

# EISA

*European Institute for Sciences and Their Applications*



## **Sustainability assessment of future accelerators**

### **LDG WG**

C.Bloise (INFN-LNF), M.Titov (CEA-Saclay)

Workshop on Future Accelerators Corfu 22 May 2024

# Sustainability assessment of future accelerators

The Laboratory Directors Group is the Advisory Committees set up by the CERN management to supervise the development of the roadmap for the accelerator R&D

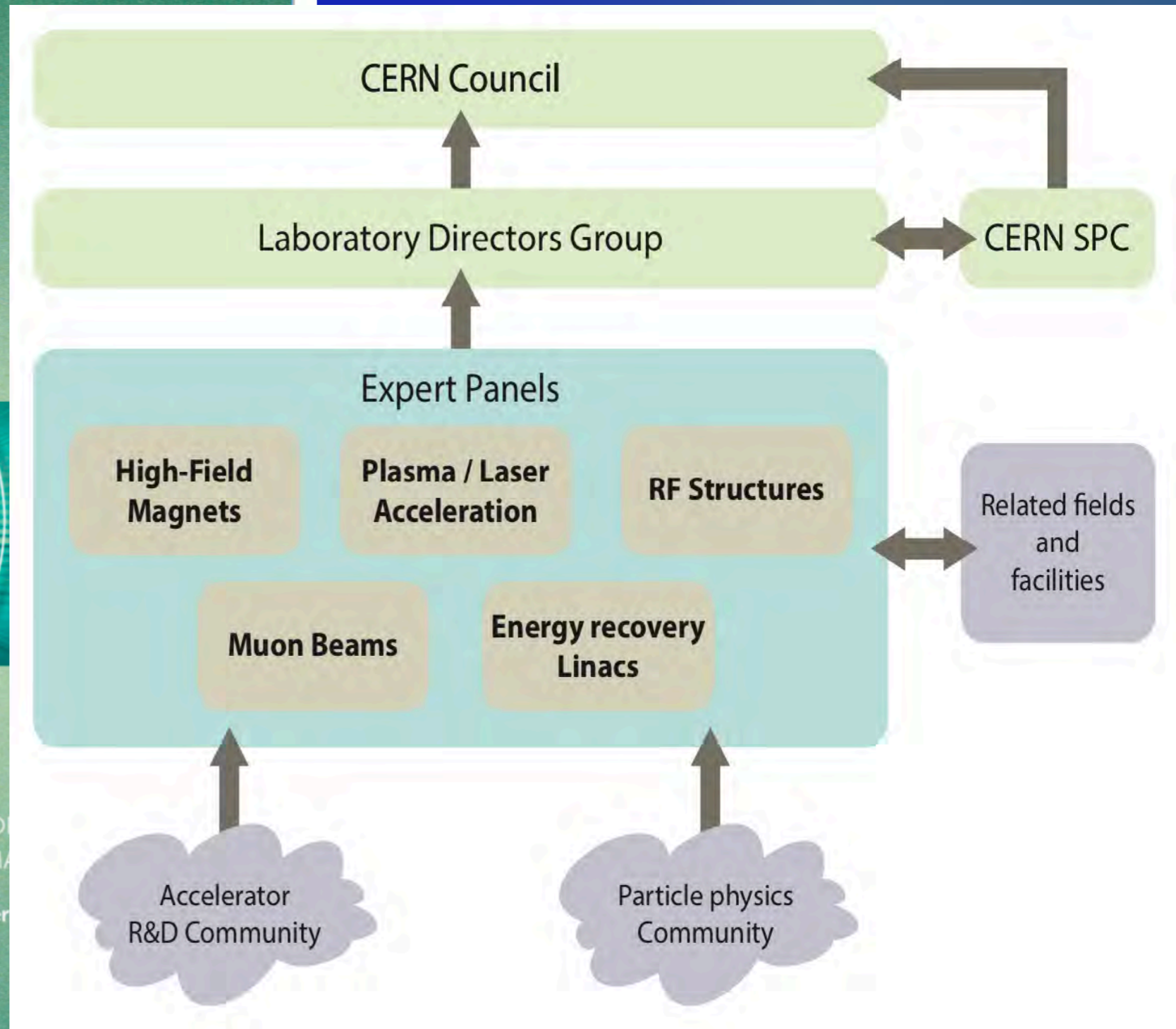
In November 2023 the LDG took the decision to establish a working group for the assessment of the sustainability of future accelerators

The WG mandate is the development of guidelines and a minimum set of key indicators pertaining to methodology and scope of reports on sustainability in future HEP projects





SYNOPSIS OF THE 2021 ECFA DETECTOR  
RESEARCH AND DEVELOPMENT ROADMAP  
by the European Committee for Future Accelerator  
Detector R&D Roadmap Process Group



**Sustainability Working Group  
(added to 5 LDG Expert Panels)  
since January 2024**



# Working Group's Mandate

- Definition of key indicators to be reported, such as peak luminosity or integrated luminosity per year, lifetime - and performance specific energy consumption, lifetime- and specific Global Warming Potential including the contribution of construction. These figures should be supplemented by margins of uncertainty and possibly an assessment of the potential for improvement
- Definition of methodology and assumptions to be applied for transparent determination of the key figures across proposals. The maturity of a proposal should be determined, for example adopting a classification scheme such as Early Concept Phase, CDR, TDR or TRL levels
- Identification of other high level environmental impacts that could be relevant for all or specific collider proposals

# Further Suggestions

Best practices determining the GWP for large infrastructure would be considered

The working group may comment on other aspects if deemed appropriate, for example:

- Treatment of future carbon intensity of electricity and materials: what scenarios should be assumed?
- Assessing the potential for dynamic operation of the various facilities, i.e. the ability to adapt to a fluctuating energy supply in a grid fed by renewables. This may include standby mode power consumption, recovery time to full luminosity and fraction of integrated luminosity per year preserved in a dynamic operation scenario.
- Treatment of regional vs global parameters: How to treat differences e.g. in carbon intensity between different host countries?
- Carbon intensity / lifecycle inventory (LCI) studies of materials specific to the accelerator projects: high-purity niobium, permanent magnet alloys etc.
- How to interface with open-source LCI databases and LCA tools to potentially ease/automate the assessment for future research infrastructures
- How the recommendations for colliders can be extended to other scientific endeavours related to HEP
- How HEP labs represented in the LDG can share/build up expertise jointly

# Update of Particle Physics Strategy in Europe

A draft of the recommendations from the WG is expected by end 2024

On time for an input document to the ESPPU due by March 2025

Subjects focused on for the ESPPU inputs incrementally enlarged

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Dear Colleagues,

On 21 March 2024, the CERN Council decided to launch the process for updating the European Strategy for Particle Physics.

I am pleased to announce that the deadline for submitting written input has been set for 31 March 2025, with a view to concluding the European Strategy update process in June 2026.

The process will be managed by the Strategy Secretariat, which the Council will establish in June 2024, and more information, together with the call for input, will be issued by the Secretariat in due course.

In the meantime, the input that was submitted for the 2020 Strategy update can be consulted at the following link:  
<https://indico.cern.ch/event/765096/contributions/>.

Kind regards,

Eliezer Rabinovici  
President of CERN Council

# LDG Sustainability WG Composition

LEARN, SHARE and BUILD-UP expertise with other HEP initiatives

WG composition endorsed by LDG in March 2024

15 people involved, from

Horizon programs on accelerators

panels established at CERN,  
DESY, ESS, NIKHEF, STFC

ICFA panel

projects for future accelerators

External contributions planned

- Walib Kaabi - iSAS, PERLE
- Mats Lindroos - ESS - he died on 2 May 2024
- Roberto Losito - CERN Sustainability Panel
- Ben Shepherd - STFC Sustainability Task Force
- Andrea Klumpp - iSAS, DESY Sustainability Panel
- Hannah Wakeling - ISIS-II Neutron & Muon Source
- Patrick Koppenburg - NIKHEF Sustainability Panel
  
- Johannes Gutleber - FCC
- Yuhui Li - CePC
- Benno List - ILC
- Emilio Nanni - ICFA and CCC
- Vladimir Shiltsev - LHeC/FCC-eh
- Steinar Stapnes - CLIC/muon collider
  
- Caterina Bloise - Co-Chair
- Maxim Titov - Co-Chair



# Work organization

1) Inputs from the Initiatives on Sustainability and from the projects for future accelerators

2) Topics to focus on

3) Discussion and Report Elaboration

**1st LDG WG Meeting on the Sustainability Assessment of Accelerators**  
Tuesday 19 Mar 2024, 15:00 → 17:00 Europe/Zurich  
Caterina Bloise (Laboratori Nazionali di Frascati (LNF)), Maksym Titov (IRFU, CEA Saclay, Université Paris-Saclay (FR))  
Description <https://cern.zoom.us/j/61888272480?pwd=S2ZpRWlaS2xoTFBsQmxaZDR5T25xZz09>

**15:00 → 15:30 Presentation of the Mandate received by the LDG and proposal for work organization**  
Speakers: Caterina Bloise (INFN e Laboratori Nazionali di Frascati (IT)), Dr Maksym Titov (IRFU, CEA Saclay, Université Paris-Saclay (FR))  
2024\_03\_1st-LDG... 2024\_03\_1st-LDG...

**15:30 → 16:00 Self-introduction of the WG Members**

**16:00 → 16:15 Calendar for the WG meetings: Discussion**

**16:15 → 16:30 Agenda for Next Meeting(s): Discussion**

**2nd LDG WG Meeting on the Sustainability Assessment of Accelerators**  
Monday 8 Apr 2024, 15:00 → 17:00 Europe/Zurich  
Description <https://cern.zoom.us/j/66928561166?pwd=OWRyNVpOVDFLQ0kwZVBCYTFFMa0NkZz09#success>

**15:00 → 15:15 News, Minutes Approval (1st Meeting), Calendar for the next WG Meetings**  
Speakers: Caterina Bloise (Laboratori Nazionali di Frascati (LNF)), Dr Maksym Titov (IRFU, CEA Saclay, Université Paris-Saclay (FR))  
LDG\_WG\_Sustaina...

**15:15 → 15:30 CERN Sustainability Panel & Framework for estimating the evolution of CO2 load from Energy in France.**  
Speaker: Roberto Losito (CERN)  
Sustainability in fut... Sustainability in fut...

**15:40 → 15:55 Sustainable Accelerator R&D in the UK: Key Inputs to the LDG WG Activities**  
Speakers: Ben Shepherd, Mr Ben Shepherd  
2024-04-08 Shephe...

**16:05 → 16:20 Experience from ESS on Green Facilities: Key Inputs to the LDG WG Activities**  
Speakers: Dr Mats Lindroos (European Spallation Source ERIC), Mats Lindroos (ESS - European Spallation Source (SE))  
Green Accelerators... Green Accelerators...

**3rd LDG WG Meeting on the Sustainability Assessment of Accelerators**  
Monday 29 Apr 2024, 15:00 → 17:15 Europe/Zurich  
Description <https://cern.zoom.us/j/61888272480?pwd=S2ZpRWlaS2xoTFBsQmxaZDR5T25xZz09>

**15:00 → 15:05 News and Minutes Approval**  
Speakers: Caterina Bloise (Laboratori Nazionali di Frascati (LNF)), Dr Maksym Titov (IRFU, CEA Saclay, Université Paris-Saclay (FR))  
2024\_04\_3rd-SUST... 2024\_04\_3rd-SUST... LDGSAW\_M1\_Minu... LDGSAW\_M2\_Minu...

**15:10 → 15:30 Sustainability Studies for ILC/CLIC: Key Inputs to the LDG WG Report**  
Speaker: Dr Benno List (Deutsches Elektronen-Synchrotron (DE))  
LC\_Sustainability\_L... LC\_Sustainability\_L...

**15:40 → 16:00 Sustainability Studies for FCC: Key Inputs to the LDG WG Report**  
Speaker: Johannes Gutleber (CERN)  
FCC-2404041500-J... FCC-2404041500-J...

**16:10 → 16:30 Sustainability Studies for C3: Key Inputs to the LDG WG Report**  
Speakers: Emilio Nanni (SLAC National Accelerator Laboratory), Emilio Nanni  
LDG\_C3\_Sustainabi...

**16:40 → 17:00 Sustainability Studies for CEPC: Key Inputs to the LDG WG Report**  
Speaker: yuhui li (Institute of High Energy Physics)

**4th LDG WG Meeting on the Sustainability Assessment of Accelerators**  
Monday 13 May 2024, 15:00 → 17:00 Europe/Zurich  
Description <https://cern.zoom.us/j/61888272480?pwd=S2ZpRWlaS2xoTFBsQmxaZDR5T25xZz09>

**15:00 → 15:05 News and Minutes Approval**  
Speakers: Caterina Bloise (Laboratori Nazionali di Frascati (LNF)), Dr Maksym Titov (IRFU, CEA Saclay, Université Paris-Saclay (FR))  
2024\_05\_4th-SUST... 2024\_05\_4th-SUST...

**15:10 → 15:30 ARUP experience on decarbonisation and large research infrastructure**  
Speaker: Heleni Pantelidou (ARUP)

**15:40 → 16:00 Key LCA Issues**  
Speaker: Dr Hannah Wakeling (John Adams Institute, Oxford University)  
2024\_05\_13\_LDG...

**16:00 → 16:15 General LCA Discussion**

**16:15 → 16:55 Towards Open LDG Meeting @BNL (June 6-7): Sustainability Discussion**  
Speakers: Caterina Bloise (Laboratori Nazionali di Frascati (LNF)), Maxim TITOV (CEA Saclay)

**16:55 → 17:00 AoB**



# Sustainability of Research Infrastructures



**Long-Term Sustainability of Research Infrastructures**

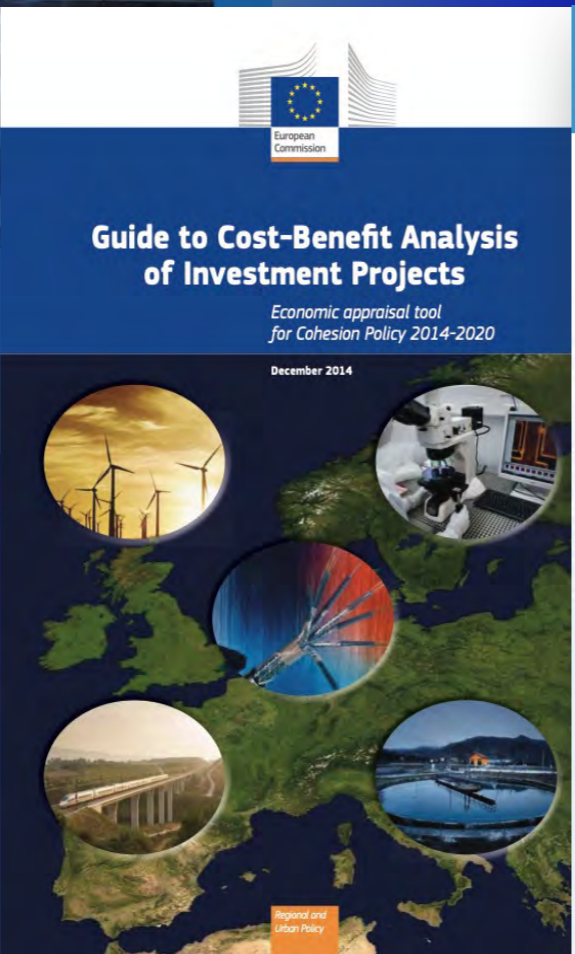
Reference for the integrated model FCC:



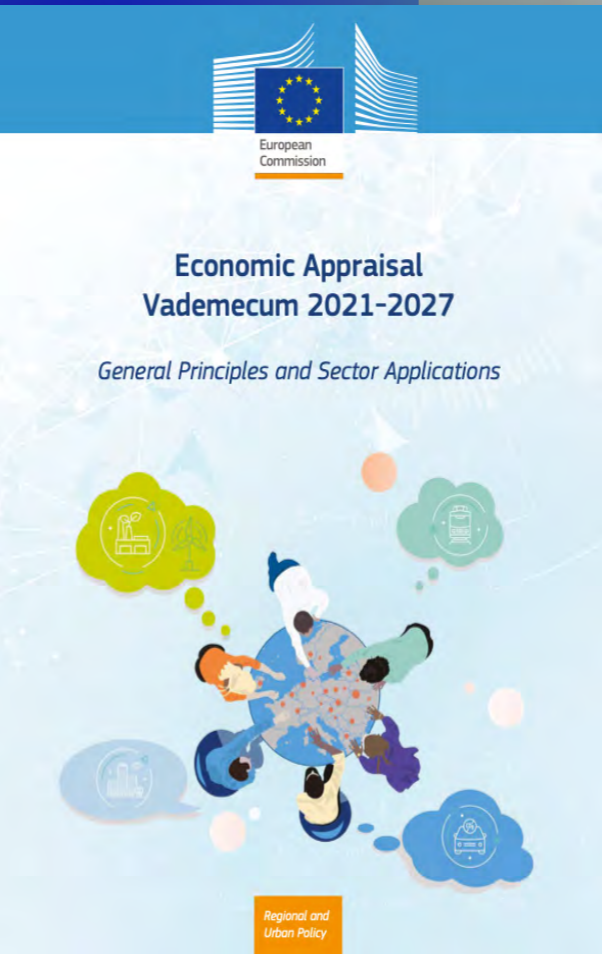
**SUSTAINABLE**  
European Research Infrastructures  
*A call for action*



ESFRI SCRIPTA



**Guide to Cost-Benefit Analysis of Investment Projects**  
*Economic appraisal tool for Cohesion Policy 2014-2020*  
December 2014



**Economic Appraisal Vademecum 2021-2027**  
*General Principles and Sector Applications*

<https://data.europa.eu/doi/10.2777/76269>

[https://ec.europa.eu/regional\\_policy/sources/studies/cba\\_guide.pdf](https://ec.europa.eu/regional_policy/sources/studies/cba_guide.pdf)



# Sustainability Assessment

Sustainability matters are in relation with Environment, Society and Governance

WG focus is on the assessment of sustainability of the infrastructures for Environment and Climate Change

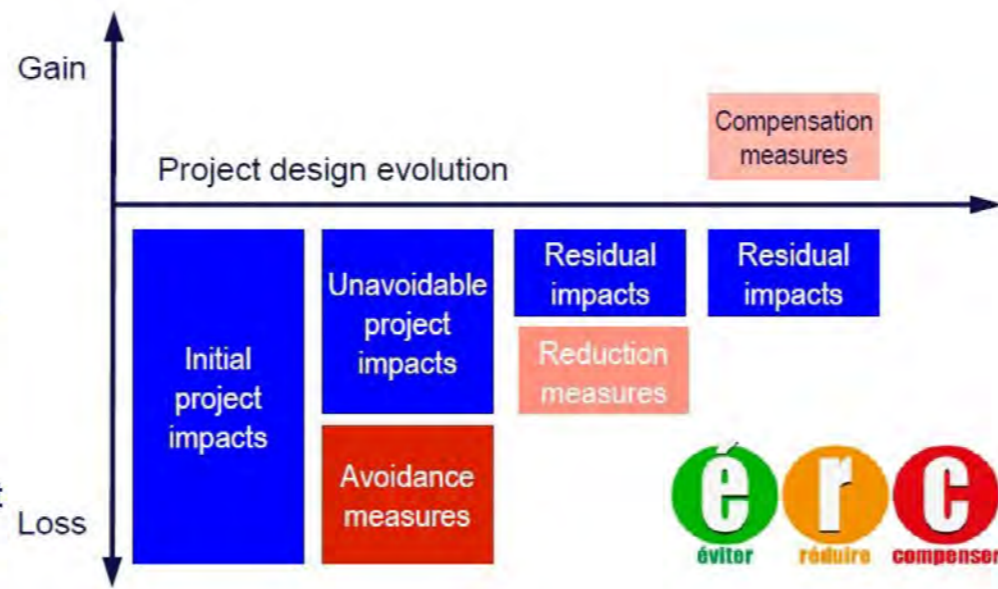
## Regulatory guiding principle

An iterative 3 step approach :

**Avoid:** measures taken to avoid creating impacts from the outset or set aside key conservation areas / delete a potential impact

**Reduce:** measures taken to reduce the intensity and/or extent of impacts that cannot be completely avoided

**Compensate:** measures taken to compensate for any significant residual, adverse impacts that cannot be avoided, reduced and/or restored



**3**  
KEY ELEMENTS OF THE  
**PARIS AGREEMENT**  
ON CLIMATE CHANGE

▶▶ 1.  
Limit temperature rise to 1.5C

▶▶ 2.  
Review countries' commitments to cutting emissions every five years

▶▶ 3.  
Provide climate finance to developing countries



# Carbon Footprint and Green House Gas emissions

<https://energy.ec.europa.eu/topics/renewable-energy/enabling-framework->

## Energy

- Reduction of energy consumption
- Optimized designs for energy saving
- Novel technologies

Increase of renewables share

## Civil Engineering

Concrete

## Specific Materials

Manufacturing

Re-use

The screenshot shows the European Commission website page for 'Power purchase agreements'. The page header includes the European Commission logo, the language 'EN', and a search bar. The main navigation menu includes 'Home', 'Topics', 'Data and analysis', 'Studies', 'Publications', 'Consultations', 'Energy explained', 'Events', and 'News'. The breadcrumb trail is 'Home > Topics > Renewable energy > Enabling framework for renewables'. The main content area features a large image of people in a meeting and a row of wind turbines. The 'PAGE CONTENTS' sidebar lists: 'Simplifying permitting processes', 'Power purchase agreements' (highlighted), 'Study and public consultation', 'Workshops', 'Renewable energy communities', and 'Related links'. The main text under 'Power purchase agreements' discusses the importance of PPA contracts and mentions a 'Recommendation and a guidance document on permit-granting processes and PPAs' published in May 2022. A 'Study and public consultation' link is also visible at the bottom of the page.



# Europe-Horizon Sustainability - Supporting Programs

- ✓ **Innovation Fostering in Accelerator Science and Technology (I.FAST):** <https://ifast-project.eu>
- ✓ **Europe-America-Japan Accelerator Development Exchange Programme (EAJADE):** <https://www.eajade.eu/>
- ✓ **Innovate for Sustainable Accelerating Systems (iSAS):** <https://indico.ijclab.in2p3.fr/event/9521/>

## iSAS Objectives – **Technology Areas**

- **TA#1: energy-savings from RF power** – While great strides are being made in the energy efficiency of various RF power generators, the objective of iSAS is to ensure additional impactful energy savings through **coherent integration of the RF power source with smart digital control systems and with novel tuners that compensate rapidly cavity detuning from mechanical vibrations, resulting in a further reduction of power demands by up to a factor of 3.**
- **TA#2: energy-savings from cryogenics** – While major progress is being made in reusing the heat produced in cryogenics systems, the objective of iSAS is to **develop superconducting cavities that operate with high performance at 4.2 K (i.e., up to 4.5 K depending on the cryogenic overpressure) instead of 2 K, thereby reducing the grid-power to operate the cryogenic system by a factor of 3 and requiring less capital investment to build the cryogenic plant.**
- **TA#3: energy-savings from the beam** – Significant progress has been achieved in maintaining the brightness of recirculating beams to provide high-intensity collisions to experiments, but most of the particles lose their power through radiation or in the beam dump system. The objective of iSAS is to **develop dedicated power couplers for damping the so-called Higher-Order Modes (HOMs) excited by the passage of high-current beams in the superconducting cavities, enabling efficient recovery of the energy of recirculating beams back into the cavities before it is dumped, resulting in energy reduction for operating, high-energy, high-intensity accelerators by a factor ten.**

<https://indico.cern.ch/event/1326603/timetable/#20240215.detailed>

ESS also participates in iFAST (addition of solar panels to power modulators) and FlexRICAN (studying flexibility in power supply)

<https://indico.cern.ch/event/1326603/timetable/#20240215.detailed>

## WP11 Overview

**task 1: Sustainable Concepts for RIs:** networking, workshops on selected topics  
deliverable: report

- 1) System Efficiency of Accelerator Concepts (N.Catalan Lasheras, CERN)
- 2) Key Technologies and Components for High Efficiency (A.Sunesson [C.Martins], ESS)
- 3) Cross Linking Accelerator R&D with Industrial Approaches (P.Spiller, GSI)
- 4) Ecological Concepts (D. Voelker, DESY)

**task 2: High Efficiency Klystron** (O.Brunner CERN, THALES, ULANC)

- deliverable: industrial prototype
- replacing klystrons in LHC



**task 3: Permanent Combined Function Magnets for Light Sources** (B.Shepherd, UKRI, DLS, KYMA, DESY)

- deliverable: magnet prototype, applicable for Diamond upgrade
- several advantages of permanent magnets, not just power consumption

## EAJADE Workshop on Sustainability on Future Accelerators (WSFA2023)

MORIOKA, JAPAN, SEPTEMBER 25-27, 2023

Aiina Center, the same venue as LCWS2016, hosted by Iwate University



<https://wsfa2023.huhep.org/> ; <https://indico.desy.de/event/39980/>

**Four blocks (not limited to future Higgs Factories and to Linear Colliders):**

- I. Large-Scale Research Facilities & Sustainability / Life Cycle Assessment(LCA)
- II. Sustainable Accelerator Technologies
- III. Europe-Horizon and National Sustainability-Supporting Programmes
- IV. Green ILC and Local Industries

<https://wsfa2023.huhep.org/>



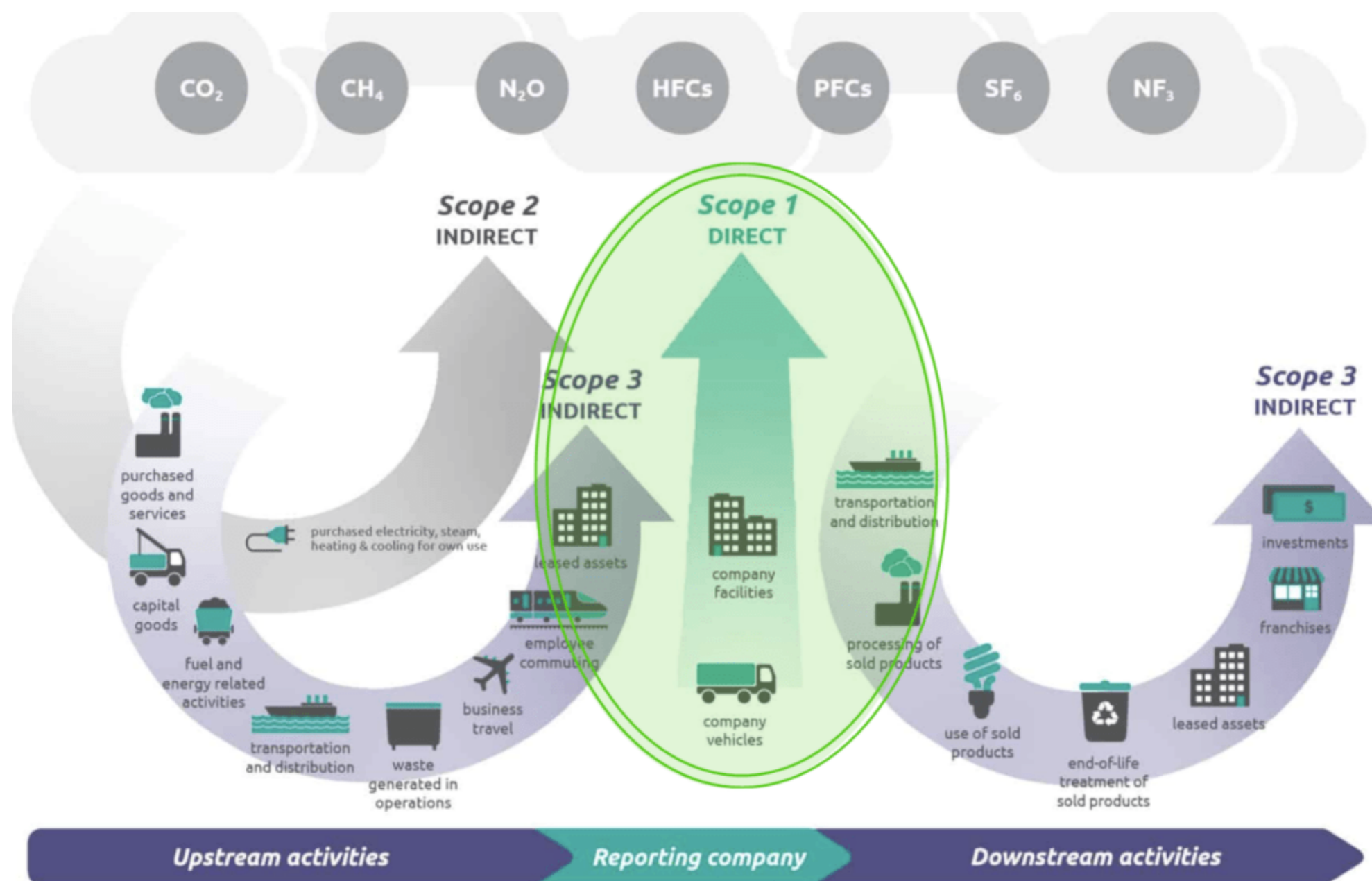
# Approaches to Increase Sustainability

- Overall system design
  - Compact accelerator -> high gradients, high field magnets
  - Energy efficient -> low losses
  - Effective -> small beam sizes to maximize luminosities
  - Energy recovery concepts
  - Civil engineering including landscaping and “community” integration
- Subsystem and component design
  - High-efficiency cavities and klystrons
  - Permanent magnets, HTS magnets
  - Heat-recovery. e.g. in tunnel linings, possibly other components
  - Responsible sourcing and material choices for all parts
- Sustainable operation concepts
  - Renewables
  - Adapt to power availability
  - Exploit energy buffering potential
  - Recover energy

# Green House Gases Emissions

According to the 2015 Paris Agreement carbon emissions have to be halved by 2030.

Emissions are categorised into scope 1, 2, and 3



<https://ecochain.com/blog/scope-1-emissions-explained/>



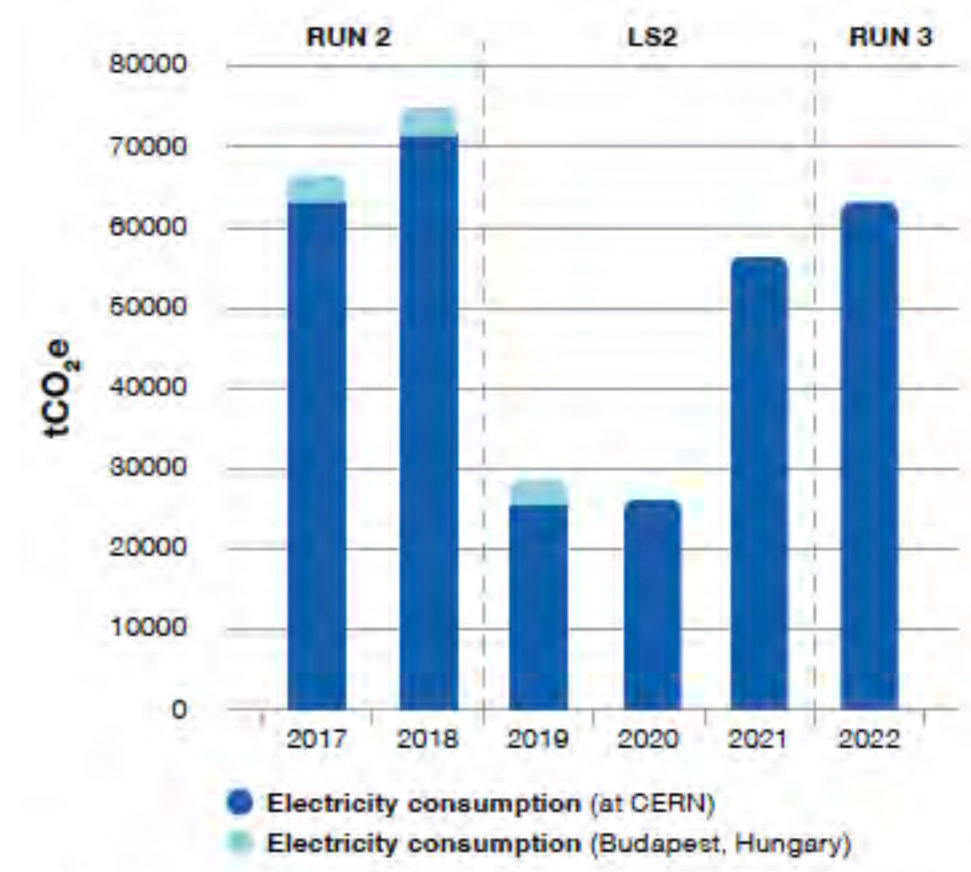
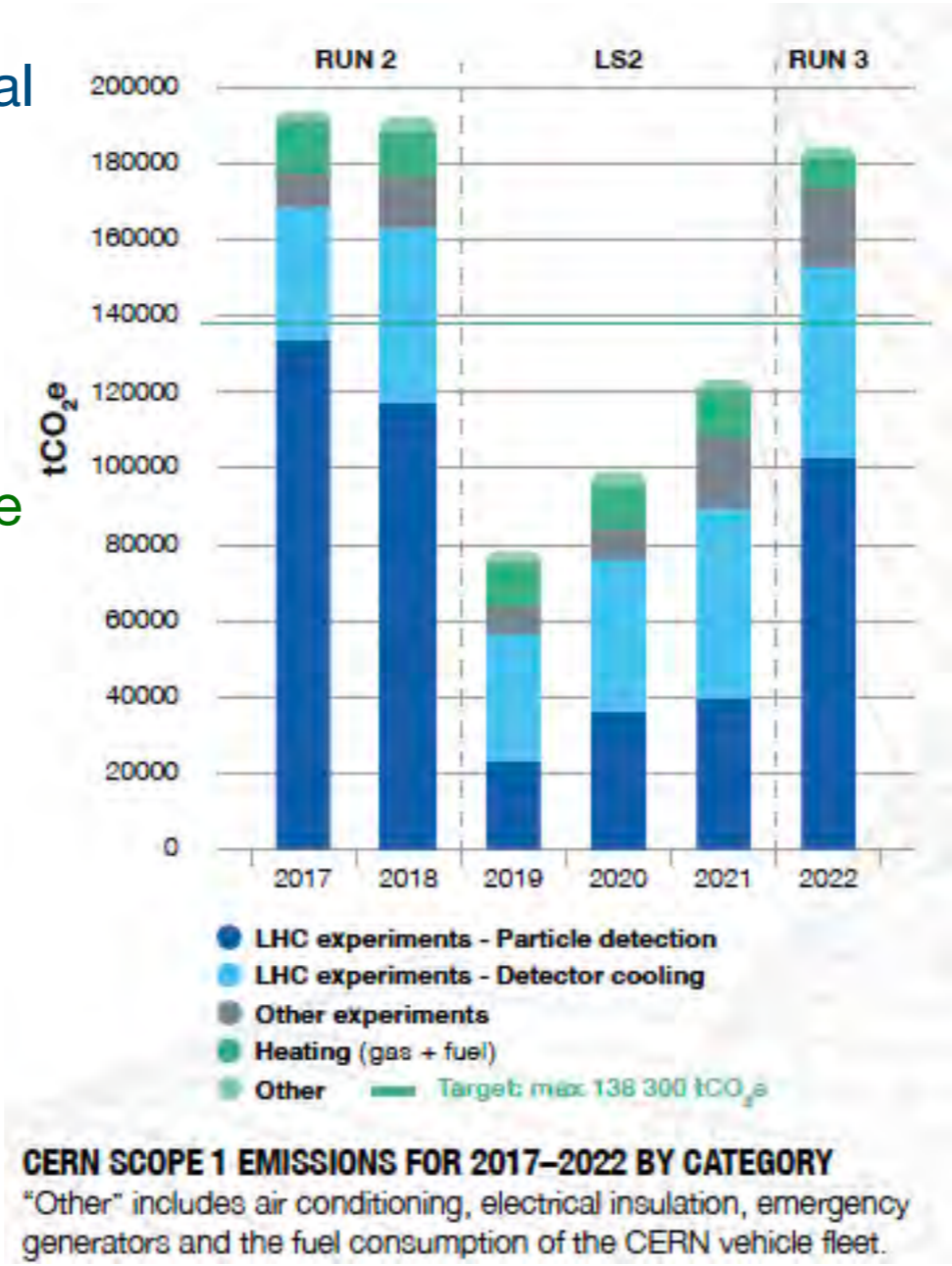
# Decarbonisation and Large HEP RI

CERN publishes environmental reports following standards of Global Reporting Initiative since 2017

CERN has developed a strategy for energy sourcing and monitoring obtaining the ISO50001 certification for energy management

Scope 1 Direct Emissions: @LHC are dominated by gas mixtures used by particle detectors and detector cooling

Scope 2 Emissions (Energy Consumption): location-based methodology provides emission factors depending on energy sources in use



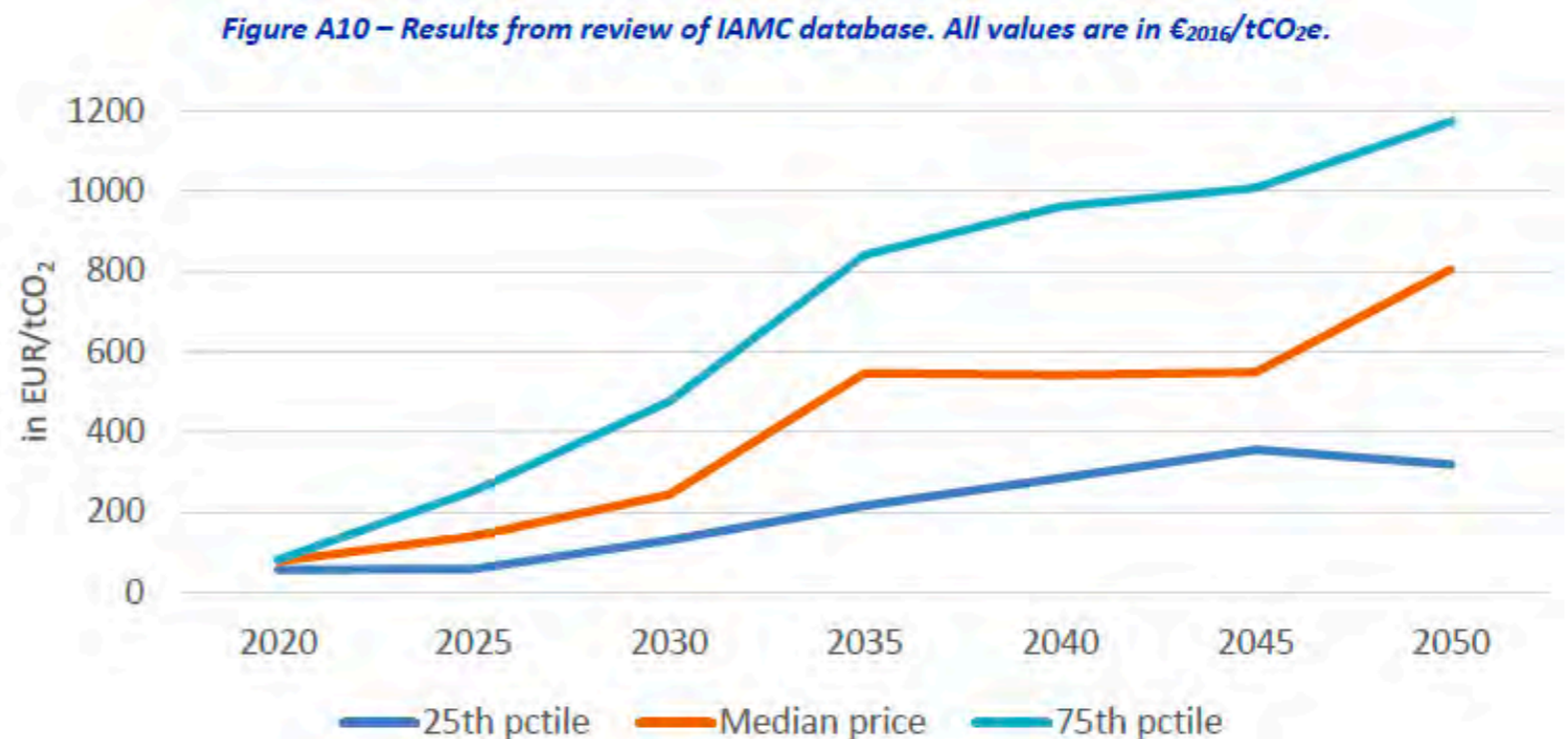
Reference: CERN Environment Report 2021-22

# Decarbonisation

## Evaluation of shadow carbon price

Various measures to abate carbon emissions are considered and their cost evaluated

Uncertainty from the evaluation methodology that considers different scenarios



EIB Group Climate Bank Roadmap 2021-2025

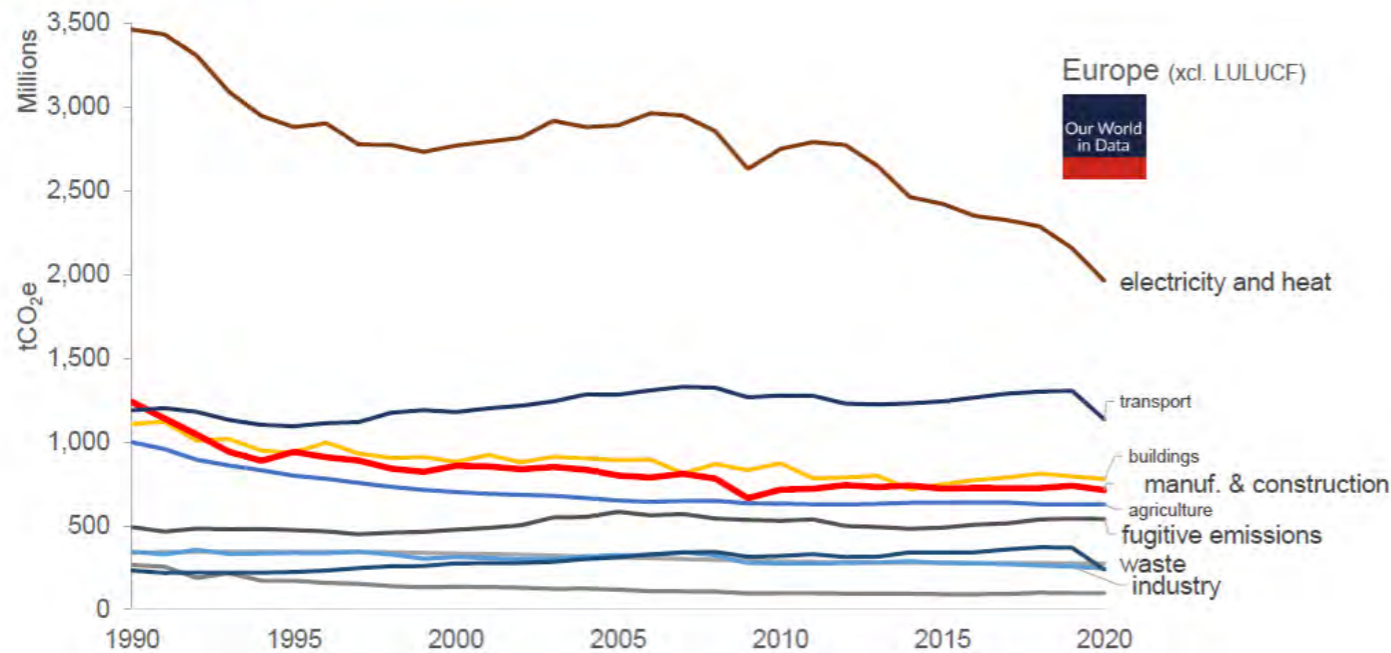
<https://www.eib.org/en/publications/the-eib-group-climate-bank-roadmap>



# Decarbonisation & Large Research Infrastructures

## Europe's decarbonisation progress – by sector

Which sectors does Large Research impact on?



- Funding and financing landscapes are changing rapidly in Europe and beyond, which will require addressing carbon explicitly in the business case for large research infrastructure

## Context, progress and future needs

ARUP

H. Pantelidou

Transition risks for Large Research and potential financial impacts

**Net zero laggard** | Fees to mitigate exposure to penalties, compliance costs and insurance premiums, asset impairment

**Slow grid decarbonisation – not enough for all** | Cost to deploy new agreements, capex to secure electricity supply, increased energy costs

**Shift in market and research priorities** | Reduced funding, changes in grant decisions, large research infrastructure maybe deemed a stranded asset

**Organisational reputation** | Stakeholder pressure, workforce management, employee attraction/retention, research restructuring

TCFD | TASK FORCE ON CLIMATE-RELATED FINANCIAL DISCLOSURES

### TCFD in a nutshell

Framework to disclose risks, opportunities and financial impacts associated with climate change



- Identifying relevant decarbonisation initiatives: prioritising nature-based interventions, integration in local environment (e.g. CERN generally, Green ILC concept) as part of the asset management – potential to contribute towards carbon removal through environmental enhancement.



# Power Purchase Agreement - Running on Renewables

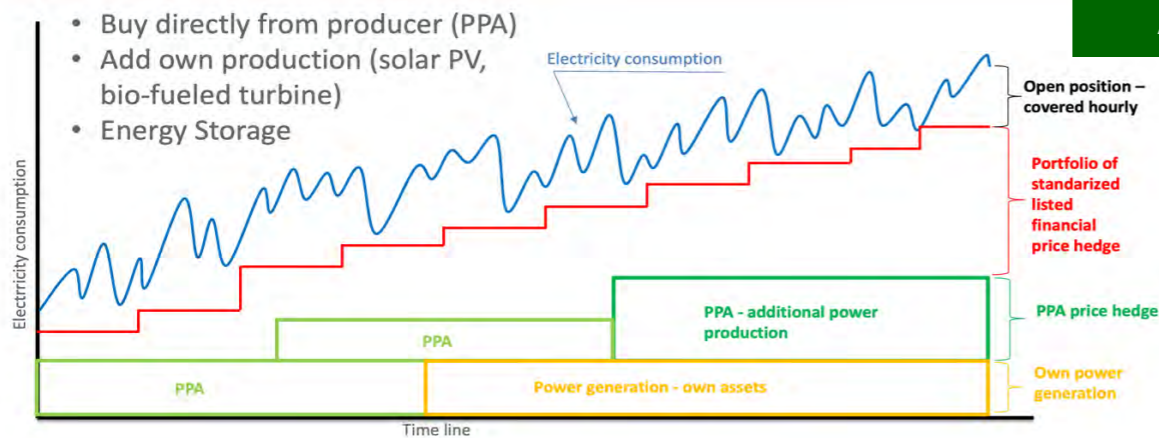
Approaches to **reduce power consumption**:

- Reduce power (by higher efficiency)
- Re-use waste energy (heat)
- Modulate power according to availability (price)
- Use regenerative power

Enabling framework for renewables - **physical power purchase agreement (PPA)** is a long-term contract for the supply of electricity for a defined period (generally 20 years). Largely configurable

Possible Future Energy Strategy

A. Sunesson



## Power Purchase Agreements:

The screenshot shows the European Commission website. The page title is 'Enabling framework for renewables'. The main text states: 'The EU aims to accelerate renewable energy projects, remove administrative obstacles in the permitting processes and further empower citizens.' Below the text, there is a 'PAGE CONTENTS' section with links to 'Simplifying permitting processes', 'Power purchase agreements', 'Study and public consultation', and 'Workshops'. There is also a small image of wind turbines.

Study by Fraunhofer Institute (2018) considered running CLIC (380 GeV) for a total power of 200 MW (in reality only 110 MW needed) on renewables and participating in **demand side flexibility**:

- **CLIC's total energy consumption could be generated from renewables** (using local solar plant of 330 MWp a local wind farm of 220 MWp), but still needs public grid for continuity
- Flexible operating modes were investigated

The top part of the block shows the cover of a report from Fraunhofer IML titled 'ENERGY LOAD AND COST ANALYSIS Final Report Version 1.0 | 29.11.2018'. The bottom part is a state transition diagram for CLIC power modes.
 

- Main states (green boxes):** 10 (Off), 20 (scheduled Standby and Intervention (S&I)), 30 (unscheduled Standby and Intervention (S&I)), 40 (Low Power Running (LPR)), 50 (Full Operation (OP)).
- Transition states (blue boxes):** 12 (OFF → S&I), 21 (S&I → OFF), 31 (S&I → OFF), 45 (LPR → OP), 54 (OP → LPR).
- Transition equations:** a12,1; a12,2; a21,1; a21,2; a31,1; a31,2; a45,1; a45,2; a54,1; a54,2.

<https://edms.cern.ch/document/2065162/1>



# Power Purchase Agreement - Running on Renewables

Align to future energy markets, using green and more renewable energy (power purchase agreements), remain flexible customer and deal with grid stability/quality

## Requirements for future colliders: **Energy**

R. Losito

### • CERN policy on renewables:

- Increase share of renewables through purchase of long term PPAs (15 to 20 years commitment towards solar plants or wind farms), within the boundaries of present energy contract with EDF (and future ones)
- Limited by the flexibility required on the total share
- Would require massive curtailment, not necessarily technically feasible and socially acceptable.



**FCC-ee future:** has warm magnets but a large SRF system with stable power required for cryogenics:

- Large oscillations among operational modes makes it difficult to manage the excess energy with the legal framework of today.
- Energy required in stand-by ~25% of energy during beam operation.

### • Two factors provide uncertainty today in a scenario fully based on renewables:

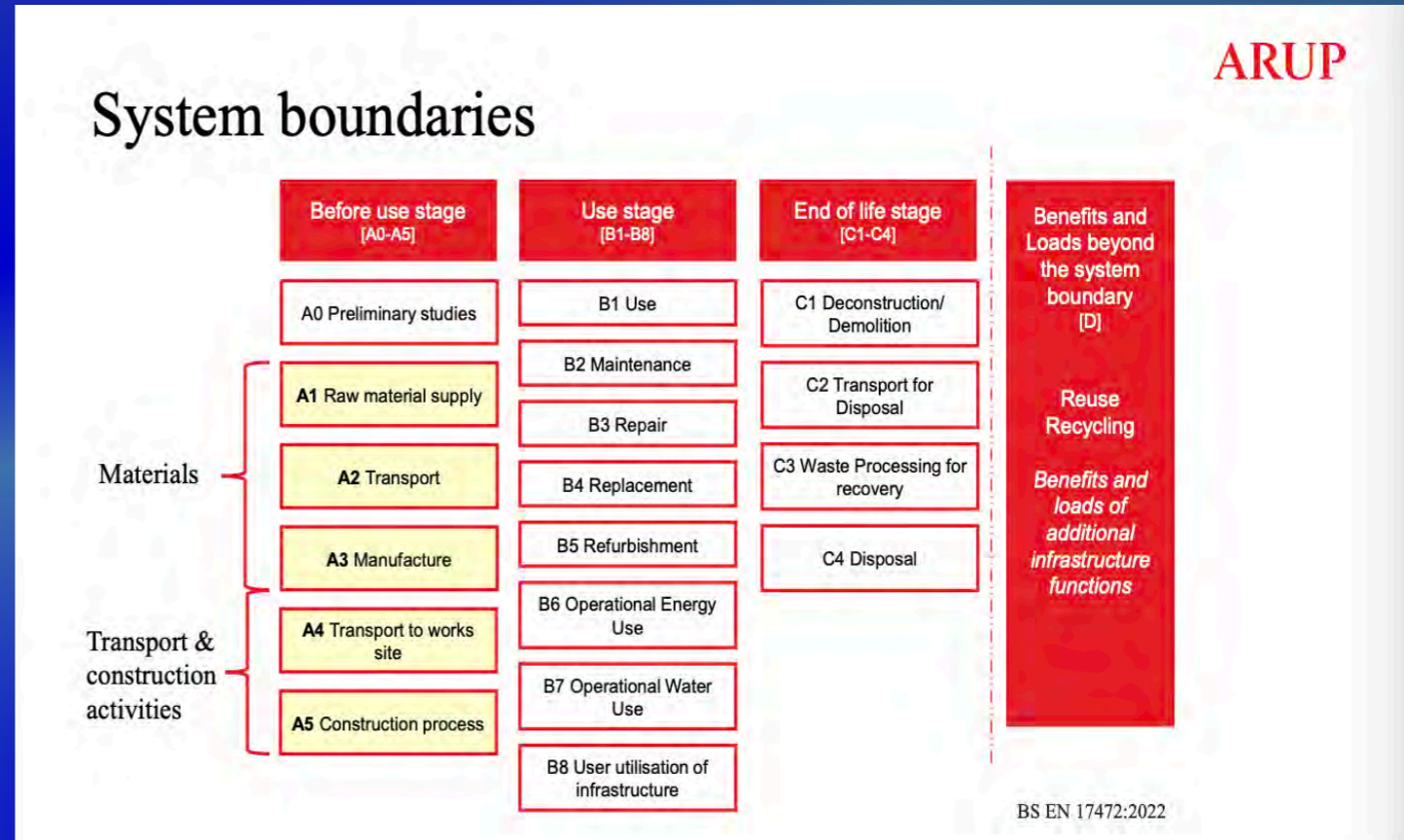
- ✓ Lack of one or more efficient technology to store energy in order to provide a sufficiently stable baseload → adapt to fluctuating power supply will remain a concern
- ✓ Lack of capacity and of the possibility to reserve capacity to move energy across borders.



# Sustainable Construction: Life-Cycle Assessment (LCA)

Accepted way to quantify the sustainability of a project is to assess the impacts across the whole lifecycle. International standard ISO 14040/4 define the LCA

- Covering all project stages: **design, construction, operation, decommissioning/disposal**
- Covering all parts: accelerator, detector, civil construction, infrastructure, computing
- Covering the full scope, including raw material extraction and **electricity generation**



## Inventory Analysis:

Materials, Energy, waste, production process

-> domain specific

-> input from accelerator, detector and CFS experts

- tunnel/cavern/shaft dimensions & type
- component types and numbers
- production of components

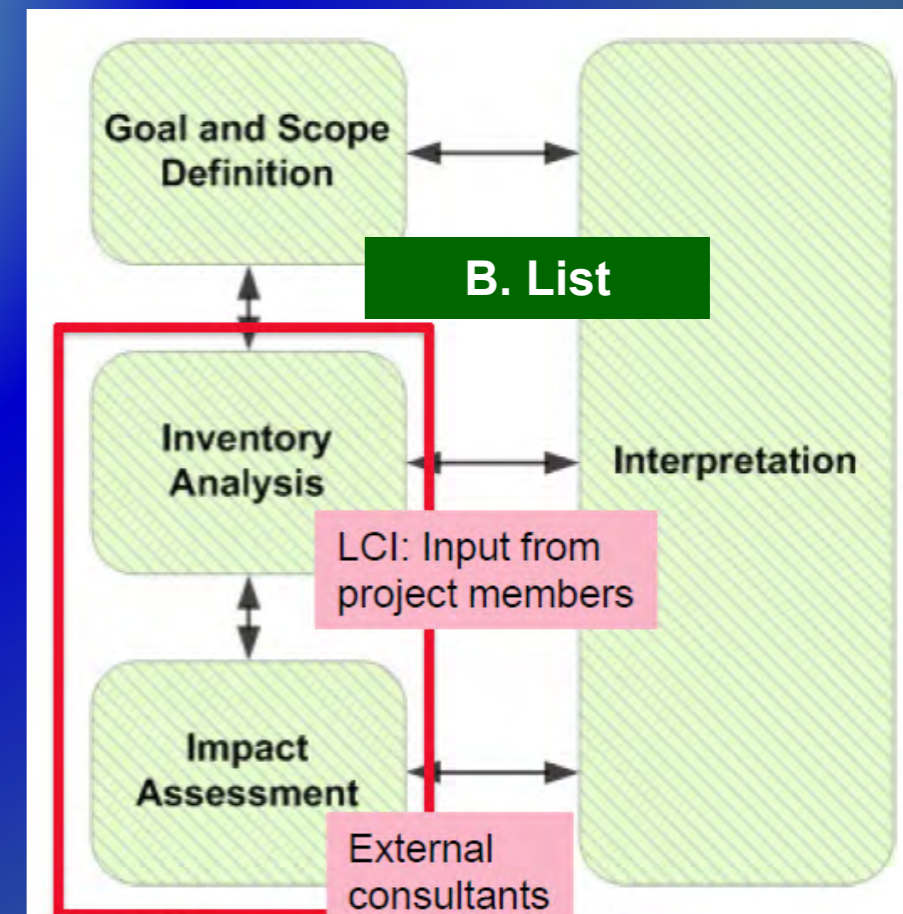
## Impact Assessment

Impact of materials on environment

-> methodology

-> based on specific software (e.g. OpanLCA, Simapro) and databases (e.g. ecoinvent)

-> external consultants (e.g. ARUP) can be quite helpful

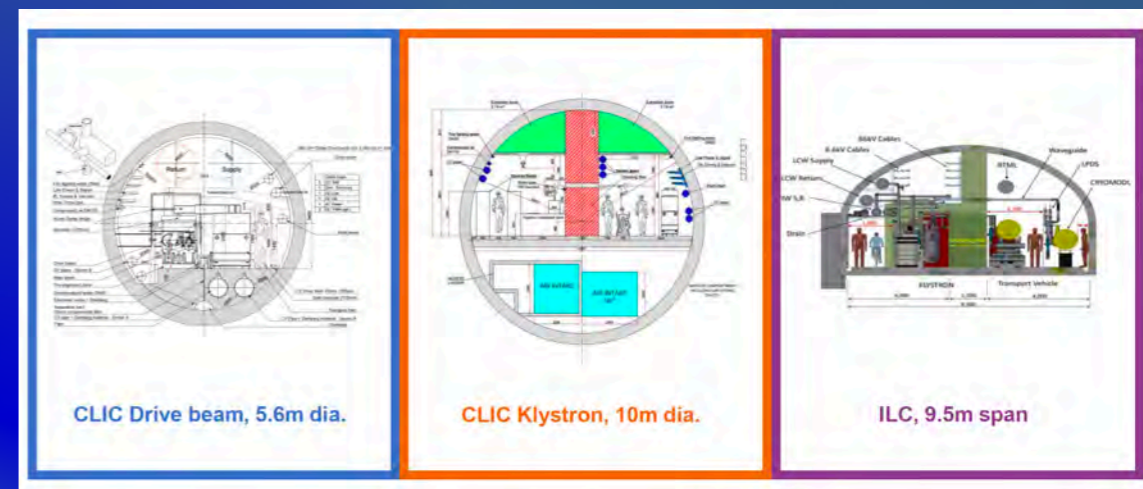




# Example: ILC & CLIC LCA Studies

CERN commissioned a study with ARUP to perform a Lifecycle Assessment for the CLIC and ILC civil infrastructure (tunnels, shafts, caverns)

Full ARUP report:  
<https://edms.cern.ch/document/2917948/1>



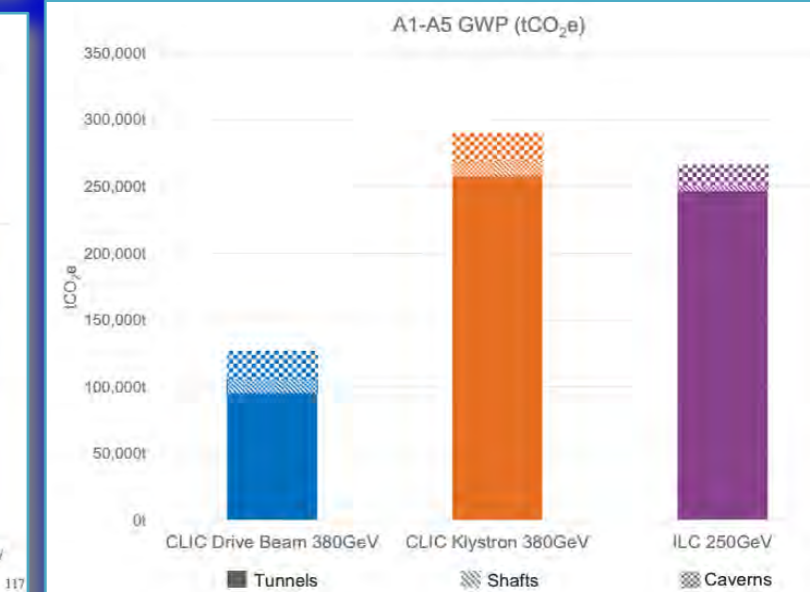
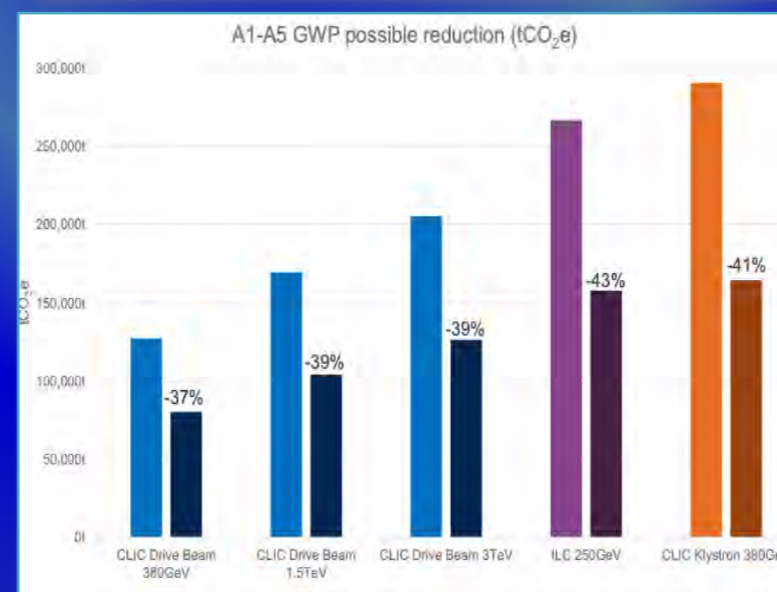
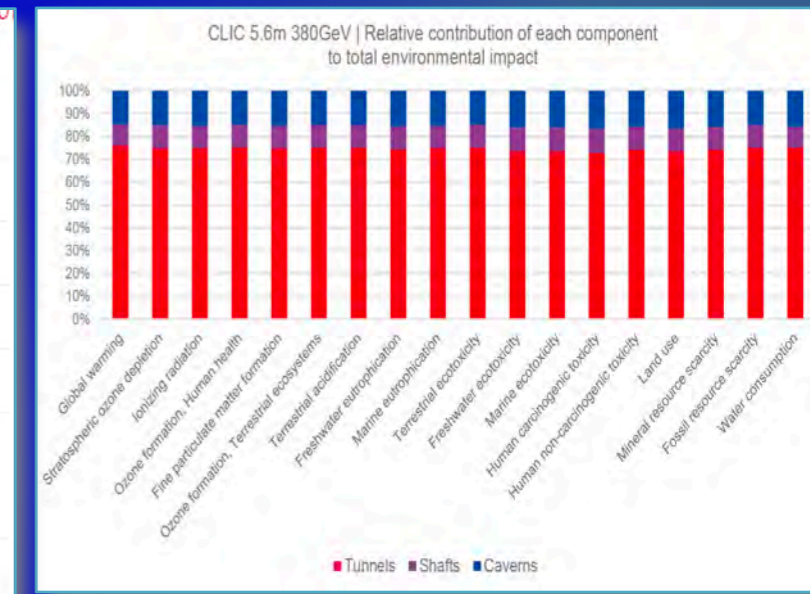
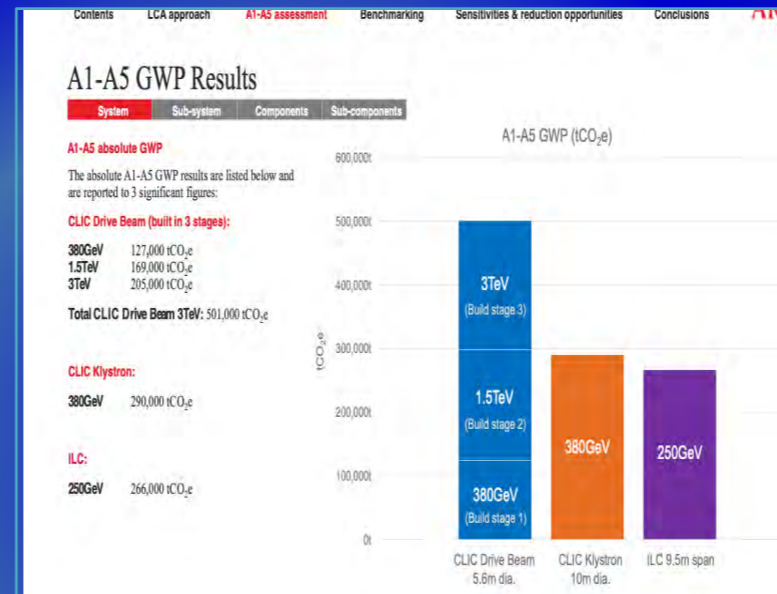
## Study provided results on:

- Greenhouse gas emissions from construction
- Full set of ReCiPe 2016 impact categories
- Reduction potential (40%) from optimized design and use of lower carbon material

New LCA study with external company (ARUP) to start soon to provide LCA data for ILC and CLIC accelerator and detector

Goal: quantify lifecycle impact of the full project

-> results will be available by end of 2024



Reduction potential: 40% reduction through use of low-CO<sub>2</sub> materials (steel, concrete) and reduction of tunnel wall thickness)

CO<sub>2</sub>-eq from underground civil engineering and electricity for operation



# Open Questions: Regional versus Globally Averaged Impacts

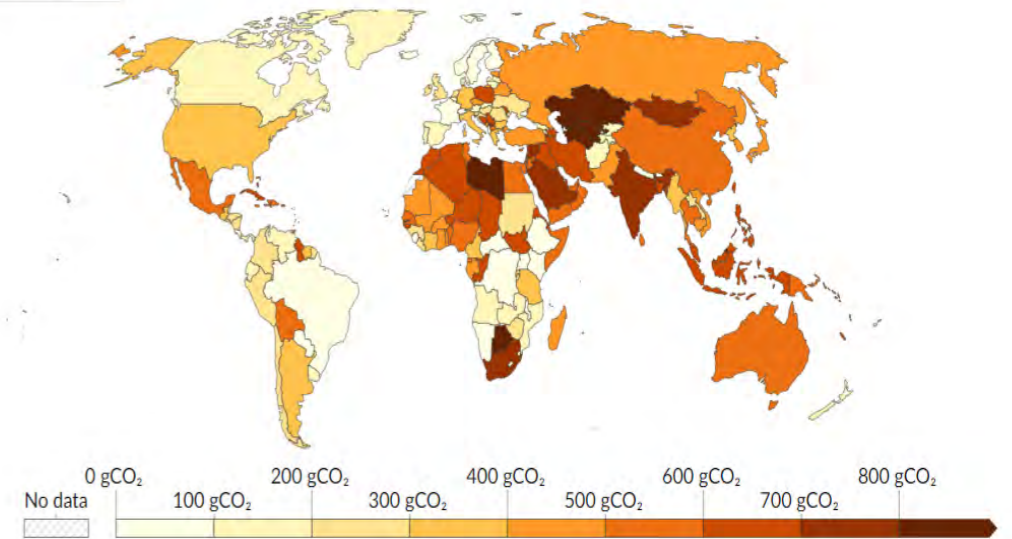
B. List

- Carbon intensity of electricity production varies enormously across regions / countries
- Carbon intensity of materials also varies
  - Different local standards
  - Different geology, primary minerals, concentrations
  - Different carbon intensity for local energy, esp. electricity (-> copper, niobium)
- Civil construction: steel and cement mostly from local sources, adhere to local codes
- Result of LCA depends heavily on
  - Source of used materials
  - Construction and operation site
  - Method of LCA: use local values or global averages
- Should one evaluate impacts using site-specific or globally averaged impact values?  
-> or provide both?
- Distinguish impact of intrinsic accelerator design and site specific impact
- Can we give reference values for assumed CO2 intensity of electricity for relevant regions / labs?

## Carbon intensity of electricity generation, 2023

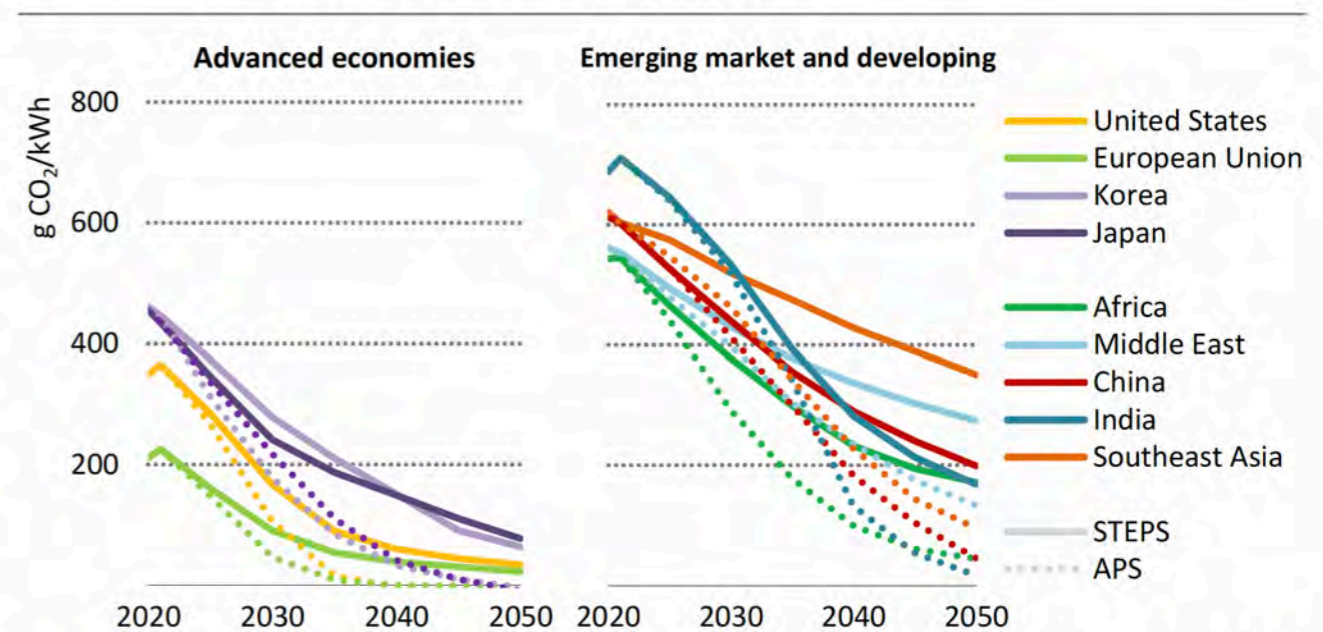
Carbon intensity is measured in grams of carbon dioxide-equivalents emitted per kilowatt-hour of electricity generated.

Table Map Chart



<https://ourworldindata.org/grapher/carbon-intensity-electricity>

Figure 6.14 > Average CO<sub>2</sub> intensity of electricity generation for selected regions by scenario, 2020-2050



IEA (2022), World Energy Outlook 2022, IEA, Paris <https://www.iea.org/reports/world-energy-outlook-2022>, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A)



# High Efficiency Klystron Project at CERN

High Efficiency klystrons activity was initiated at CERN in 2014. In 2021 it was transformed into a CERN's project.

Objectives: Development, design, fabrication and testing of the new HE klystrons for application in various particle accelerators.

High Efficiency Klystrons



I. Syratcev @ WSFA2023



First commercial X-band 10 MW HE (56%) klystron. CERN-Canon collaboration.

- Task 4: High efficiency X-band pulsed klystrons in the power range 10-50MW
- Strong Collaboration with industry (Canon, CPI and Thales).
  - Important for multiple projects (CompactLight, DEFT, EUPRAXIA etc.).
  - Great show case for CERN's technology and contribution to worldwide society.

400 MHz HE Two-Stages MBK for FCC<sub>ee</sub>. Performance summary.



Efficiency vs. saturated RF power at different klystron voltages

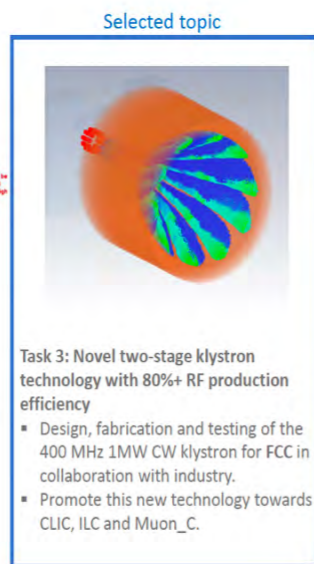
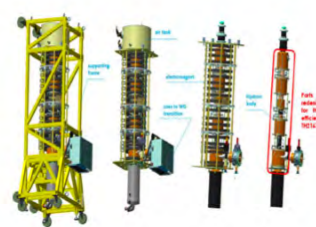
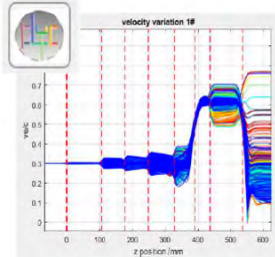


Featured:

- Very efficient. 86% @ Z,W,H and 83% @ ttbar2.
- Compact. Total length <3m.
- Low Voltage. Up to 64kV @ 1 MW.
- High RF power gain. 43dB @ 1MW.
- Broadband. 3.5 MHz @ -1dB.
- Robust. Can handle mismatch up to -15dB.

Project status @ CERN

- ✓ RF circuit
- ✓ Collector
- ✓ Cathode
- ✓ Solenoid
- ✓ Special High Voltage isolated RF feedthrough (prototype).
- Integration
- Thermal/mechanical analysis



Task 1: Design & simulations

- Maintenance and distribution of the CERN made klystron code KlyC.
- High level expertise in using commercial tools like CST PIC, HFSS etc.

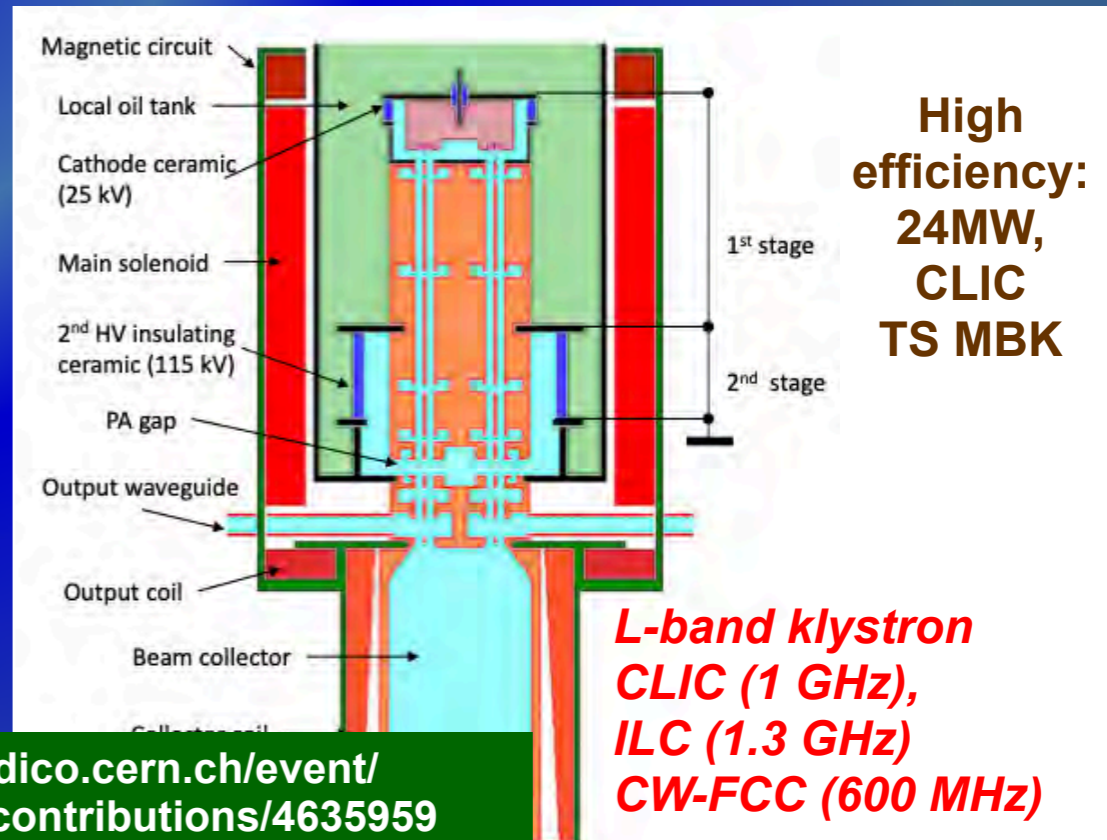
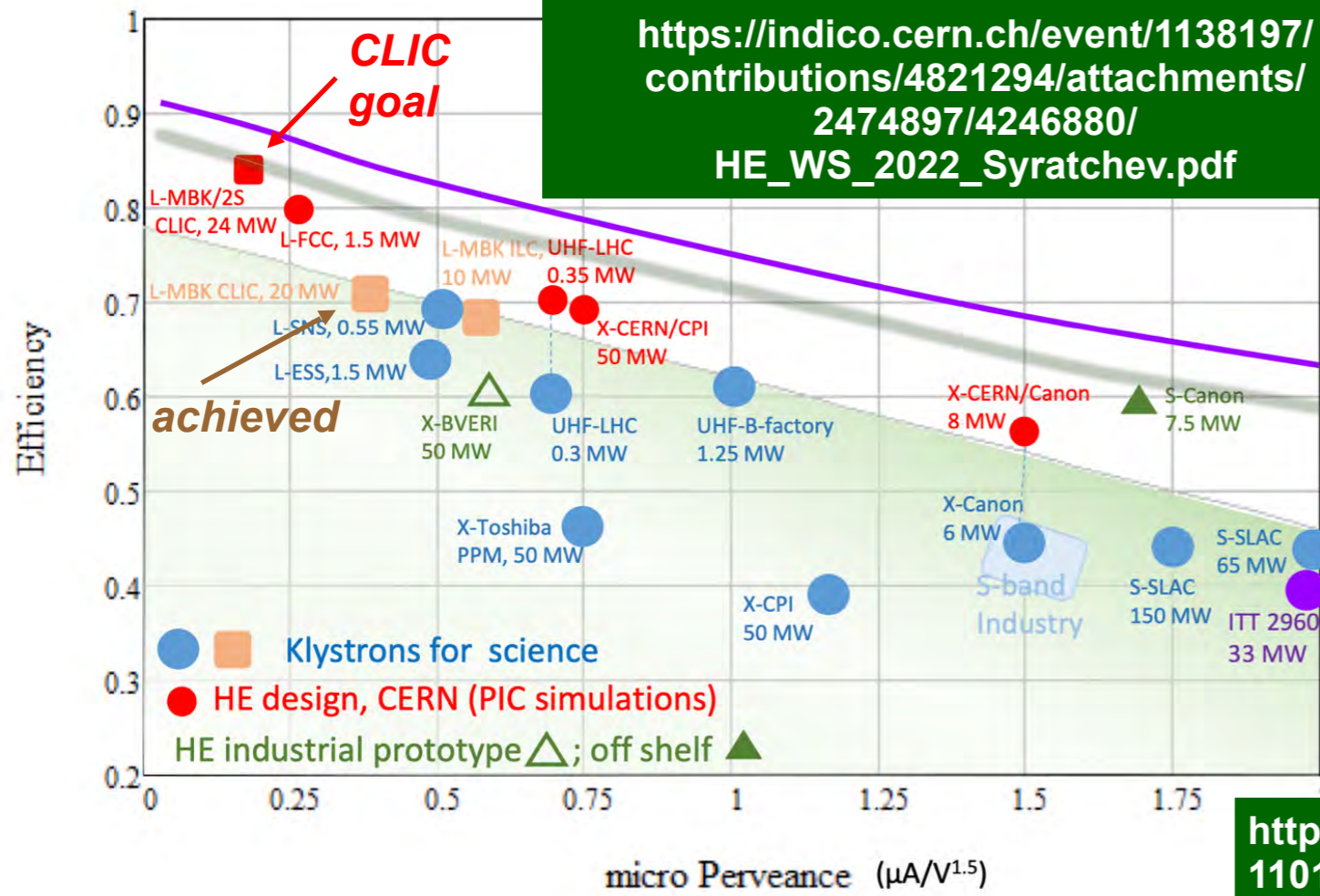
Task 2: HE LHC 400 MHz klystron

- Retrofit upgrade of Thales klystron (60% to 70%) in close collaboration with industry.
- A base line option for HL-LHC.

Task 3: Novel two-stage klystron technology with 80%+ RF production efficiency

- Design, fabrication and testing of the 400 MHz 1MW CW klystron for FCC in collaboration with industry.
- Promote this new technology towards CLIC, ILC and Muon\_C.

Drive beam klystron: The klystron efficiency (circles) and the peak RF power (squares) simulated for the CLIC TS MBK (solid lines) and measured for the Canon MBK E37503 (dashed lines) vs beam power.



<https://indico.cern.ch/event/1101548/contributions/4635959>



# R&D for Improved SRF Performance & Sustainability

Major progress during past 10 years:



- bulk niobium (1.3 GHz as ILC & FEL linacs), improvements in gradient, processing steps; surface treatment, cavity shapes; power efficiency ( $Q_0$ ) always an integrated part of studies

- **Raise Gradient:**

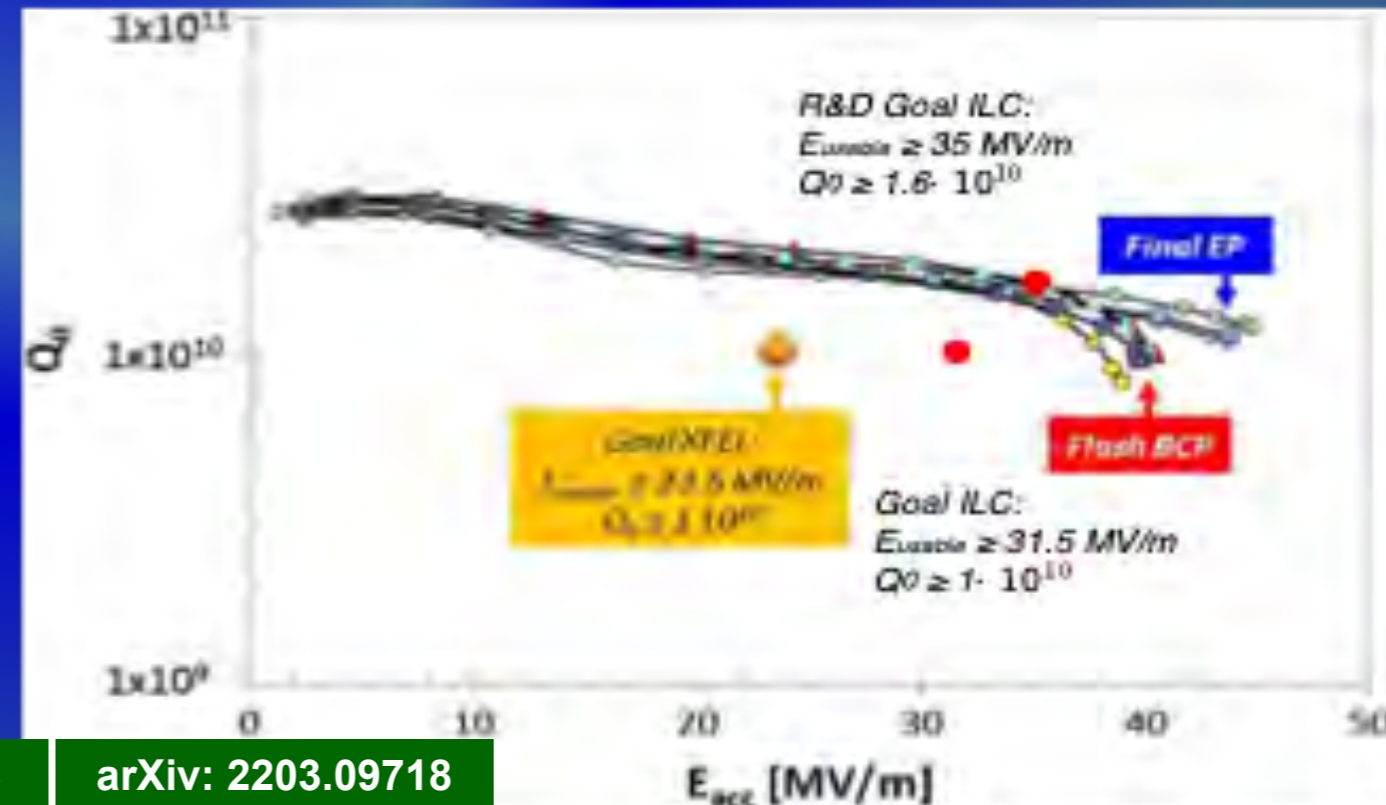
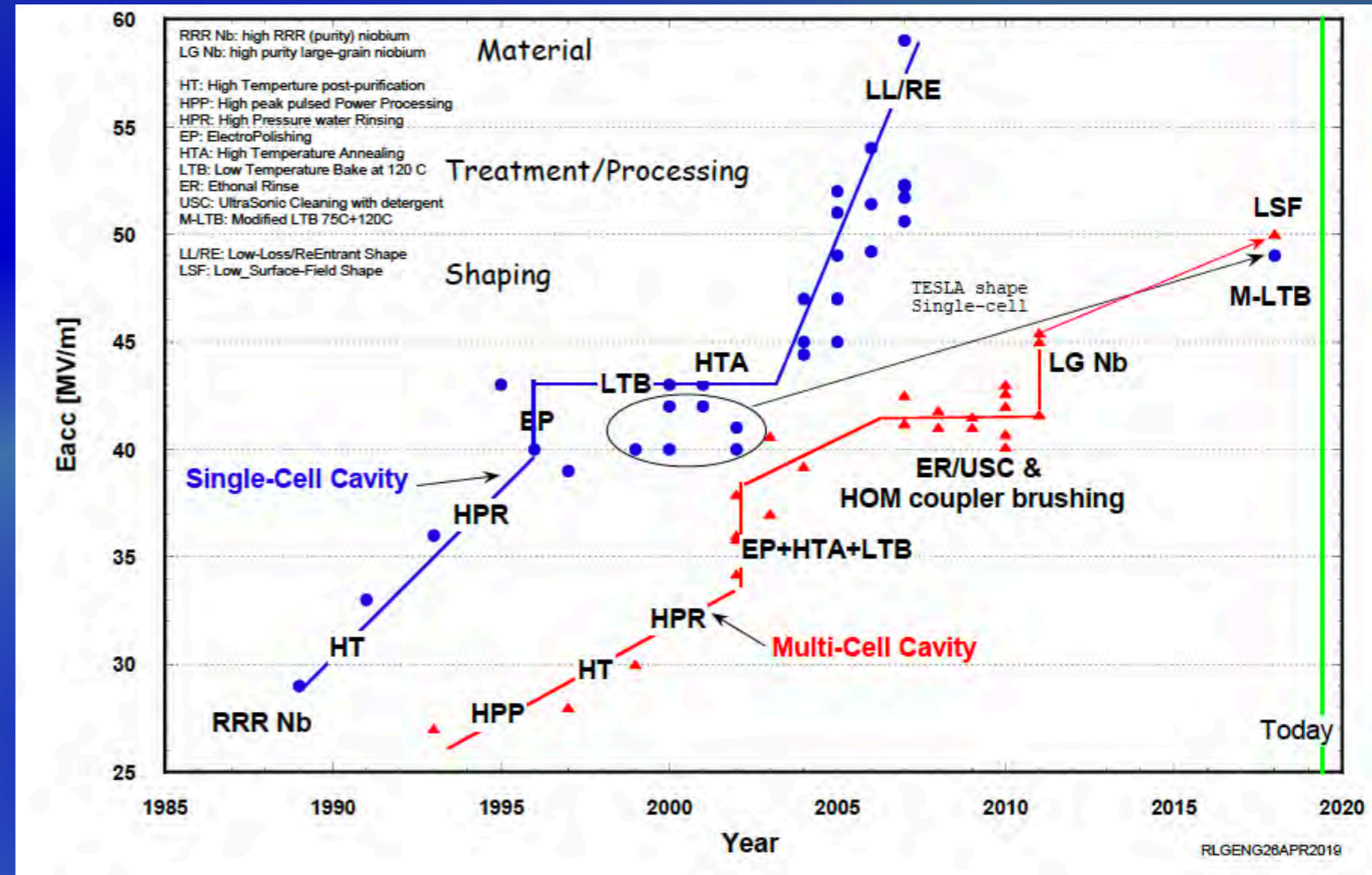
Short term goal: 31.5MV/m → 35MV/m  
 Medium term goal: 45MV/m  
 Lab record: 59MV/m

- **Improve  $Q_0$ : reduce cryogenic losses**

(1W @ 2K requires ~750W AC power!)  
 Short term goal:  $1E10$  →  $2E10$

- **State-of-the-art surface treatment of bulk Nb:** baking/annealing/doping, plasma processing (possibly reducing aggressive chemicals, required for electropolishing)

- **R&D into replacement of bulk niobium cavities with Nb or Nb<sub>3</sub>Sn coated copper** (beyond bulk Nb – thin-film SRF): reduce Nb consumption, increase performance





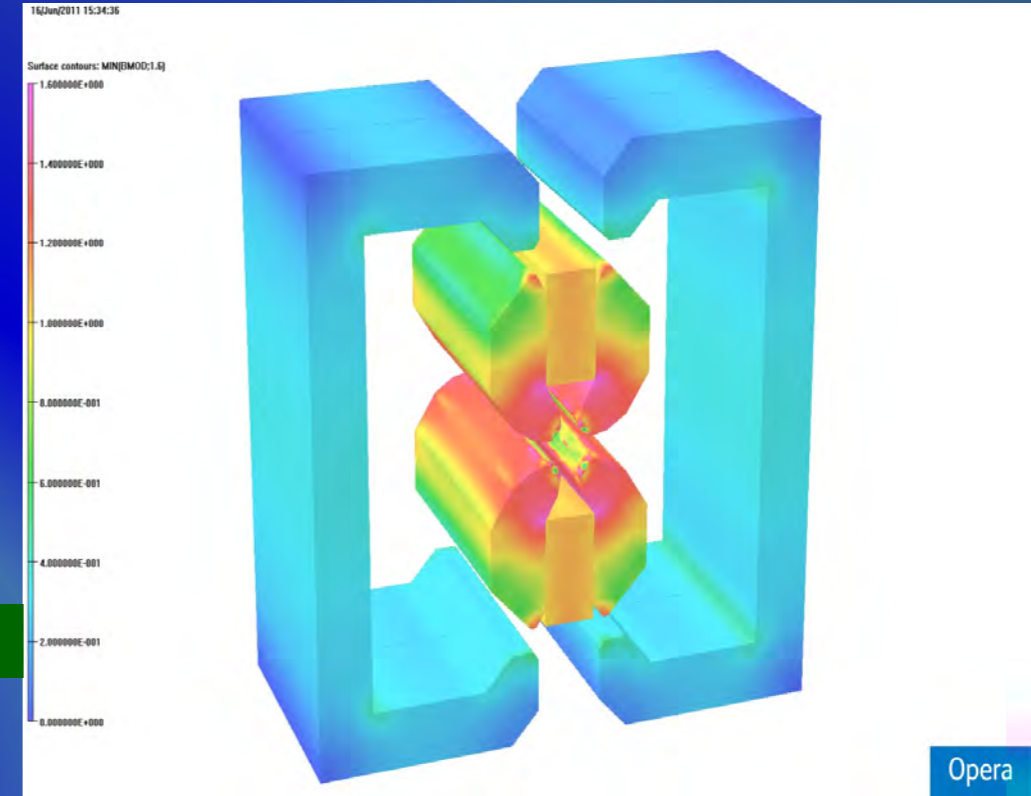
# R&D for Permanent Magnets

ZEPTO (Zero Power Tuneable Optics) project is a collaboration between CERN and STFC Daresbury Laboratory to save power and costs by switching from resistive electromagnets to permanent magnets

## Green Projects: ZEPTO

- **Zero-Power Tuneable Optics**
- Tunable PM quadrupole and dipole magnets to replace electromagnets
  - Large **tuning range** using motors to move PMs
  - Same **physical footprint**
  - No **energy usage** (except a tiny amount when adjusting)
  - Less **infrastructure** required (no big current cables, power supplies, cooling)
- 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

Ben Shepherd



Opera

Bainbridge et al, IPAC2022

## ZEPTO at Diamond Light Source



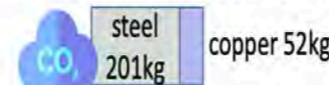
- Aim: demonstrate operation of a ZEPTO quadrupole on a working accelerator
- Use a **tunable PM quadrupole** as a drop-in replacement for an electromagnet
- Step towards **commercialisation** of ZEPTO technology
- **Assembly and testing at Daresbury complete**
- **Installed at Diamond in August 2022 shutdown**
- Now operating successfully at Diamond for 18 months

- Similar design to ZEPTO-Q2
  - Outer shell for large tuning range
- Gradient range **0.5-19 T/m**
- Movement range **90 mm**
- Aperture diameter **32 mm**
- **Improvements to design:**
  - **SmCo blocks**
    - improved temperature stability
    - better radiation resistance
  - **Splittable** to allow installation around vacuum chamber
  - **Two independent motors** for magnetic centre correction
  - **Ice cube tray** concept for easy installation of PM blocks

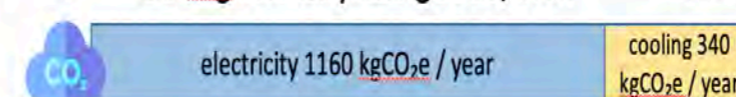


## ZEPTO: comparing carbon footprints

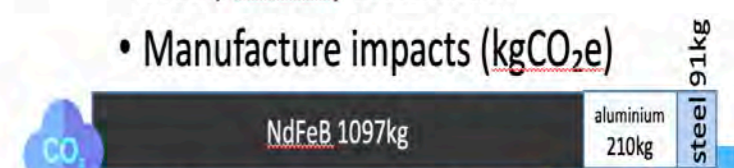
- Electromagnetic quadrupole
- Main materials: steel, copper
- Manufacture impacts
- Operation costs



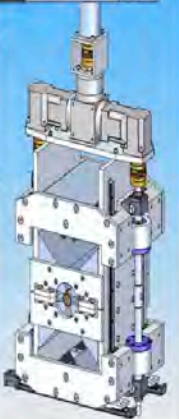
- 856W at 100% excitation
- Another 250W for cooling
- Assume 251 days / year operation
- 6.7 MWh / year
- EU avg intensity 225 gCO<sub>2</sub>e/kWh



- Permanent magnet quadrupole
- Main materials: steel, NdFeB, aluminium
- Manufacture impacts (kgCO<sub>2</sub>e)



- Operation costs: negligible
- "Carbon payback": 1 year





# Conclusions

Goal of the WG is to propose a motivated list of key parameters for the sustainability assessment of future accelerators

Inputs from different kinds of sustainability panels related to medium and large RI for fundamental physics are being considered

Environmental sustainability is the focus

The evaluation is quite complex:

assessment criteria deserve to be

- properly tuned to the maturity of the project and
- differently developed for Researchers (our community), Management, and Society

The WG aims to elaborate a proposal for the LDG on time to be submitted to the ESPPU in March 2025