International Development Team

LCWS Sessions on Sustainability

Benno List, DESY
IDT WG2

May 30, 2023

Lifecycle Thinking

- 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, …

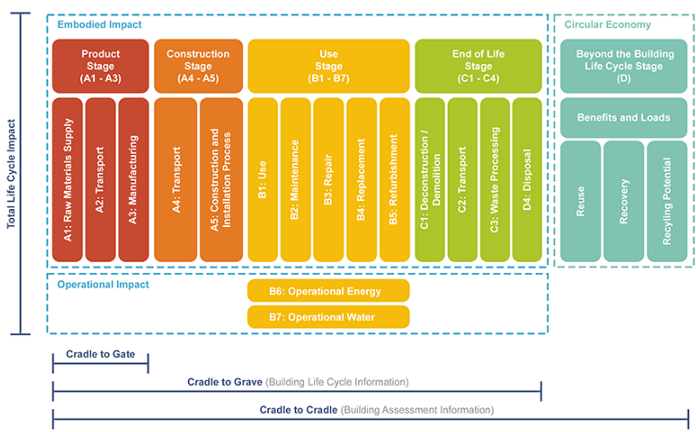
https://www.nist.gov/el/systems-integration-division-73400/lifecycle-graphic

Quantitative Approach: Lifecycle Assessment LCA

Whole Lifecycle

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

Defined in International Standards

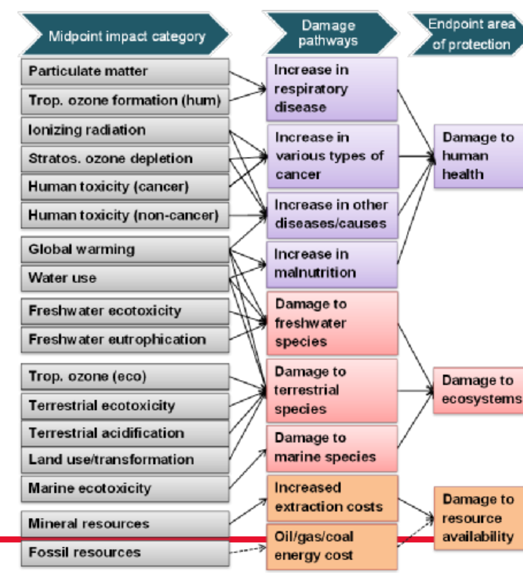


Lifecycle stages according to EN 15978

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

Whole Environmental Impact

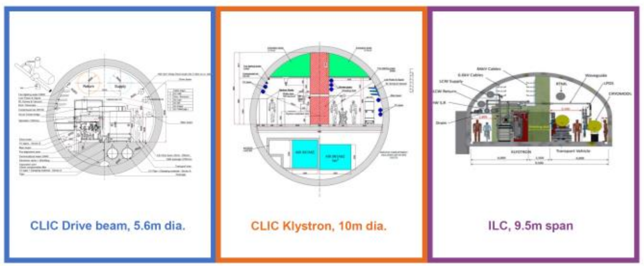
- Quantifying total damage by **endpoint** indicators (e.g. damage to human health) possible but difficult
- "**Midpoint** indicators" asses impact on environment in a quantitative way:
  - Greenhouse Warming Potential (GWP) – kg CO2 eqiv
  - Ozone Depletion Potential (ODP) – kg CFC-11 equiv
  - Ecotoxicity – kg 1,4-DCB equiv

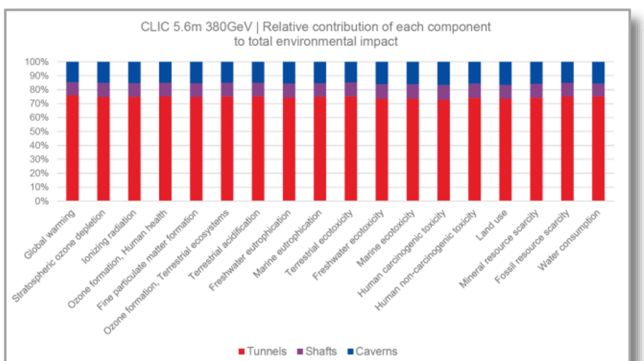


M.A.J. Huijbregts et al., Int. J. Life Cycle Ass. **22** (2017) 138, DOI:10.1007/s11367-016-1246-y

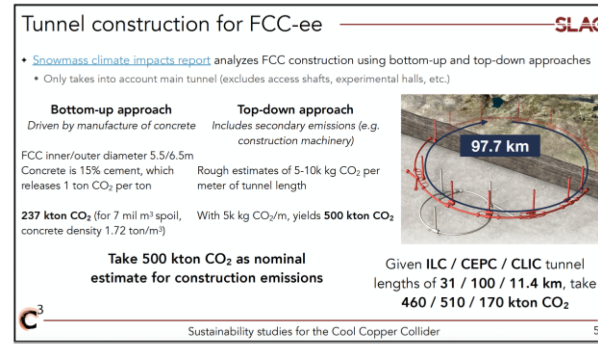
Quantifying the Impact of Civil Construction

Suzanne Evans: ***Linear Collider Carbon Assessments: A Life Cycle Assessment of the CLIC and ILC Linear Collider Feasibility Studies*** ***- Today***





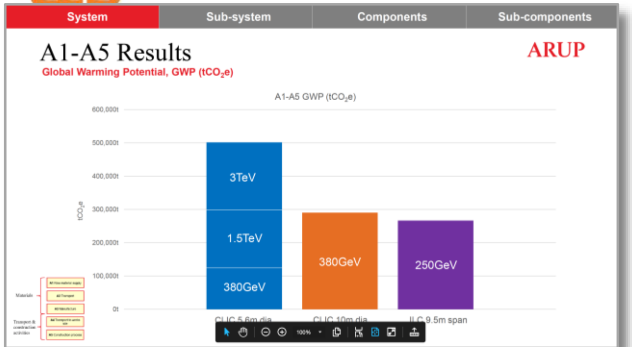
Brendon Bullard: *Sustainability studies for the Cool Copper Collider* *- Thursday*



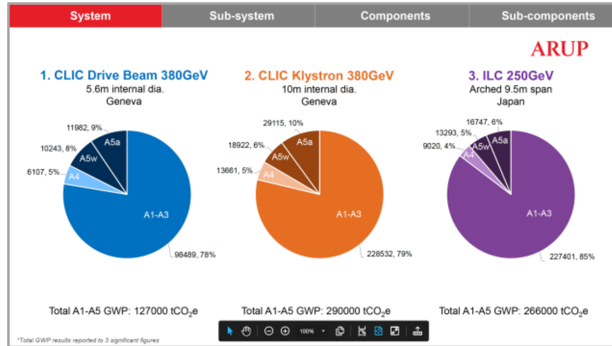
No spoilers here:
please watch these presentations

One number: 6.5 tons CO2/m tunnel
(CLIC main linac tunnel, 5.6m)

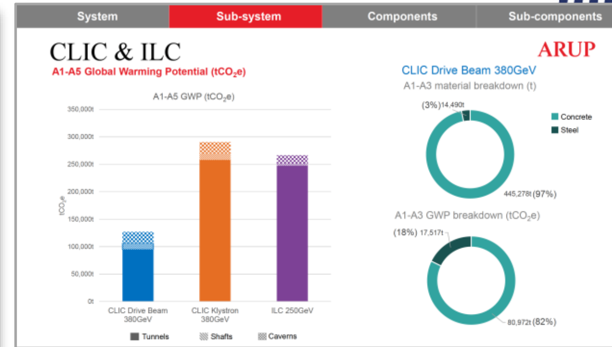
ARUP Study: Results



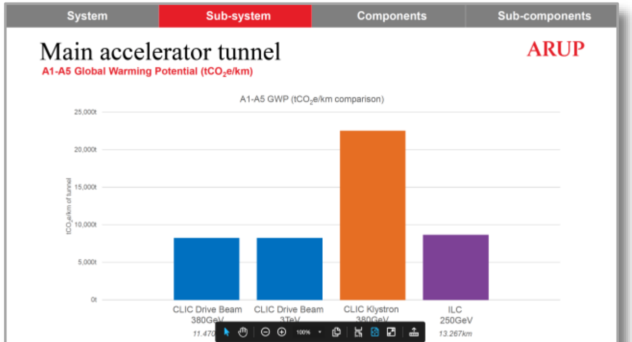
Total CO2



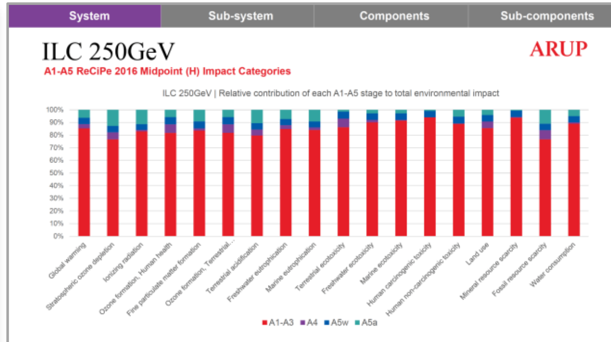
Per phase



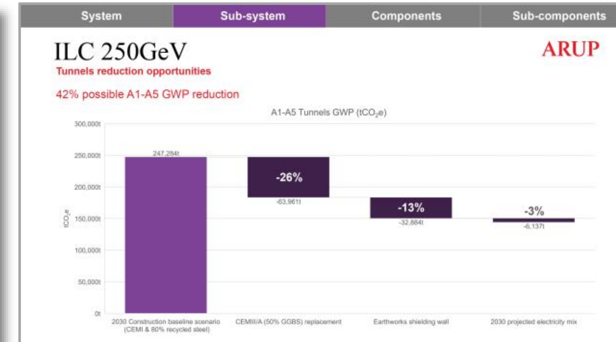
Concrete and steel



CO2 per meter (ML tunnel)



Other impacts

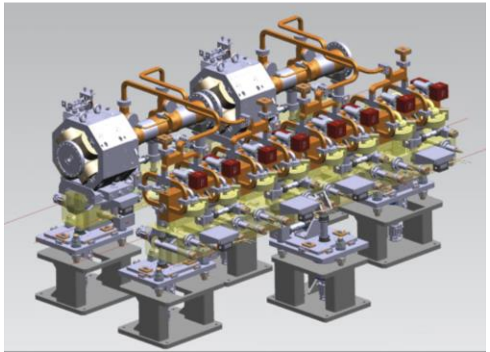


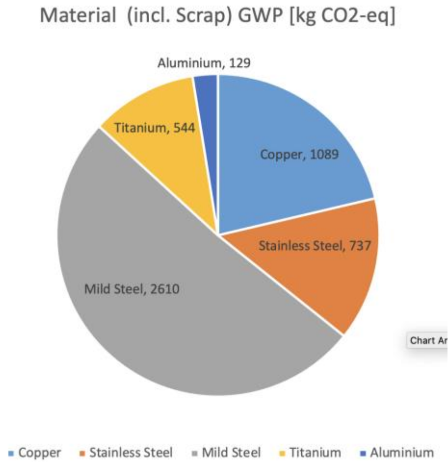
Reduction potential

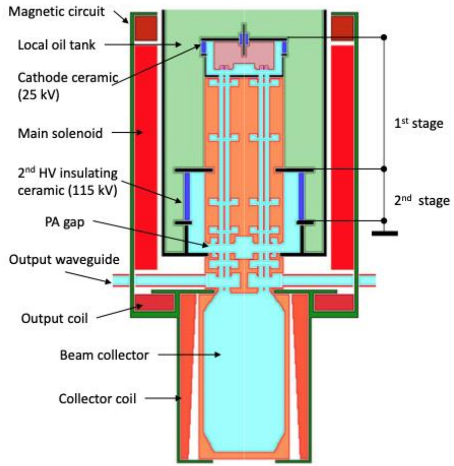
Looking at the Impact of the Accelerator

- 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

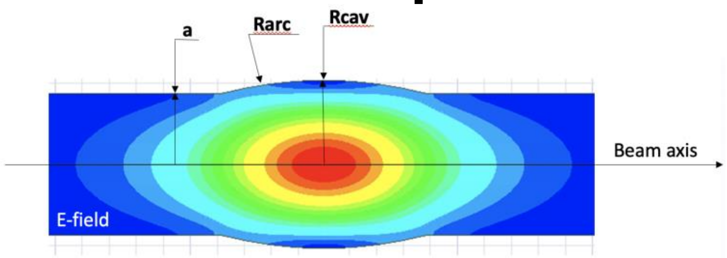
CO2 impact of accelerator components is comparable to CO2 of tunnel

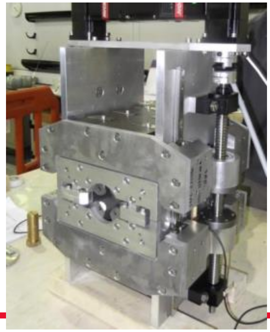






Optimization of Components and Subsystems



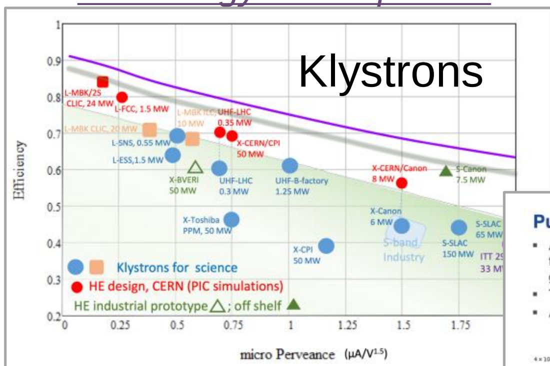


Components and Subsystems

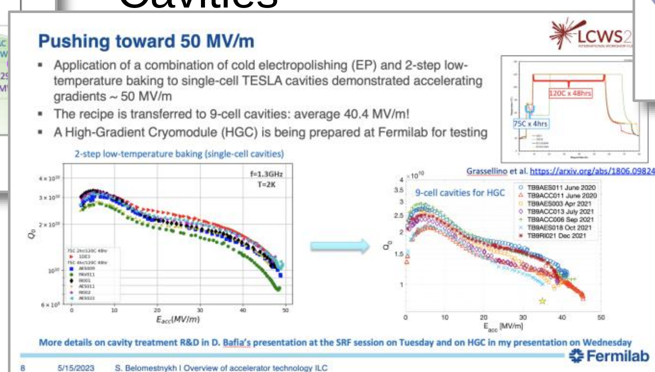
Better performance through better technology at same or lower cost

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

Sergey Belomestnykh: *Overview of accelerator technology development* - *Monday*

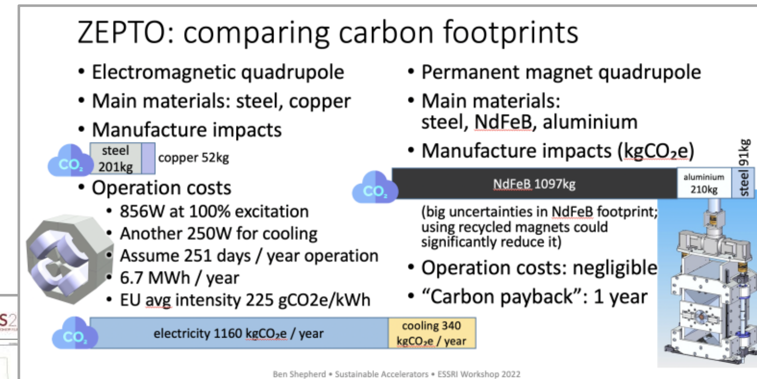


Cavities

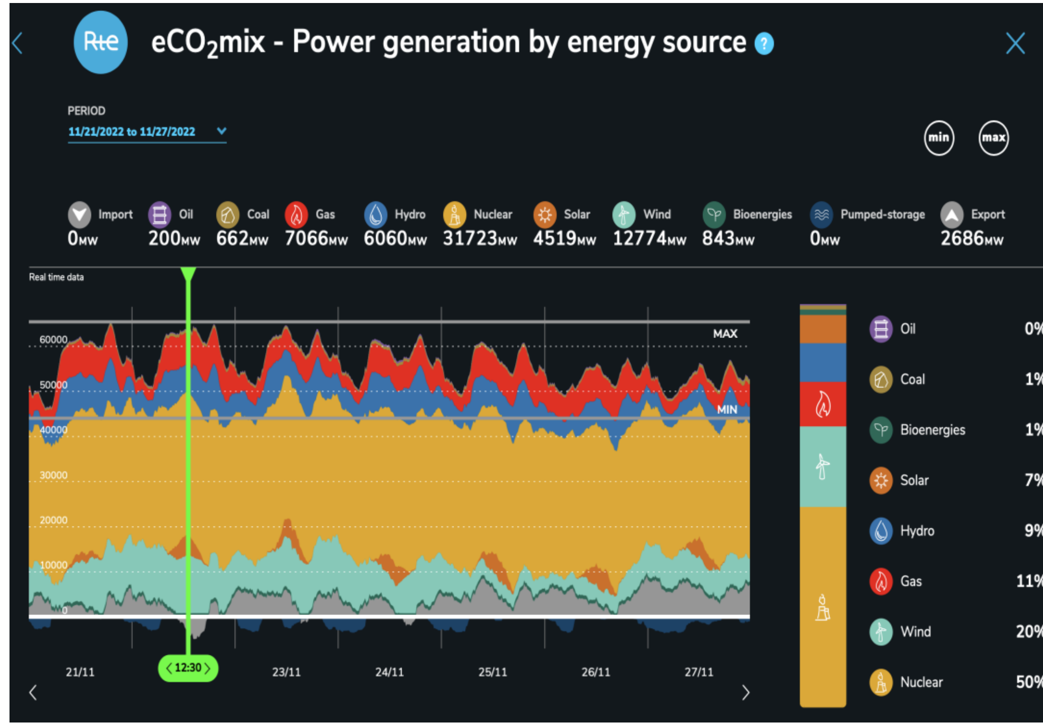


Difficult: lower operating cost through higher invest – needs trade off studies (LCA)

Ben Shepherd: *Permanent magnet technology* - *Today*



Sustainable Operation



CO2 Intensity of Electricity in the Future

What will the CO2 impact of electricity be for the next generation of colliders?

- CO2 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…)

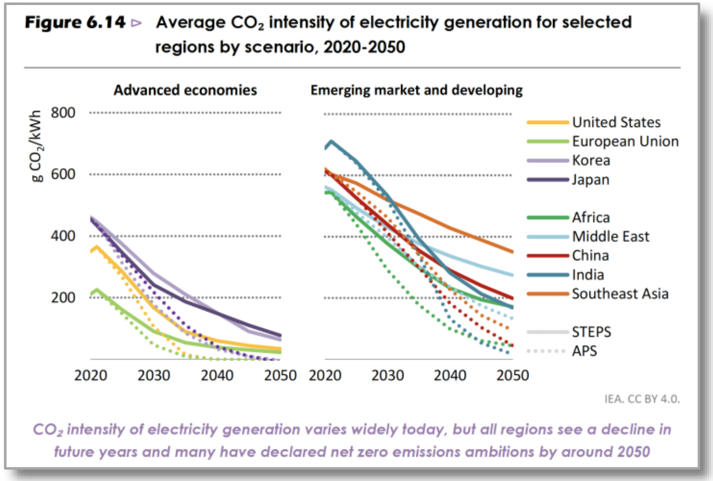


Figure 6.14 ▷ Average CO_2 intensity of electricity generation for selected regions by scenario, 2020-2050

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

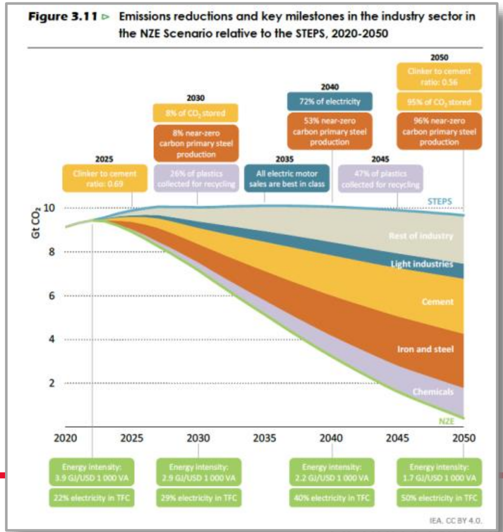


Figure 3.11 ▷ Emissions reductions and key milestones in the industry sector in the NZE Scenario relative to the STEPS, 2020-2050

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,

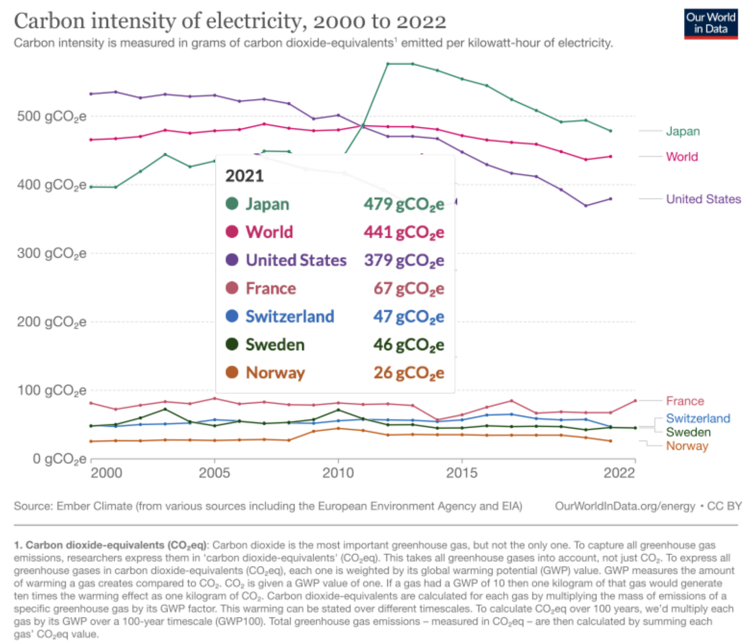
Carbon Intensity of Electricity and Accelerator: CLIC

- 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

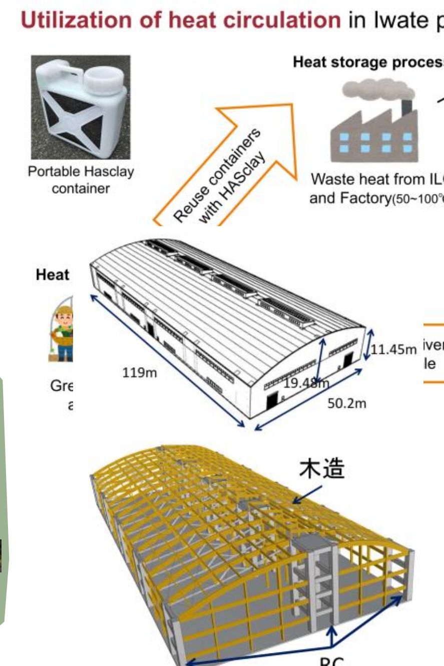
(*) https://app.electricitymaps.com/zone/FR
based on https://unece.org/info/publications/pub/371403

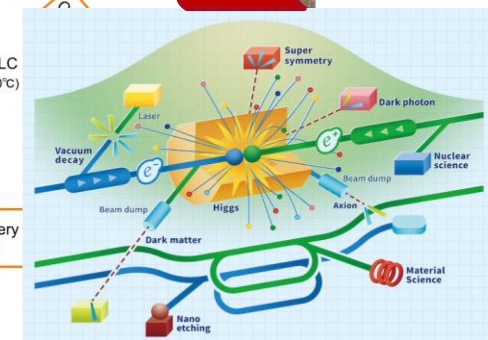
Green ILC Studies in Tohoku Area

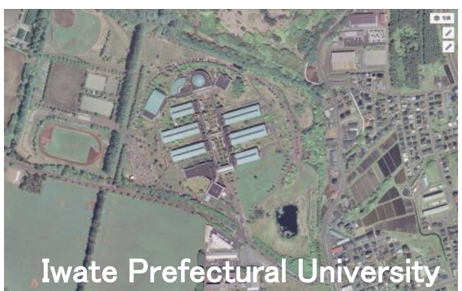
- Studies conducted on
  - Exhaust heat recovery from the ILC and the creation of business derived from it
  - Connecting the ILC with the local forestry industry
  - Utilization of solar heat
  - The ”Green ILC” concept and community development and planning - building an energy recycling society based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

Summary and Conclusions

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

We need an inter-project working group on sustainability assessment methods

- 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!

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

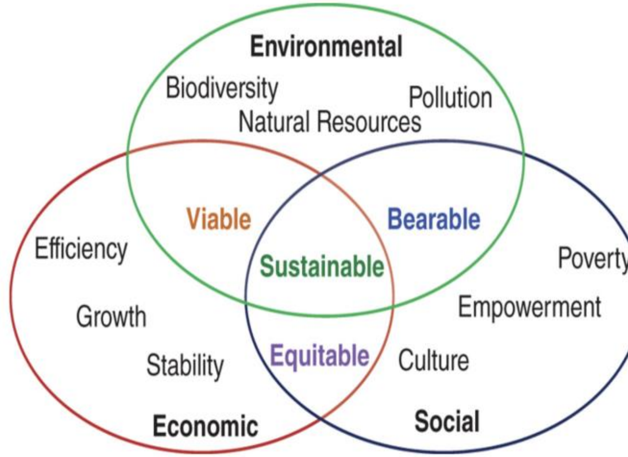
Sustainability: What It Is…

Cover of the “Brundtland Report” 1987

Gro Harlem Brundtland 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

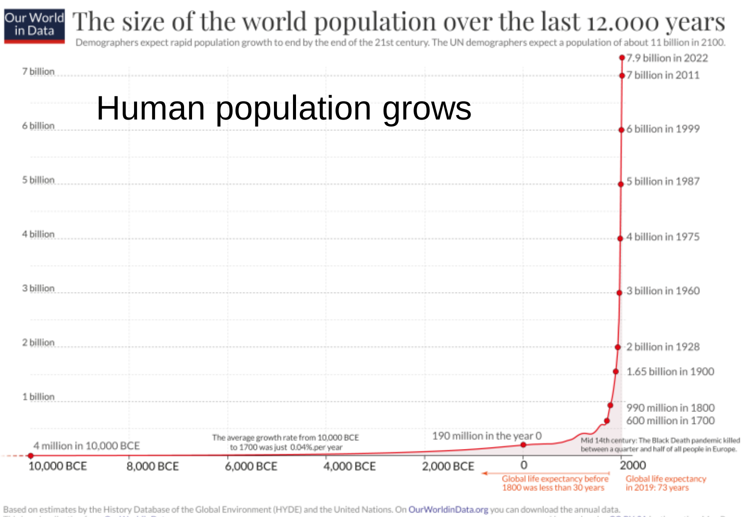
… and Why It Matters

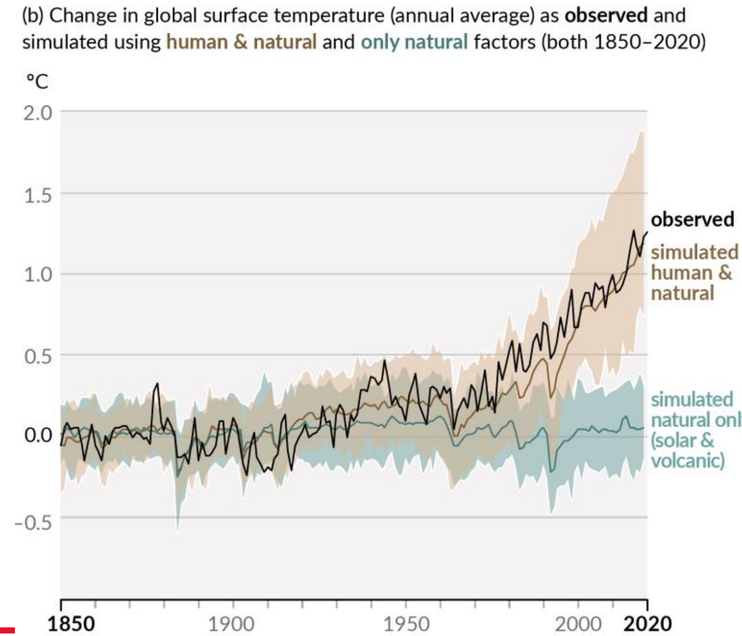
*It is **unequivocal** that **human influence** has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.*

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

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

Accelerating NEWS

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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)

February 24, 2023

Global research facility could change Tohoku

Sustainable Japan Magazine

ILC PROJECT

By TOSHICHIKA IZUMI, TRANSLATOR: EDAN CORKILL

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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

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

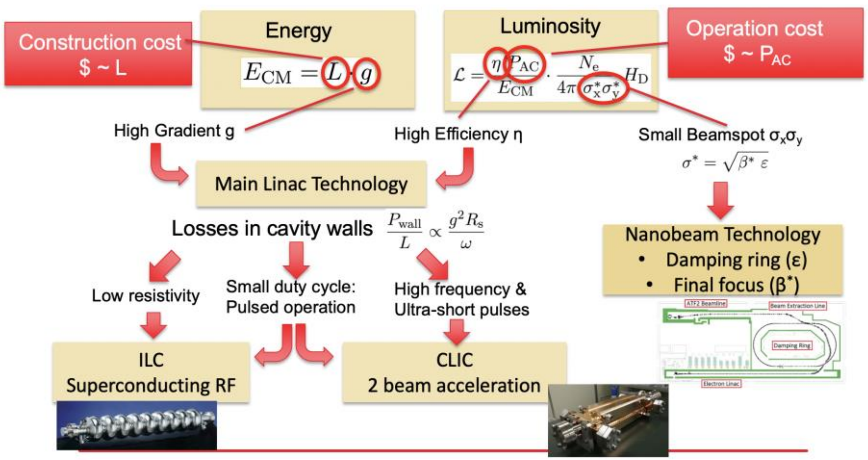
Approaches to Improve Sustainability

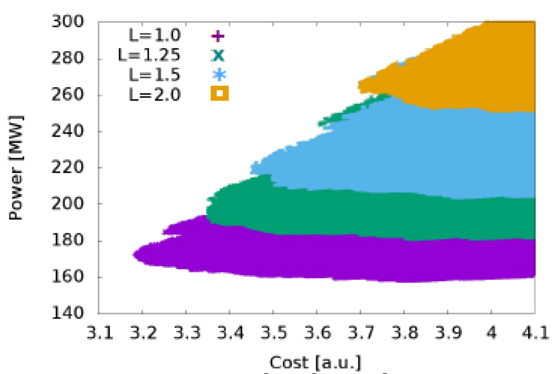
- Accelerators for High Energy Physics are at the leading edge of technology: beam energy, intensity, luminosity…
- Ressource conservation is paramount:
  - Tunnel length -> construction cost
  - Power consumption -> operating costs
- Sustainability adds new cost measures: e.g. CO_2, rare earth usage

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





Parameter optimization at CLIC

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

- 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:

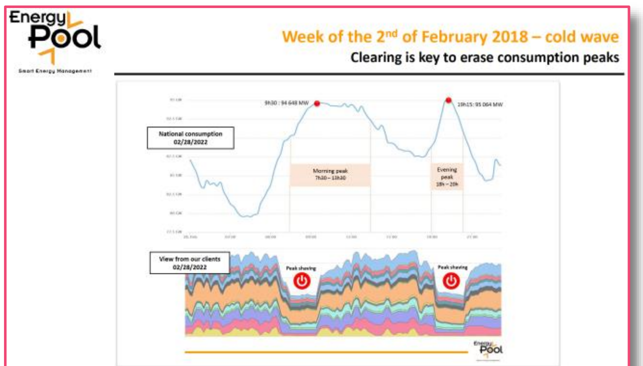
Lifecycle Assessment

Collaborate: Demand Side Flexibility

(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/

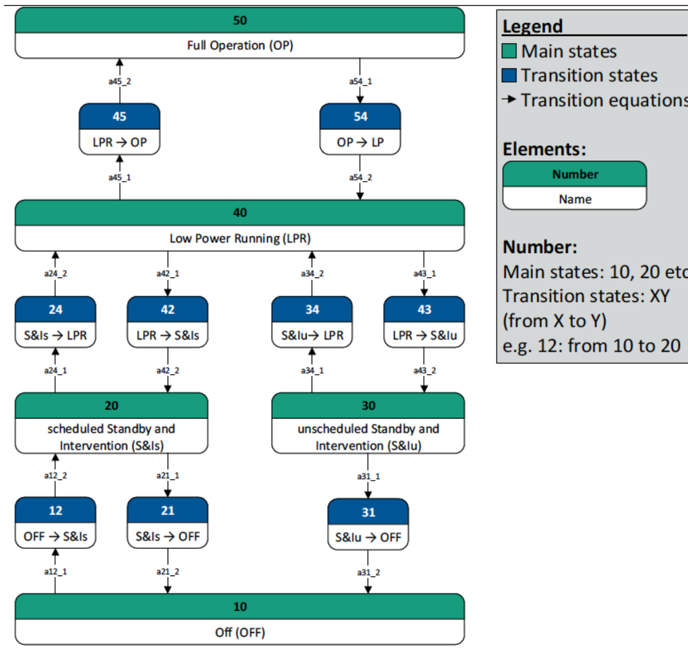
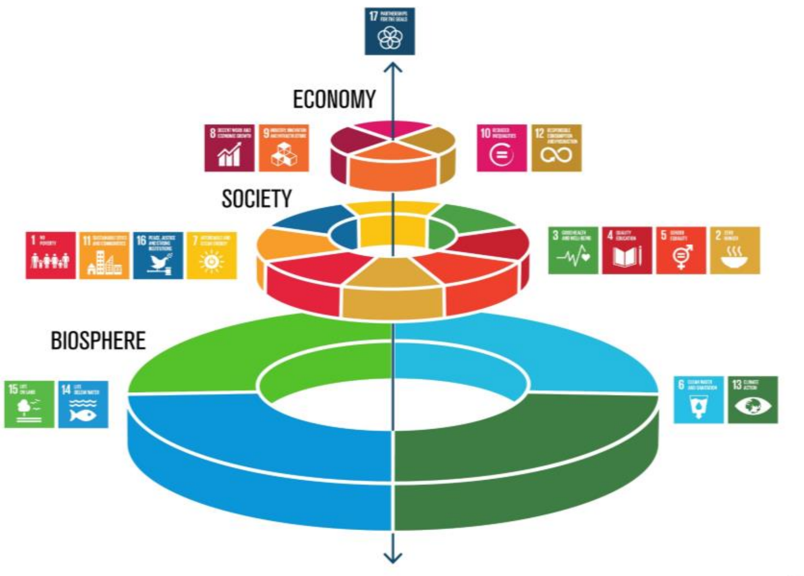


Figure 1-1: Schematic representation of the finite state machine

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

Relating to the UN Sustainable Development Goals



- 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 our sustainability activities in relation to UN SDGs