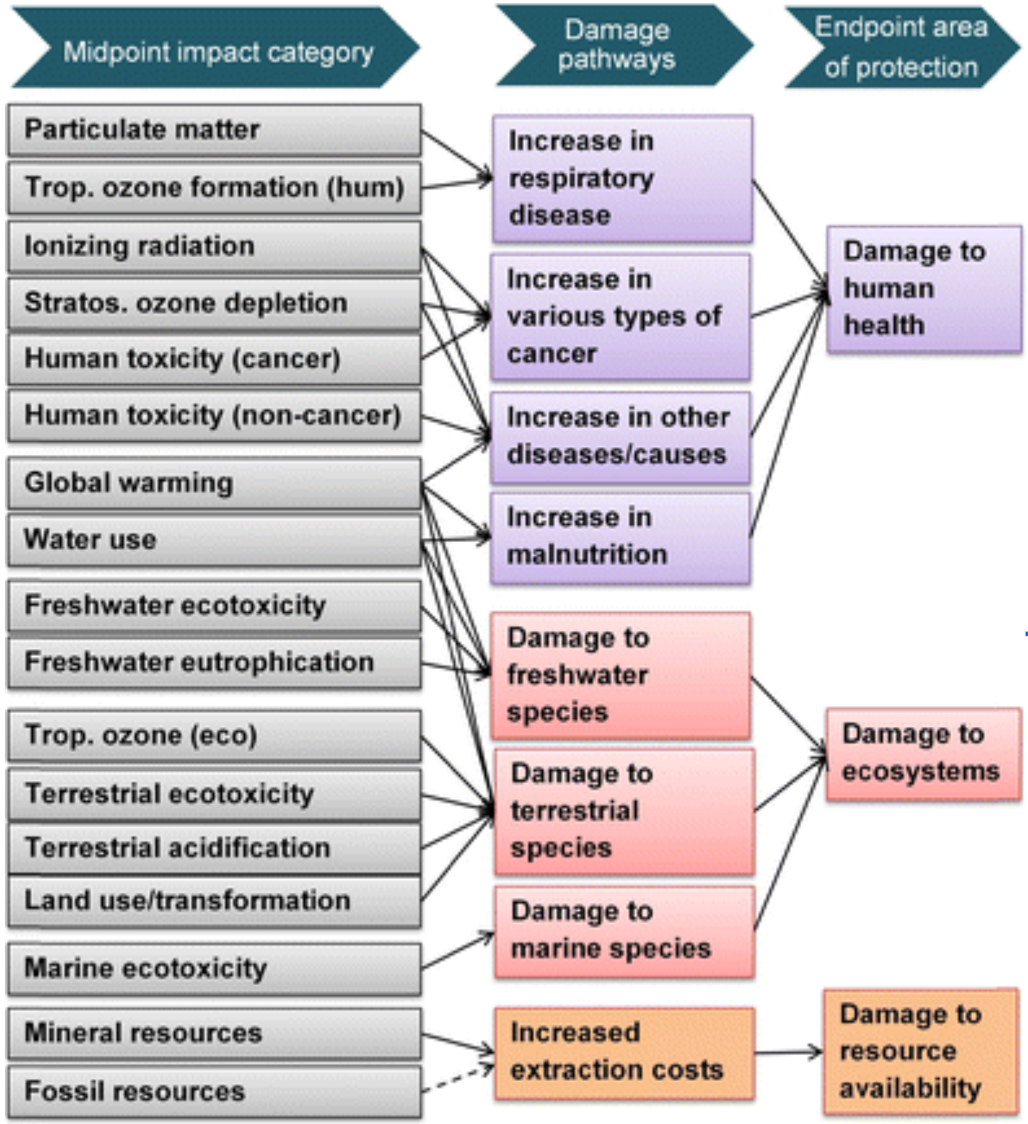


BS EN 17472:2022

A. Construction
B. Operation
C. Decommissioning

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.



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