Sustainability Studies for Future Linear Colliders.

Making the next generation of accelerators more sustainable

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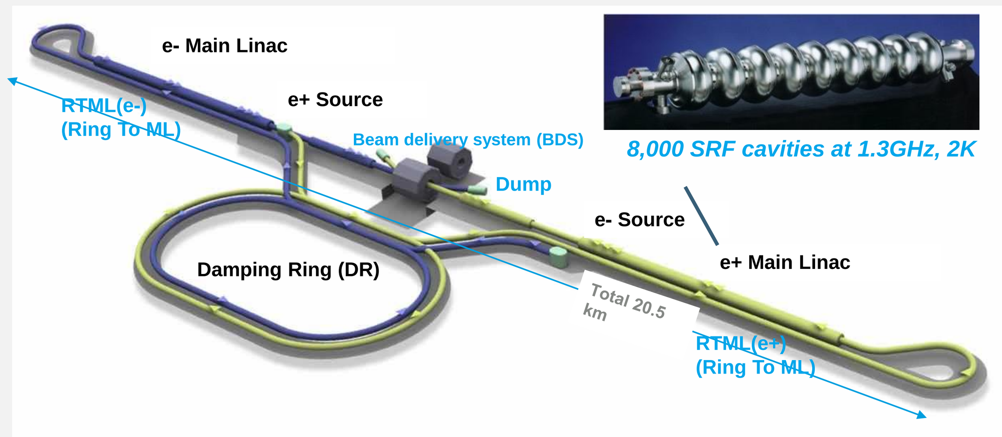
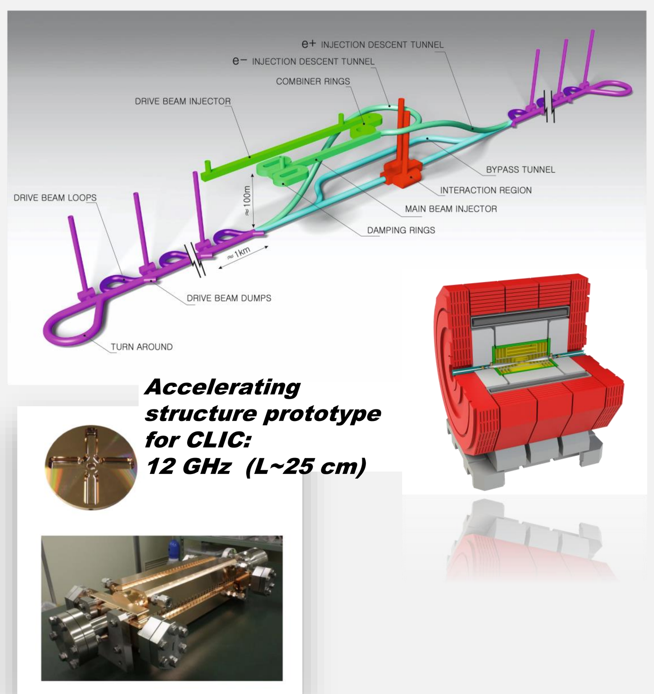
International Linear Collider ILC



Item	Parameters
C.M. Energy	250 GeV
Length	20km
Luminosity	1.35 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	7.7 nm@250GeV
SRF Cavity G. Q_0	31.5 MV/m (35 MV/m) Q_0 = 1x10^{10}

- Proposed Higgs factory in Tohoku (Japan), 250GeV initial energy
- Superconducting Main Linac for energy efficiency
- Timeline: 4 year preparation + 10 years construction -> operation 2037
- Expandable to 1TeV
- Cost: 6.3 – 7.0 B$, including human ressources
- Power: 111 MW at 250GeV

Compact Linear Collider CLIC



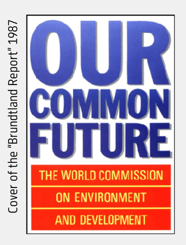
- **Timeline:** Electron-positron linear collider at CERN for the era beyond HL-LHC
- **Compact:** Novel and unique two-beam accelerating technique with high-gradient room temperature RF cavities (~20'500 structures at 380 GeV), ~11km in its initial phase
- **Expandable:** Staged programme with collision energies from 380 GeV (Higgs/top) up to 3 TeV (Energy Frontier)
- CDR in 2012 with focus on 3 TeV. Updated project overview documents in 2018 (Project Implementation Plan) with focus 380 GeV for Higgs and top.
- **Cost:** 5.9 BCHF for 380 GeV
- **Power:** **110** MW at 380 GeV corresponding to ~50% of CERN's energy consumption today
- Comprehensive **Detector and Physics** studies

SUSTAINABILITY

Goals

In 2015, the UN adopted "2030 Agenda for Sustainable Development" with 17 goals, addressing economy, society and environment. Global accelerator projects contribute to many of these goals, including fostering peace and understanding and education.

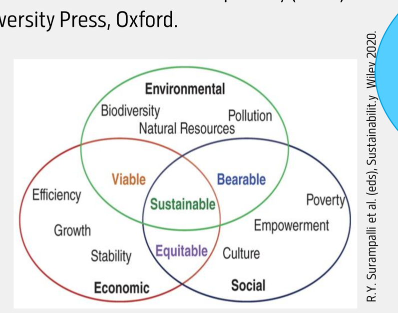
Definition



Development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations. (WCED, 1987)

WCED (World Commission for Environment and Development) (1987) *Our Common Future*, Oxford University Press, Oxford.

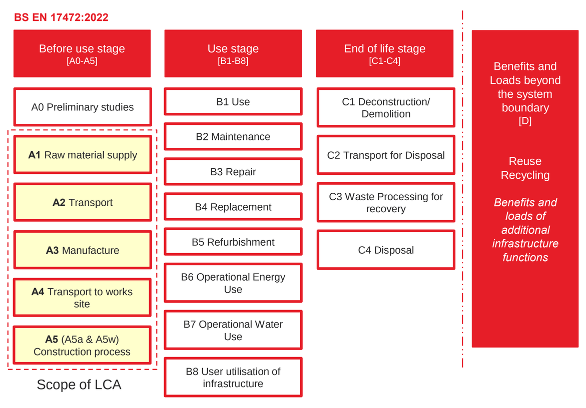
Sustainability comprises environmental, economic and social dimension. For a project to be sustainable, all dimensions need to be considered and balanced.



Full Lifecycle

Considering the full lifecycle of a product, facility or system is crucial for the evaluation and overall optimisation of its impact to the environment, society and economy.

Follow Standards

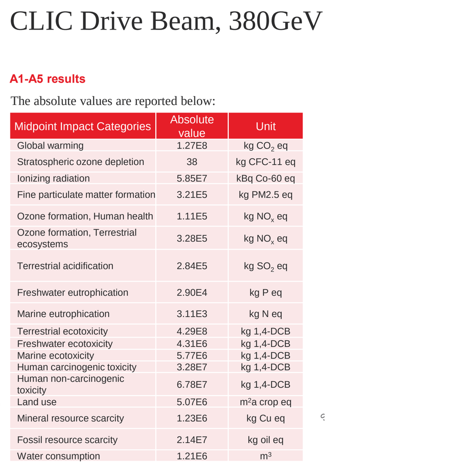


Lifecycle Stages according to BS EN 17472: *Sustainability of construction works – Sustainability assessment of civil engineering works – Calculation methods.*

Impact Categories

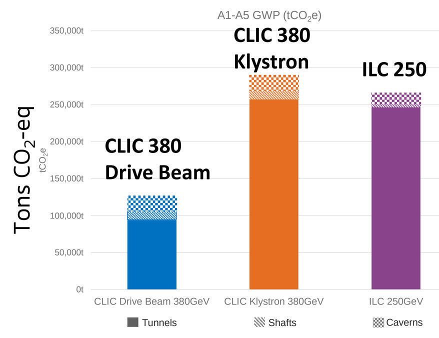
Impact categories according to the RCiPe Midpoint(H) 2016 method.

Considering more impact categories in addition to Global Warming Potential (GWP) is crucial for trade-off studies, e.g. in the case of permanent magnets which require problematic materials such as rare earths.



Lifecycle Assessment

Global Warming Potential

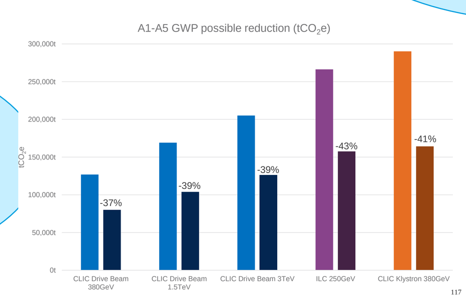


Result of a comparative Lifecycle Assessment (LCA) for the construction stages (A1-A5) of the CLIC and ILC underground civil engineering structures (tunnels, caverns, and shafts) according to BS EN 17472.
ARUP 2023

Lifecycle Thinking

Professional Lifecycle Assessment (LCA) studies consider the full lifecycle of a project in corformance to international standards. One such study on the underground civil facilities was performed by the ARUP company on behalf of CLIC and ILC.
ARUP 2023

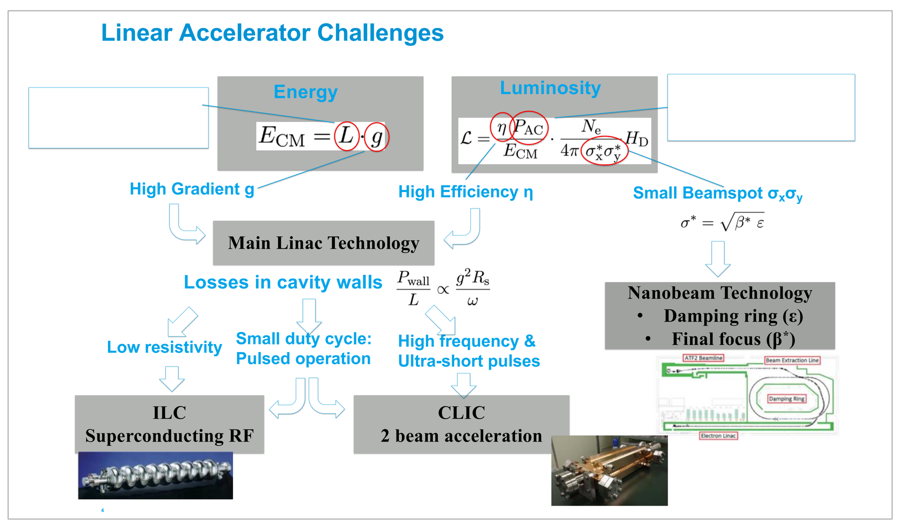
Reduce Impacts



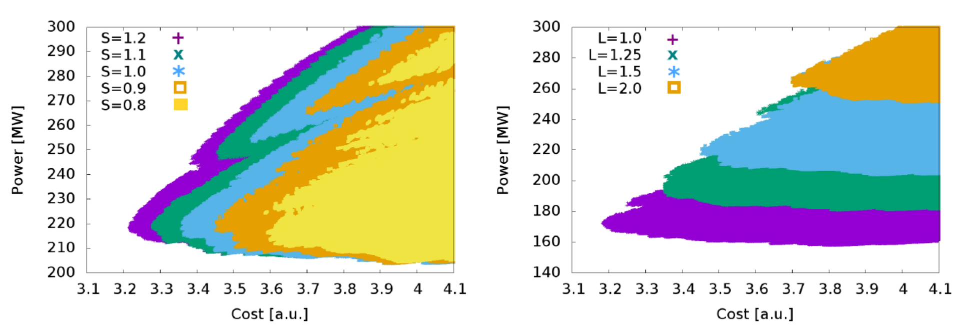
The lifecycle assessment of CLIC and ILC tunnels identified reduction potentials around 40%, e.g. through
- Use of less CO2 intensive materials
- Reduction of tunnel lining thickness

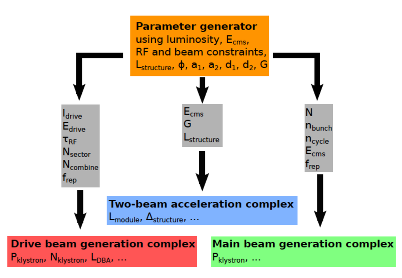
Improve

System Design



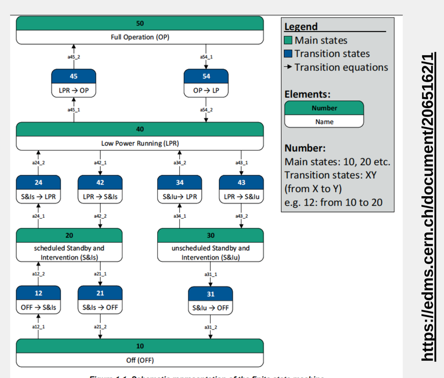
Optimize the overall systems design with respect to costs (monetary or environmental cost) while keeping the key performance indicators as required.





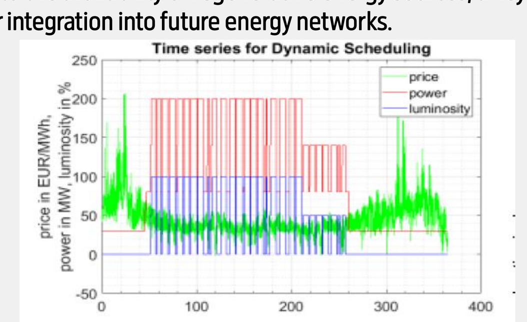
A scan of the CLIC parameter space was performed to find the optimal combination of parameters such as cavity gradient, iris, cells per structure, etc.
Ref: arXiv:1608.07537, Sec. 3.3, and CLIC-Note-1031

Operation



A study by Fraunhofer Institute investigated in howfar CLIC could be running exclusively on renewable energy resources.

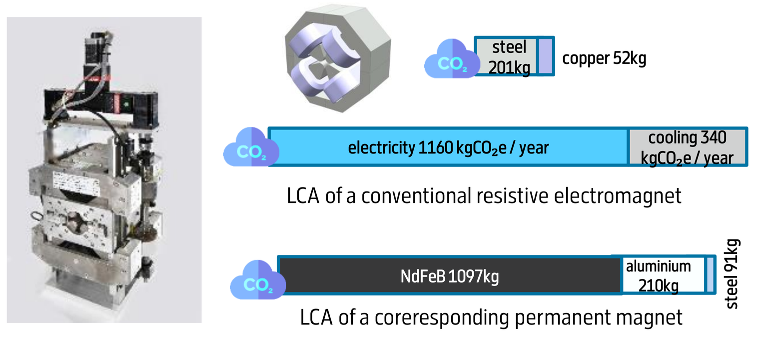
Linear accelerators are capable of modulating power consumption according to the availability of renewable energy sources, a key feature for integration into future energy networks.



Components

Optimisation of key components for better performance, efficiency and waste during production reduces the overall environmental impact of the project.
Lifecycle assessments help in balancing overall costs, CO2 and other impacts such as ecotoxicity or resource scarcity.

Magnets

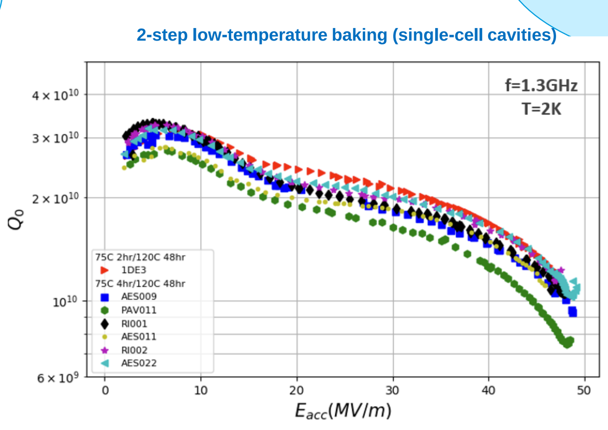


LCA of a conventional resistive electromagnet

LCA of a coreresponding permanent magnet

Replacing resistive electromagnets by permanent magnets has a large potential to reduce power consumption. The ZEPTO project has successfully produced ands tested tuneable permanent magnet quadrupoles. It is important to consider the full lifecycle to assess whether the savings are beneficial overall.
Ref: B. Shepherd, ESSRI workshop 2022.

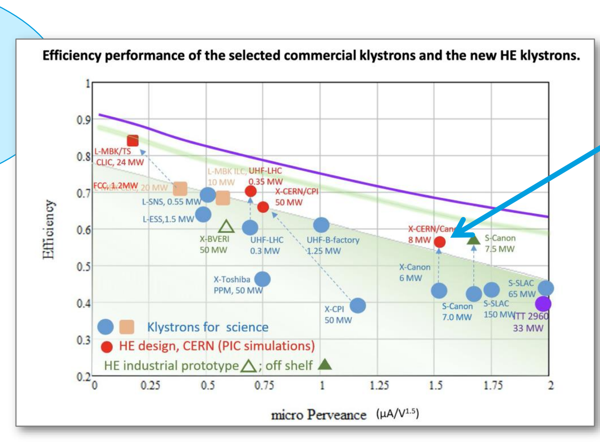
Cavities

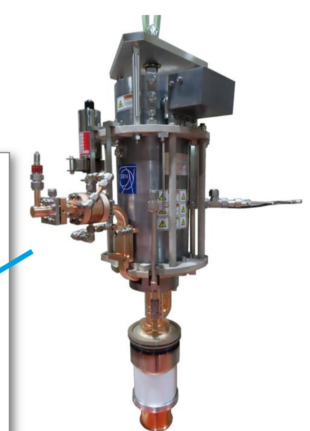


R&D pushes performance of superconducting cavities

New materials (Nb3Sn) and new surface treatments (shown here: mid-RT bake [Grasselino et al arXiv:1806.09824]) make it possible to obtain higher gradients with lower cryogenic losses at lower cost and/or (for Nb3Sn) at higher temperature.
This leads to
- Reduced raw material use,
- Reduced use of chemicals for electro polishing
- Reduced cryogenic power

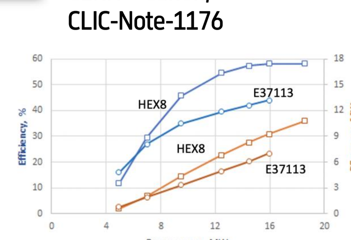
Klystrons





Prototype of 8MW high-efficiency X-band klystron CERN – Canon, CLIC-Note-1176

Development of high-efficiency klystrons based on novel beam optics (Core Stabilisation Method, Core Oscillation Method, Two Stage) greatly improves output power and efficiency of klystrons, reducing the energy demand of accelerators.



I. Syratchev, https://indico.cern.ch/event/1138197/contributions/4821294/ and https://indico.slac.stanford.edu/event/7467/contributions/6129/

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