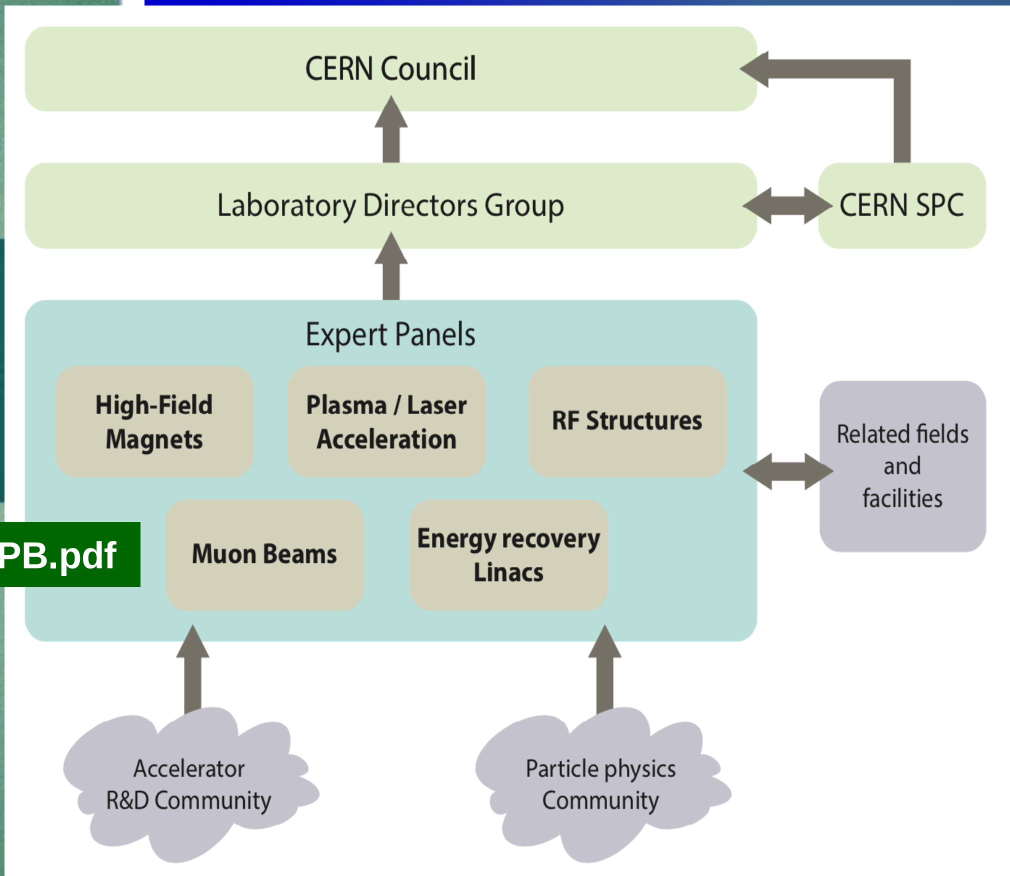
Sustainability Assessment of Future Accelerators: Report from the LDG Working Group

Caterina Bloise (INFN Frascati), Maxim Titov (CEA Saclay)
(on behalf of the LDG Working Group)

115th Plenary ECFA Meeting, CERN, November 14-15, 2024

CERN Council has mandated the Laboratory Directors Group (LDG) to *define and maintain a prioritized accelerator R&D roadmap* towards future large-scale facilities for particle physics.

https://cds.cern.ch/record/2800190/files/146-138-PB.pdf



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

LDG Sustainability WG Mandate and Composition

Development of guidelines and a minimum set of key Indicators for the sustainability assessment of future accelerators

Panel consisting of 15 members with technical expertize in evaluation of accelerator sustainability and future collider project representatives

Ensuring broad community representation:

- Sustainability Lab. Panels established at CERN, DESY, ESS, NIKHEF, STFC
- ICFA Sustainability Panel
- EU- Horizon Programs
- Future accelerator projects: FCC, ILC, CePC, CLIC/Muon, LHeC, C3
- Invited experts on specific topics

- Walib Kaabi - PERLE, EU-iSAS
- Mats Lindroos - ESS (deceased May 2, 2024)
- Roberto Losito - CERN Sust. Panel
- Ben Shepherd - STFC Sust. Task Force
- Andrea Klumpp - DESY Sust. Panel, EU-iFAST
- Hannah Wakeling - ISIS-II Neutron & Muon Source
- Patrick Koppenburg - NIKHEF Sust. Panel

- Johannes Gutleber - FCC
- Yuhui Li - CePC
- Benno List - ILC
- Emilio Nanni - ICFA Sust. Panel & C3
- Vladimir Shiltsev - LHeC
- Steinar Stapnes - CLIC & Muon collider

- Caterina Bloise - Co-Chair
- Maxim Titov - Co-Chair, EU-EAJADE

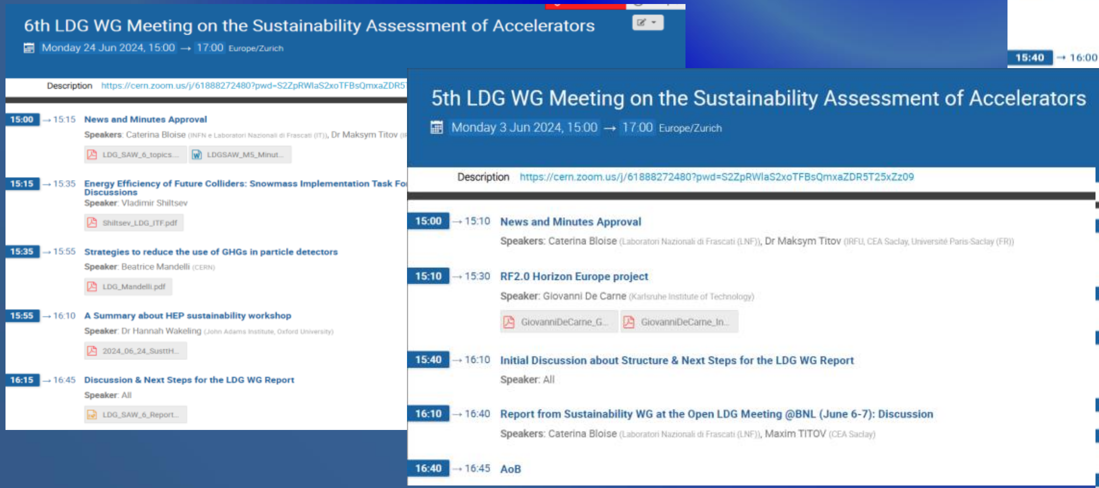
in the Editorial Board also

- Enrico Cennini (CERN), Luisa Ulric (CERN).
- Beatrice Mandelli (CERN), Niko Neufeld (CERN)
- Thomas Schoerner (DESY)

Working Group Activities

Broad range of topics shared:

- *Reports* from the CERN and STFC *Sustainability Panels*, ESS, Snowmass ITF
- *Evaluations* carried out for *Future Higgs Factories* (FCC, ILC, C3, CEPC)
- *Key LCA issues*
- *Invited expert contributions*: Decarbonisation for Large RI (H.Pantelidou, ARUP), LCA of engineering civil works for the FCC (D. Mauree, WSP), EU-Horizon Project RF2.0 (G. DeCarne, KIT), Reduction of GHGs in particle detectors (B. Mandelli, CERN)



Working Progress Status

- *Editorial work assigned*
- *Report elaboration advanced, many relevant topics drafted*

Focus on Sustainability Assessment for Future Accelerators:

Content:

- ***Landscape & Highlights***
- ***Recommendations***
- ***Open Questions***

7th LDG WG Meeting on the Sustainability Assessment of Accelerators

Monday 15 Jul 2024, 15:00 → 17:00 Europe/Zurich

Description https://cern.zoom.us/j/61888272480?pwd=S2ZpRWlaS2xoTFBsQmxaZDR5T25xZz09

15:00 → 15:15 **News and Minutes Approval**
Speakers: Caterina Bloise (INFN e Laboratori Nazionali di Frascati (IT)), Dr Maksym Titov (IRFU, CEA Saclay, Université Paris-Saclay (FR))
LDGSAW_M6_Minu...

8th LDG WG Meeting on the Sustainability Assessment of Accelerators

Monday 26 Aug 2024, 15:00 → 17:00 Europe/Zurich

Description https://cern.zoom.us/j/61888272480?pwd=S2ZpRWlaS2xoTFBsQmxaZDR5T25xZz09

15:00 → 15:15 **News and Minutes Approval**
Speakers: Caterina Bloise (INFN e Laboratori Nazionali di Frascati (IT)), Dr Maksym Titov (IRFU, CEA Saclay, Université Paris-Saclay (FR))

15:15 → 15:45 **FCC LCA study: sensitivity of the use of databases and EPDs to the final result.**
Speakers: Dasardan Mauree (WSP / BG Ingénieurs Conseils SA), Johannes Gutleber (CERN)

15:45 → 16:45 **Current Status of the WG report: Discussion on Content**
Speakers: Caterina Bloise (Laboratori Nazionali di Frascati (LNF)), Dr Maksym Titov (IRFU, CEA Saclay, Université Paris-Saclay (FR))

9th LDG WG Meeting on the Sustainability Assessment of Accelerators

Monday 16 Sept 2024, 15:00 → 17:00 Europe/Zurich

Description https://cern.zoom.us/j/61888272480?pwd=S2ZpRWlaS2xoTFBsQmxaZDR5T25xZz09

...n Titov (IRFU, CEA Saclay, Université Paris-Saclay (FR))

...ov (IRFU, CEA Saclay, Université Paris-Saclay (FR))

10th LDG WG Meeting on the Sustainability Assessment of Accelerators

Monday 7 Oct 2024, 15:00 → 17:00 Europe/Zurich

Description
https://cern.zoom.us/j/61888272480?pwd=S2ZpRWlaS2xoTFBsQmxa...
LDGSAW_M10_Min...

15:00 → 15:10 **News and Minute Approval**
Speakers: Caterina Bloise (INFN e Laboratori Nazionali di Frascati (IT)), Maxim TITOV (CEA S...
LDGSAW_M9_Minut...

15:10 → 15:40 **Status of the WG Report**
Speakers: Caterina Bloise (INFN e Laboratori Nazionali di Frascati (IT)), Maxim TITOV (CEA S...
LDGWG_Oct7.pptx

15:40 → 16:50 **Discussion on Content**
Speaker: All

16:50 → 17:00 **AoB**

11th LDG WG Meeting on the Sustainability Assessment of Accelerators

Monday 21 Oct 2024, 15:00 → 17:00 Europe/Zurich

Description
https://cern.zoom.us/j/61888272480?pwd=S2ZpRWlaS2xoTFBsQmxaZDR5T25xZz09

15:00 → 15:10 **News and Minute Approval** — 10m
Speakers: Caterina Bloise (INFN e Laboratori Nazionali di Frascati (IT)), Maxim TITOV (CEA Saclay)
LDGSAW_M10_Min...

15:10 → 15:40 **Status of the WG Report** — 30m
Speakers: Caterina Bloise (INFN e Laboratori Nazionali di Frascati (IT)), Maxim TITOV (CEA Saclay)

15:40 → 16:50 **Discussion on Content** — 1h 10m
Speaker: All

16:50 → 17:00 **AoB** — 10m

LDG Working Group REPORT

- ✓ *Structure and basic content suggested by reports to the WG and follow-up discussions*
- ✓ *Draft report is expected early 2025*
- ✓ ***Executive summary as an input to the ESPPU due by March 2025***

Caveat:

- *not all of these topics can be addressed in details in a limited time by end of 2024*
- ***A homogeneous evaluations of all issues will probably need more time to develop and deserves a strategy to be pursued***

REPORT: Social – Economic Benefit Analysis

✓ ***Social - Economic Benefits of HEP accelerator-based Research Infrastructures:***
in relation to the UN Sustainability Development Goals (environment, economy, society)

- SDG Reference Matrix from UN (2024)
    - Fundamental Physics Knoweledge, Accelerator and Detector R&D
    - Economic Growth (regional, international, developing countries)
    - Education, Innovation, International Cooperation, Cultural Exchange

✓ ***Comprehensive sustainability assessment based on quantitative Cost-Benefit Analysis:***
state-of-the-art economics knowledge that integrates total costs, negative environmental externalities, industrial, social and environmental benefits

Reference for the integrated model FCC

EU Policies

- Global Reporting Initiative
- European Sustainability Reporting Standards
- European Union Eco-Management and Audit Scheme (EMAS)
- EC Economic Appraisal Vademecum
- National Guidelines (France, Germany, Switzerland, …)

Carbon Footprint Accounting and Reporting

- Shadow Carbon Cost

✓ ***European Strategy Forum for Research Infrastructures (ESFRI):***
socio-economic impact has become one of important considerations in the roadmap process that identifies European investment priorities in Research Infrastructures

REPORT: Life-Cycle Assessment (Methodology & Reporting)

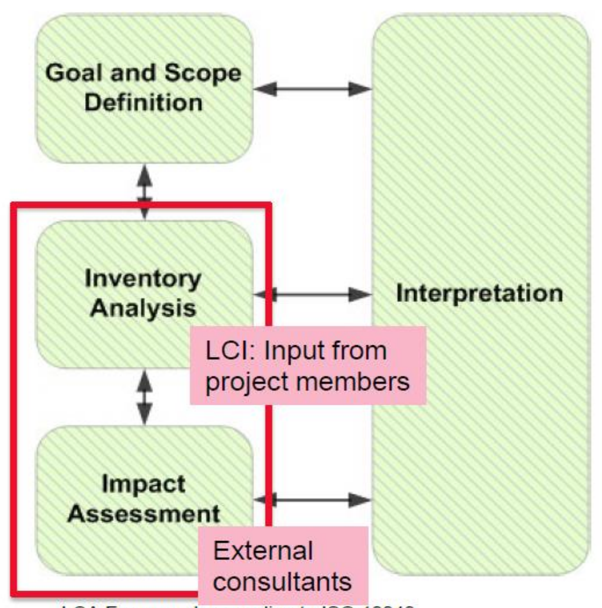
- **LCA Goal and Scopes Definition**
  - project stages: design, construction, operation, decommissioning
  - functional units: accelerator, supporting infrastructures, cryogenic systems, detector, computing
  - boundaries: Cradle-to-gate, Cradle-to-grave

- **LCA Methodology**
  - Impact Categories (Midpoint vs Endpoint)
  - Impact of Emission on Climate Change: GWP_{100}
  - Beyond GWP : ReCiPe2016, ILCD2011, CML-IA2012

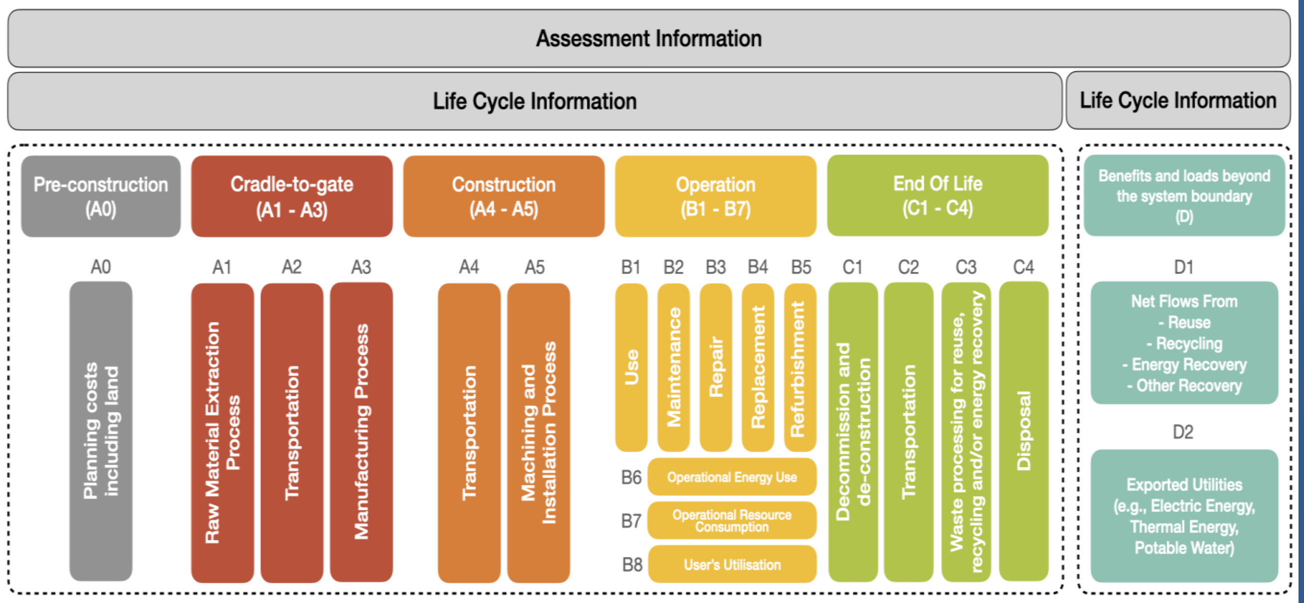
- **LCA Inventory Analysis**
  - infrastructure, materials, energy, production process
    - Construction Phase
    - Operation Phase
    - Decommissioning

- **LCA Assessment and Interpretation**
  - environmental impact,
  - methodology, specific software, databases,
  - evaluation of uncertainties

- **Environmental Product Declaration**



LCA Framework according to ISO 10040
Public Domain, https://commons.wikimedia.org/w/index.php?curid=40862556



BS EN 17472:2022

REPORT: Life-Cycle Assessment (Target and Issues)

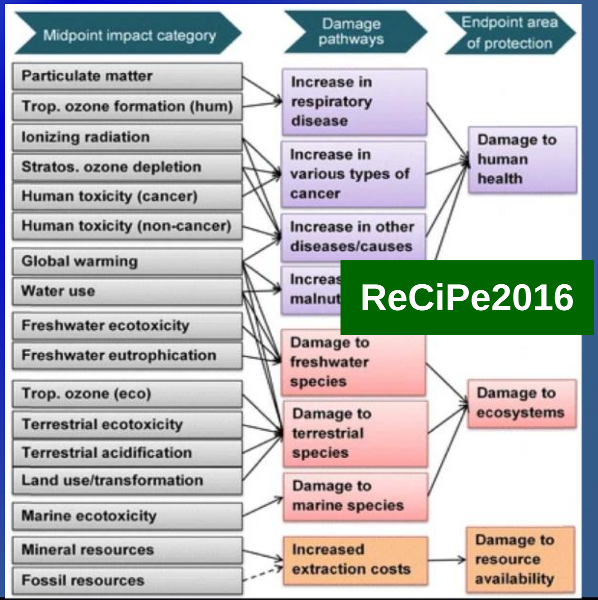
Goals & Scope also depends on target audience: <u>optimize facility</u> (researchers), <u>recommend improvements</u> (Management), <u>communicate to public</u> (society)

LCA** standards for the **assessment of future accelerators are not well set:

- Common approach how to report and evaluate the data for accelerator RI's (which impact categories, treatment of CO_2 intensities, attribution of impacts to long term projects);
- Common table for sustainability parameters (e.g. parameters for GHG emissions) ;
- ISO standards may be too rigid for accelerators to perform full LCA → "simplified LCA";
- Many LCA software available → different packages can give different results (data handling)
- LCA database is the most impactful element (global vs. local, age of database);
- Collect reference data on materials and specific fabricaition methods for accelerators;
- Are there relevant differences in Standards / categories (e.g. Midpoint ReCiPe 2016 vs Endpoint EN 17472 that need to be addressed?

LCA Categories:

- ✓ Conversion factors used in the evaluation of Midpoint categories are usually considered reliable
- ✓ Endpoint evaluations are obtained by weighting results obtained on Midpoint ones
- ✓ A number of categories classes exist
- ✓ European Production Declarations from the International Reference Life Cycle Data system (ILCD) follow EN 15804



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LCA Targets for future accelerators infrastructures:

- ✓ **Understand in each area what are the largest sources**
- ✓ **What to focus on and not focus on (at each project stage)**
- ✓ **Start to look at mitigation strategies**
- ✓ **Developing the tools to do this type of analysis for the future**

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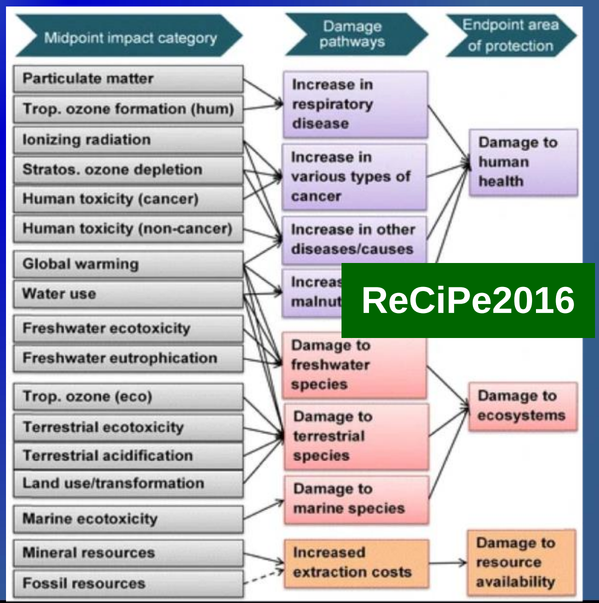


REPORT: Green House Gas Emissions

Green House Gas Emissions (GHG) footprint for future accelerator facilities:
Developing a tool and guidance for quantification could be a good recommendation for the strategy: e.g*. **evaluate & optimize CO2 impact in a staged approach*** at concept phase, CDR, TDR levels

- *Civil engineering works: LCA for accelerator infrastructure (e.g. tunnels, caverns) & Civil engineering (LCA A1-A5), Excavated material*

- *Accelerator construction: accelerator construction: early assessment of areas with the largest emission, beam line shielding, steel girders and supporting structures, magnets, RF cavities, power supplies, material manufacturing*
  - develop reference set of impact values for some commonly used accelerator materials (high-purity niobium, permanent magnet alloys, etc…)

- *Accelerator operation: power for operation (air conditioning and water cooling, cryogenic plants, RF and klystrons, Magnets)*
  - Treatment of carbon intensity of electricity related to energy source - depending on future energy mixes and regions - scenarios, differences e.g. in carbon intensity between different host countries (regional vs globally averaged impacts), shadow cost scenarios)

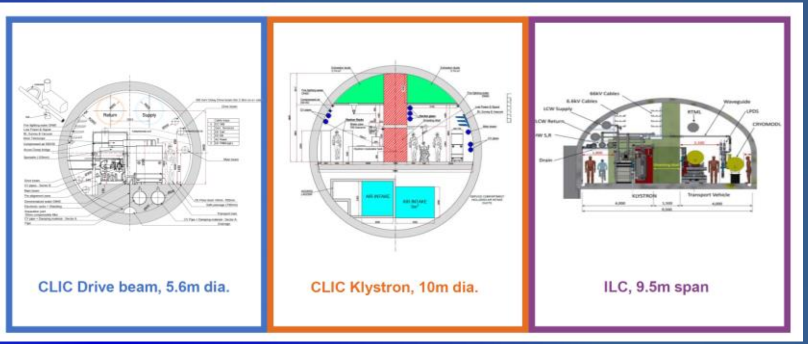
- *Particle detectors/computing operation : Impact of gases for particle detectors, Optimisation of power consumption/environmental impact of computing*

- *Decommissioning: radioactive waste, recycling, site reuse*

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

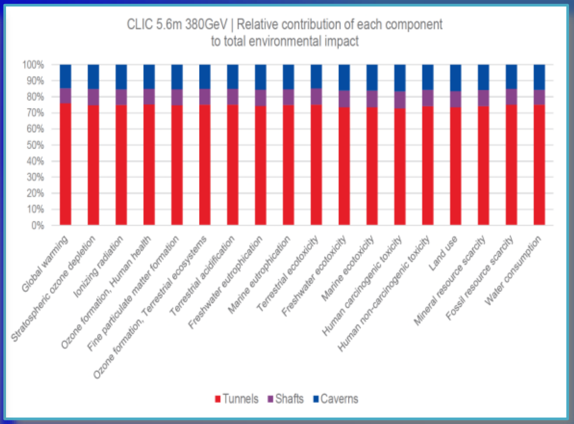


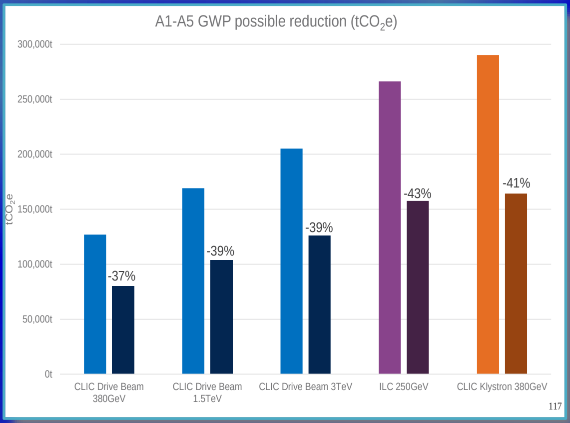
- *Study provided results on:*

  - Greenhouse gas emissions from construction

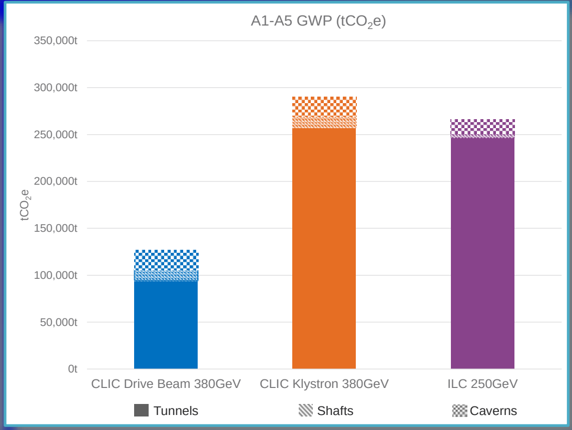
  - Full set of ReCiPe 2016 impact categories
  Reduction potential (40%) from optimized design and use of lower carbon material

- New LCA study on accelerator construction is being prepared:
  - Quantify LCA impact of the full project (data inventory for ILC and CLIC accelerator & detector components)





Reduction potential: 40% reduction through use of low-CO2 materials (steel, concrete) and reduction of tunnel wall thickness)



CO2-eq from underground civil engineering and electricity for operation

Example: Towards Carbon Accounting with LCA

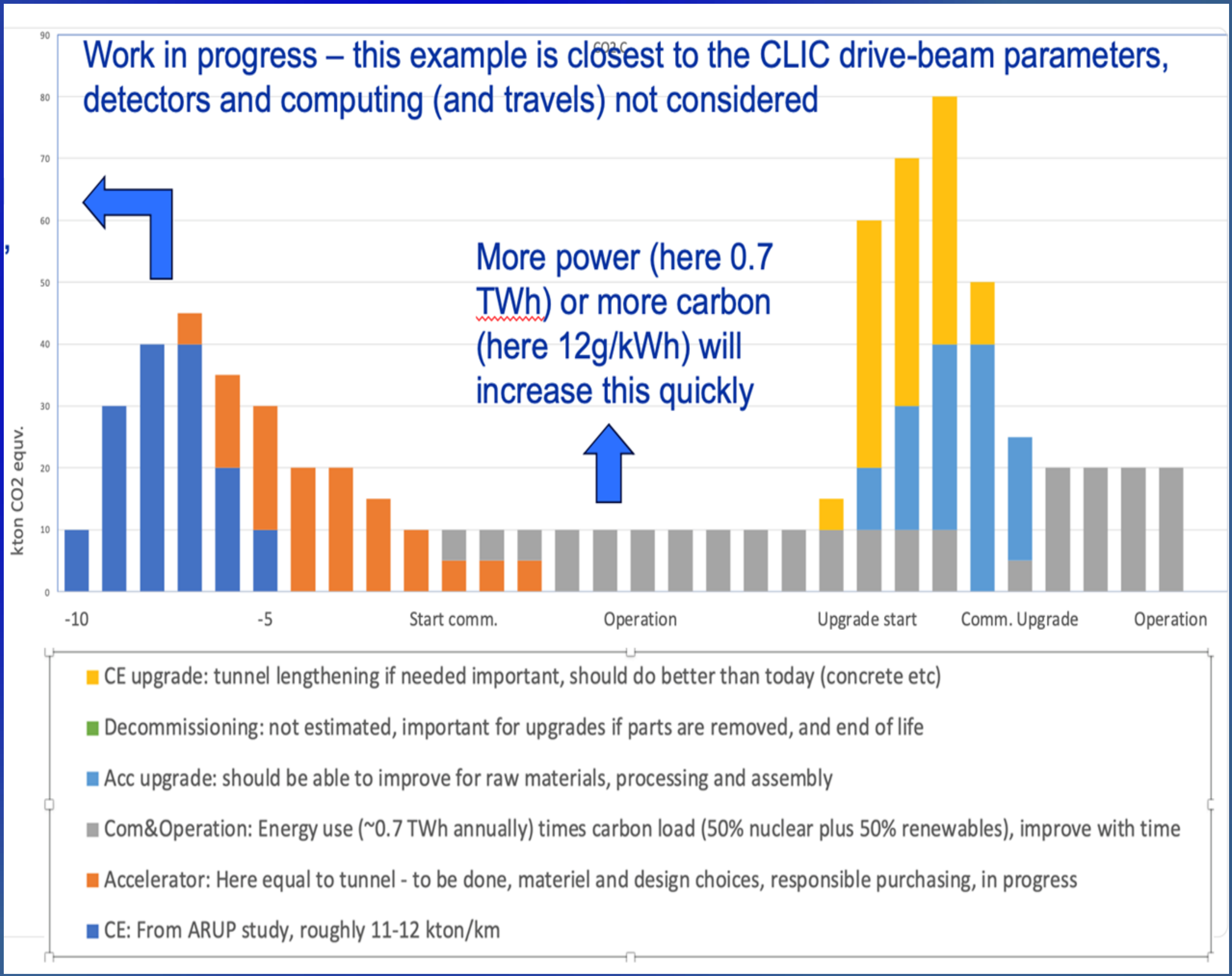
S. Stapnes

CLIC, also (being) done for ILC, C3, HALHF

This plot (blue part) is for 11 km of tunnel, scales with length, injectors will add

NEXT: working on machine parts here, orange graph assumes accelerator hardware & infrastructure = equal civil engineering impact

Most likely this is optimistic, i.e. orange and light blue part will be higher



REPORT: Mitigation and Compensation Strategies

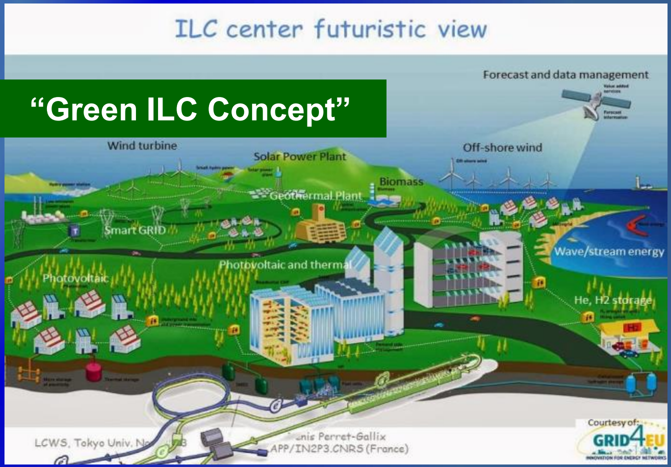
Mitigation and Compensation Strategies, Decarbonisation and Impact Reduction

- *Optimization of large civil & accelerator construction footprint & better/greener materials (inventory of concrete, steel, Cu, niobium)*
- *Responsible procurement*
- *Energy/power optimization (improving energy efficiency of key technologies) and recuperation (heat management, ERL, …)*
- *Heat Recovery and supply*
- *Investment in R&D on green technologies*
- *Sustainable operational concepts (dynamic operation, power purchase agreements)*
- *Nature-based interventions for carbon removal (e.g. environmental studies, integration in local environment):*

(SOME) EXAMPLES:

J. Gutleber, FCC Renewable Energy Supply Feasibility Study, https://zenodo.org/records/10023947

Figure 7: A single 25 MWh energy storage unit (white containers) built from used electric car batteries, deployed for a PV energy plant in Lancaster, CA (south of Los Angeles, US) put in operate by B2U Storage Solutions in early 2023. Capacities of new systems are increasing fast. A 260 MWh[25] is by now being commissioned and today's largest systems in the range of 1 400 MWh are being extended to 3 000 MWh[26].



"Green ILC Concept"

Annexes:

Snowmass process and P5 Report
Plans to reduce accelerator energy consumption in China
Research infrastructure project appraisal
Comprehensive sustainability assessment based on Cost-Benefits Analysis

Summary and Outlook

- ✓ Funding landscape are changing rapidly in Europe and beyond, which will require addressing sustainability and GWP potential for the future large-scale research infrastructures

- ✓ *Sustainability assessment for future large-scale accelerator infrastructures is quite complex:*
  → assessment criteria needs to be properly tuned to the maturity of the project (stage)
  → differently developed for Researchers, Management and Society

- ✓ *The LDG Sustainability WG report is advancing,* the bulk of issues elaborated pertain to:
  - socio-economic benefits of accelerators-based reaserch infrastructures
  - basis of sustainability assessment
  - methodology and reporting of LCA for future HEP accelerators
  - evaluation of Greenhouse gas (GHG) emissions in construction, operation, decommissioning
  - mitigation and compensation strategies

- ✓ The Goal of Sustainability WG is to submit report as an input to the ESPPU in March 2025
  → not all of items can be addressed at this timescale, some might need more time to mature

BACK-UP SLIDES

Mandate / Charge of Sustainability LDG Working Group

Charge for a Working Group on "Sustainability Assessment of Accelerators" for the next European Particle Physics Strategy Update (EPPSU)

J. Clarke, B. Heinemann, M. Seidel, June 23rd 2023

Sustainability is increasingly in the focus of public discourse. Accelerator facilities, in particular for High Energy Physics, are among the largest scientific endeavors in terms of construction and energy consumption, with lifetimes spanning decades. For this reason, and as a community representing forefront research, we have a special obligation to assess and optimize sustainability. Several next generation facilities were proposed at the last EPPSU and are expected to be proposed for the next update (likely in 2026/2027).

Recently, proponents of projects have started to report on and compare projects on the basis of Green House Gas (GHG) emissions, predominantly from electric power consumption during operation, with first efforts to quantify also embodied GHG from construction. The quoted numbers differ in terms of parameters used for comparison, methodology, considered scope, and assumptions about current and future CO2 intensity e.g. of electrical power, making it difficult to compare projects impartially in terms of their sustainability. Energy consumption and construction result in GHG emissions, or rather Global Warming Potential (GWP). Other indicators such as water consumption, Helium consumption, Ozone depletion, ecotoxitity etc., habitually used in Lifecycle Assessments (LCA), may present important aspects for the environmental sustainability of specific proposals, and these should be assessed at least qualitatively.

This working group is asked to develop guidelines and a minimum set of key indicators pertaining to the methodology and scope of the reporting of sustainability aspects for future HEP projects:

- Define key indicators to be reported, such as peak (or instantaneous?), lifetime- and performance specific (per luminosity) energy consumption, lifetime- and specific GWP including the contribution of construction. These figures should be supplemented by margins of uncertainty and possibly an assessment of the potential for improvement.
- Define the methodology and assumptions to be applied, to allow a transparent determination and comparison of these key figures across the proposals. The maturity of a proposal should be determined, for example early concept phase, CDR, TDR or TRL levels.
- Identify other high level environmental impacts that may be relevant for all or specific collider proposals.

In general, best practices determining the GWP for large projects in Europe should be followed.

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 renewable energy sources. This may include standby mode power consumption, recovery time to full luminosity and fraction of integrated luminosity 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? (Should one compare technical merit of projects by using globally averaged carbon intensities, or site dependency by using local carbon intensity?)
- Carbon intensity / lifecycle inventory (LCI) studies of materials specific to accelerator projects: high-purity niobium, permanent magnet alloys etc.

✓ ***Definition of key indicators* to be reported**

Possible examples:

- Peak / instantaneous lifetime- & specific (per luminosity) energy consumption
- Lifetime and specific Global Warming Potential (GWP), including construction
- Include margins of uncertainty and possibly an assessment of the potential for improvement

✓ ***Definition of methodology* & assumptions to be applied for transparent determination of key figures across proposals**.

- The maturity of a proposal should be determined, for example, at early concept phase, CDR, TDR levels

✓ ***Identification* of additional *high level environmental impacts* that may be relevant for all or specific collider proposals**

✓ ***Also, VERY IMPORTANT - impact on society and public appreciation of the WG report: HEP benefits and decarbonization path for the future large – scale accelerator RI's***

Some Other (More Technical) Objectives

LDG WG may comment on other aspects if deemed appropriate, for example:

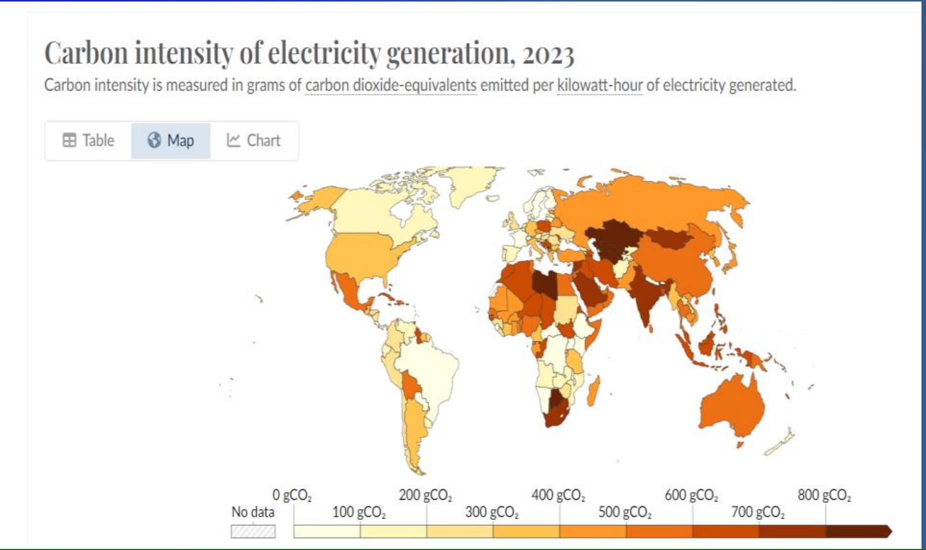
- Treatment of future carbon intensity of electricity and materials:
  - what scenarios should be assumed?
- Assessing the potential for dynamic operation of the various facilities:
  - i.e. the ability to adapt to a fluctuating energy supply in a grid fed by renewables. This may include standby mode 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

Open Questions: Regional versus Globally Averaged Impacts

- Carbon intensity of electricity production varies enormously across regions &countries
  → reference values for assumed CO2 intensity of electricity for relevant regions/labs

- 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
  - LCA Method: use local values or global averages

*Should one evaluate impacts using **site-specific or globally averaged impact** values?*
→ or use general LCA database and move to more local information as the project matures (for materials CO2 content) ?



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