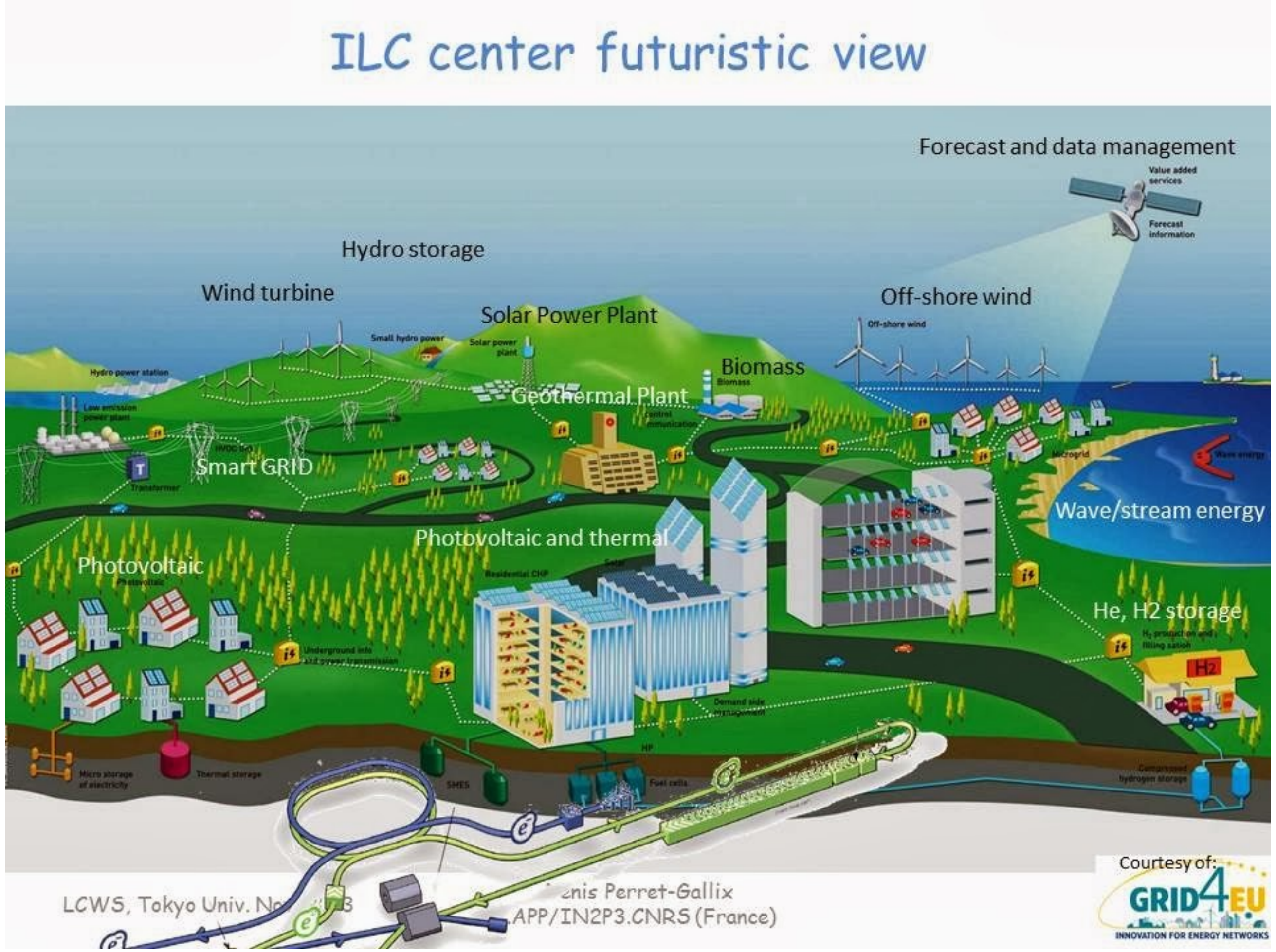
Sustainability for Future Accelerators

Making future accelerators more sustainable

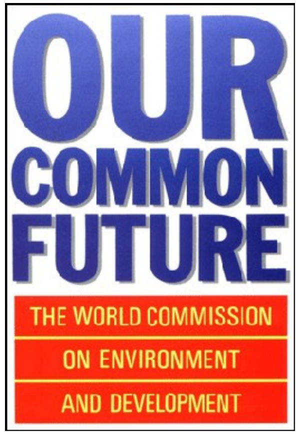


Benno List
Sustainability Forum 6.11.23

HELMHOLTZ

DESY.

Sustainability: What It Is…

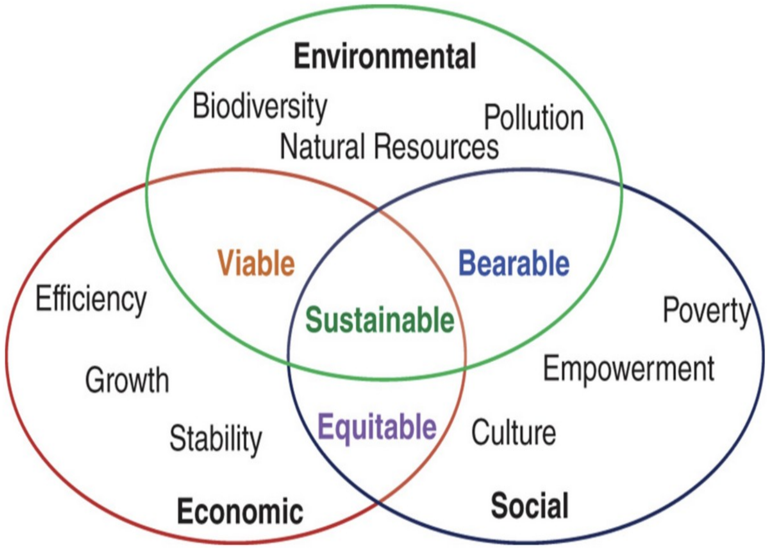


Cover of the "Brundtland Report" 1987

Gro Harlem Brundlandt at WEF 1989

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.



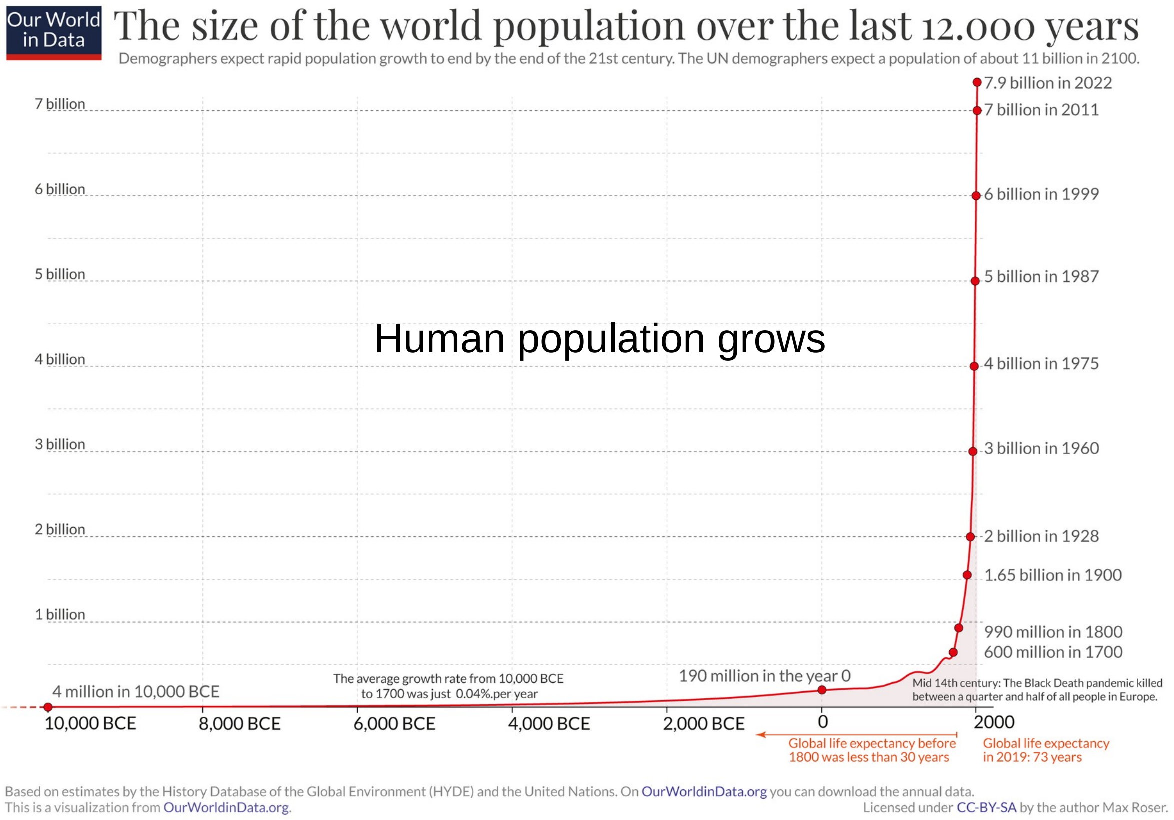
R.Y. Surampalli et al. (eds), Sustainability. Wiley 2020.

Long term projects:
Legacy or Liability?

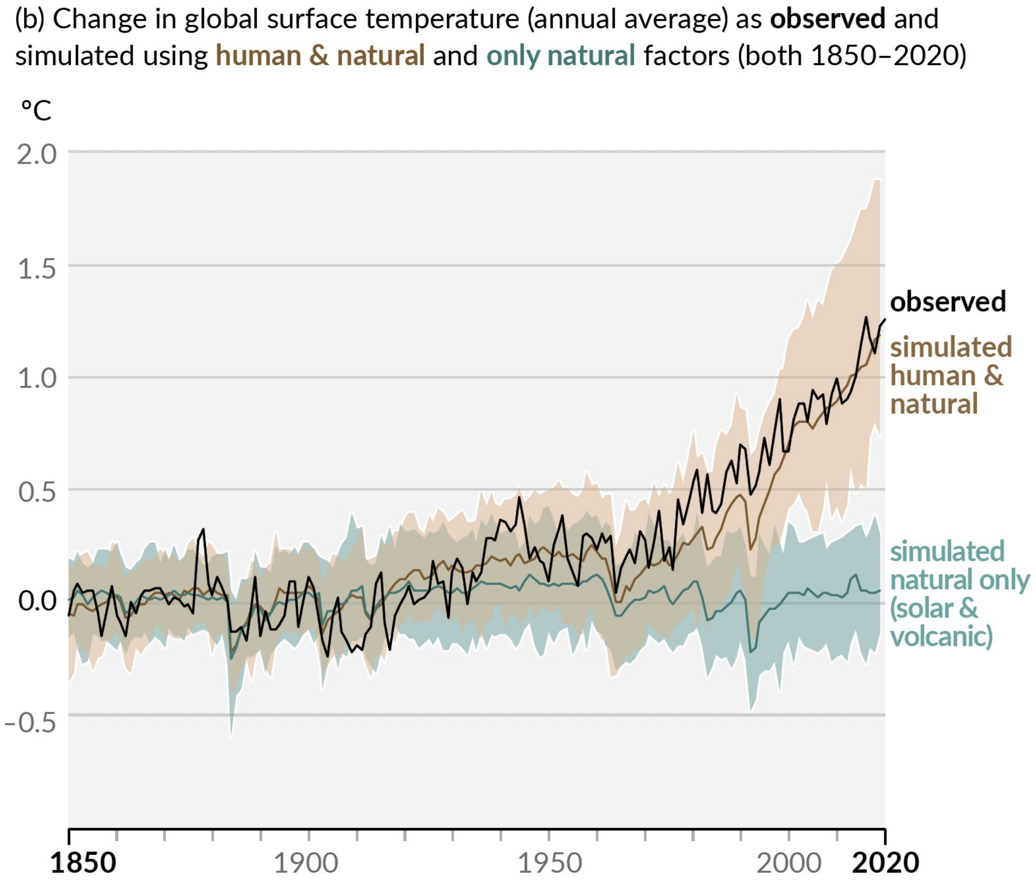
Three aspects:
- environmental
- economical
- social

… and Why It Matters

> *It is* ***unequivocal*** *that* ***human influence*** *has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.*
>
> **IPCC AR6**



https://ourworldindata.org/world-population-growth
CC-BY-SA Max Roser



IPCC AR6 WG1 SPM, Fig SPM 1
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

Sustainability Gets Increasing Attention

atingnews.web.cern.ch/news/issue-41/compact-linear-collider-clic/optimising-clic-reducing-electricity-consumption-machine

Accelerating NEWS

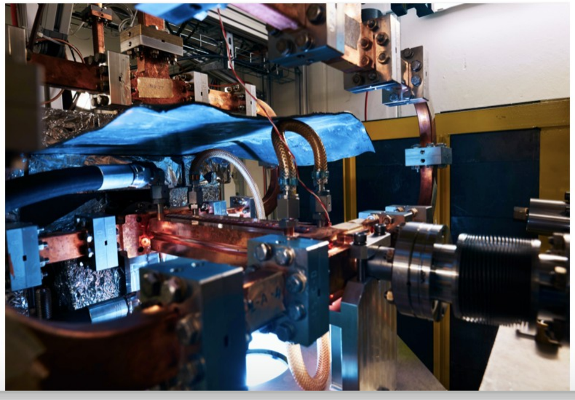
HOME PAST ISSUES ALL NEWS

News › › Issue 41 › Topic: Compact Linear Collider (CLIC)

Optimising CLIC for reducing the electricity consumption at machine and laboratory level

Optimised system designs for power efficiency, high efficiency klystrons, permanent magnets, renewable power… The linear collider projects are working to address power efficiency and reduce the environmental impact of the facilities.

19 SEPTEMBER, 2022 | By Steinar Stapnes (CERN) & Alexej Grudiev (CERN)



https://sustainable.japantimes.com/magazine/vol21/21-01

February 24, 2023

Global research facility could change Tohoku

Sustainable Japan Magazine

ILC PROJECT

By TOSHICHIKA IZUMI, TRANSLATOR： EDAN CORKILL

SHARE THIS ARTICLE facebook twitter instagram

Japanese

A cross-section of part of the linear accelerator planned for the ILC
© REY.HORI / KEK

The Kitakami Mountains in the Tohoku region stretch for about 260 kilometers, mostly within Iwate Prefecture. At the moment few people outside of Japan know about them, but if a planned research facility goes ahead, they could be thrust to the fore of international science. In the coming years, the International Linear Collider (ILC) might be built 100 meters underground in the mountains. When we hear the term "accelerator," we are likely to think of the Large Hadron Collider (LHC) at CERN (the

Approaches to Improve Sustainability

- Accelerators for High Energy Physics are at the leading edge of technology:
  beam energy, intensity, luminosity…
- Ressource conservation is paramount:
  - Tunnel length -> construction cost
  - Power consumption -> operating costs
- Sustainability adds new cost measures:
  e.g. CO_2, rare earth usage

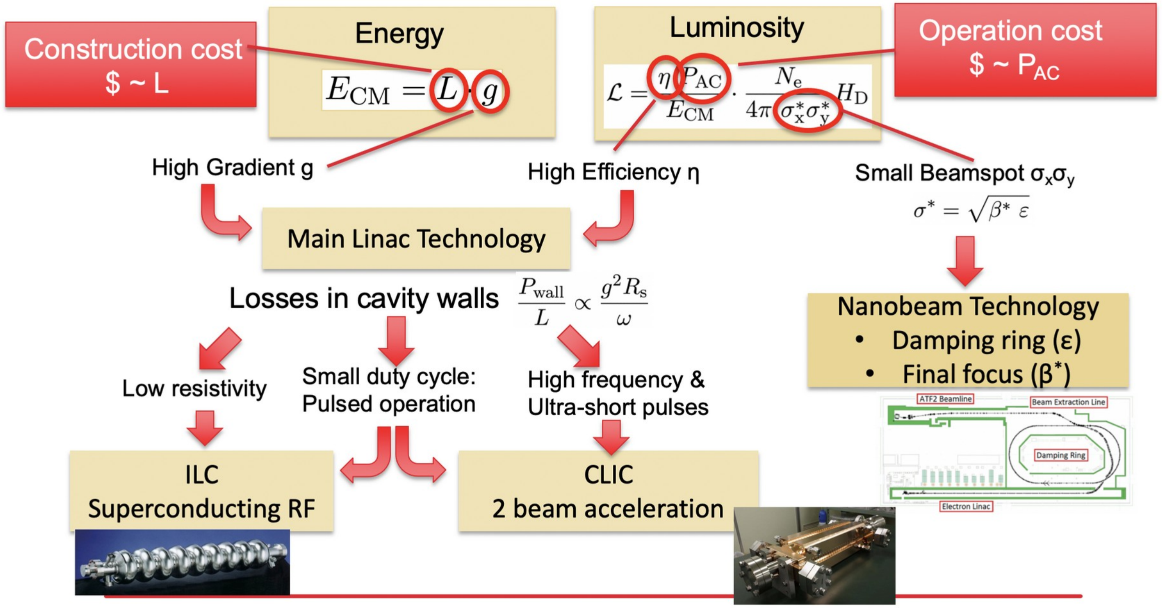
Approaches to increase sustainability

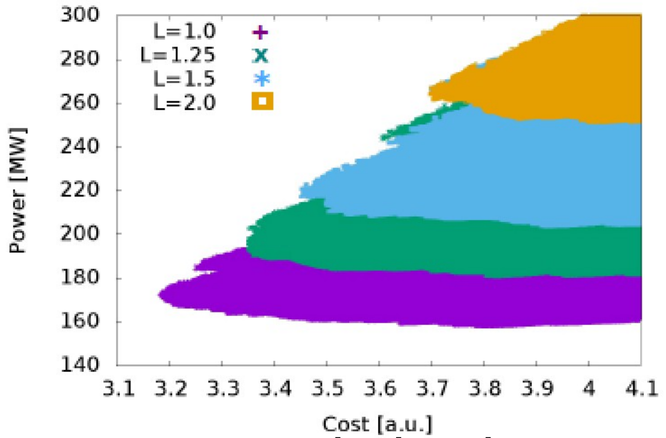
- **Overall system design**
  - Compact (short) accelerator -> high gradient
  - Energy efficient -> low losses
  - Effective -> small beam sizes
- **Subsystem and component design**, e.g.
  - High-efficiency cavities and klystrons
  - Permanent magnets
  - Heat-recovery in tunnel linings
- **Sustainable operation concepts**
  - Recycle energy (heat recovery)
  - Adapt to regenerative power availability
  - Exploit energy buffering potential

Overall System Design

Making the overall system as sustainable as possible requires a Lifecycle Approach

BL: https://indico.cern.ch/event/981823/contributions/4328846/





Parameter optimization at CLIC

- Challenge: Achieve target **energy** and **luminosity** with least possible amount of **resources**
- Conserve resources for construction:
  - compact -> high acceleration gradient
- Conserve ressources in operation:
  - Energy-efficiency (limit losses in cavity walls): superconducting RF – ILC
    high frequency & ultra-short pulses: CLIC
  - Effectiveness: maximum luminosity per charge
    -> nanobeam technology
- ILC and CLIC:
  - different solutions to the efficiency problem
  - Final power consumption similar

Inherent tension between invest and operation requires a quantitative approach:

Lifecycle Assessment

Lifecycle Thinking

The whole life from cradle to grave matters

- Consider the whole lifecycle and its impact:
  - Raw material extraction
  - Manufacture, Transport & Installation
  - Operation
  - Disposal
- Already challenging for a pair of jeans, much more for a complete accelerator
- Requires scope definition: what's in, what's out
  - What is the complete project to consider? Full operation with all (unknown!) upgrades? Baseline stage only?
  - How to attribute environmental cost to different project stages / future upgrades?
- How to treat impact of **future** consumables (material, energy)?
- Avoid **burden shifting**: Moving problems elsewhere
- Consider all categories: Global Warming Potential ("CO2"), Ozone depletion, Ecotoxicity, …

https://www.nist.gov/el/systems-integration-division-73400/lifecycle-graphic

Quantitative Approach: Lifecycle Assessment LCA

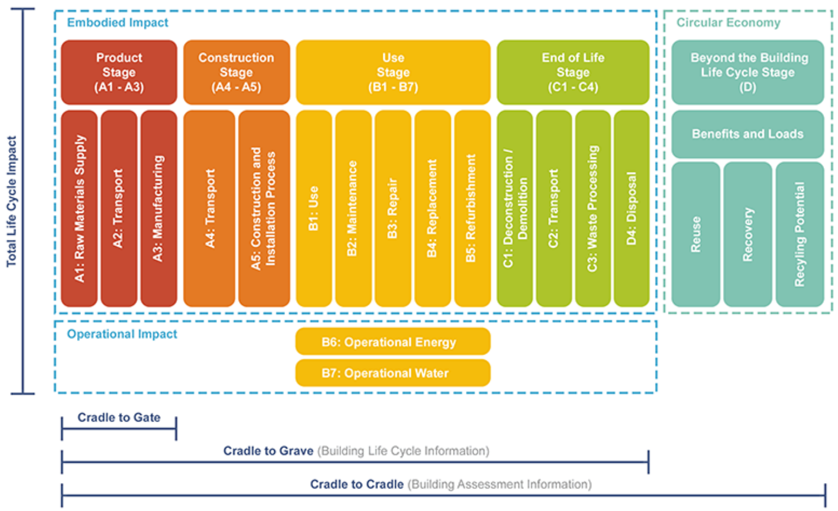
There’s more than CO2 to sustainability

Whole Lifecycle

- Raw materials, fabrication & construction
- Usage: operation, maintenance, refurbishment
- End of life: demolition, disposal

Defined in International Standards

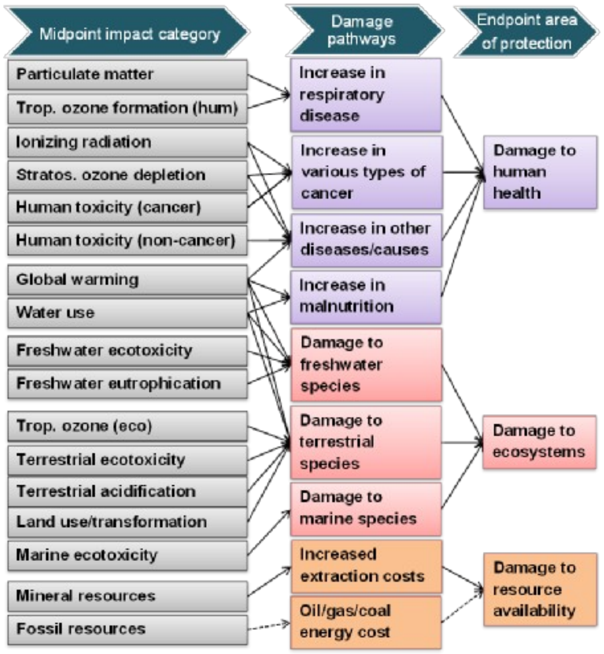
https://browningday.com/news/lca-stages-matter-when-tracking-embodied-carbon/
https://www.buildingenclosureonline.com/blogs/14-the-be-blog/post/89547-lca-stages-matter-when-tracking-embodied-carbon



Lifecycle stages according to EN 15978

Whole Environmental Impact

- Quantifying total damage by **endpoint** indicators (e.g. damage to human health) possible but difficult
- ”**Midpoint** indicators” asses impact on environment in a quantitative way:
  - Greenhouse Warming Potential (GWP) – kg CO_2 eqiv
  - Ozone Depletion Potential (ODP) – kg CFC-11 equiv
  - Ecotoxicity – kg 1,4-DCB equiv

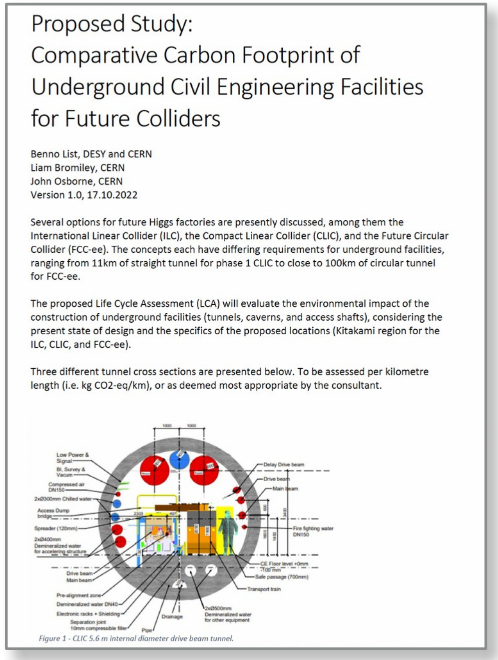


M.A.J. Huijbregts et al., Int. J. Life Cycle Ass. **22** (2017) 138, DOI:10.1007/s11367-016-1246-y

Tunneling LCA Study

A first comprehensive LCA study of the impact of civil engineering work

- CERN commissioned a study by ARUP (international civil construction consultancy) to study carbon footprint (and other environmental impacts) of underground civil construction
- Comprehensive study
  - Covering tunnels, caverns and shafts
  - Assesses material, transport, construction
  - Covers CO2, but also other impact categories
  - According to international standards



Proposed Study:
Comparative Carbon Footprint of Underground Civil Engineering Facilities for Future Colliders

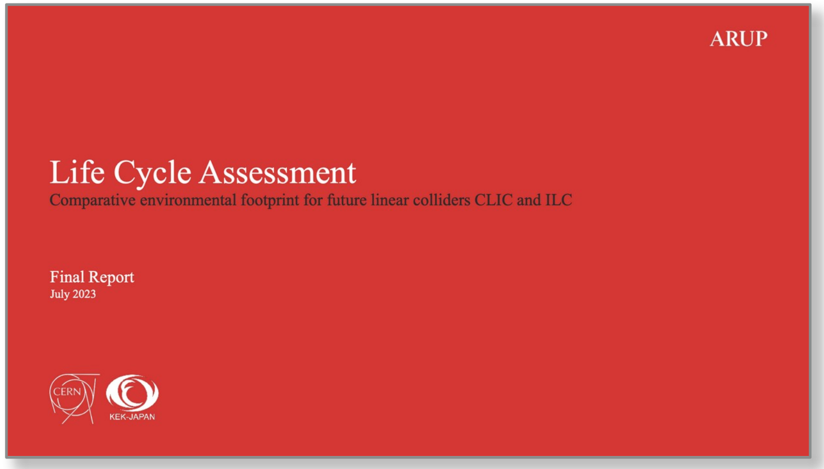
Benno List, DESY and CERN
Liam Bromiley, CERN
John Osborne, CERN
Version 1.0, 17.10.2022

Several options for future Higgs factories are presently discussed, among them the International Linear Collider (ILC), the Compact Linear Collider (CLIC), and the Future Circular Collider (FCC-ee). The concepts each have differing requirements for underground facilities, ranging from 11km of straight tunnel for phase 1 CLIC to close to 100km of circular tunnel for FCC-ee.

The proposed Life Cycle Assessment (LCA) will evaluate the environmental impact of the construction of underground facilities (tunnels, caverns, and access shafts), considering the present state of design and the specifics of the proposed locations (Kitakami region for the ILC, CLIC, and FCC-ee).

Three different tunnel cross sections are presented below. To be assessed per kilometre length (i.e. kg CO2-eq/km), or as deemed most appropriate by the consultant.

Figure 1 - CLIC 5.6 m internal diameter drive beam tunnel.

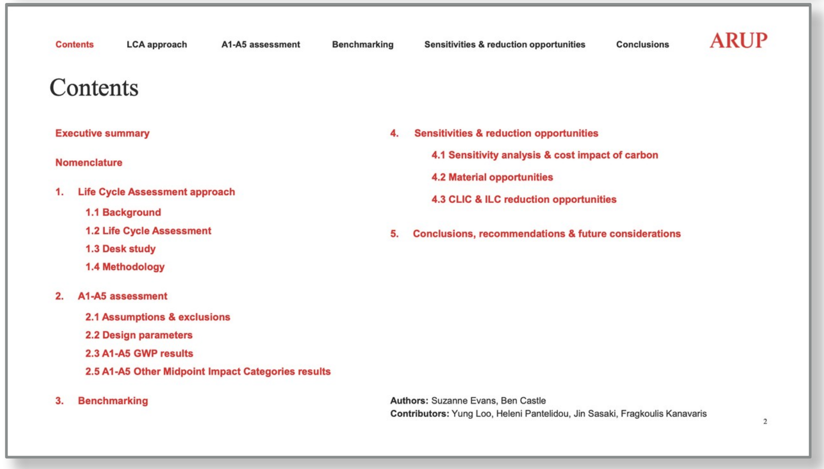


ARUP

Life Cycle Assessment
Comparative environmental footprint for future linear colliders CLIC and ILC

Final Report
July 2023

KEK-JAPAN



Contents | LCA approach | A1-A5 assessment | Benchmarking | Sensitivities & reduction opportunities | Conclusions   ARUP

Contents

Authors: Suzanne Evans, Ben Castle
Contributors: Yung Loo, Heleni Pantelidou, Jin Sasaki, Fragkoulis Kanavaris

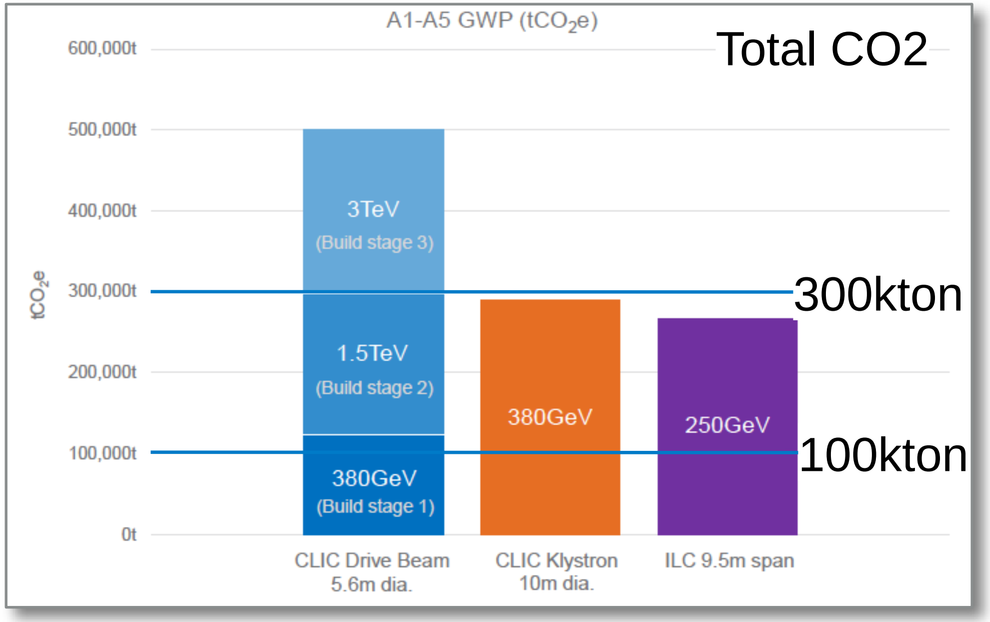
2

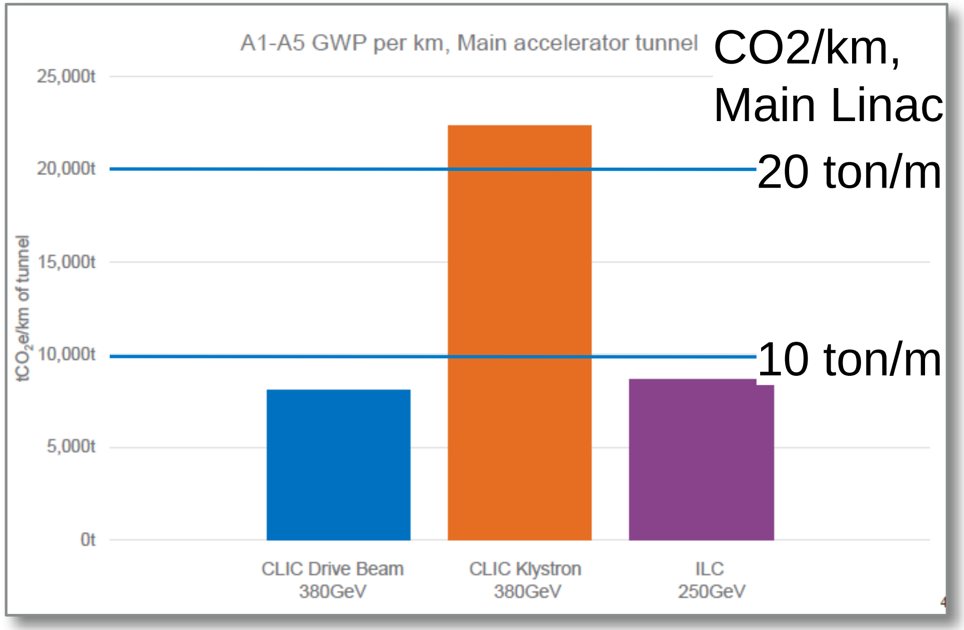
https://edms.cern.ch/document/2917948/1

Main Results

The CO2 budget

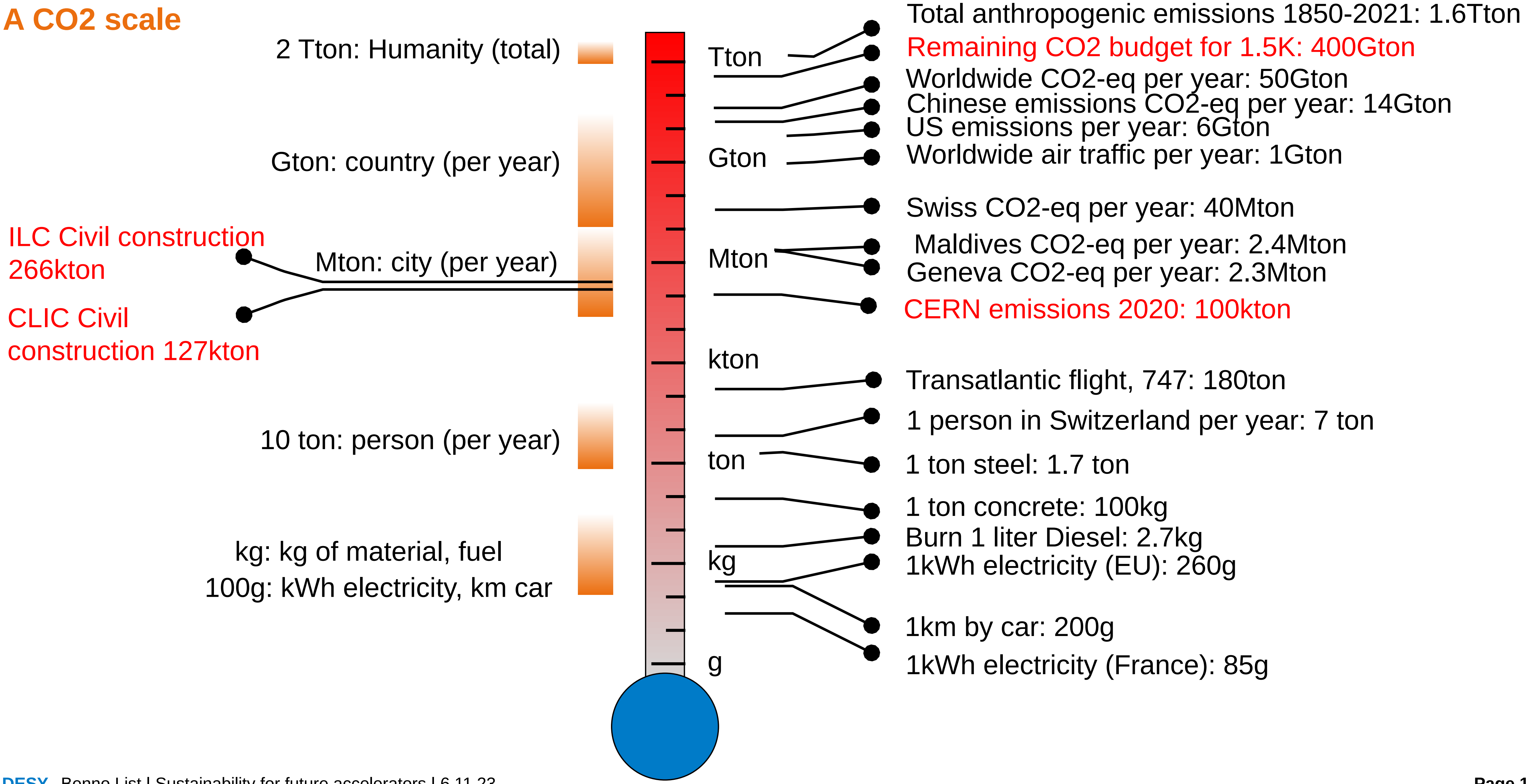
- Global Warming Potential of underground civil construction:
- CLIC 380GeV:
  - 127kton CO2-eq (two-beam option)
  - 290kton CO2-eq (klystron option)
- ILC 250 GeV:
  - 266kton CO2-eq



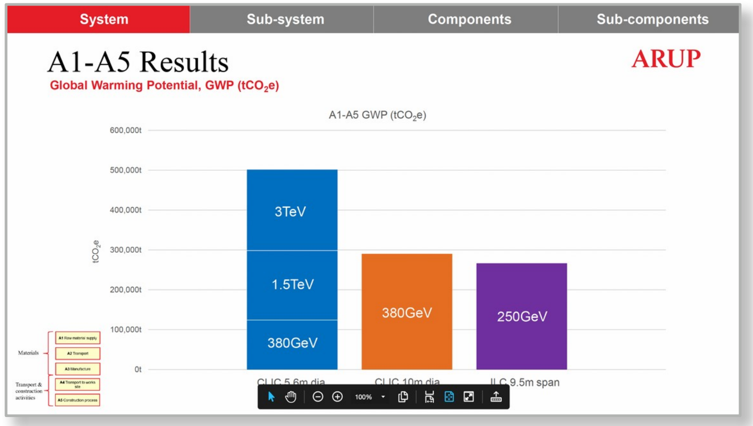


How much is it?

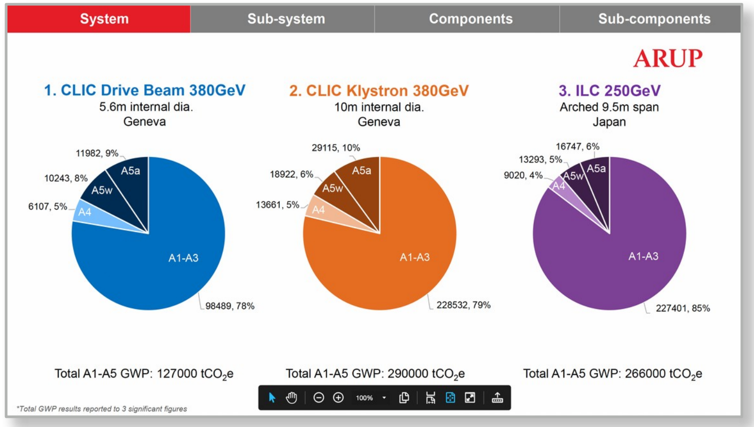
A CO_2 scale



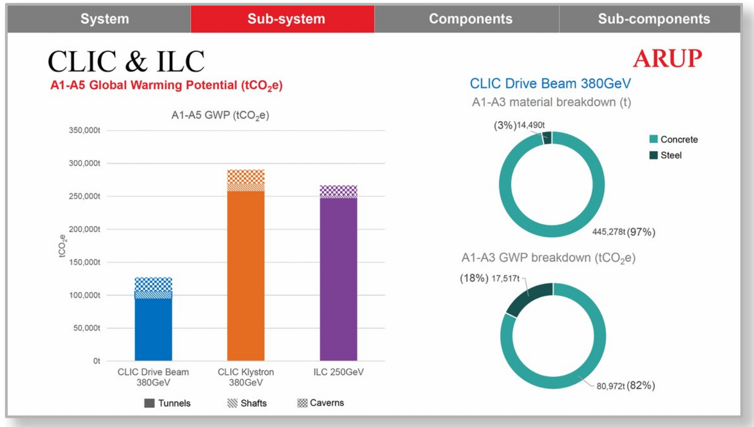
Tunneling LCA Study: Further Results



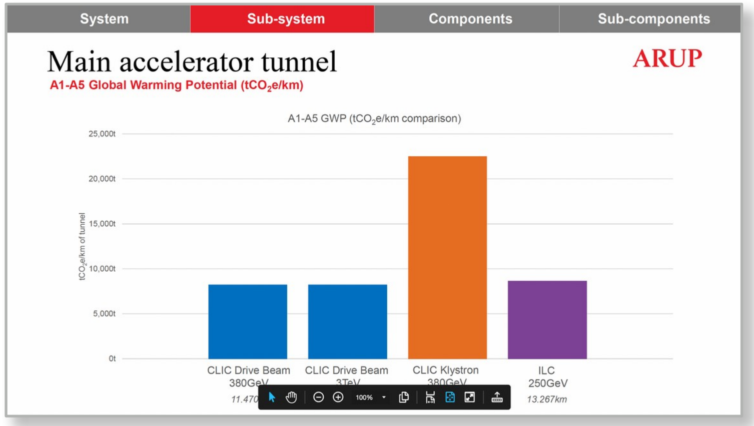
Total CO2



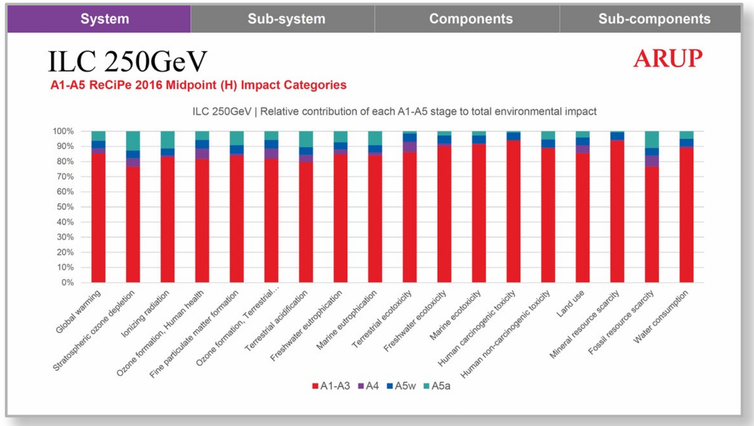
Per phase



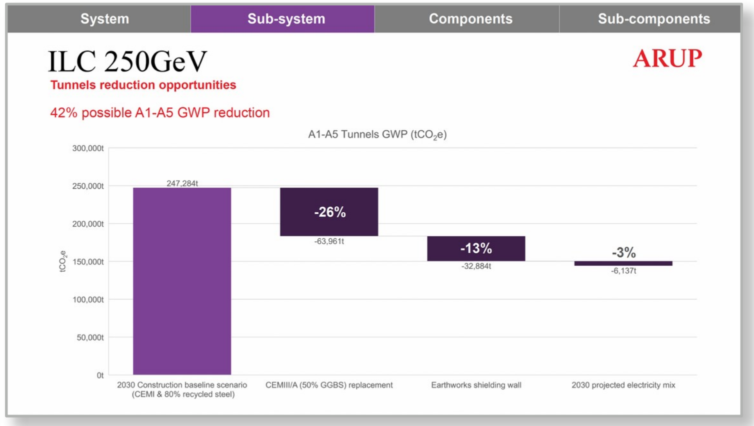
Concrete and steel



CO2 per meter (ML tunnel)



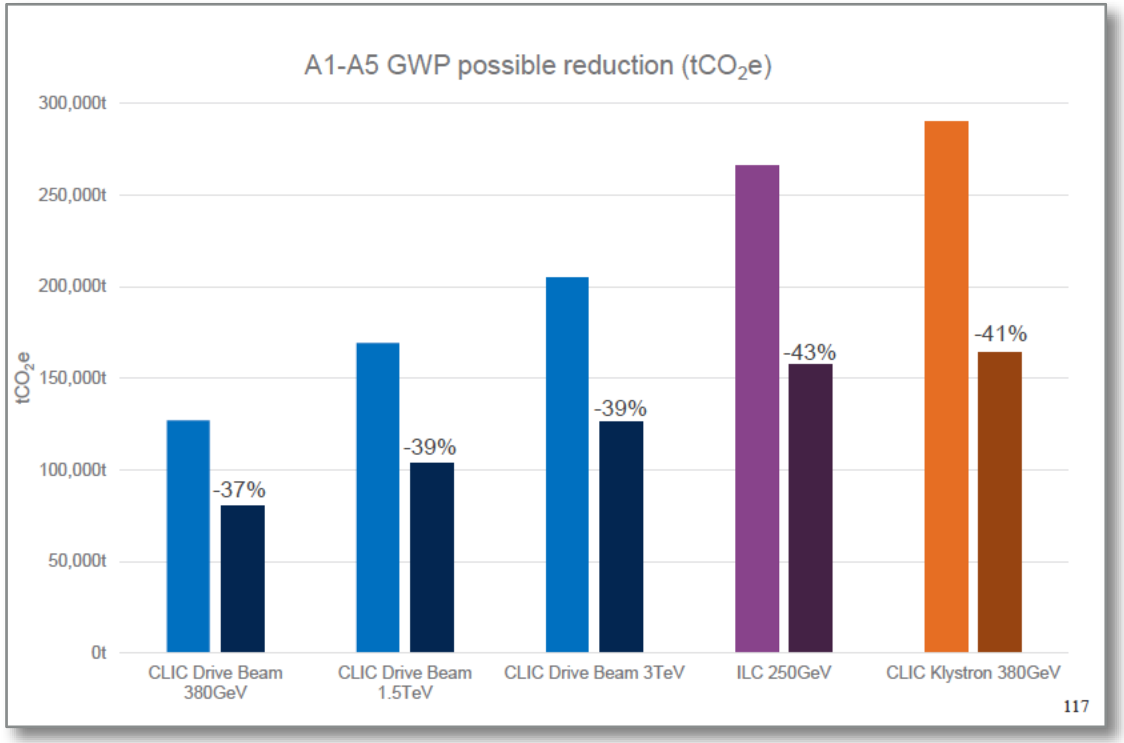
Other impacts

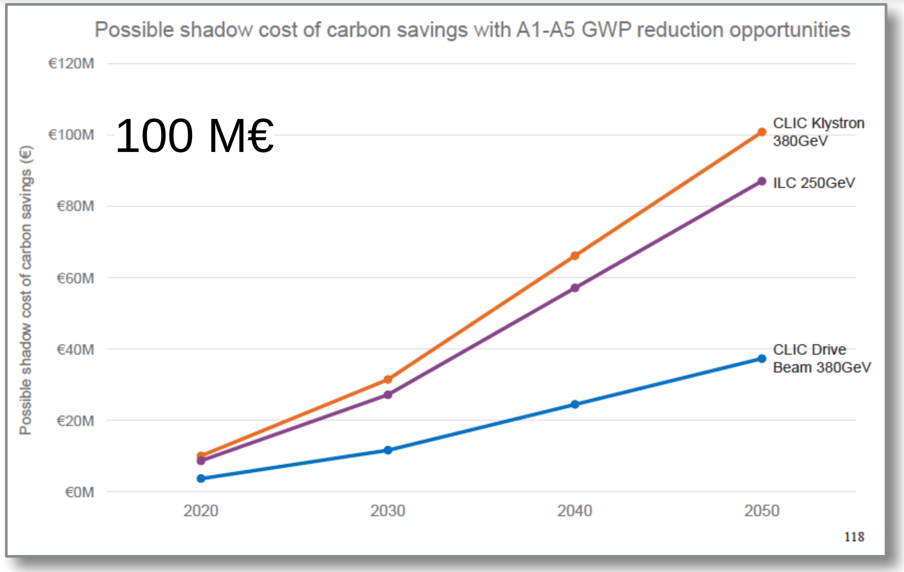


Reduction potential

Conclusion LCA Tunnel Study

- Full report is public: https://edms.cern.ch/document/2917948/1
- Evaluation of impact is the first step towards optimisation:
  - Report includes section on ways to reduce CO2 impact
  - “Shadow cost” of CO2 gives a monetary value to these reductions – “is it worth it”
- This study sets a new standard for lifecycle assessment studies of future accelerator facilities
- It goes beyond just GWP and includes other impacts such as ecotoxicity



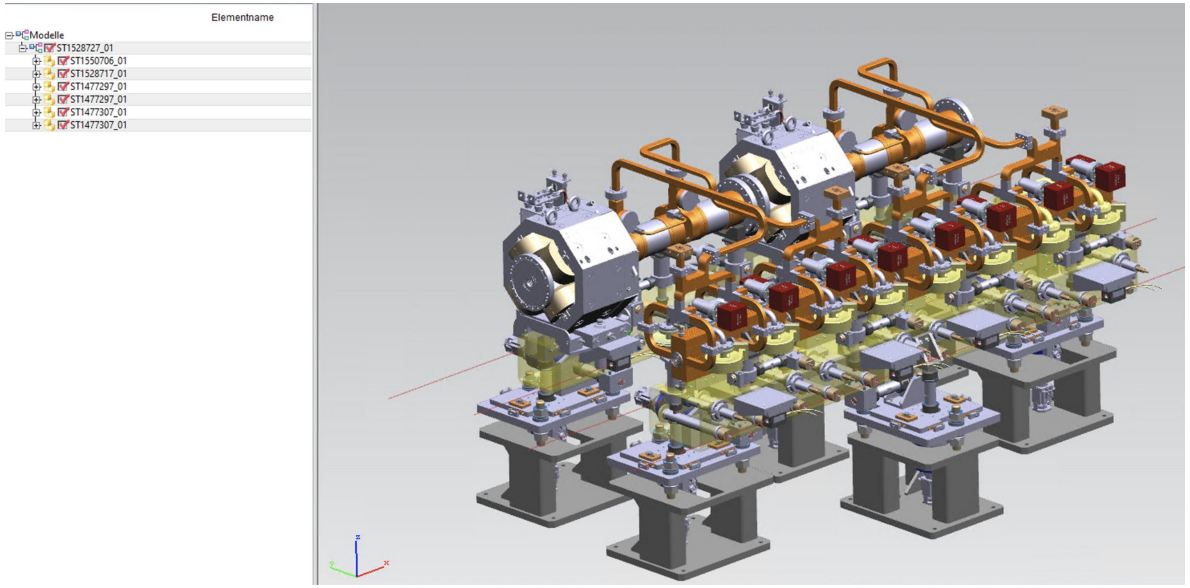


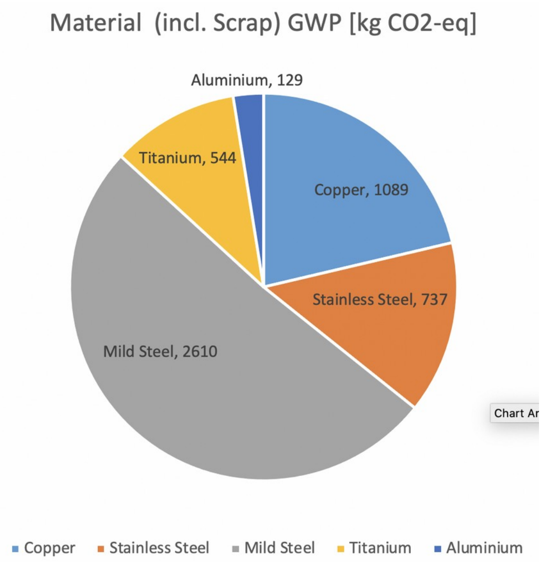
Looking at the Impact of the Accelerator

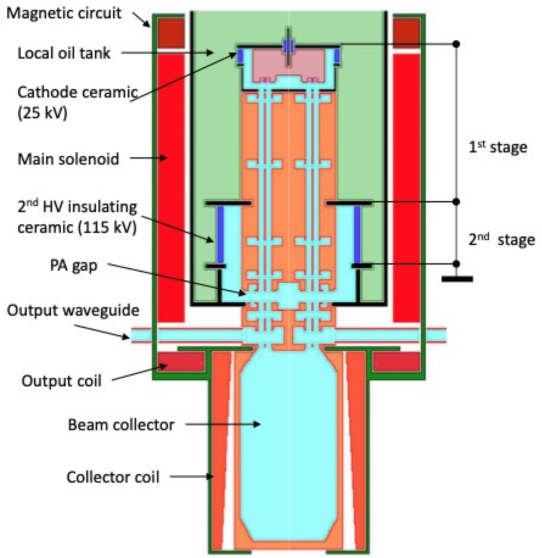
Start of an LCA of the accelerator components

- Study to estimate the Green House Gas emissions from raw materials in **CLIC 2-beam module**, including waveguides and supports
- ~2.5t CO2-eq / m:
  -> about half of CO2 for tunnel
- Half of CO2 impact is steel for supports
  -> optimization potential
- Services (power, cabling, cooling, ventilation) not included
- Situation in magnet-heavy sections (e.g. damping rings) may be different

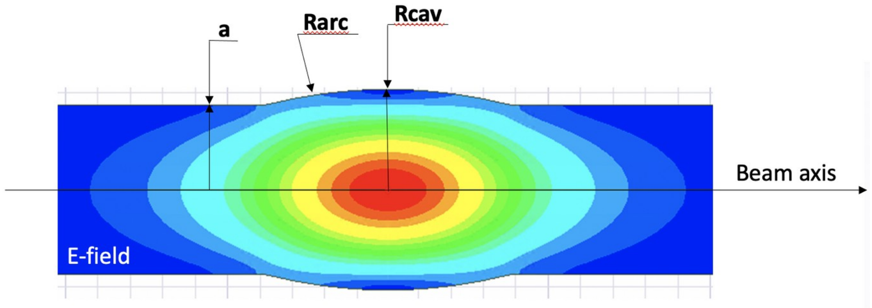
CO2 impact of accelerator components is comparable to CO2 of tunnel

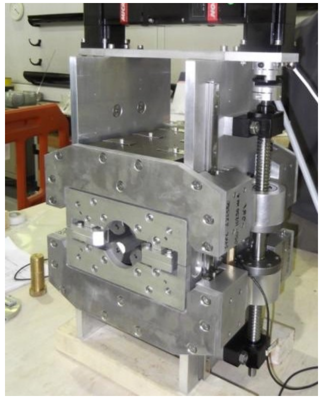


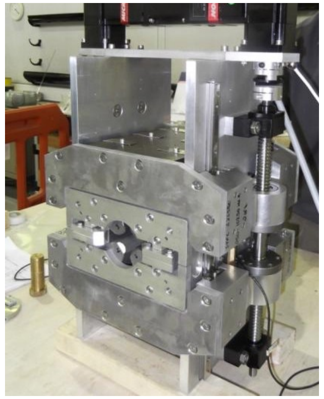




Optimization of Components and Subsystems



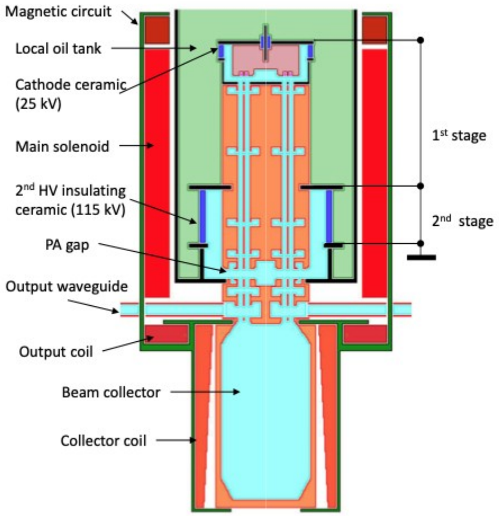


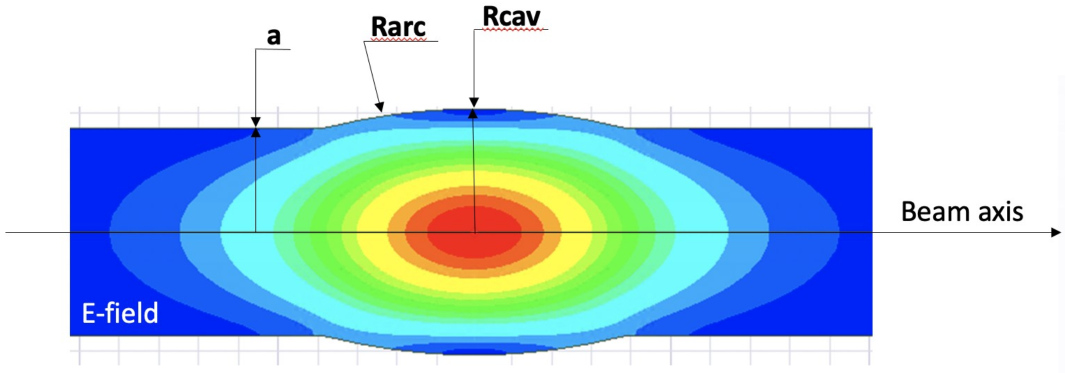


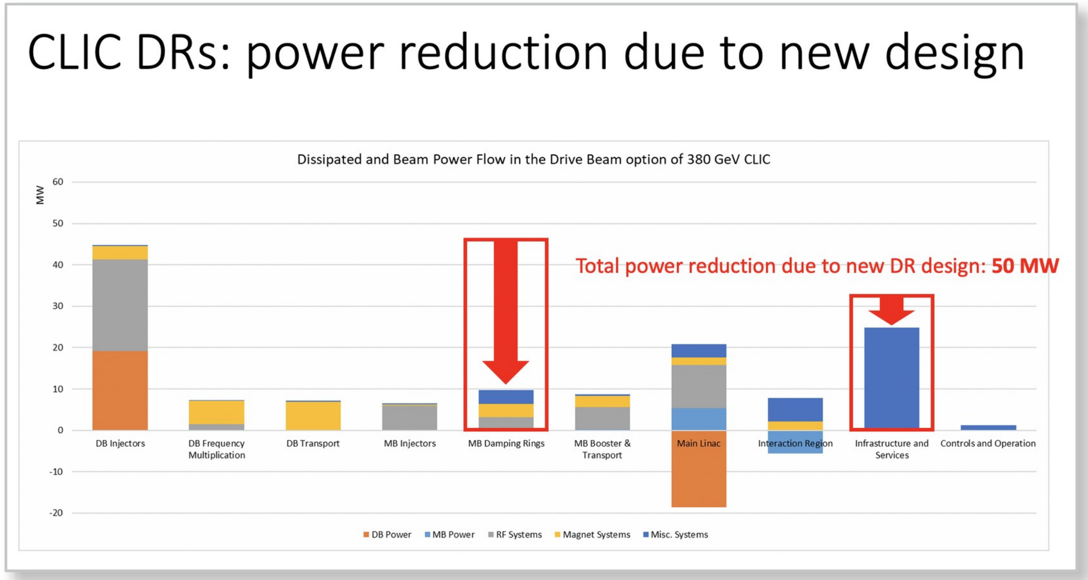
Reducing Power by Better Components

A CLIC example: Damping Ring power optimisation

- Ultra low R/Q Cavities +
  High efficiency klystrons
  => Tremendous Saving!
- Reduced power ->
  reduced operating cost
  without large investment penalty







A. Grudiev, CLIC Project Meeting 21.11.2021
https://indico.cern.ch/event/1101548/contributions/4635959

Components and Subsystems

Presentations at LCWS 2023

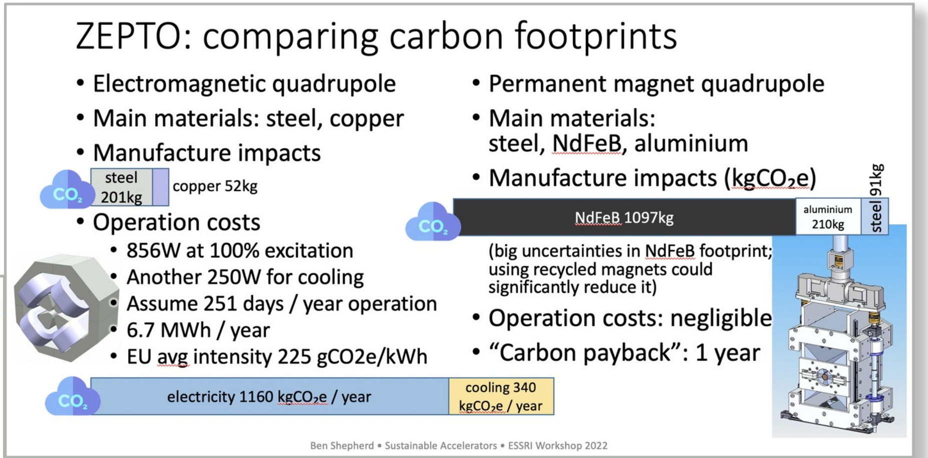
Better performance through better technology at same or lower cost

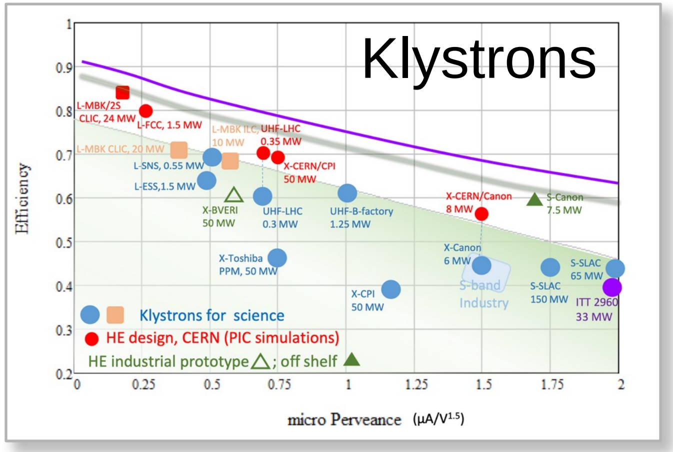
Igor Syratchev: *High efficiency klystrons at CERN;*
Zysheng Zhou: *IHEP high efficiency klystrons*

Sergey Belomestnykh
: Overview of accelerator technology development

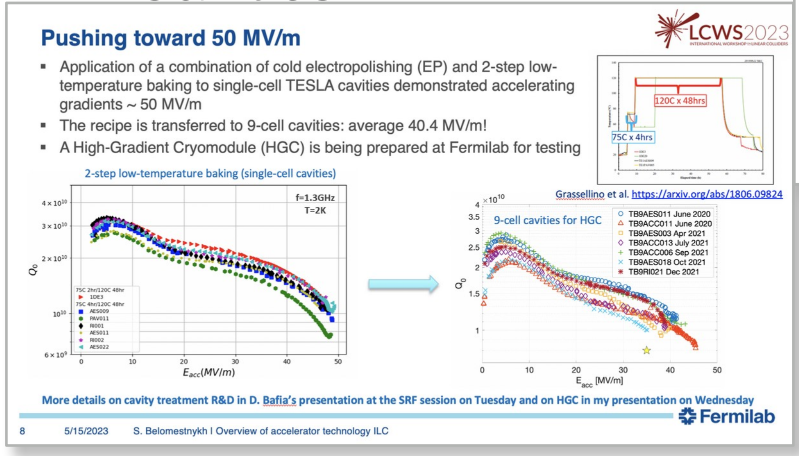
Difficult: lower operating cost through higher invest – needs trade off studies (LCA)

Ben Shepherd: *Permanent magnet technology*





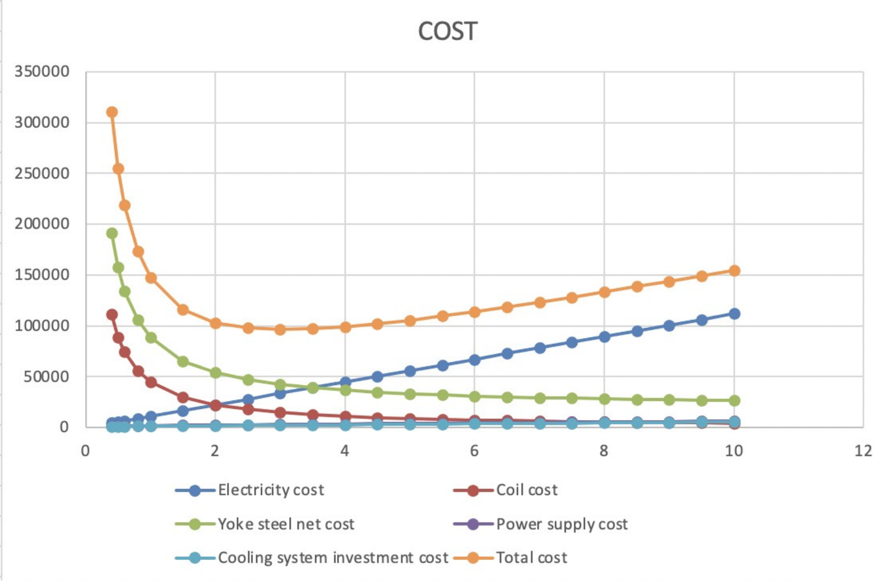
Cavities

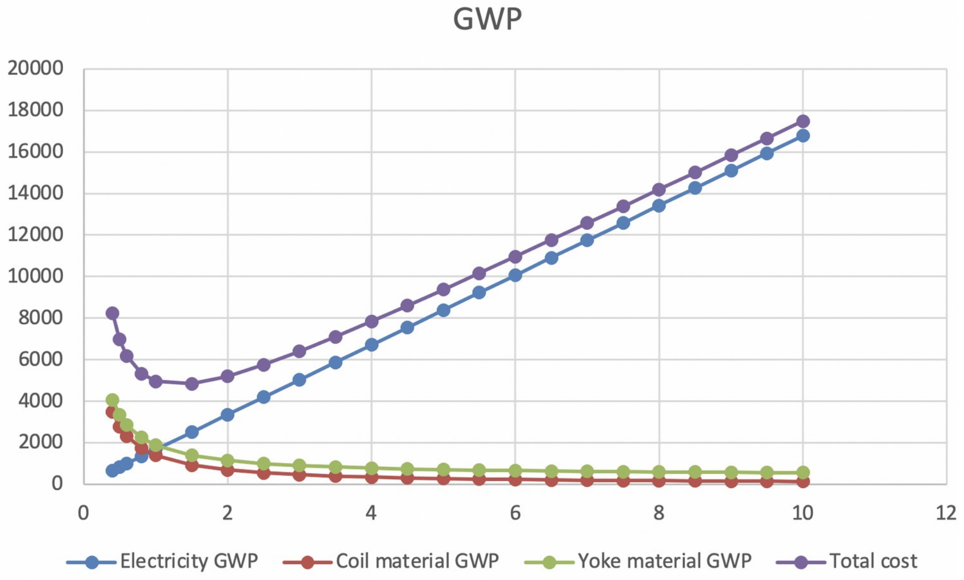


Trading Operation vs Invest

Again: consider the full lifecycle

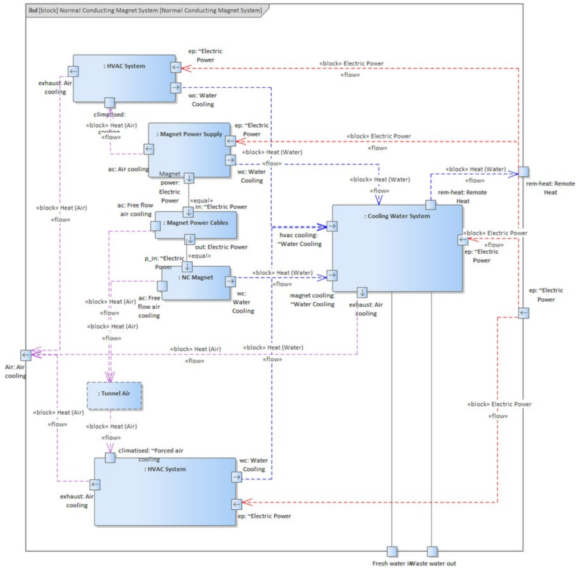
- Magnets:
- Consume a lot of power
  -> dominates CO_2 footprint by far
- Have a high invest
- Reducing power/CO2 is easy:
  bigger coil cross sections
  -> leads to higher embodied emissions and a higher invest
- Balance
- Operation vs invest/embodied CO_2
- CO_2 vs Cost



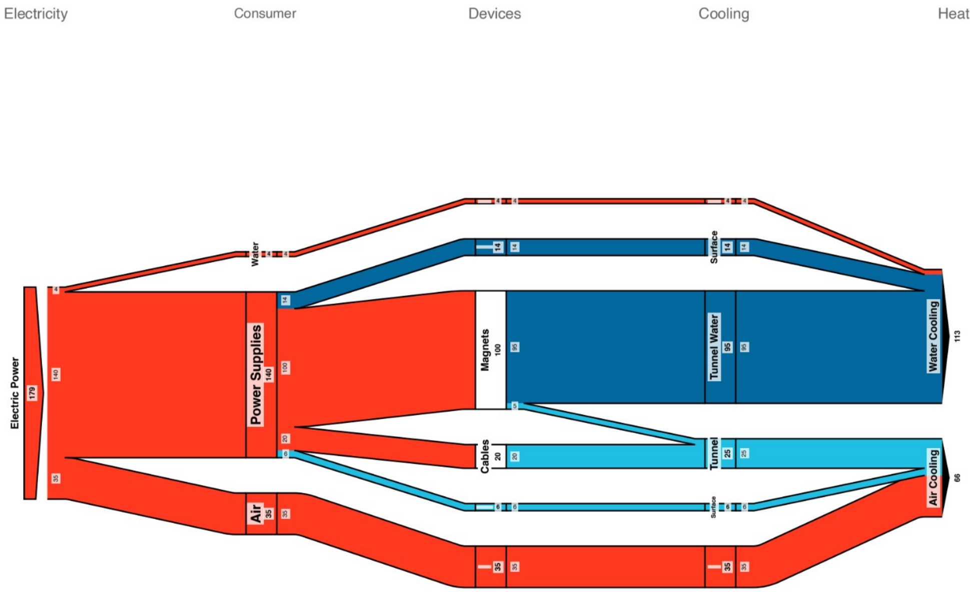


Defining the Right System Boundary

When different concepts are compared, make sure to look at the full picture



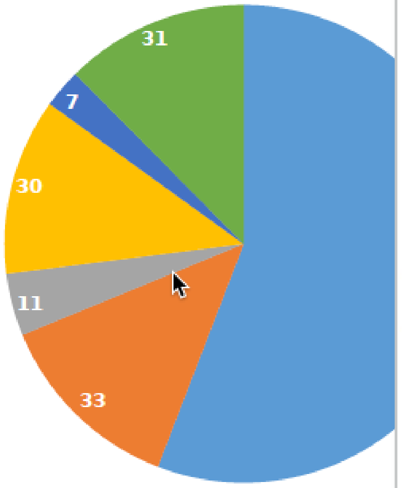
- Magnet is not isolated:
  requires cables, power supplies,
  water and air cooling
- Consider the whole system to
  evaluate impact of changes
- Invest in larger coils saves invest in power supplies and cooling
- Savings in operation costs are larger than for magnet alone
- Crucial when evaluating radical alternatives: permanent magnets



Magnets

ZEPTO (Zero Power Tuneable Optics) project is a ... Daresbury ... witching from ... agnets.

1.5 TeV CLIC power ... Magnets second lar...

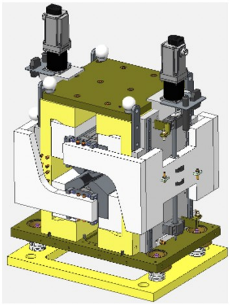


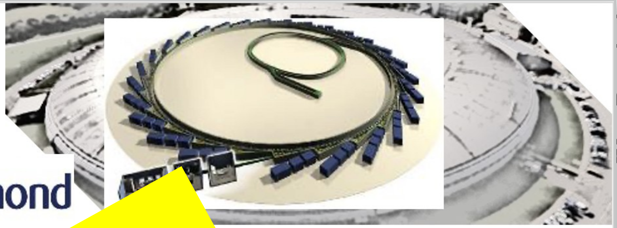
... ve-beam ... tested as ... nets

Bainbridge *et al*, IPAC2022

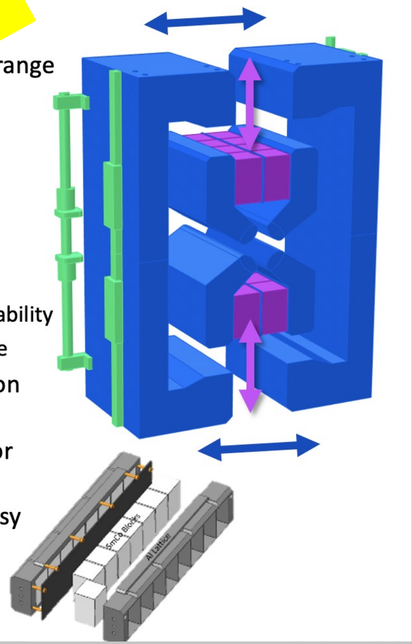
ZEPTO at Diamond Light Source

- 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 co...
- Installed at Diamond in August ...



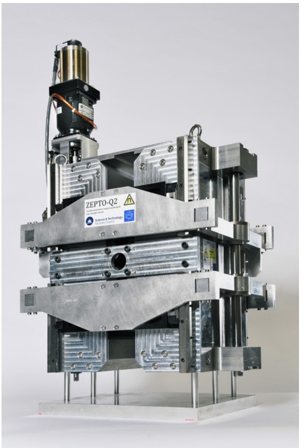


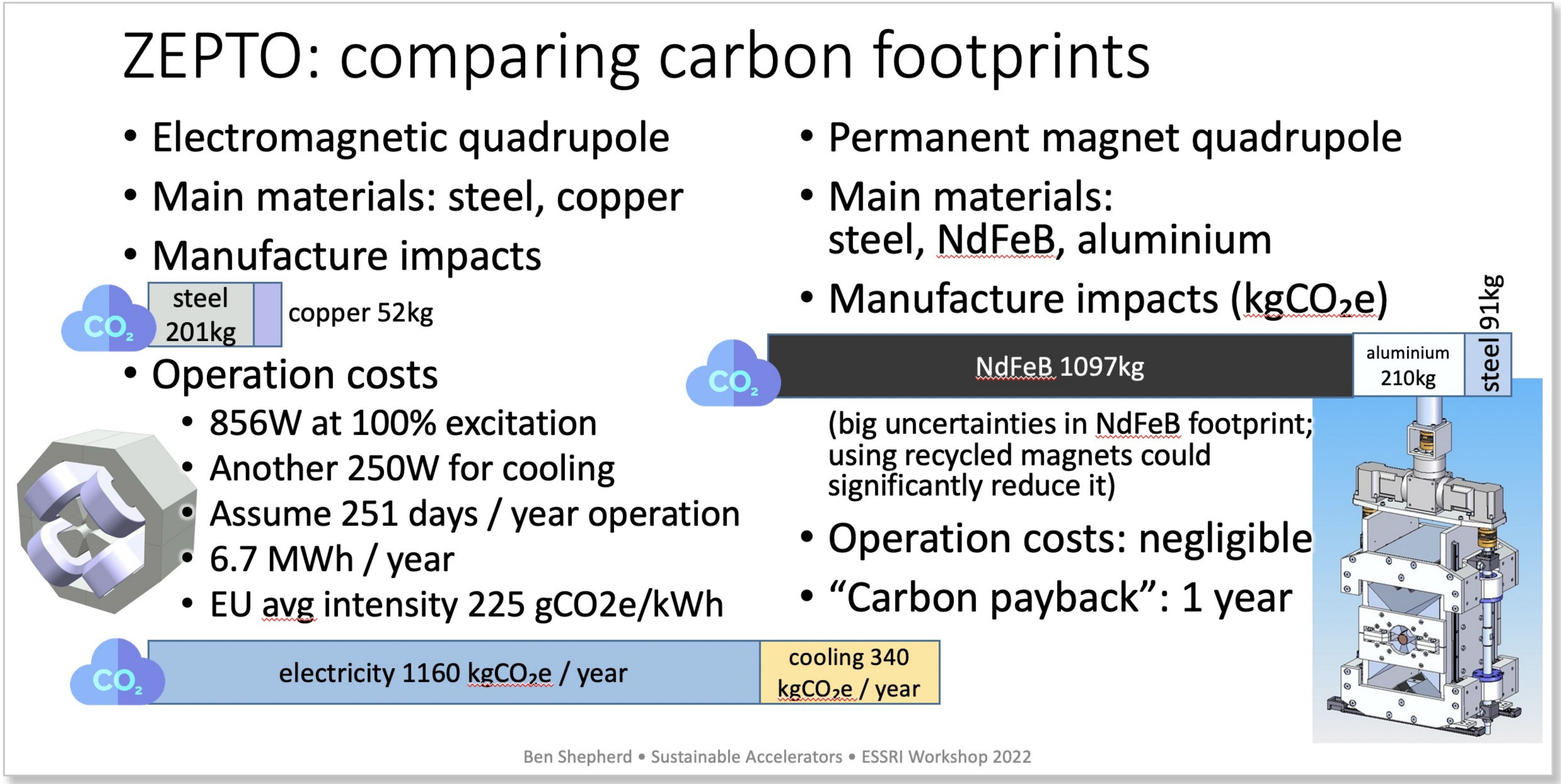
- Similar desi...
  - Q... ...ing range
- G... ...-19 T/m
- ... range **90 mm**
- ...ure diameter **32 mm**
- **Improvements to design:**
  - **SmCo blocks**
    - improved temperature stability
    - better radiation resistance
  - **Splittable** to allow installation around vacuum chamber
  - **Two independent motors** for magnetic centre correction
  - **Ice cube tray** concept for easy installation of PM blocks



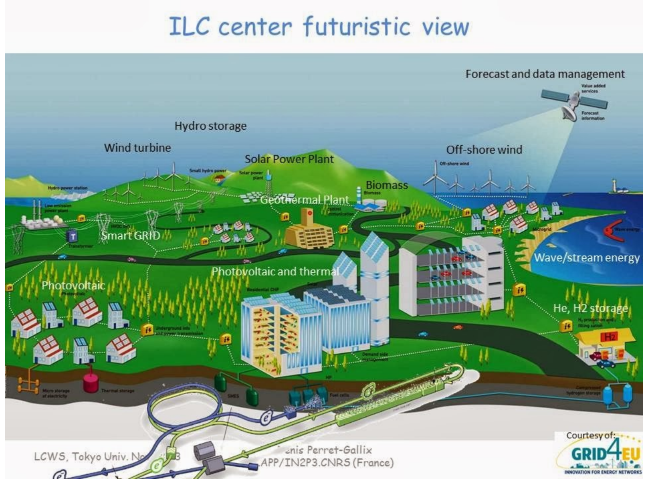
...ccelerators • ESSRI Workshop 2022

Successful installation and operation in a running light source!

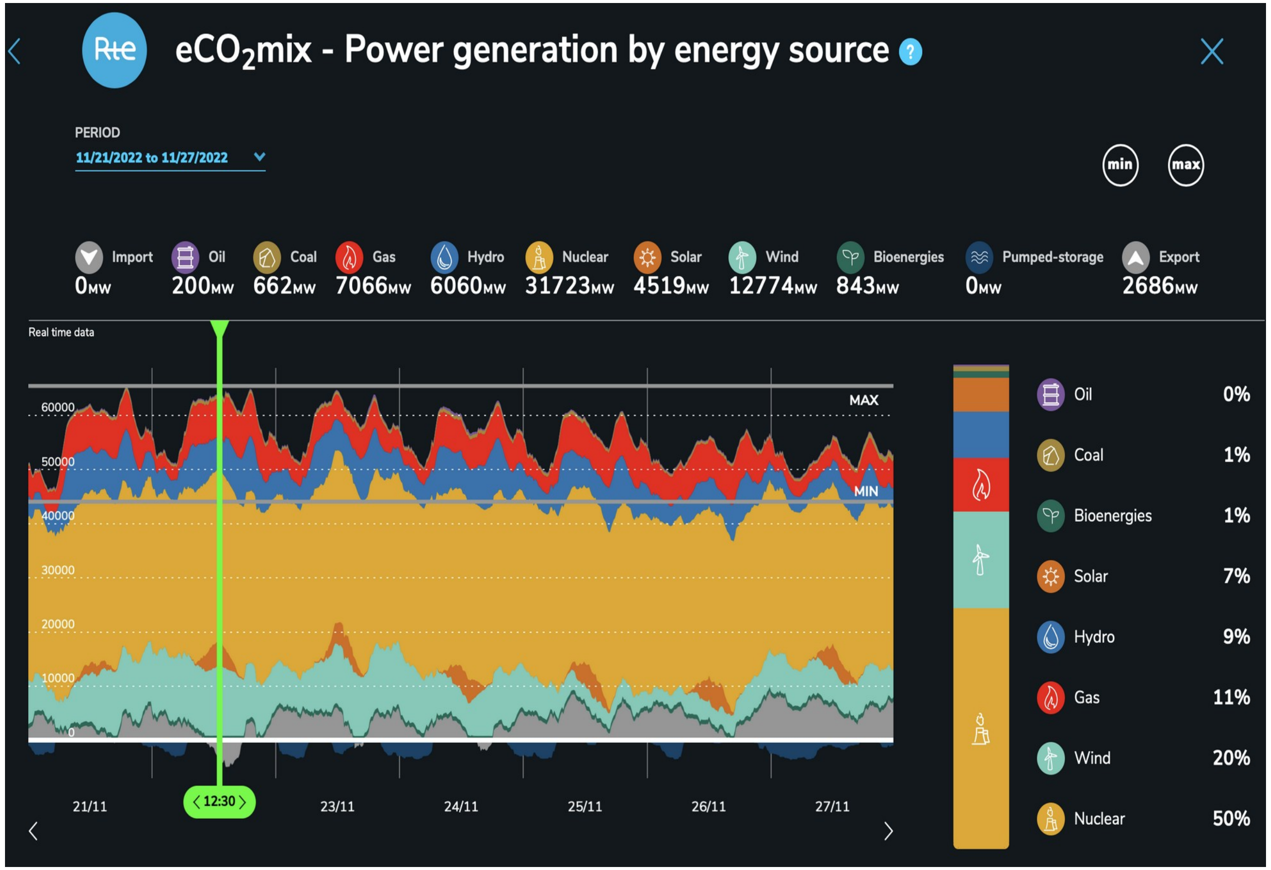




Ben Shepherd, ESSRI Workshop 2022, https://indico.esrf.fr/event/2/contributions/108/



Sustainable Operation



CO2 Intensity of Electricity in the Future

What will the CO_2 impact of electricity be for the next generation of colliders?

- CO_2 intensity of electricity will go down
- Regenerative energies will rise

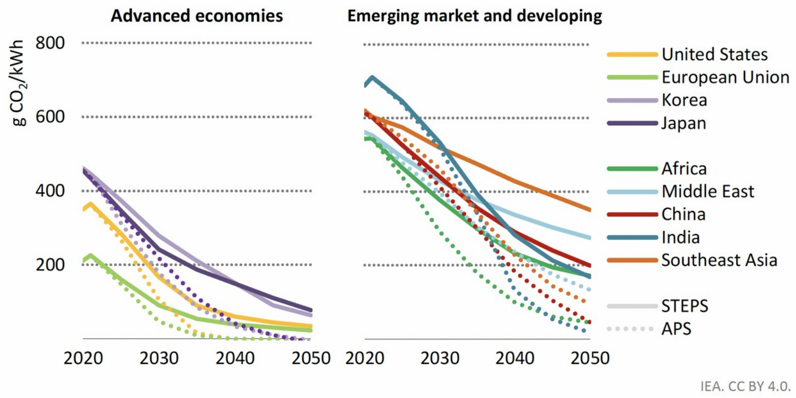
But

- Not enough – big gap between stated policies to announced pledges, even bigger to net zero
  -> we are not on a path to net zero!
- The energy transition will be a huge effort:
  - Energy storage
  - Energy transport (grid)
- Carbon intensity heavily site dependent
- Electricity will remain expensive

Therefore

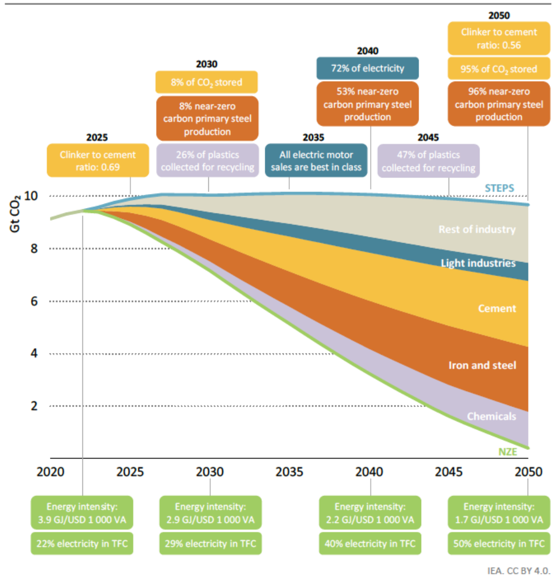
- Power consumption remains important
- Consensus needed which values to use
- How to treat site dependencies?
  (All projects would look best in Norway…)

Figure 6.14 ▷ Average CO_2 intensity of electricity generation for selected regions by scenario, 2020-2050



CO_2 intensity of electricity generation varies widely today, but all regions see a decline in future years and many have declared net zero emissions ambitions by around 2050

Figure 3.11 ▷ Emissions reductions and key milestones in the industry sector in the NZE Scenario relative to the STEPS, 2020-2050



Gap between Stated Policies and Net Zero Scenarios

IEA (2022), World Energy Outlook 2022, IEA, Paris
https://www.iea.org/reports/world-energy-outlook-2022,

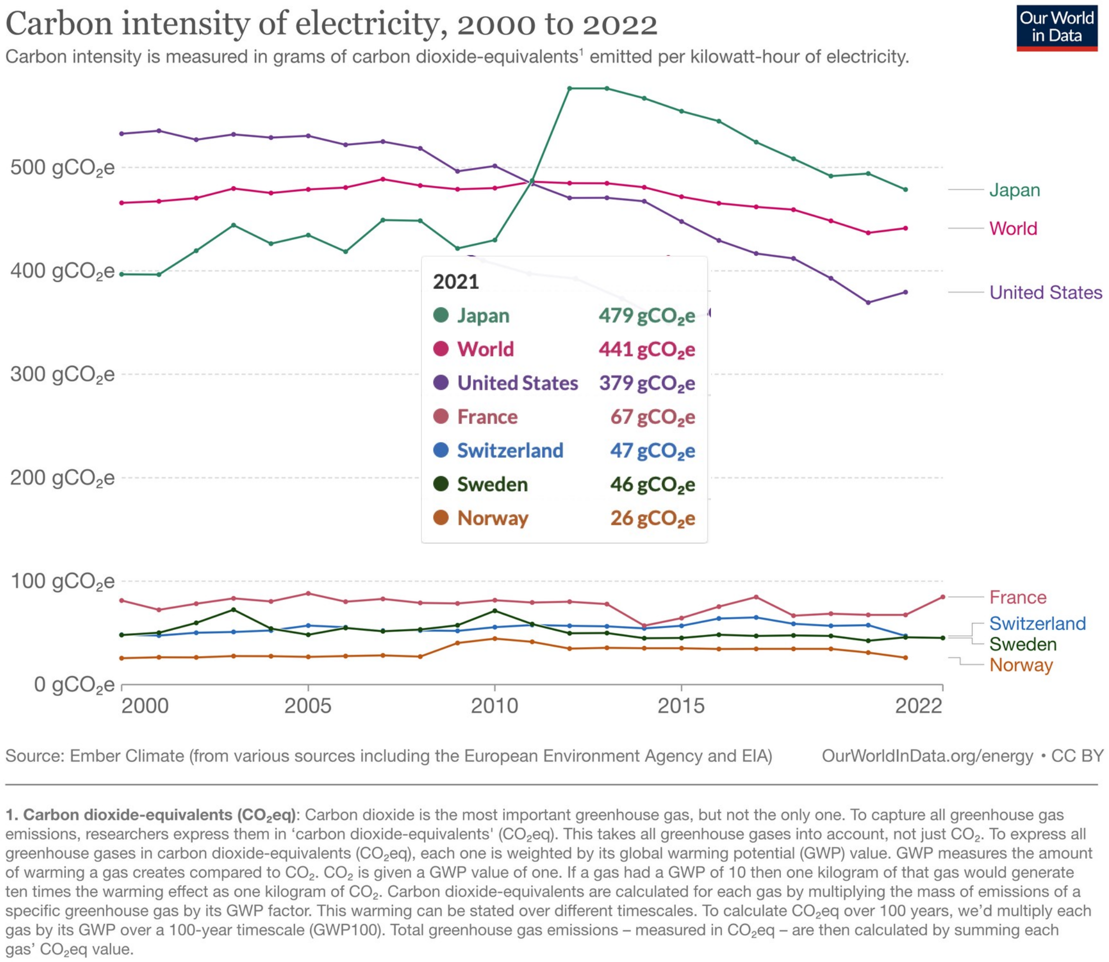
Carbon Intensity of Electricity and Accelerator: CLIC

- Example: For CERN / France in 2040 (summer) assume (*)
  - 50% nuclear power @ 5g CO2/kWh
  - 50% regenerative @ 20g CO2/kWh
  - -> 12.5g CO2/kWh
- 1TWh -> 12.5ktons CO2
- ILC / CLIC: ~0.6TWh / a

Compare to accelerator:

- Tunnel: ~6.5 ktons / km
- Accelerator: 2.5 ktons / km
- Services etc: ???

Very roughly, for CLIC:
1km of main linac = 1 year of operation



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

(*) https://app.electricitymaps.com/zone/FR
based on https://unece.org/info/publications/pub/371403

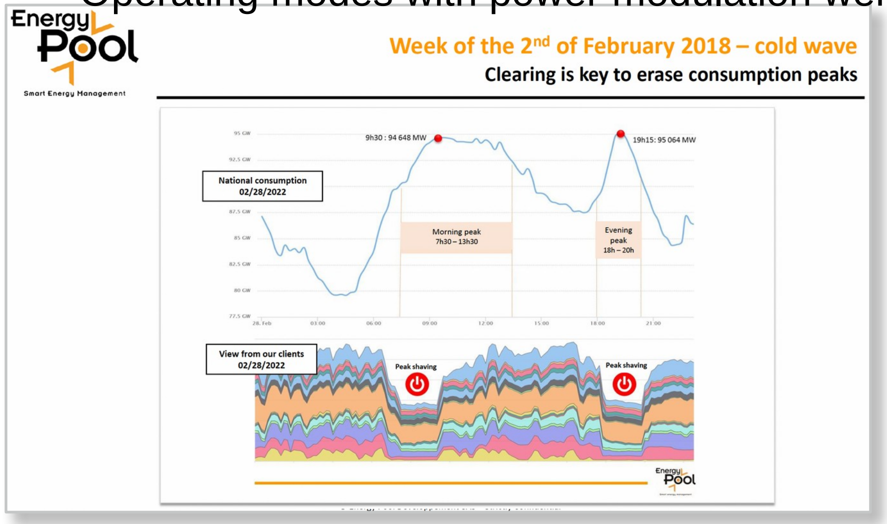
Collaborate: Demand Side Flexibility

There is enough regenerative energy available, but not 24/7

(Regenerative) Power availability varies
Linear accelerators have no stored beam -> ideal for flexible operation

Study by Fraunhofer institute considered running on renewables and participating in **demand side flexibility**

- CLIC's total energy consumption could be generated from renewables, but still needs public grid for continuity
- Operating modes with power modulation were inverstigated



C. Gaunand, B. Remenyi: *Introduction to Demand Side Flexibility*
ESSRI Workshop 2022 https://indico.esrf.fr/event/2/contributions/94/

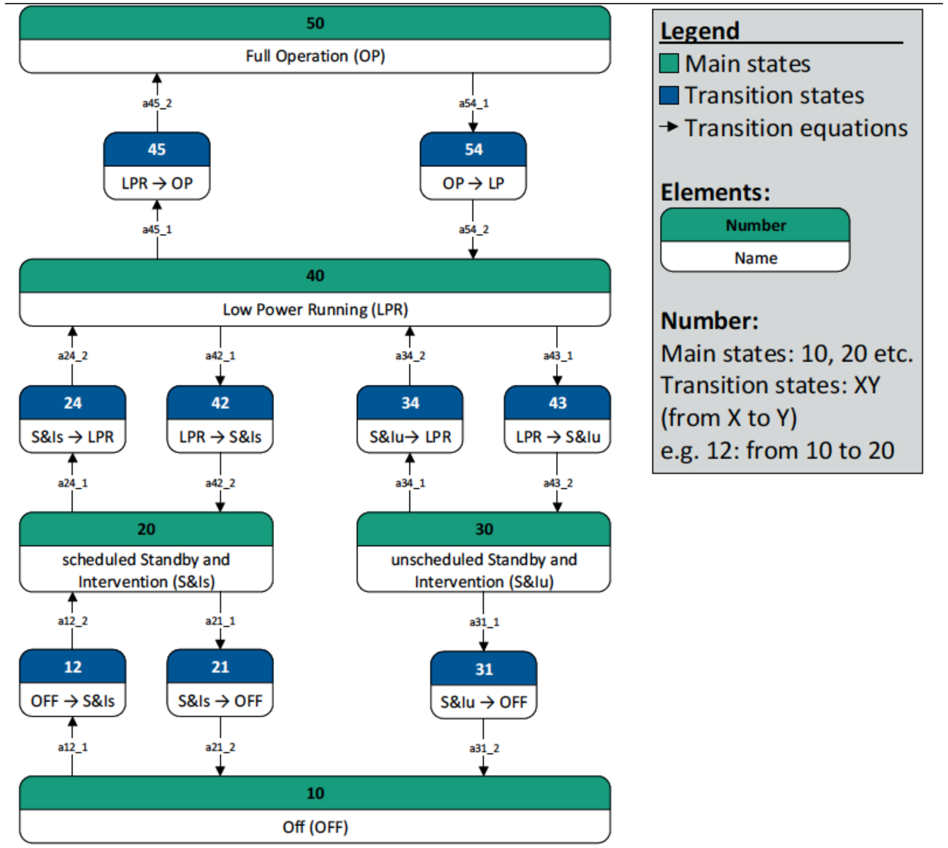


Figure 1-1: Schematic representation of the finite state machine

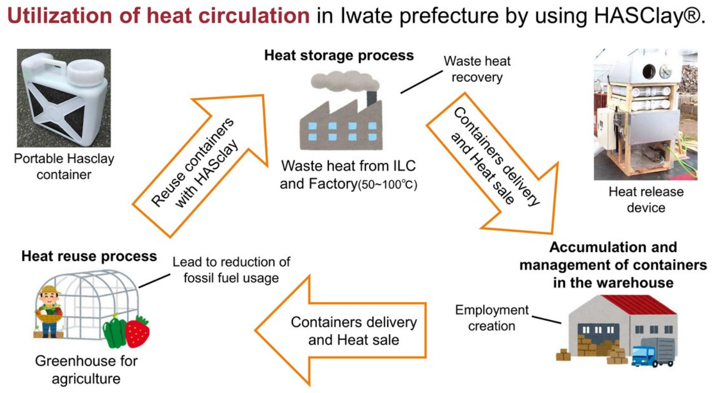
https://edms.cern.ch/document/2065162/1

Green ILC Studies in Tohoku Area

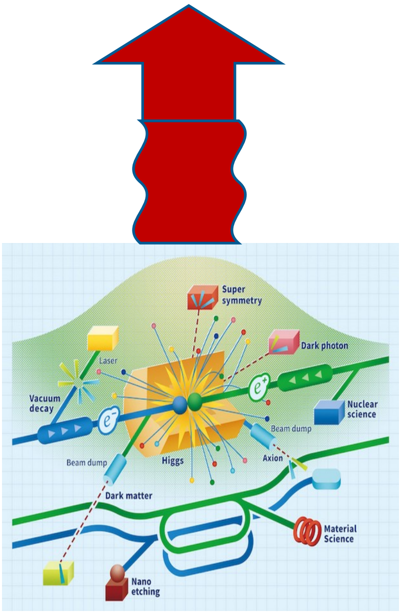
Further studies

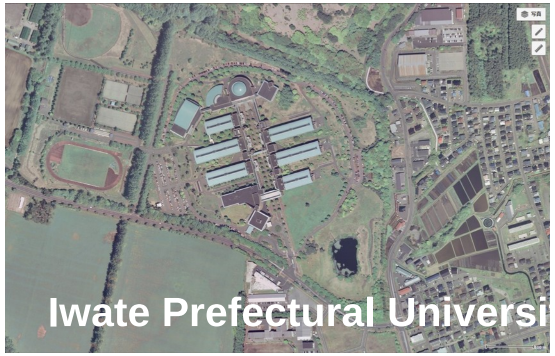
- Studies conducted on
  - Exhaust heat recovery from the ILC and the creation of business derived from it
  - Connecting the ILC with the local forestry industry
  - Utilization of solar heat
  - The ”Green ILC” concept and community development and planning - building an energy recycling society based on the Global Village Vision

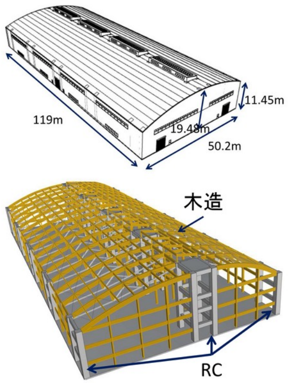
Masakasu Yoshioka
: Green ILC Concept - Today



320ktonCO2/year



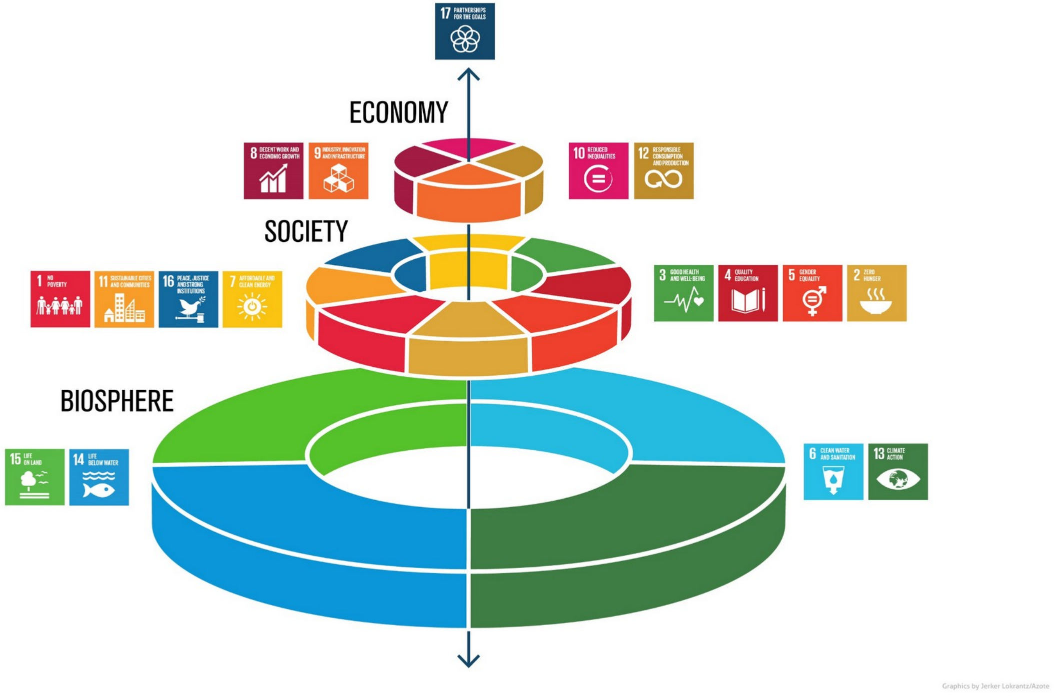




M. Yoshioka: https://agenda.linearcollider.org/event/9211/contributions/49408/
M. Yoshioka et al.: https://www.pasj.jp/web_publish/pasj2020/proceedings/PDF/WEPP/WEPP57.pdf

Relating to the UN Sustainable Development Goals

Communicate in a manner that resonates with society and politics



Azote for Stockholm Resilience Centre, Stockholm University CC BY-ND 3.0.
https://www.stockholmresilience.org/research/research-news/2016-06-14-the-sdgs-wedding-cake.html

- 2015: “2030 Agenda for Sustainable Development” adopted by UN
- 17 Sustainable Development Goals
- Accelerator Projects and Laboratories contribute to many of these goals:
  - Preservation of environment
  - Society: Education, Peace&Understanding
  - Economy: Spin Offs, Procurement

Communicate sustainability activities in relation to UN SDGs

Summary and Conclusions

- Sustainability studies are becoming an integral part of project preparation
- Lots of progress in recent years
- Many interesting results in this session
- Many things I have not mentioned

-> enjoy!

The way forward

- We need Lifecycle Assessments of complete projects
  - LCA of accelerator and experiment
  - Cover complete lifecycle
  - Professional (standard conforming) LCA
- LCA quantifies the project “cost” to the environment
  -> as important as monetary costs
  -> should be integral part of project proposal
- We need **common standards** for future projects
  - What are the Key Performance Indicators
  - What are the assumptions about future developments
  - How to treat site dependent factors

Thank you

Many thanks to
Steinar Stapnes, Maxim Titov, Shin Michizono, Takayuki Saeki, John Osborne, Liam Bromiley, Suzanne Evans, Yung Loo, Igor Syratchev, Ben Shepherd, Caterina Vernieri, Sergey Belomestnykh, Masakasu Yoshioka, and many others

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