Environmental Sustainability and Particle Accelerators

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JAI Accelerator Course, Oxford

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John Adams Institute for Accelerator Science

Overview

Particle Accelerators

- Intersection with The Climate Crisis
- Reducing environmental impact
- Evaluating environmental impact

The Climate Crisis

- How does this actually relate to the field of accelerator physics?

Definitions:

- **Sustainability** has many varied definitions: "a social goal for people to co-exist on Earth over a long time."
- **Greenhouse Gas** (GHG) – any gas that absorbs infrared radiation emitted from the Earth's surface
- **Global Warming Potential** (GWP) measures the heating effect of a GHGs compared to CO_2
  - **CO_2e** – Carbon Dioxide Equivalent
    - CO_2, methane, nitrous oxide and fluorinated gases

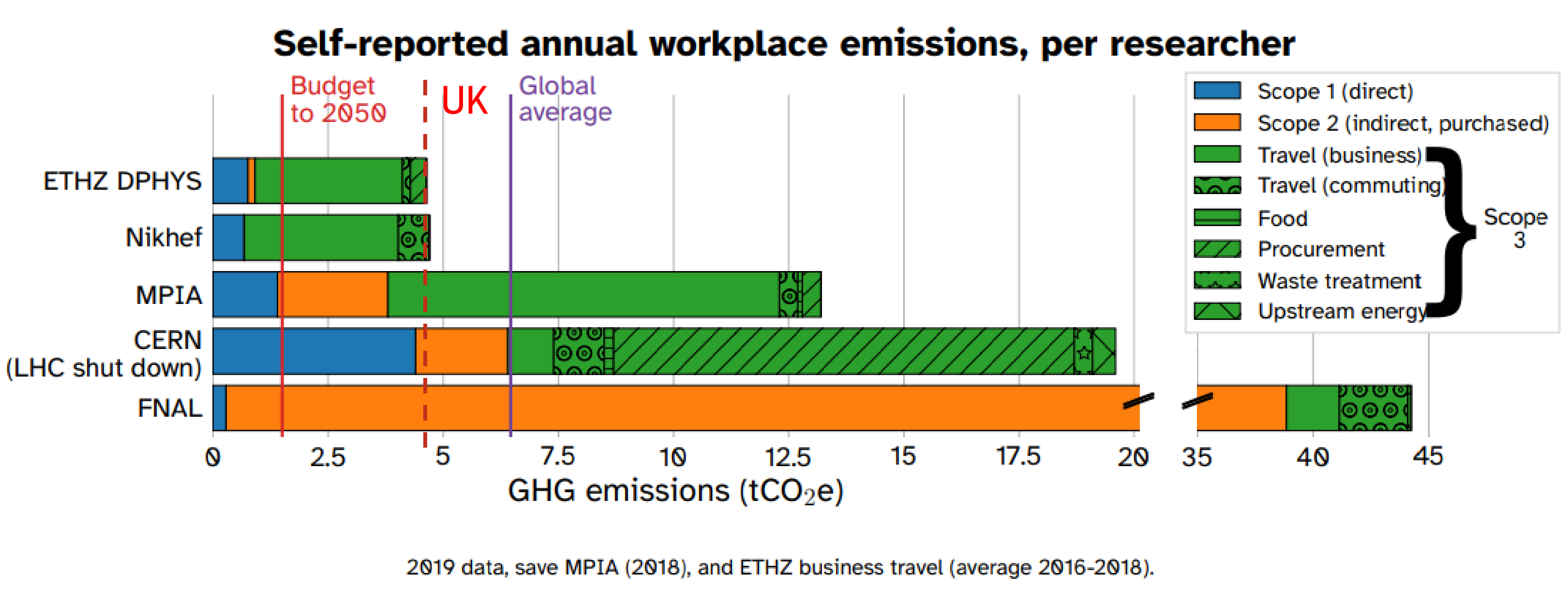
GWP of GHGs

The climate issue | Nature Astronomy

Why particle accelerators?

Large accelerator facilities are generally unsustainable:

- resource consumptive, and
- next generations aim to grow in size and/or power, and therefore (generally) consumption.



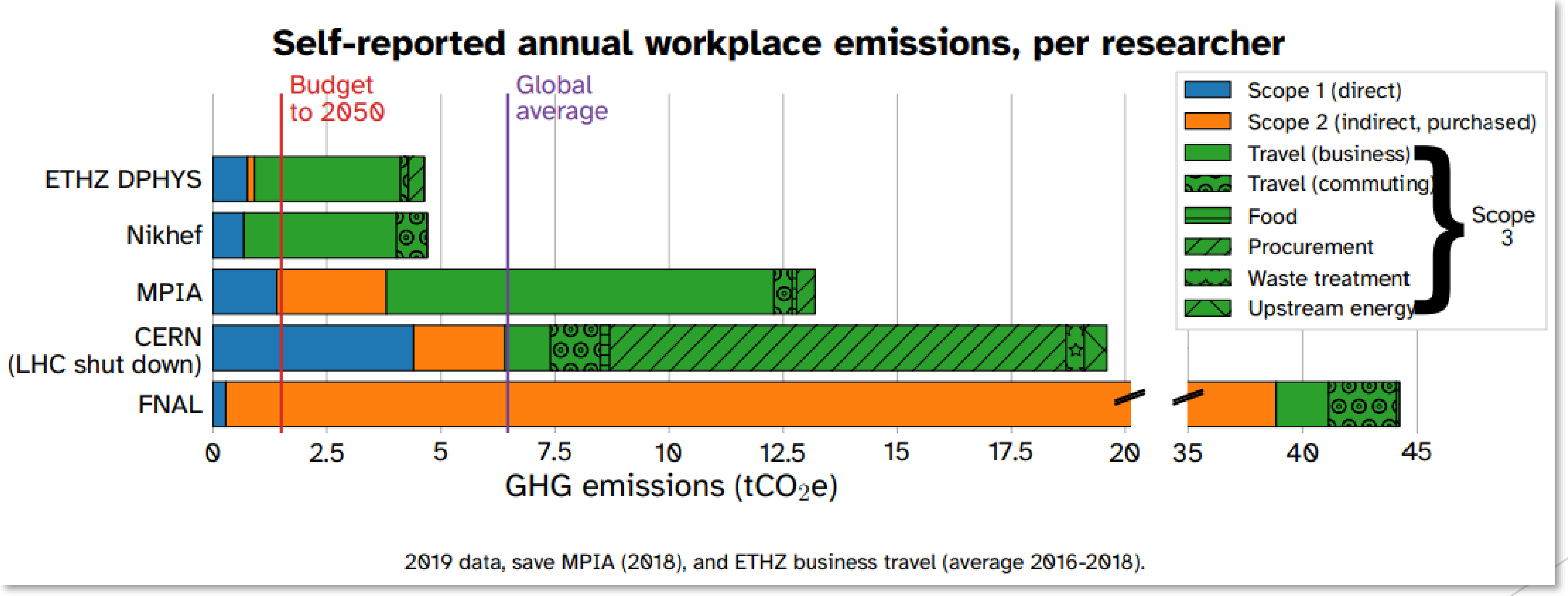
Reported workplace GHG emissions[1].

For comparison, in the UK an average person emits 4.7 t CO_2e a year

[1] Environmental sustainability in basic research: a perspective from HECAP+

Why particle accelerators?

Scope 1: **direct** GHG emissions
i.e., on-site burning fossil fuels and chemical reactions.



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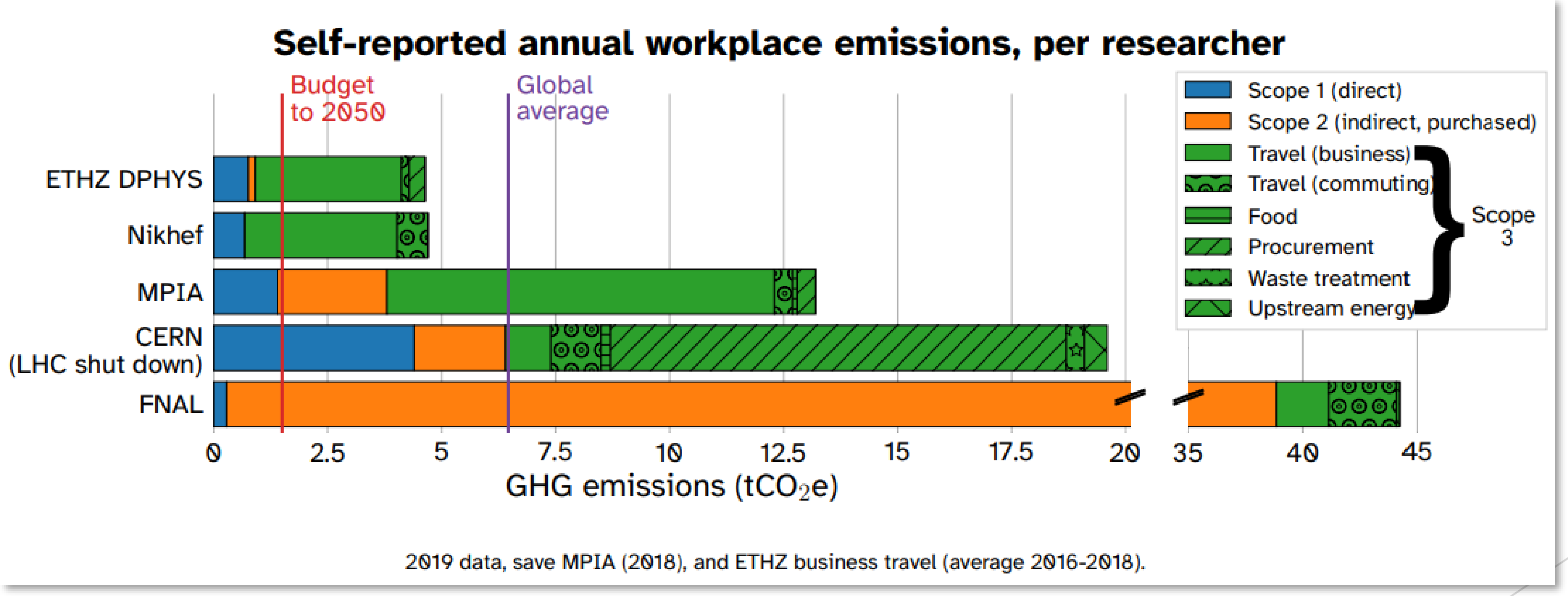
Why particle accelerators?

Scope 2: **indirect** GHG emissions
resulting from the generation of purchased electricity, heat, or steam.



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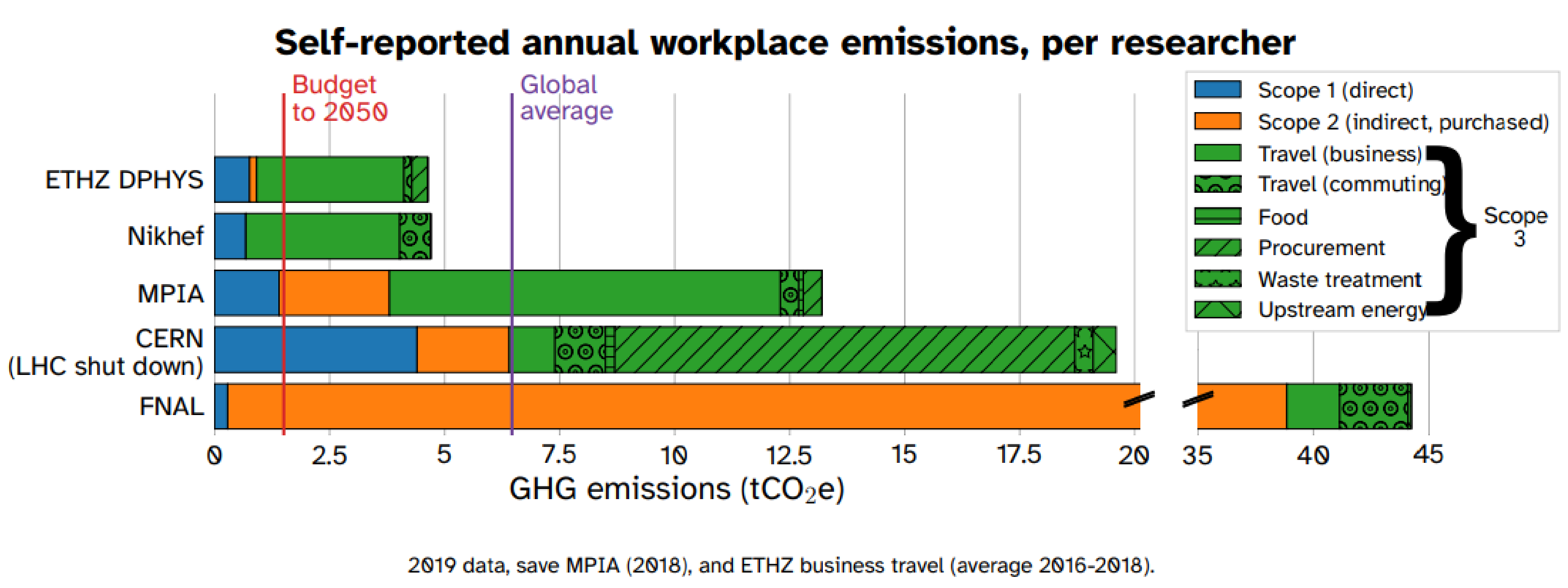
Why particle accelerators?

Scope 3: **all other indirect** GHG emissions in the value chain of the organisation associated with activities and sources including but not limited to:
transportation of goods, extraction and production of purchased materials, employee commuting, investments, …



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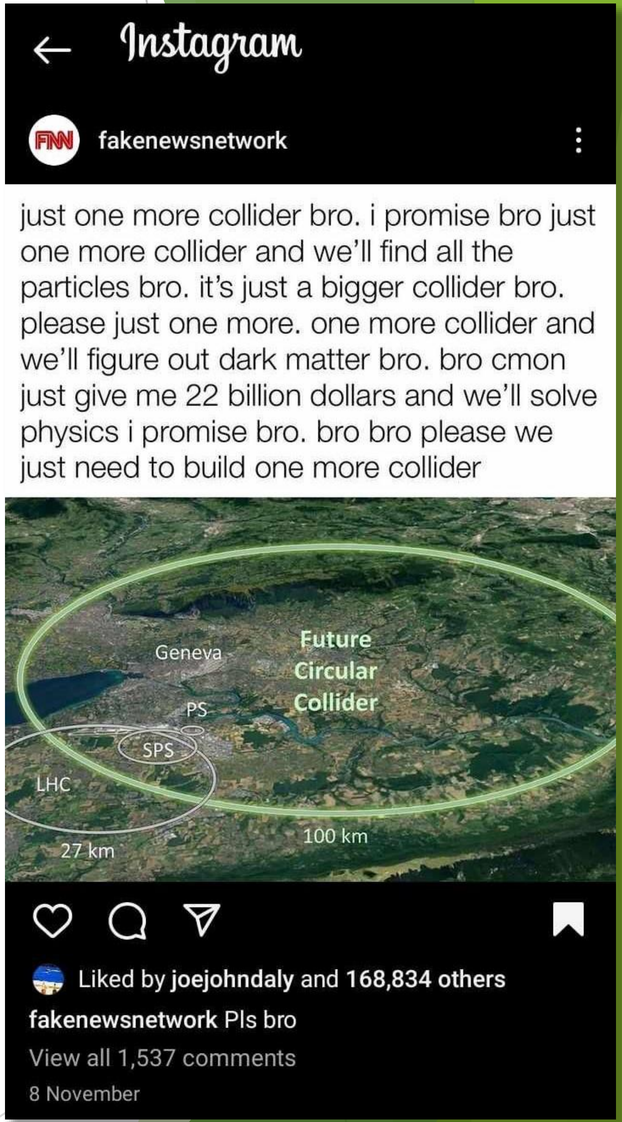
Why particle accelerators?

One *can* argue:

- There are so many other, larger and worse environmental impacts.
- Accelerator physics has contributed so much knowledge and benefits to humanity, and will continue to do so; it's worth it.

1. The Climate Crisis is a compound problem, and an issue for everyone.
2. Moral and social duty to lead by example.
3. Policy affects us.
   - The environmental impact of construction of a large collider facility will have a carbon impact similar to that of a redevelopment of a neighbourhood in a major city. We **will** come under scrutiny.
4. Often largely publicly funded. Governmental and taxpayer support is necessary.



[2203.12389] Climate impacts of particle physics

So, what can we do?

- We must adapt,
- reduce impact,
- & demonstrate our efforts

including considering and/or maintaining

- reliability,
- lifetime,
- efficiency,
- & science output

- Many efforts ongoing around the world!

Image Source

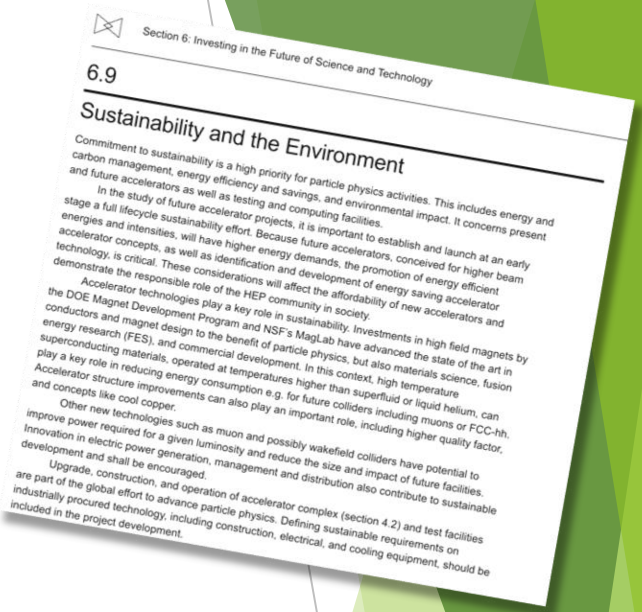
Reducing environmental impact

Efforts that are ongoing

- Policy and culture change
- Carbon emissions and environmental impact reports
- Designing with the environment in mind
  - New(er) technologies and R&D
- Resource consumption and waste

Recent policy changes

- Sustainability is getting a lot of first time mentions in physics
  - U.S. Community Study on the Future of Particle Physics Snowmass 2021
  - Particle Physics Project Prioritization Panel (P5) report 2023
  - European Particle Physics Strategy Update 2026?!
- Naturally affected by other policy:
  - Paris Agreement: Net Zero by 2050
  - UN Breakthrough (2030)
    - 100% of post-2030 projects must be net zero in operation and at least 40% less embodied carbon compared to current practice for 100% net zero for whole life cycle by 2050
  - UK Government: biodiversity net gain of 20%
- Self-imposed restrictions i.e. air travel


Section 6: Investing in the Future of Science and Technology

6.9

Sustainability and the Environment

Commitment to sustainability is a high priority for particle physics activities. This includes energy and carbon management, energy efficiency and savings, and environmental impact. It concerns present and future accelerators as well as testing and computing facilities.

In the study of future accelerator projects, it is important to establish and launch at an early stage a full lifecycle sustainability effort. Because future accelerators, conceived for higher beam energies and intensities, will have higher energy demands, the promotion of energy efficient accelerator concepts, as well as identification and development of energy saving accelerator technology, is critical. These considerations will affect the affordability of new accelerators and demonstrate the responsible role of the HEP community in society.

Accelerator technologies play a key role in sustainability. Investments in high field magnets by the DOE Magnet Development Program and NSF's MagLab have advanced the state of the art in conductors and magnet design to the benefit of particle physics, but also materials science, fusion energy research (FES), and commercial development. In this context, high temperature superconducting materials, operated at temperatures higher than superfluid or liquid helium, can play a key role in reducing energy consumption e.g. for future colliders including muons or FCC-hh. Accelerator structure improvements can also play an important role, including higher quality factor, and concepts like cool copper.

Other new technologies such as muon and possibly wakefield colliders have potential to improve power required for a given luminosity and reduce the size and impact of future facilities. Innovation in electric power generation, management and distribution also contribute to sustainable development and shall be encouraged.

Upgrade, construction, and operation of accelerator complex (section 4.2) and test facilities are part of the global effort to advance particle physics. Defining sustainable requirements on industrially procured technology, including construction, electrical, and cooling equipment, should be included in the project development.

Culture change

- We need it to make a real difference
- Embody sustainability within existing structures
- Design, manufacturing, operation etc. could carry on as normal without enforced policy/rules
- BUT with culture change
  - Not policy reliant
    - Can initiate change before policy is implemented
  - Creative, new solutions
  - Better attitudes and habits, i.e. air travel!

Carbon emissions and impact reports

- Climate impacts of particle physics
- Publish environmental impact reports
  - i.e. CERN, DESY
- Use carbon impact reports to design with the environment in mind

[2203.12389] Climate impacts of particle physics

Designing with the environment in mind

- Climate impacts of particle physics
- Publish environmental impact reports
  - i.e. CERN, DESY
- Lots of ideas in the pipeline
  - ILC, FCC, CEPC, CLIC, C^3

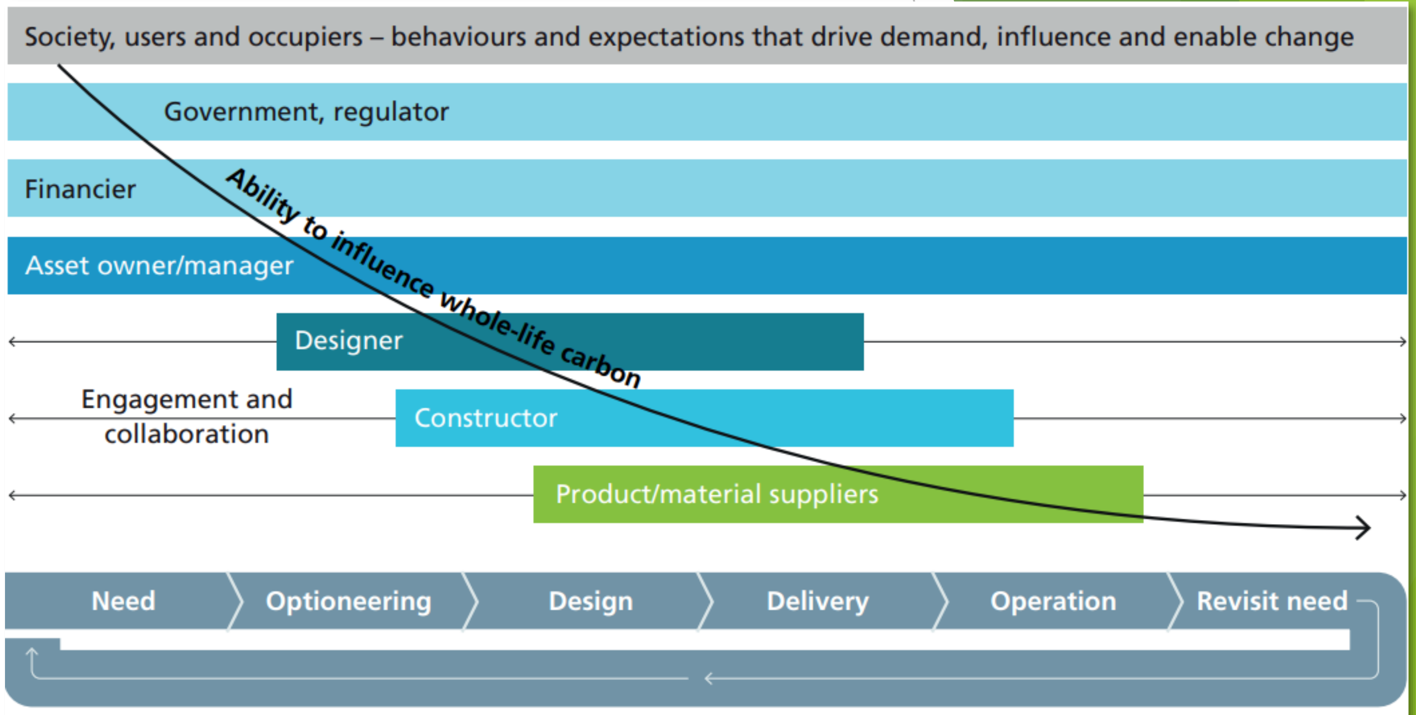


Fig 2.1: Value-chain members' ability to accelerate decarbonisation throughout the delivery process

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

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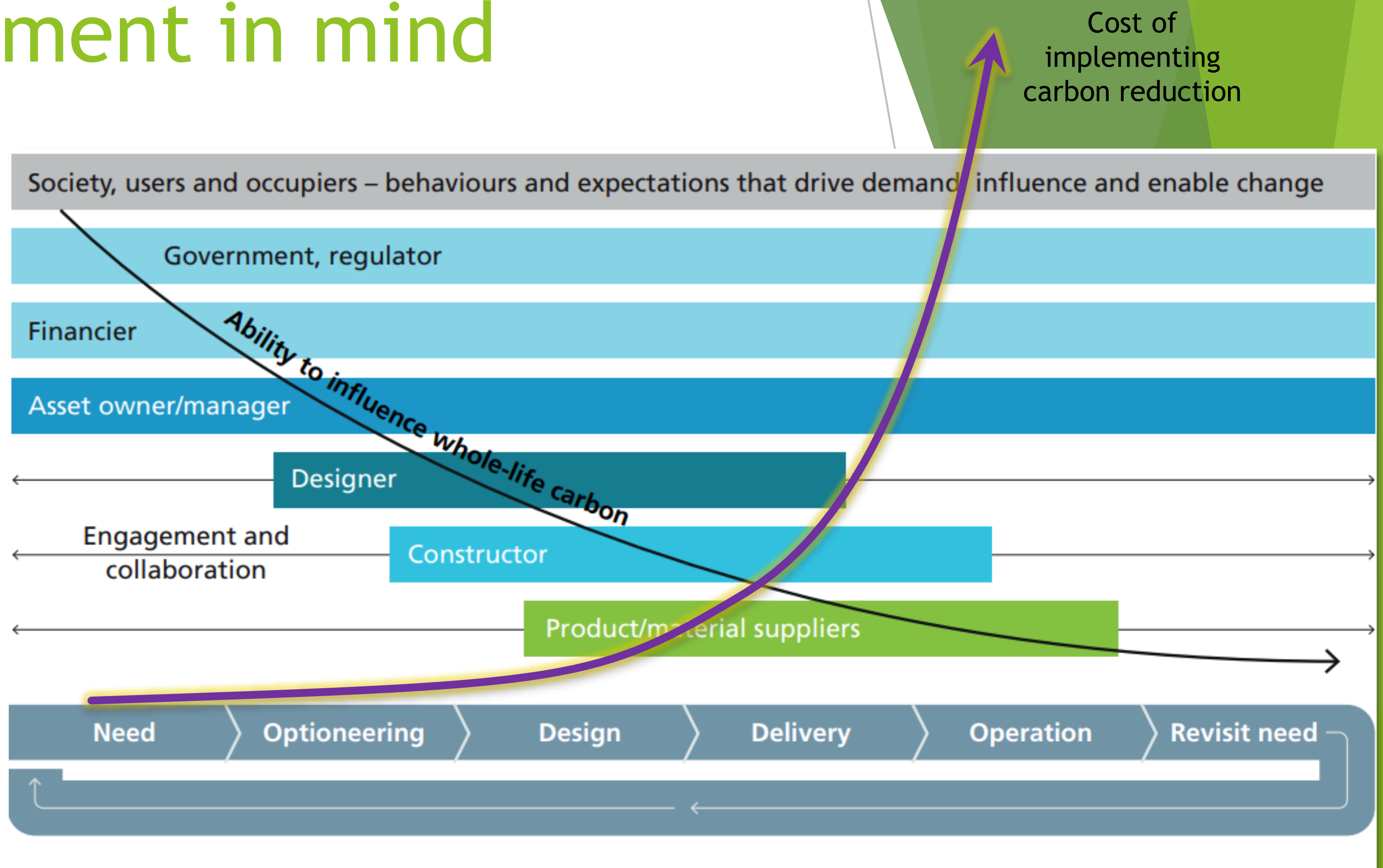


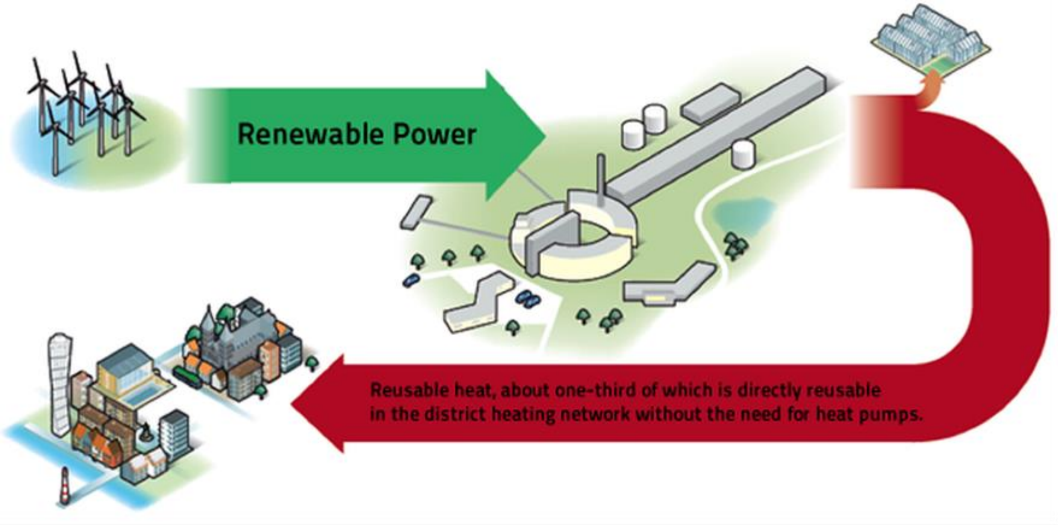
Fig 2.1: Value-chain members' ability to accelerate decarbonisation throughout the delivery process

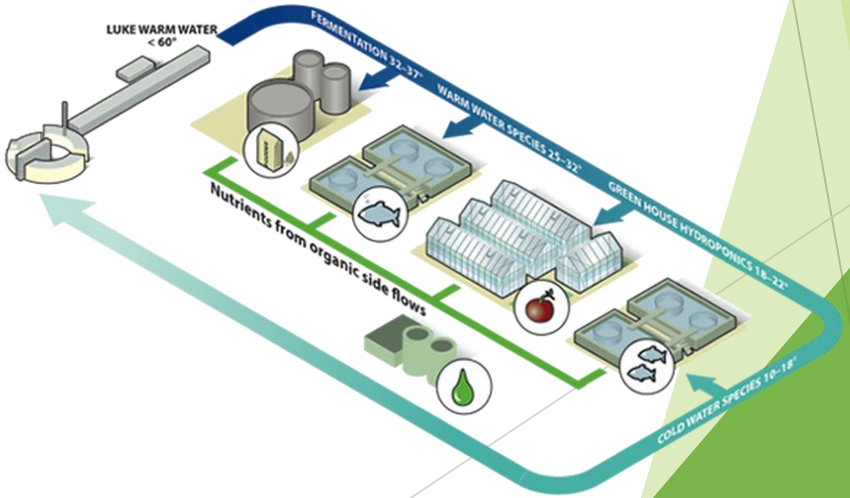
PAS 2080 guidance document: Practical actions and examples to accelerate the decarbonisation of buildings and infrastructure

European Spallation Source (ESS)

- <5 MW proton beam with a rotating target
- Committed to recycling the annual 254 GWh of waste heat energy via a district heating network
  - Built into the design of ESS
- Office (non-accelerator) buildings are BREEAM certified 'outstanding'

BREEAM



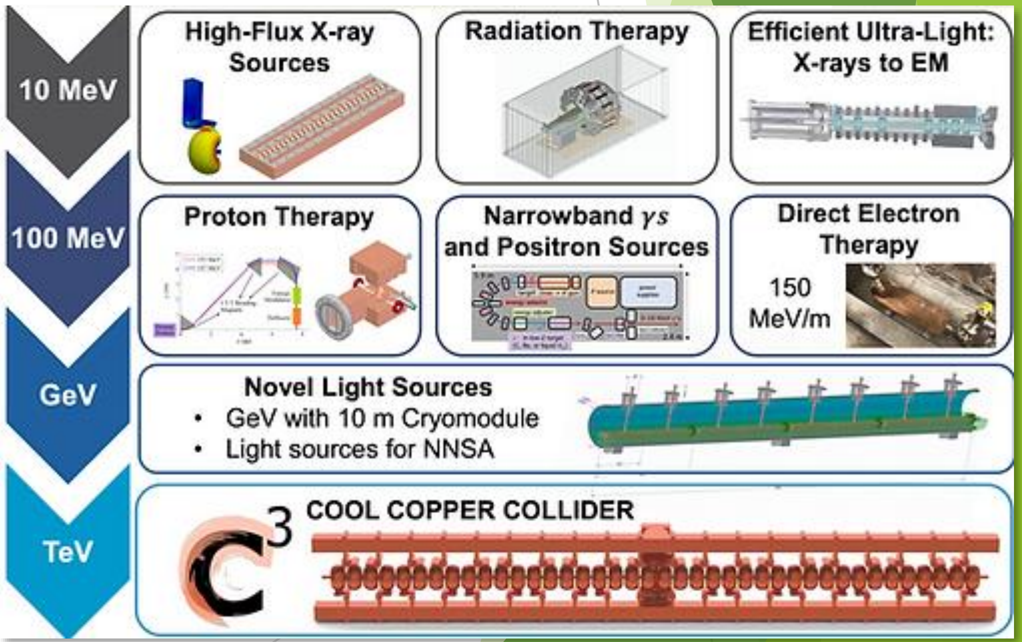


European Spallation Source Infrastructure

Cool Copper Collider (C3) at SLAC

- 250-550 GeV Linear Accelerator
- Compact 8km footprint, cut-and-cover construction evaluation
- Site power of 150 (175) MW for a beam power of 2.1 (2.45) MW
  - at an estimated 1.4% efficiency
- 185 MW solar farm could be built ($150 million), double covering the average power requirement of C3
  - Where excess power could be stored for night usage.

https://web.slac.stanford.edu/c3/about



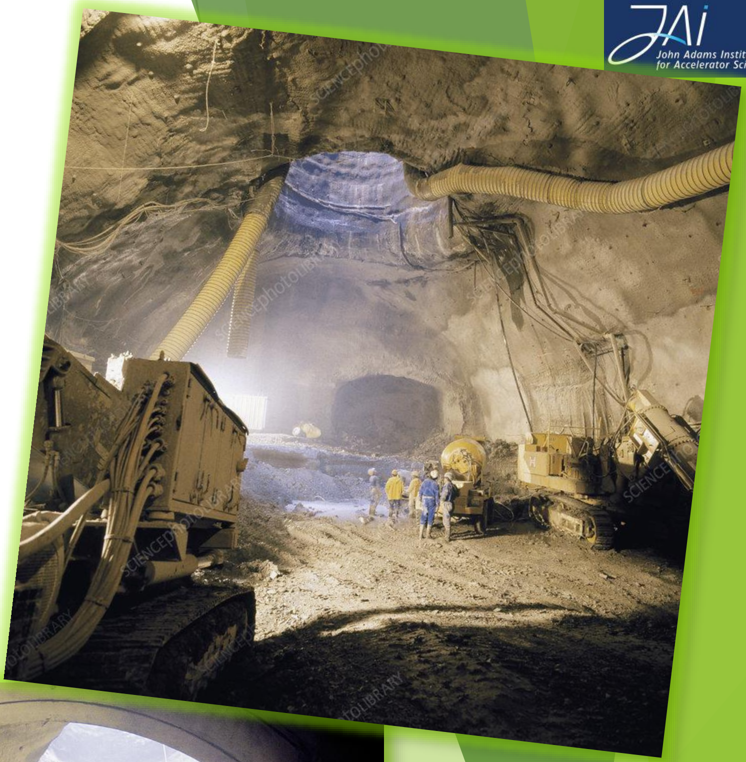
[2307.04084] Sustainability Strategy for the Cool Copper Collider

Cool Copper Collider (C^3) at SLAC

- Estimates of tunnelling impacts:

Global warming potential (GWP)

Project	Main tunnel length (km)	GWP (kton CO_2e) Main tunnel	+ other structures	+ A4-A5
FCC	90.6	578	751	939
CEPC	100	638	829	1040
ILC	13.3	97.6	227	266
CLIC	11.5	73.4	98	127
C^3	8.0	133	133	146



Science Photo Library

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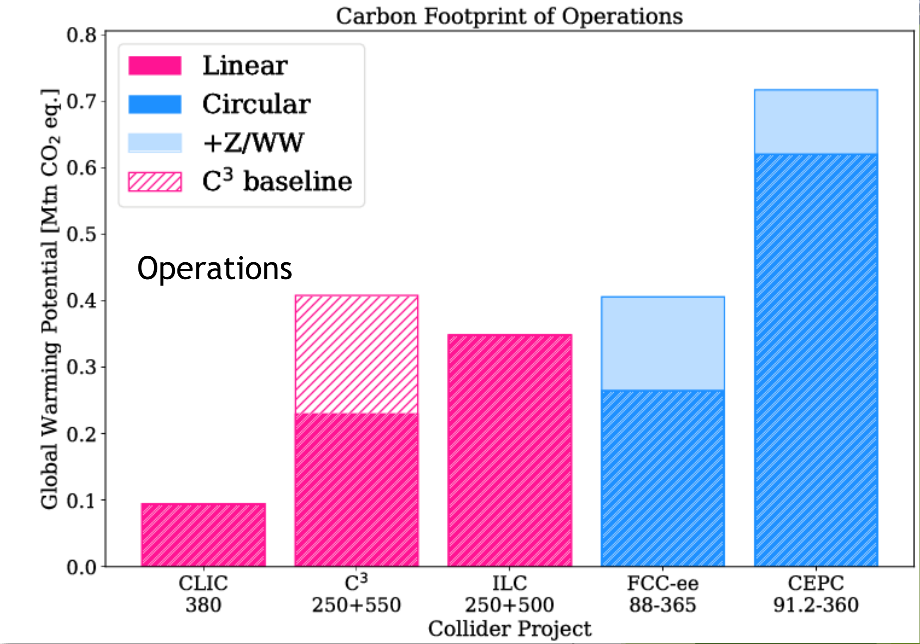

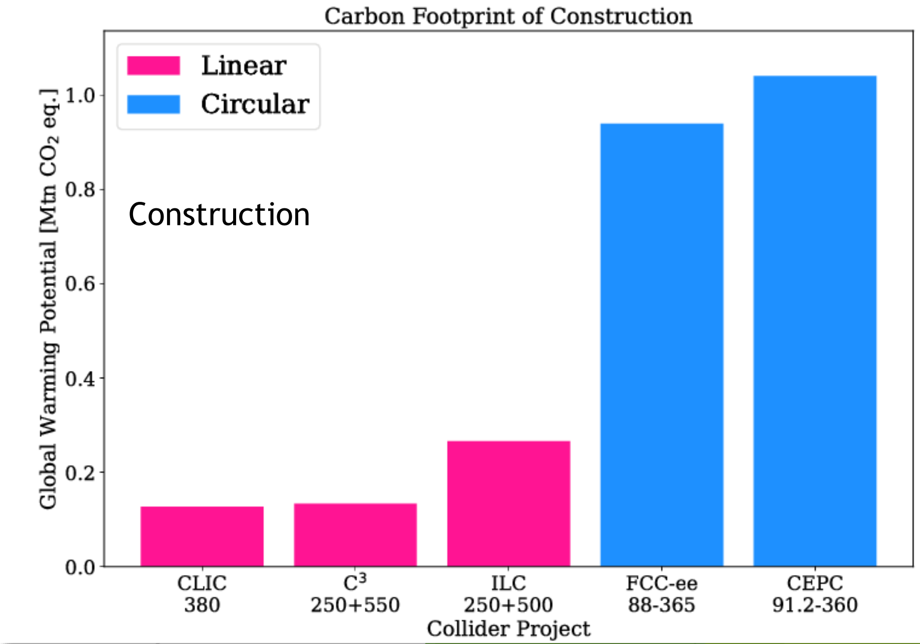

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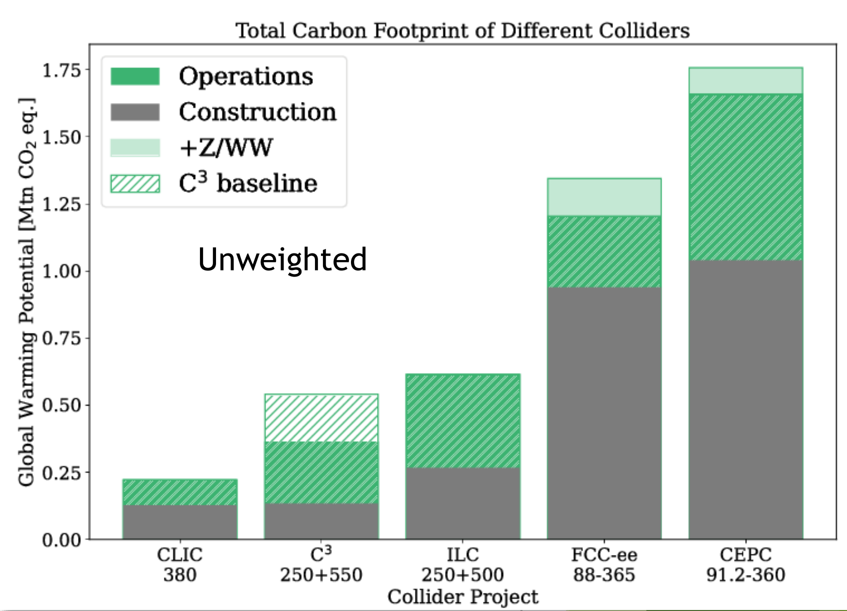
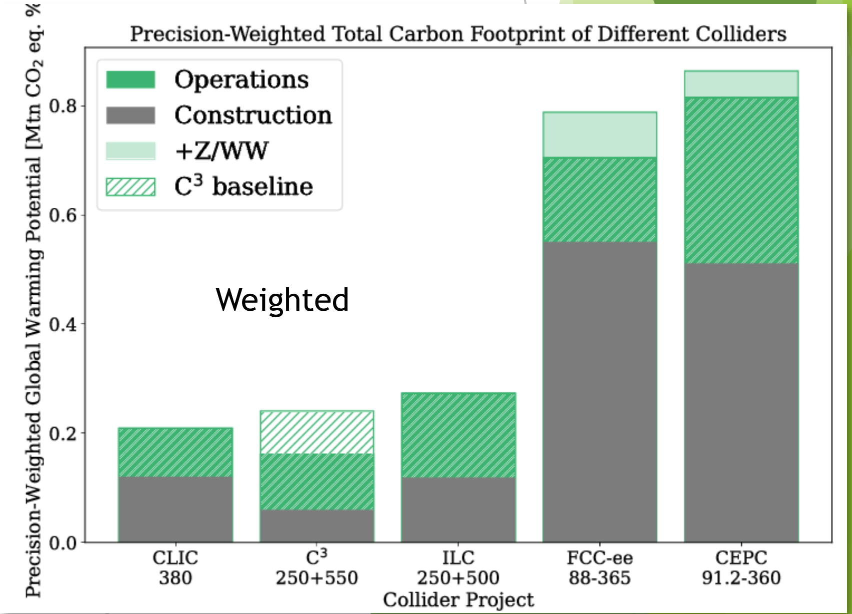
- Comprehensive comparative evaluation of carbon footprint relative to their expected precision.
  - Assumption: avg. of 20 tCO2/GWh.





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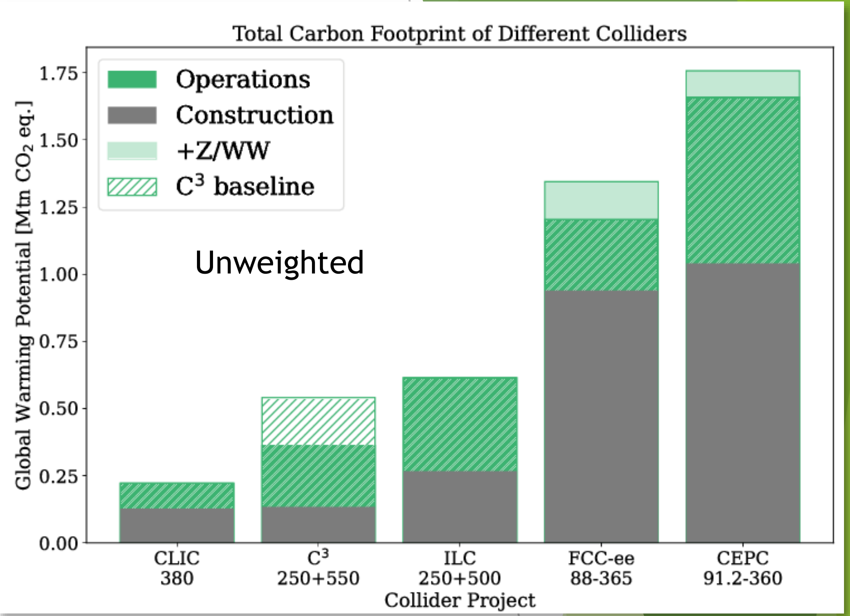
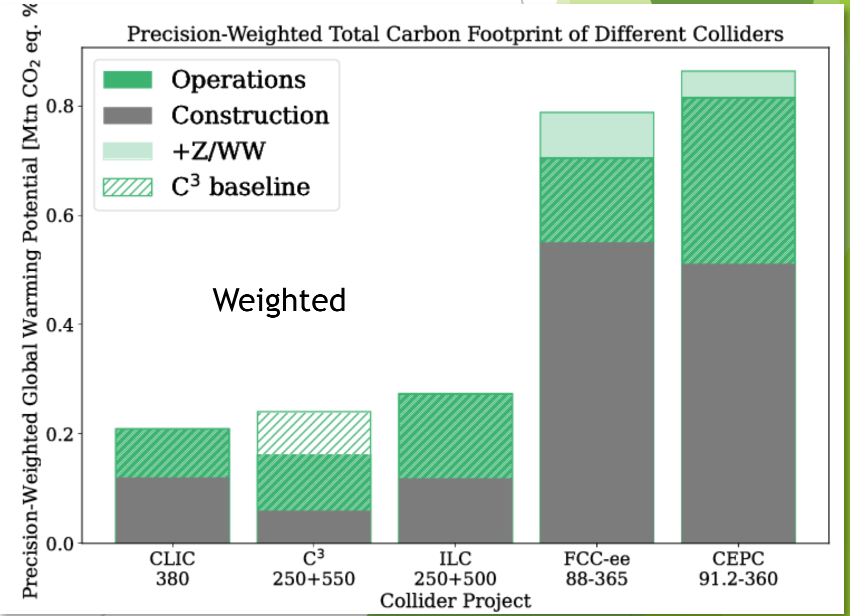
- Comprehensive comparative evaluation of carbon footprint relative to their expected precision.
  - Assumption: avg. of 20 tCO2/GWh.
- Not occurring here, but be aware of potential for greenwashing or "science-washing"



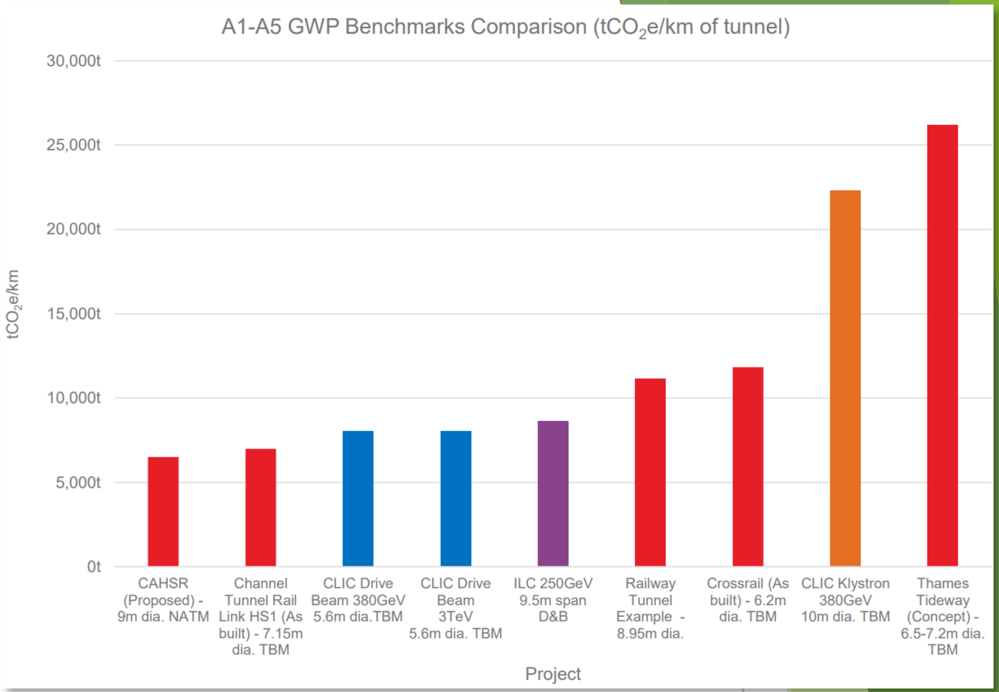


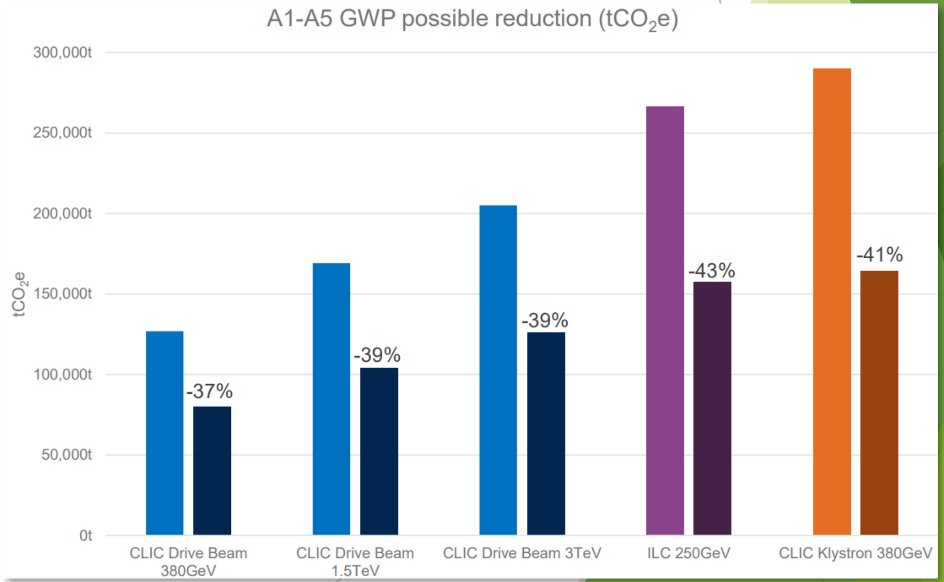
[2307.04084] Sustainability Strategy for the Cool Copper Collider

CLIC and ILC tunneling
Life Cycle Analysis (LCA)

- CLIC
  - Drive beam or Klystron
  - 380 GeV (1.5 TeV and 3 TeV) linear accelerator
  - 11 – 50 km

- ILC
  - 250 GeV (1 TeV) linear accelerator
  - 33 km

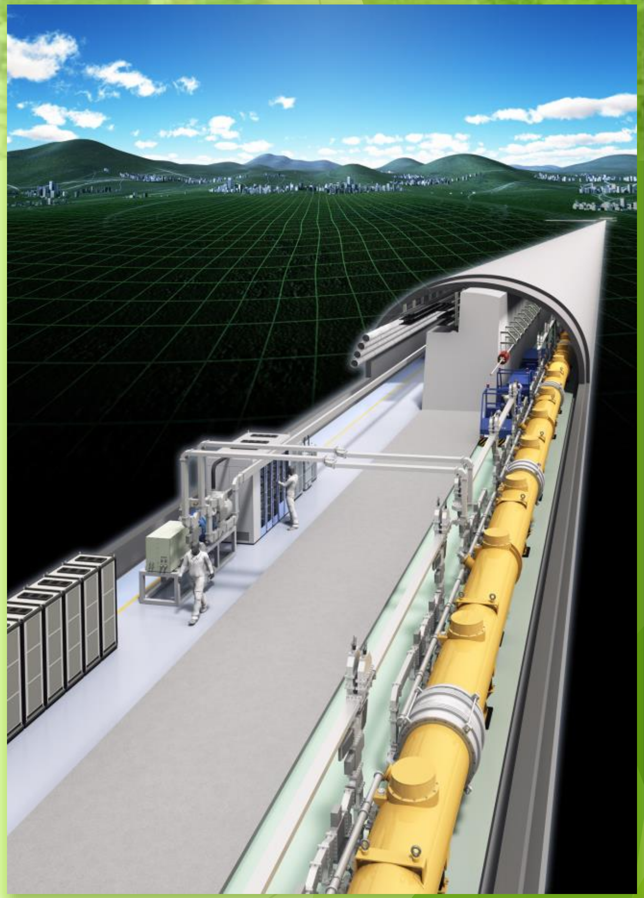




CLIC and ILC Life Cycle Assessment Final Report

Green ILC Project

- Evaluating options for a greener ILC
- Including:
  - Large wooden structures (from sustainable forestry)
  - Utilizing waste heat for greenhouses
  - Thermal storage (HASClay)



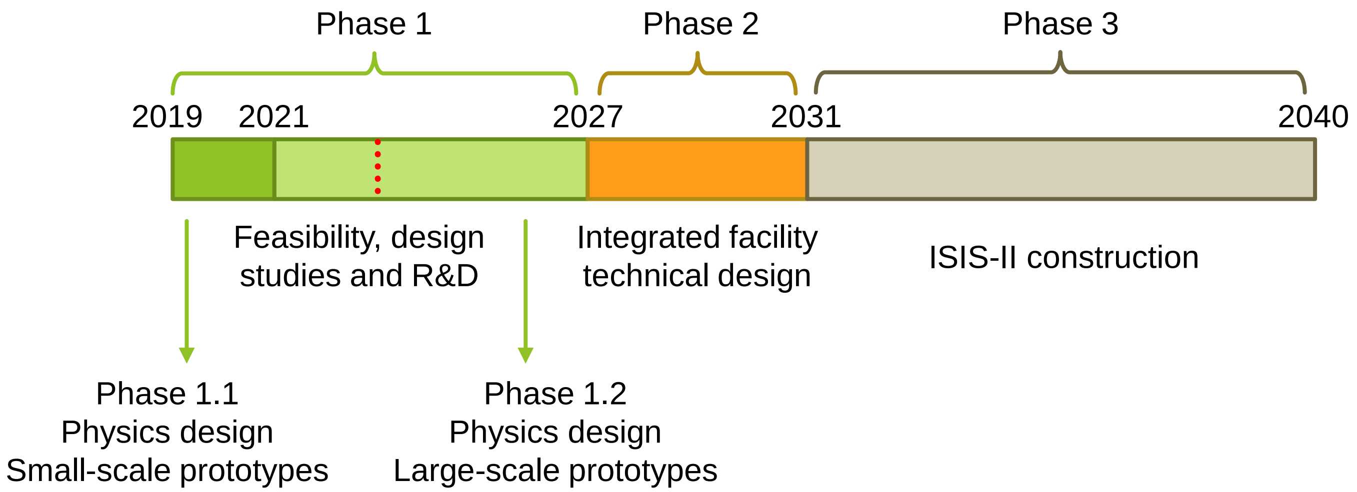
The Green ILC Project - Green ILC (in2p3.fr)

Green ILC Project

The Green ILC Project - Green ILC (in2p3.fr)

ISIS-II Neutron & Muon Source

Science and Technology Facilities Council
ISIS Neutron and Muon Source

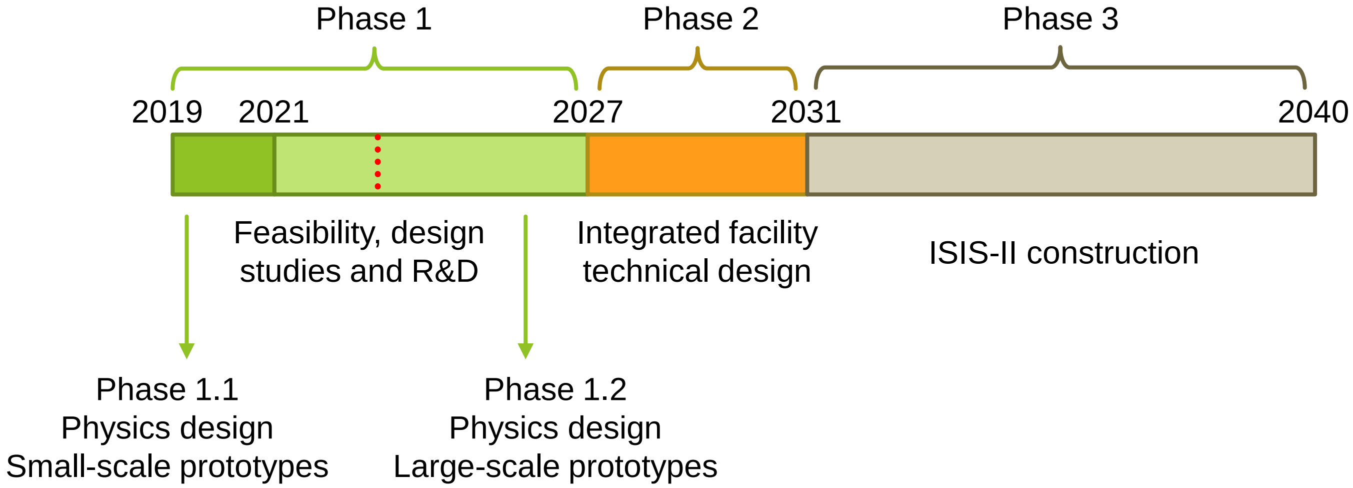


Proposed ISIS-II timeline.

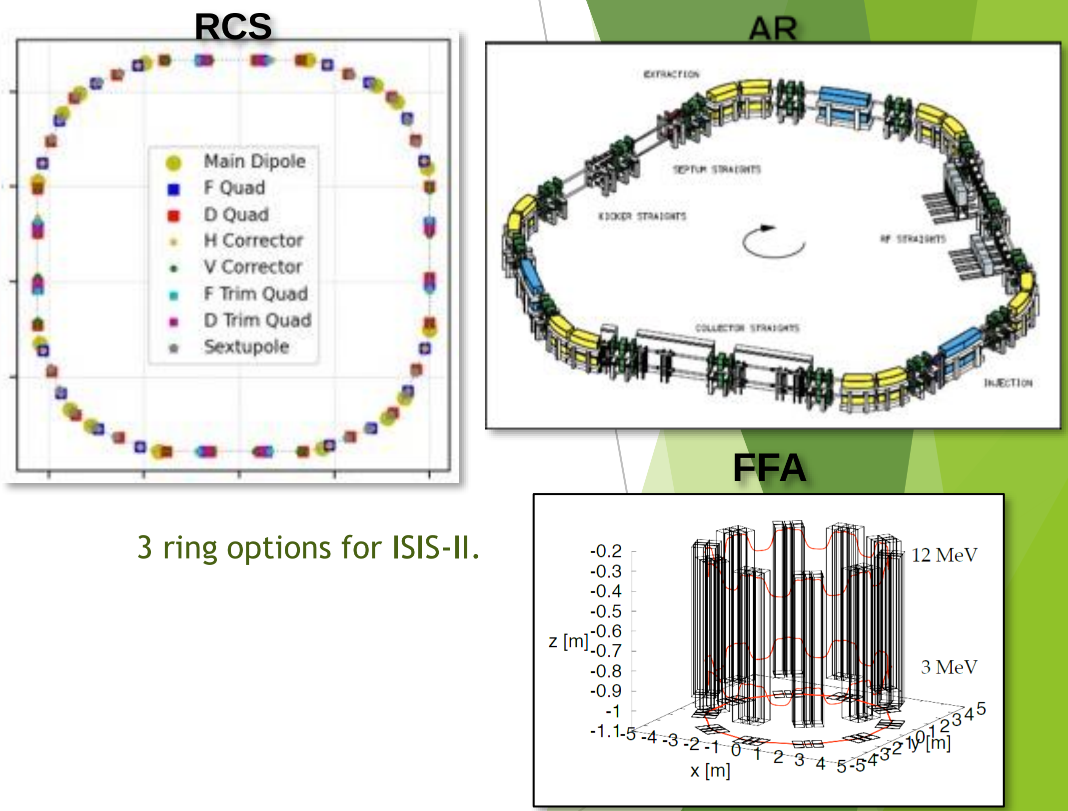
- Environmental impact evaluation of the proposed facility is underway.

ISIS-II Neutron & Muon Source

Science and Technology Facilities Council
ISIS Neutron and Muon Source



Proposed ISIS-II timeline.



3 ring options for ISIS-II.

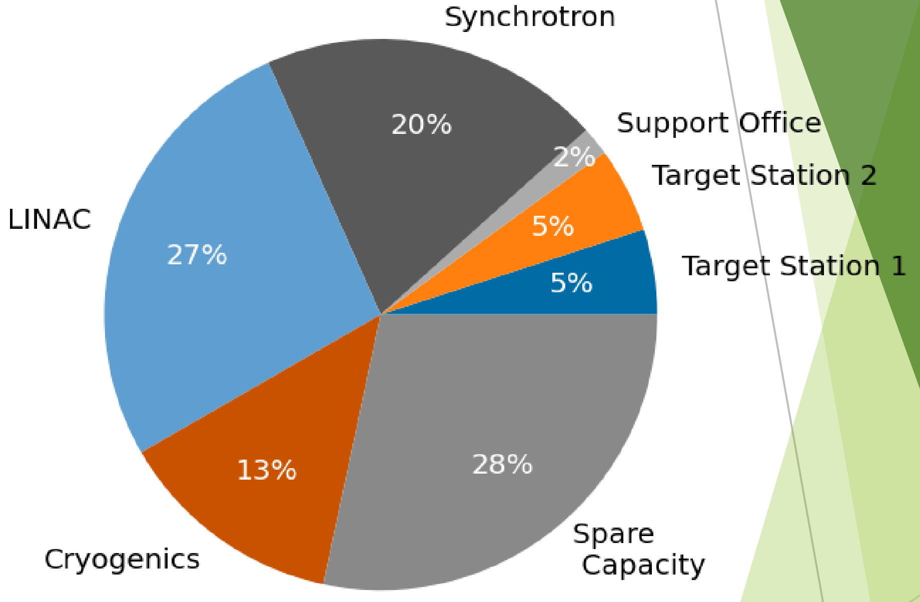
- Environmental impact evaluation of the proposed facility is underway.
- (Simplified) Life Cycle Assessment underway to inform design options.

ISIS-II Power consumption

PRELIMINARY

A first estimation of the emissions of CO_2e due to the power consumption of ISIS-II over its lifetime.

Power	Big Science Scheme	
	[MVA]	Lifetime CO_2e [tCO_2e]
Target Station 1	1.5	30,156
Target Station 2	1.5	30,156
Support Office	0.5	10,052
Synchrotron	6	120,625
LINAC	8	160,834
Cryogenics	4	80,417
Spare Capacity	8.5	170,886
TOTAL	30	603,126



Big Science Scheme

Year	CO_2 emissions [t CO_2/ kWh]
2020	1.415×10^{-4}
2030	8.51×10^{-5}
2040	6.36×10^{-5}
2050	3.32×10^{-5}

Aurora Energy Research

The power values are assumed to reflect the predicted beam on/off ratio of ISIS-II and present the 60-year operational lifetime CO_2e impact of ISIS-II, including current predicted "decarbonization of the UK grid" estimates.

Designing with the environment in mind
but at a smaller scale

- Optimize individual components:
  - Power
  - Materials

- Important to consider whole lifecycle
- E.g., it’s not just net weight, it’s gross weight too
  - Case study: FETS RFQ at RAL
  - 16 blocks of oxygen-free copper totaling 4 tonnes
  - Machined to 16 vanes: 8 major (80kg each), 8 minor (20kg each)
  - 3.2 tonnes of copper, i.e. 80%, wasted.
    - Swarf and off cuts were recycled via commercial metal recycling.

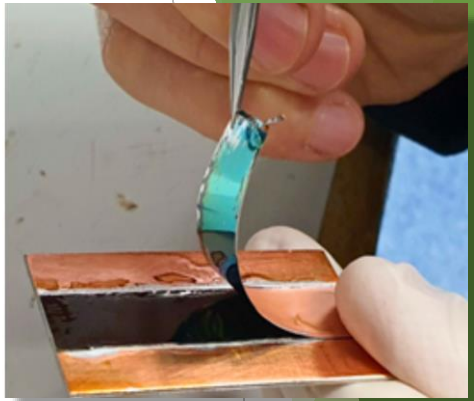
✓ Machining of materials potentially optimizable

More efficient technologies: RF Amplifiers

- Varying levels of power efficiency.
- Klystrons presently have ~50% efficiency (depending!)
- Multibeam RF sources can have RF source designs exceeding 80%
  - Modeling and Design of a High-Efficiency Multibeam Klystron
- This indicates a klystron amplifier efficiency of 70-80% is possible, leading to an overall RF source efficiency of 65%.
  - High Efficiency 50MW X-band Klystron Development
- Many other opportunities available here.

The efficiency frontiers for high RF power L-band Multi-Beam Klystrons

More efficient technologies: HTS CC



- High Temperature Superconductors (HTS): Coated Conductors (CC)
- Rare-Earth barium copper oxide (REBCO) is the material with the highest potential
- Multiple experiments found HTS CCs to have Q factors of ~4x that of copper
- HTS could work at liquid Nitrogen temperatures
- Efforts ongoing: I.FAST, CERN, SLAC + more
  - Power losses 10-15x better than copper at low-gradients
- **We need more data on behaviour of HTS for high gradient RF**

Accelerating News: How high-temperature superconductors can drie the evolution of particle accelerators
IPAC '24 CSIC-ICMAB + CERACO tape

More efficient technologies: CCM

- Carbide-Carbon Materials (CCM)
- Need for low density thermal conductor that can withstand extreme heat and structural pressure
- Toughness = carbides, versatility = carbon
- Molybdenum-graphite (MoGr)
  - Problem: manufacturing requires high energy (2600 ℃) for sintering and resource consumption, expensive (1000x copper), limited in physical size, destruction of machine insulation each cycle.
- Chromium-graphite (CrGr)
  - Nanoker & CERN collab
  - Improved size and lower sintering temperature (2000 ℃) so 50% energy saving and no failure of insulation elements, and cheaper!

Accelerating News: Newly developed thermal conducting material holds promise for use in future accelerators and industry

New technologies: Thin Film SC RF

- **Bulk niobium cavities** have been the choice for SC RF cavities 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 and 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
  - Using high T_c superconducting materials allows RF cavities to operate at **4.2 K**, instead of the **1.9 K** used for high-performance Nb cavities
    - more than doubling the efficiency of the cryogenic system

Thanks to Andrew Vick

Newer technologies: Permanent Magnets (PMs)

- Is it better to use PMs over electromagnets (EM)?

- ASTeC **Z**ero-**P**ower **T**unable **O**ptics
  - PM alternative to EM
- Proposed 3 TeV version of CLIC would require 582 MW
  - 124 MW would be used by resistive EMs.
- One magnet replacement could save 136 kg CO_2/yr.

- Great example of power vs. material impacts
- NdFeB is a rare earth magnet with non-negligible environmental impacts
  - 27.6 kg CO_2e / kg of virgin NdFeB magnet

Table 3. Life cycle impacts of producing virgin and recycled NdFeB magnets.

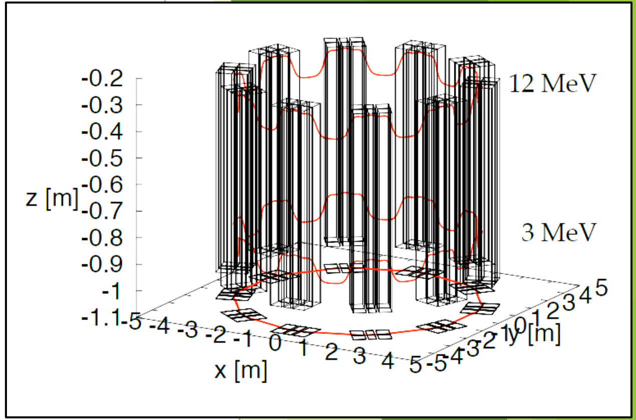
Impact category	Unit	Virgin	Recycled
Global Warming	kg CO_2 eq	27.602	12.453
Acidification	H^+ moles eq	20.524	11.320
Carcinogenics	benzene eq	0.069	0.035
Non carcinogenics	toluene eq	249.382	136.075
Respiratory effects	kg PM2.5 eq	0.124	0.059
Eutrophication	kg N eq	0.011	0.004
Ozone depletion	kg CFC-11 eq	1.25E-06	4.89E-07
Ecotoxicity	kg 2,4-D eq	94.285	45.345
Smog	kg NO_X eq	0.109	0.034

Tunable permanent magnets for sustainable particle accelerators

Comparative Life Cycle Assessment of NdFeB Magnets

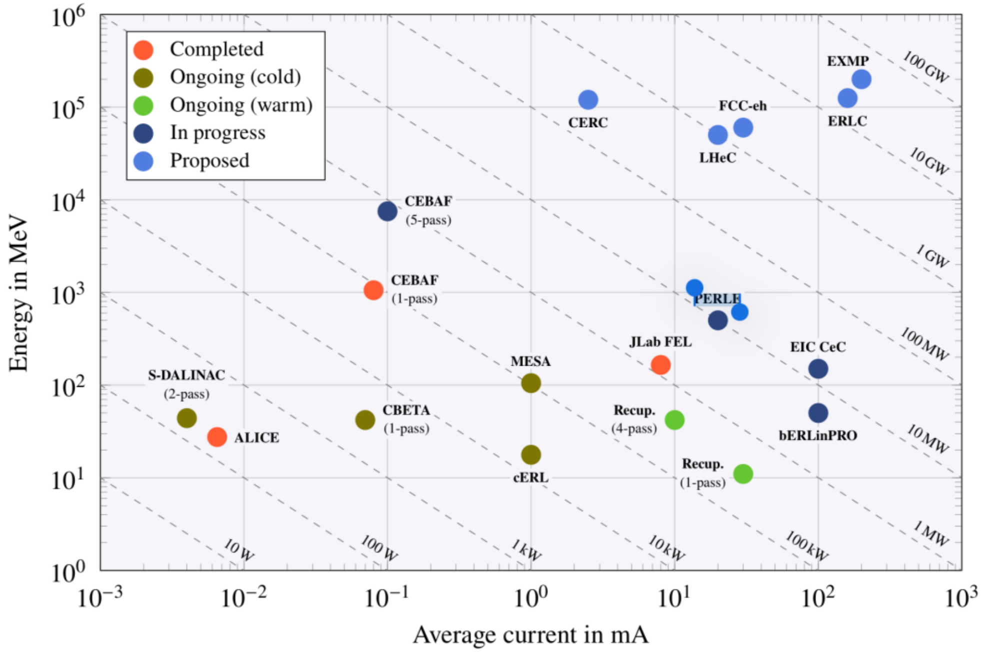
Newer technologies:
Fixed Field Alternating gradient (FFA) rings

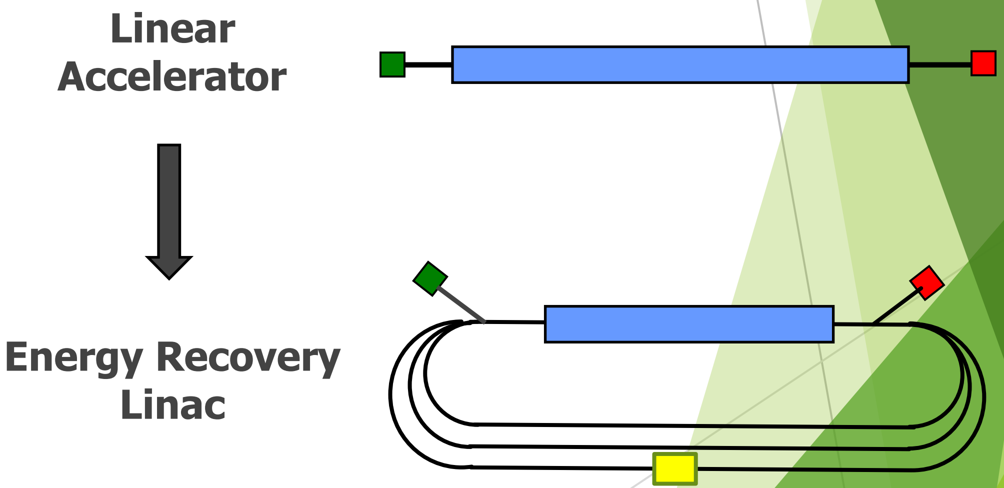
- **High energy efficiency** possible due to super-conduction or permanent DC magnets
- Can deliver a high average beam current
  - The acceleration pattern is not constrained by the B field ramping speed (as in synchrotrons)
  - Solely determined by the RF voltage and frequency
- The high repetition rate could be used to deliver pulsed beams to multiple target stations at different rates
  - Leads to neutrons beings able to be generated with a variety of time structures.



Newer technologies: Energy Recovery Linacs (ERL)

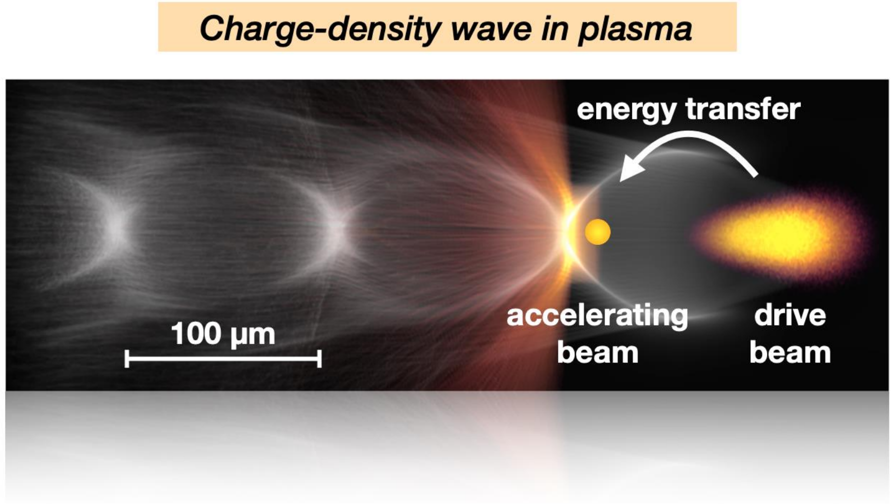
- Utilise the kinetic energy of unused particles in increasing the RF field intensity
- Accelerate → use → decelerate
- More energy efficient
- Largest energy consumption will be the cryo





https://arxiv.org/pdf/2207.02095.pdf

New technologies: Plasma accelerators



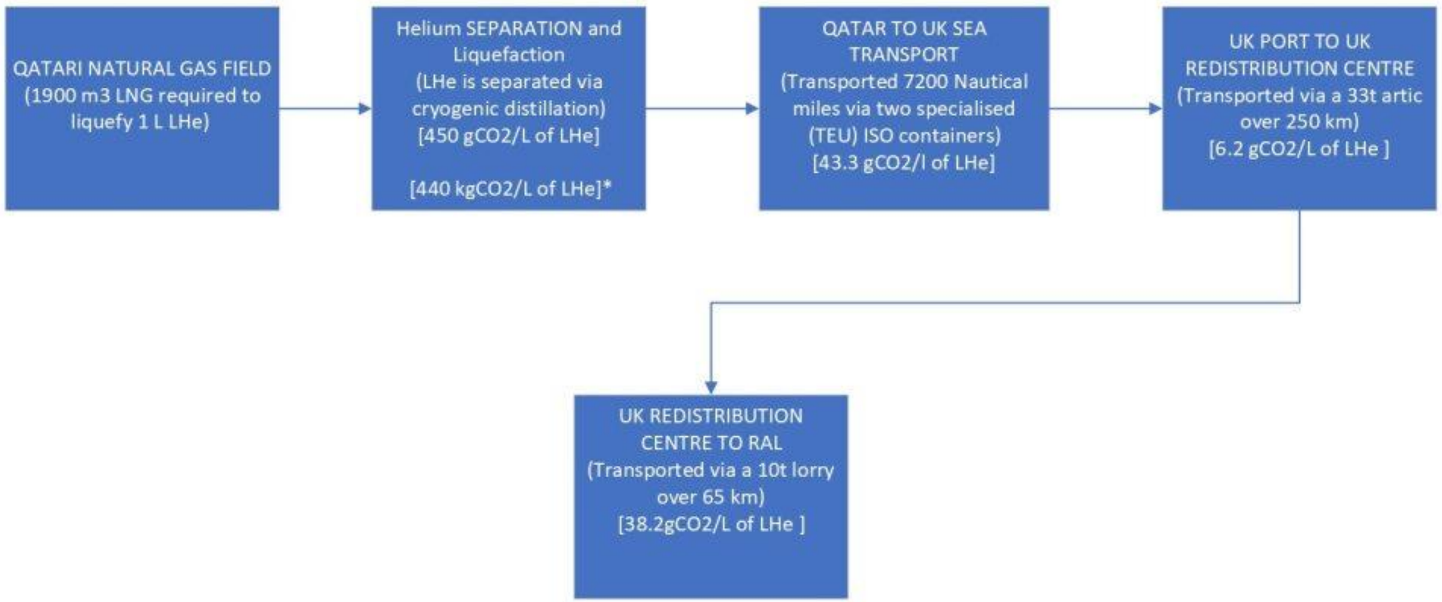
- High power-transfer efficiency
- Potential for wall plug power to beam power efficiency of 50%?

UK Accelerator Institutes Seminar Series Winter 2024 | Prof. Richard D'Arcy

Reduction in resource consumption: Helium

- Increasingly rare and expensive!
- Also comes with associated environmental impact

Helium source	Production footprint ($g\ CO_2$/ l He)	Transportation footprint ($g\ CO_2$/ l He)	Boil-off losses (%)	Total footprint ($g\ CO_2$/ l He)
ISIS helium recovery system	450	0	10	500
Gas company (excluding LNG production)	450	87.7	25	712
Gas company (including LNG production)	440,000	87.7	25	587,000



0.08% of gas company inc. Liquid Natural Gas (LNG) production

The authors have applied an assumption that ~25% of the gas suppliers' liquid helium boils off during transport, compared to ~10% at ISIS.

Carbon footprint of the Helium Recovery System at the ISIS Facility

Particle accelerator waste

- Waste occurs throughout lifetime
- Many types of waste, and lots of it
  - Especially at decommissioning

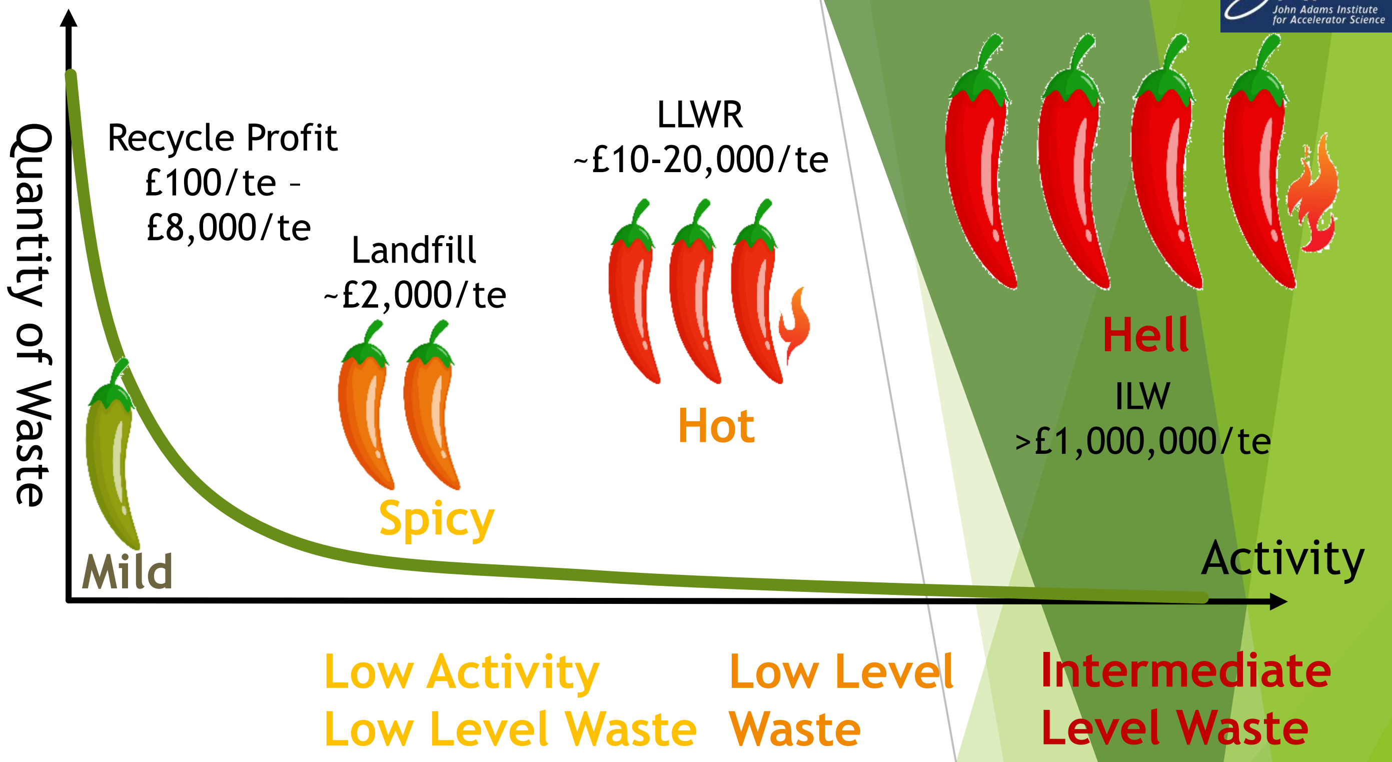
Thanks to Chris McKay

Reducing radioactive waste

- Accelerators can generate some highly active hazardous waste
  - Operational and End Of Life
- Long lived radionuclides are the relevant topic for waste management at accelerator facilities
- Electron accelerators:
  - Not (usually) significant < 13 MeV
  - Radioactivity comes from secondary photo-nuclear interactions
- Proton/ion accelerators:
  - Threshold reactions can occur at almost all energies
    - Leads to activation of accelerator components
  - Spallation and neutron production
    - Also activates surrounding materials!

Reducing radioactive waste

- The UK currently lacks enough capacity for disposal of ILW and High Activity Waste (HAW)
- Geological Disposal Facility (GDF) is in early planning stages
  - GDF schedule 2040-2108
- Waste must safely store for ~20-90 years…



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

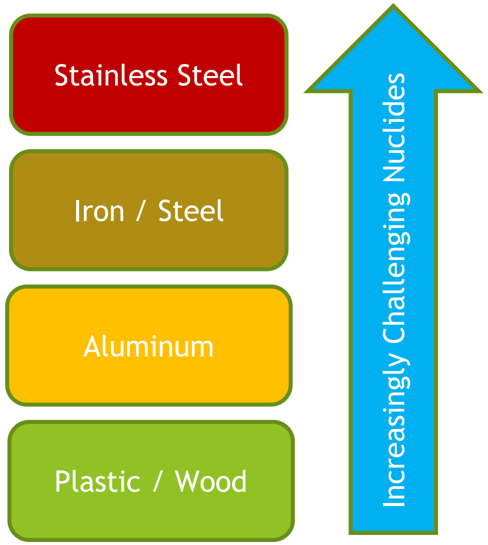
What would it cost to dispose ISIS current waste right now?

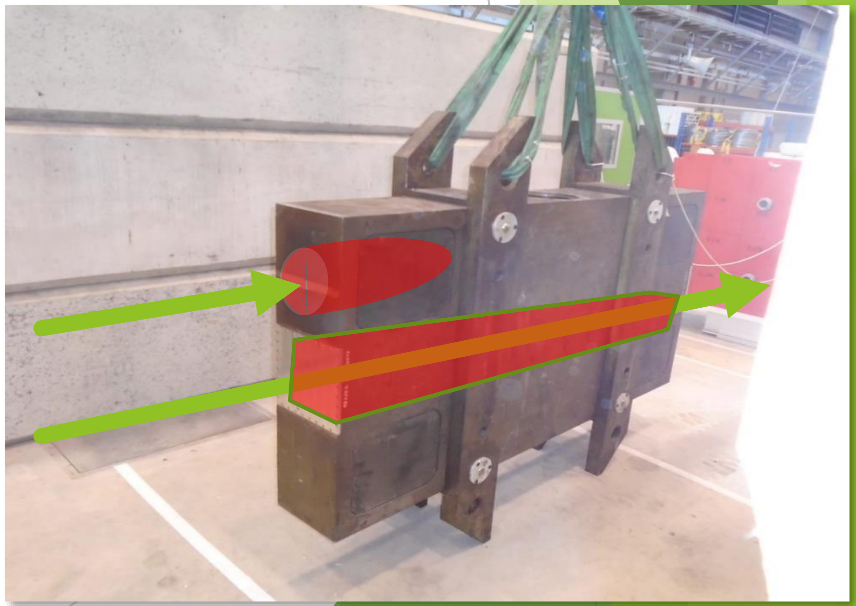
Waste Category	Current Volume	Disposal Cost
LA-LLW	1,140 te	~ £2.2 M
LLW	100 te	~ £1.5 M
ILW	70 te	~ £ 70 M

This is just disposal cost

Reducing radioactive waste

- Understand what you expect to generate
- Plan and mange through the full lifecycle
  - Minimise (beam losses, material selection)
  - Segregation
  - Characterise
  - Storage
  - Disposal
- Adequate facilities (remote waste handling)
- Plan for site legacy after operation





Other optimization

e.g. could machine learning aid us?

1. **Simulation**
   - enhance simulation and modelling of particle accelerator processes for more accurate predictions of performance and energy usage such that researchers could identify ways to improve efficiency and reduce environmental impact before physical implementation.
2. **Optimise Energy Use**
   - analyze data on energy consumption patterns of particle accelerators and reduce energy without compromising performance. Potential here for real-time adjustment of machine parameters.
3. **Optimise Material Use**
   - optimize materials used and component design in particle accelerators to improve efficiency and reduce environmental impact.
4. **Beam Control**
   - predict and control beam characteristics such as intensity, position, and stability using ML models to operate more efficiently, reduce energy consumption and minimize radioactive waste.
5. **Fault Detection**
   - proactively detect anomalies using sensors and predict potential failures in particle accelerators to prevent unexpected downtime and environmental impact associated with spares and repairs.

Evaluating environmental impacts

There are many methods to evaluate various environmental impacts

- "Back of envelope"
- Environmental impact reports
- Carbon emission/footprint reports
- Life Cycle Assessments/Analyses

- What is important is
  - Appropriate level
  - Documentation/Methodology
  - Reproducibility

Thanks to Ben Shepherd

Antec Magnet Carbon Footprint

Materials:

		$kgCO_2e/kg$	Source
Oxygen free copper	Copper, Finland	0.400	Northey, 2012
Magnetic Steel: M270-50A	Steel, Germany	1.708	Hasanbeigi, 2016
G11 plates	Fibreglass, Europe	1.500	PwC, 2016
Epoxy resin	Epoxy resin, World	6.700	Venkatesh, 2009

Supplies (location):

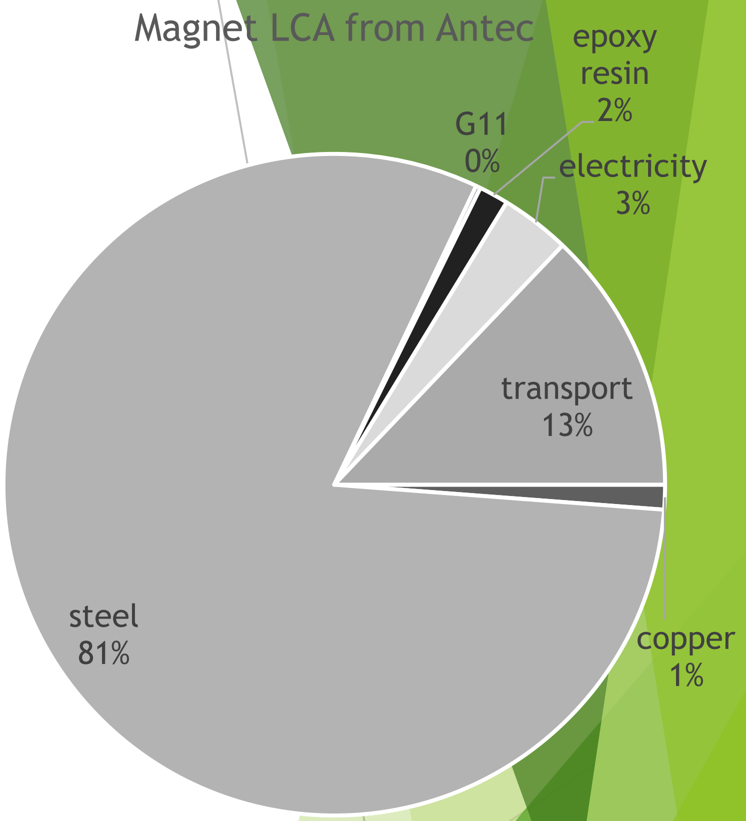
			$kgCO_2e/t.km$	km	$kgCO_2e/kg$
Copper	Finland	Road freight, Europe	0.1	3800	0.531
Magnetic Steel	Germany	Road freight, Europe	0.1	1700	0.238
G11	Spain	Road freight, Europe	0.1	410	0.057
Epoxy resin	Spain	Road freight, Europe	0.1	410	0.057

Use of materials (quantities/surplus):

	end use [kg]	consumed [kg]	$kgCO_2e$	transport $kgCO_2e$
Copper: 70kg (100% utilization)	70	70	28	37
Magnetic Steel: 1100 kg of material consumed to use 700 kg (63.6% utilization)	700	1100	1879	261
G11: Consumed 3.5 kg material to use 2.5 kg (71.5 %)	2.5	3.5	5	0
Epoxy resin: 5 kg per coil	5	5	34	0
Other materials in commercial parts not considered				
Totals	777.5	1178.5	1946	299

Energy consumption (per magnet) (*)

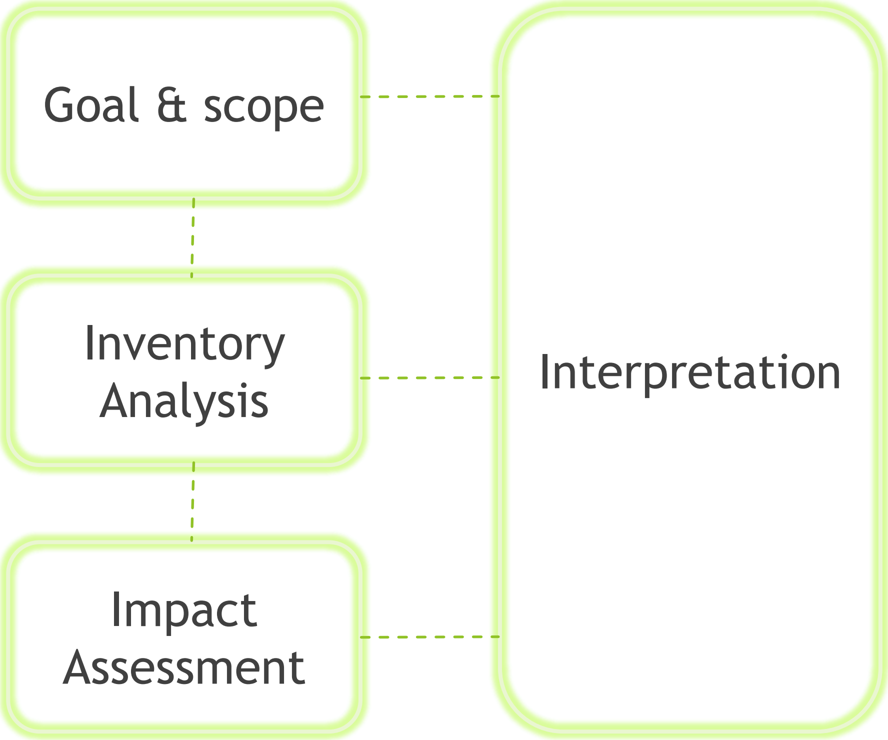
	kWh/kg		
Manufacture/yoke stacking and curing: 0.25 kWh/kg	0.25		
Winding: 0.1 kWh/kg	0.1		
Impregnation and curing: 0.3 kWh/kg	0.3		
Total	0.65	505	**kWh**
	Spain, 2020	156	**gCO2e / kWh**
		79	**$kgCO_2e$**
Overall total		2324	**$kgCO_2e$**
		2.99	**$kgCO_2e/kg$ finished product**



Scenario	$kgCO_2e$	% change
Baseline	2324	0%
Mexican steel	1449	-38%
Rail freight for steel	2091	-10%
EU-average for copper	2393	3%

A Life Cycle Analysis/Assessment (LCA)

- ISO 14040/44 standard



LCA steps.

Goal & Scope

Goal

- What is the goal of this study? Are you trying to compare designs? Identify hotspots of impact? Report on a specific component/material?

Scope

- What will the study cover? What will it ignore? What assumptions are made?
- Decide on a functional unit, e.g., "user hours delivered over 40 years of operation at an energy of 1.2 GeV".
- Define impacts considered.
  - Environmental impact is not just CO_2e (toxicity, biodiversity, human health, …)

Inventory Analysis

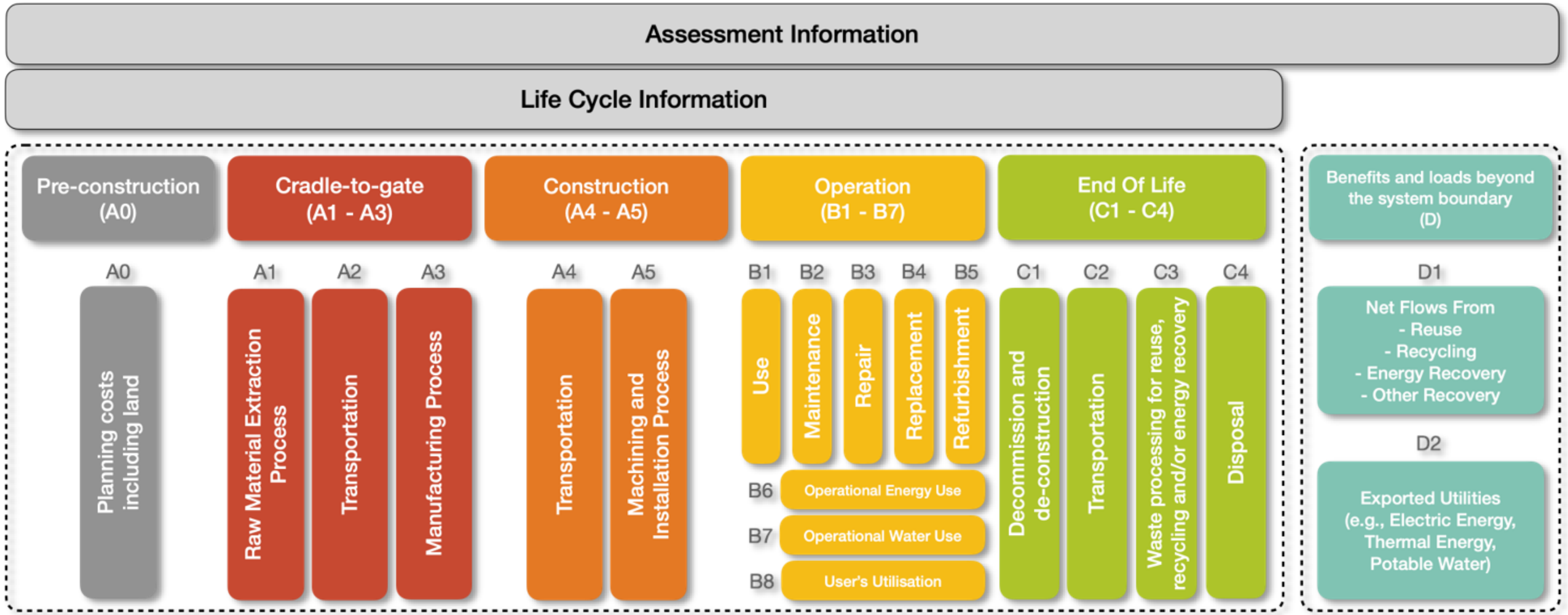
Data collection and quality control:

- Construction
  - Facility
  - Machine
  - Shielding
  - Computing
  - Location
- Operation/Active life
  - Energy consumption
  - Resource consumption inc. leakage
  - Failure likelihoods/risks inc. replacement/repair
- Decommissioning
  - Storage of radioactive materials

Input
(resources, materials, semi-products, products)
vs.
Output
(emissions, waste, valuable products)

Impact Assessment

A. Construction
B. Operation
C. Decommissioning

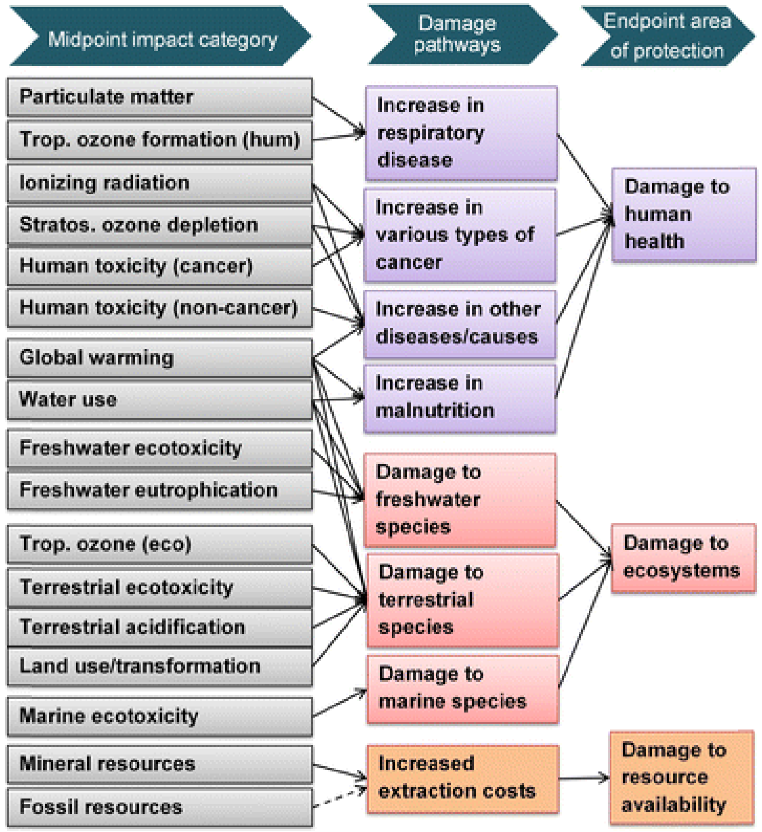


BS EN 17472:2022

- EN 17472:2022 is an engineering standard which we can use as a basis.

Impact Assessment

- Many impact assessments exist, no standard yet set within our field
- ReCiPE:2016 Midpoint (H) Life Cycle Impact Assessment Method



ReCiPe2016: a harmonised life cycle impact assessment method …

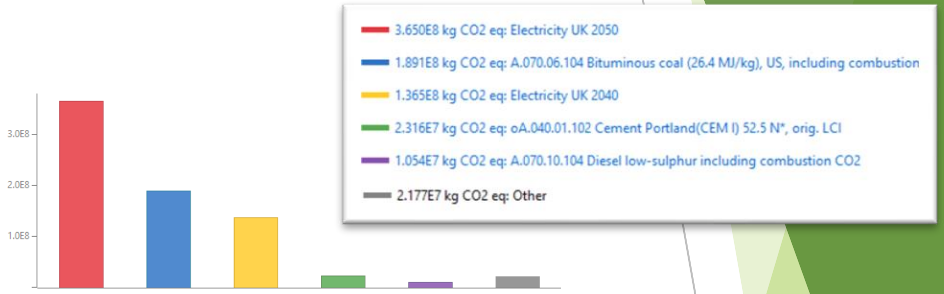
LCA Software

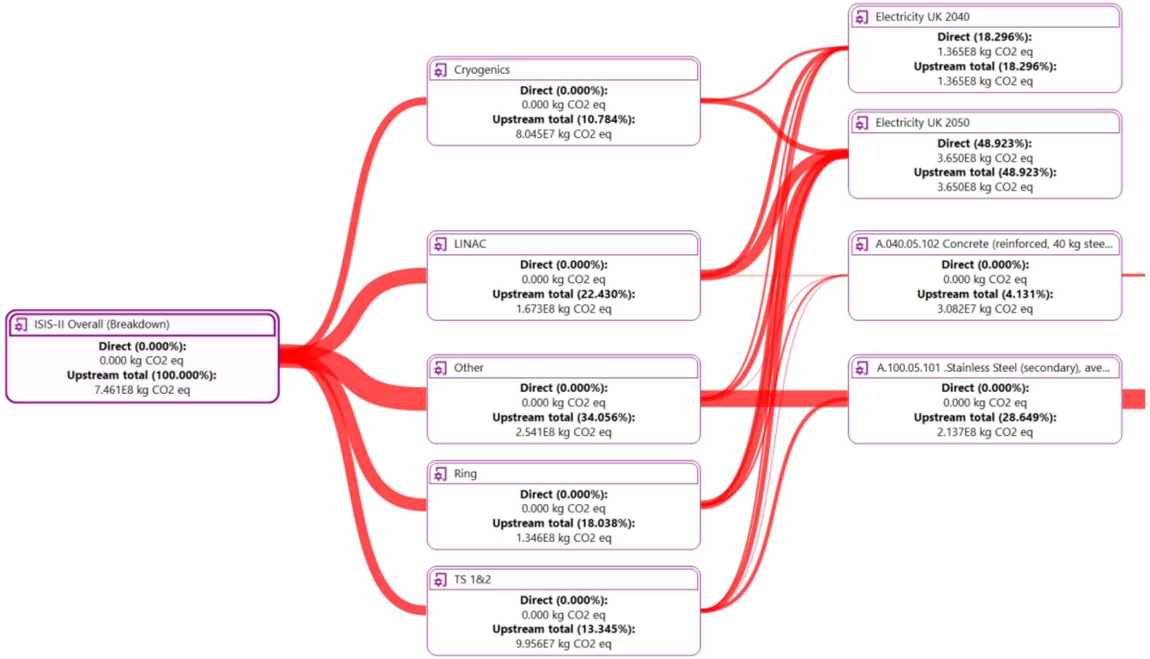
- OpenLCA
- FOOTPRINTCALC for a Fast LCA
  - recommended for your project
- Simapro
- OneClick LCA
- Ansys Granta Eco-audit
- …

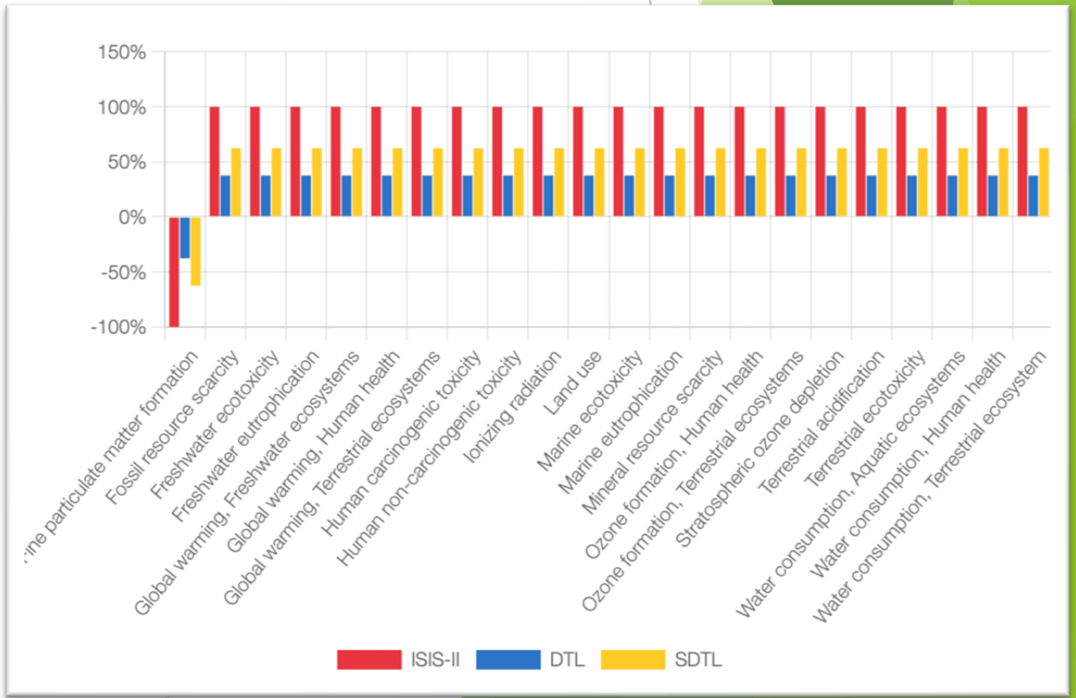
LCA Software

- OpenLCA
  - Idemat database free for academics
  - Open Source
  - Compatible with Python
  - Enables fast calculation of component lifetime impacts
  - Enables comparison of components, different designs etc.

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







Conclusion and summary

- Particle accelerators have an environmental impact
- We should reduce it
- There are endless opportunities to do so
- Each have different levels of impact themselves
- Evaluation allows identification of next steps

Backup slides

The Energy Crisis

- Humanity's power consumption is growing, and still growing, to the point of an energy crisis.
- David MacKay TED talk: How the Laws of Physics Constrain Our Sustainable Energy Options
  - Book! (free pdf and other versions)
- Energy crisis has many possible solutions and *opinions*:
  - “Renewables! Only renewables.”
  - “Slow down our development.”
  - “Technology will save us.”
- Realistically, none of these on their own is our single saviour.

Established groups, organizations and events
to be aware of

EuCARD2 – EnEfficient, WP3 Energy Efficiency

High Energy Physics, Cosmology, Astroparticle Physics, Nuclear and Hadron Physics (HECAP+) Initiative

i.FAST

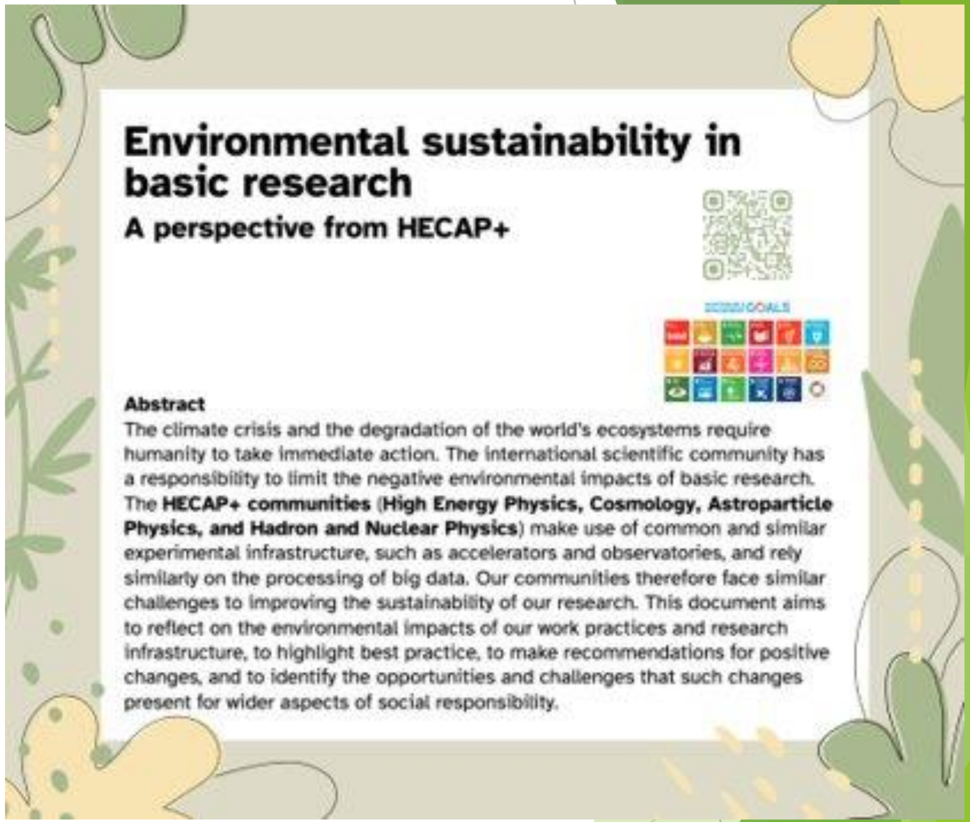
ESSRI Workshops previous 2022 workshop , next workshop: Madrid 25-27 Sep 2024

EAJADE Workshop on Sustainability in Future Accelerators (WSFA2023) (25-27 September 2023)

Sustainable HEP 2024 (**upcoming!**): Sustainable HEP 2024 — 3rd Edition (10-12 June 2024)

The Sustainable HECAP+ reflective document

- Reflects on sustainability in the context of HECAP+: High Energy Physics, Cosmology, Astroparticle Physics plus Hadron and Nuclear Physics).
- Initiative conceived at the 2021 Sustainable HEP workshop, hosted online by CERN.
- Broken down by key areas for our research, with best practice examples, case studies and recommendations.
- Relevance across big science, and all those engaged in it: scientists and non-scientists alike.
- You can show your support of this document through endorsement at the website!



Environmental sustainability in basic research

A perspective from HECAP+

Abstract

The climate crisis and the degradation of the world's ecosystems require humanity to take immediate action. The international scientific community has a responsibility to limit the negative environmental impacts of basic research. The **HECAP+ communities (High Energy Physics, Cosmology, Astroparticle Physics, and Hadron and Nuclear Physics)** make use of common and similar experimental infrastructure, such as accelerators and observatories, and rely similarly on the processing of big data. Our communities therefore face similar challenges to improving the sustainability of our research. This document aims to reflect on the environmental impacts of our work practices and research infrastructure, to highlight best practice, to make recommendations for positive changes, and to identify the opportunities and challenges that such changes present for wider aspects of social responsibility.

https://sustainable-hecap-plus.github.io

Additional Resources

- [2203.12389] Climate impacts of particle physics

- [2307.04084] Sustainability Strategy for the Cool Copper Collider
- Fraunhofer CLIC Energy Study: Energy Load and Cost Analysis
- ARUP CLIC and ILC Life Cycle Assessment Final Report