Linear colliders

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Outline

Introduction

CLIC and ILC

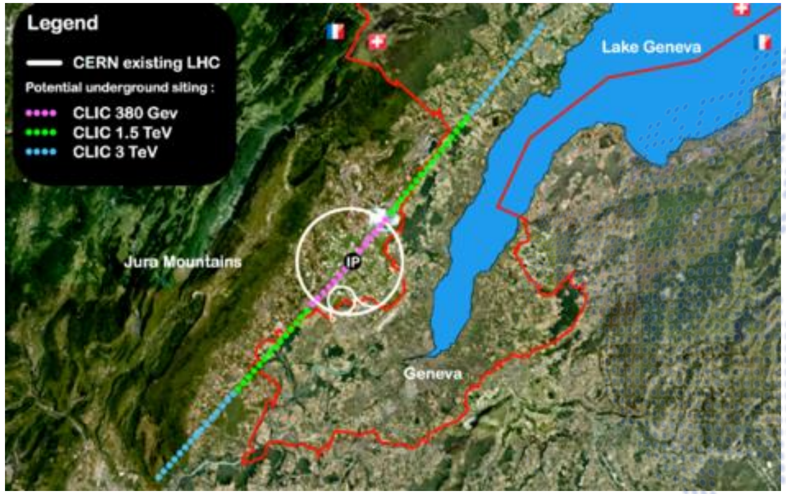
Summaries and common issues:

- Cost and power, schedules
- Sustainability studies (work in progress)

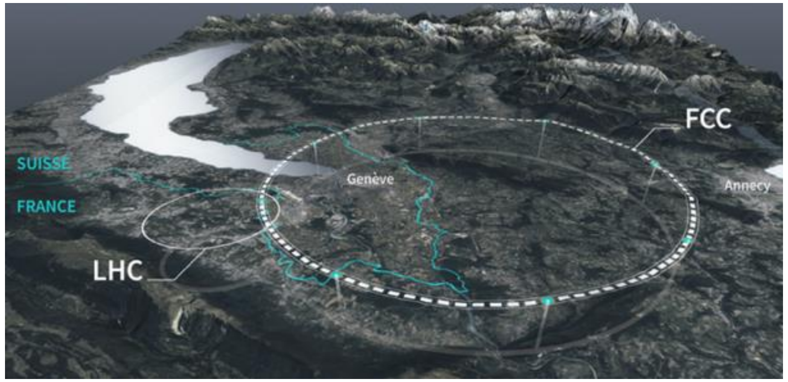
Final comments

A Higgs factory

CLIC at CERN



FCC at CERN

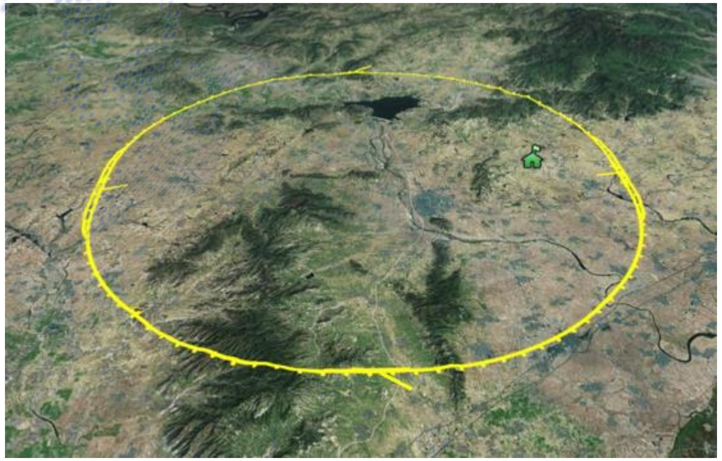


Need e+e- collisions at least at 250 GeV

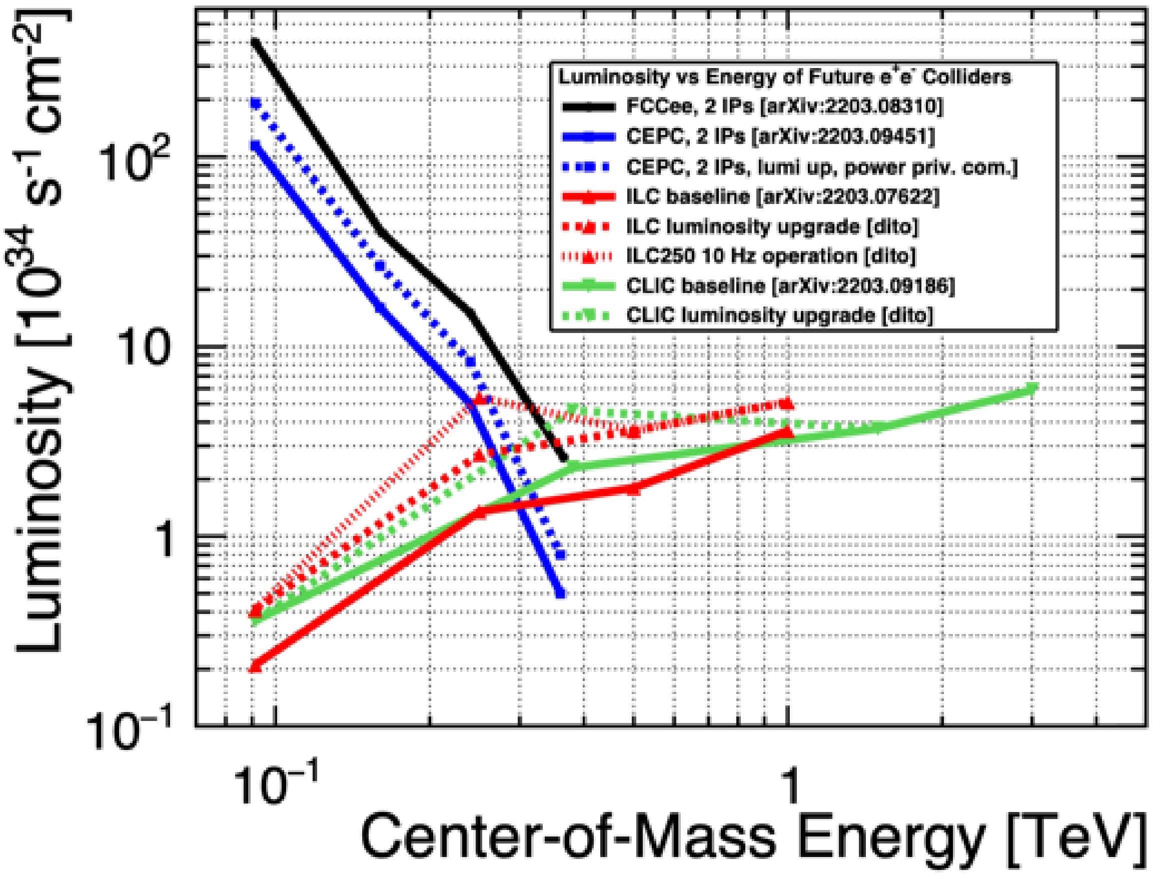
- Linear colliders: 11 (Higgs) -> 50 (max) km for higher energies later, proton or muons independent options for after
- Rings ~100km, can be used for protons after

ILC in Japan

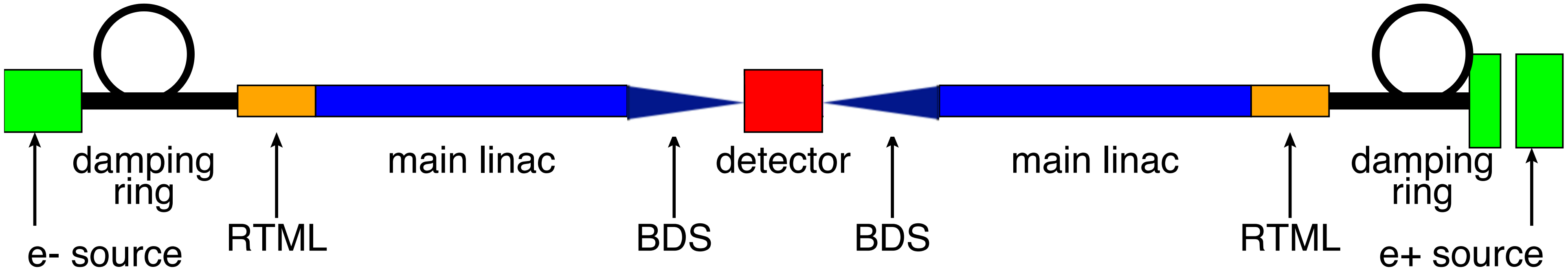
CEPC in China



A Higgs factory



Generic Linear Collider



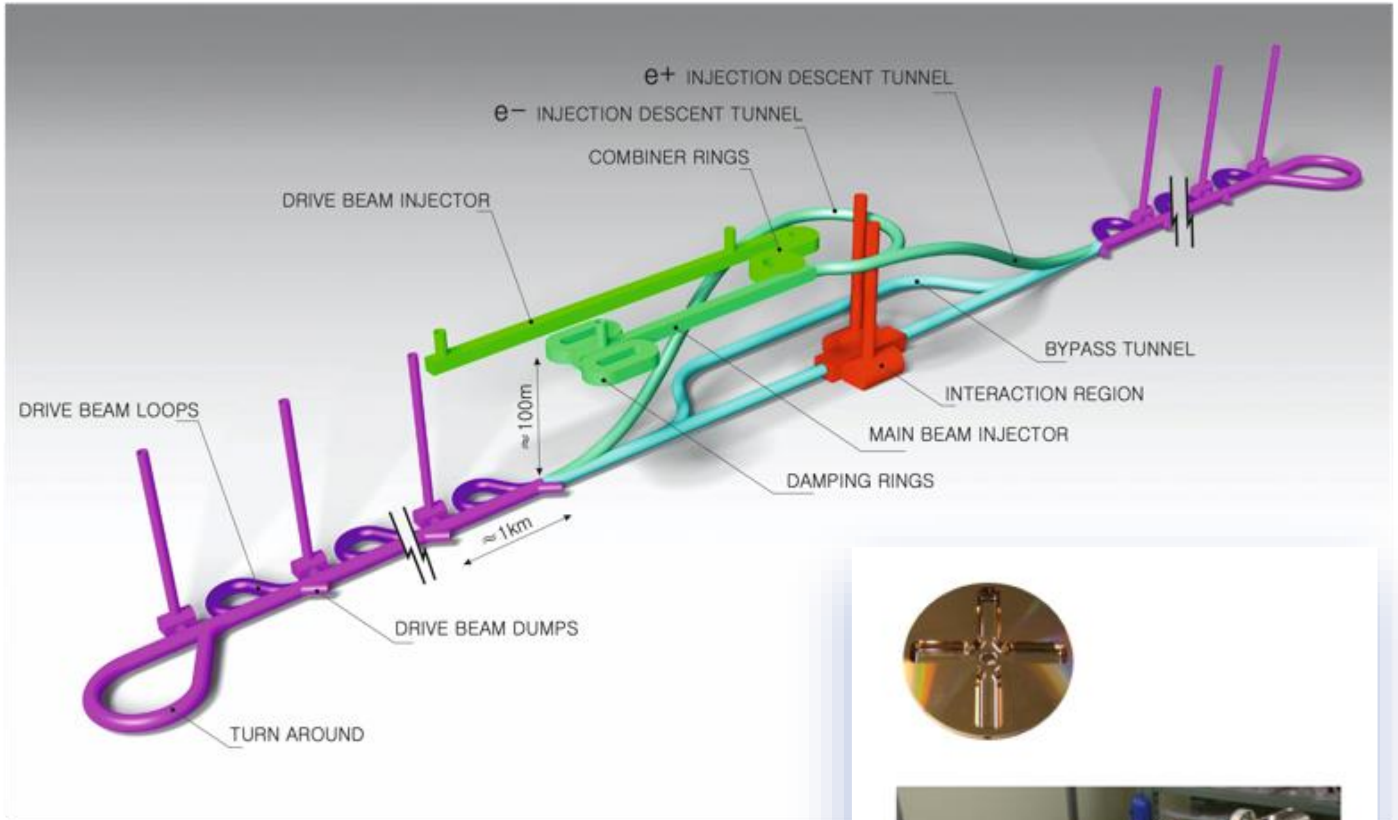
The key parameters: Energy and luminosity

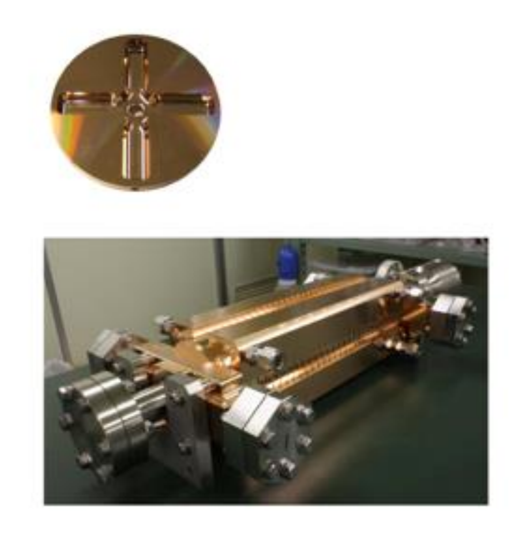
The critical steps:

Create low emittance beams (sources, injector, damping rings, ring to main linac - RTML)

1) Acceleration in main linac (energy increase per length)
2) Supply energy as efficient as possible to beam (high power at 1, 1.3 and 12 GHz)
3) Nano-beams: Squeeze the beam (Beam Delivery System – BDS)

The Compact Linear Collider (CLIC)





Accelerating structure prototype for CLIC: 12 GHz (L~25 cm)

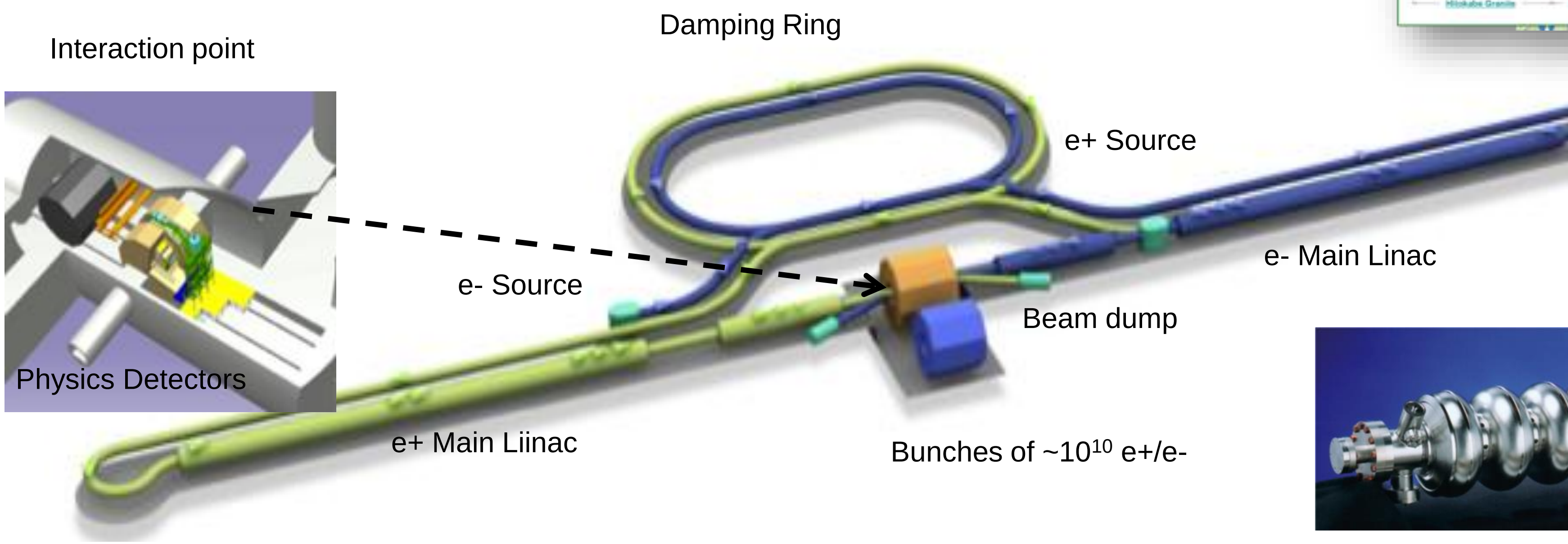
- **Timeline:** Electron-positron linear collider at CERN for the era beyond HL-LHC
- **Compact:** Novel and unique two-beam accelerating technique with high-gradient room temperature RF cavities (~20’500 structures at 380 GeV), ~11km in its initial phase
- **Expandable:** Staged programme with collision 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.

The Compact Linear Collider (CLIC)

The CLIC accelerator studies are mature:

- Optimised design for cost and power
- Many tests in CTF3, FELs, light-sources and test-stands
- Technical developments of “all” key elements

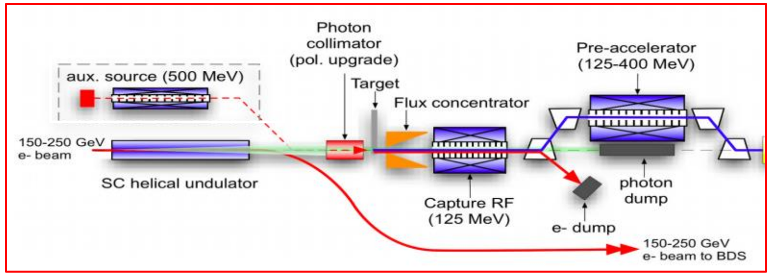
The ILC250 accelerator facility



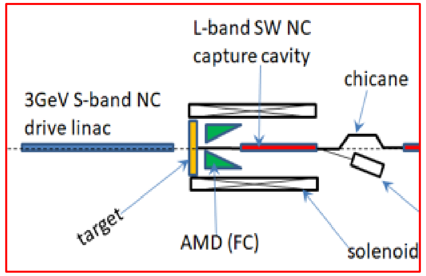
The ILC250 accelerator facility

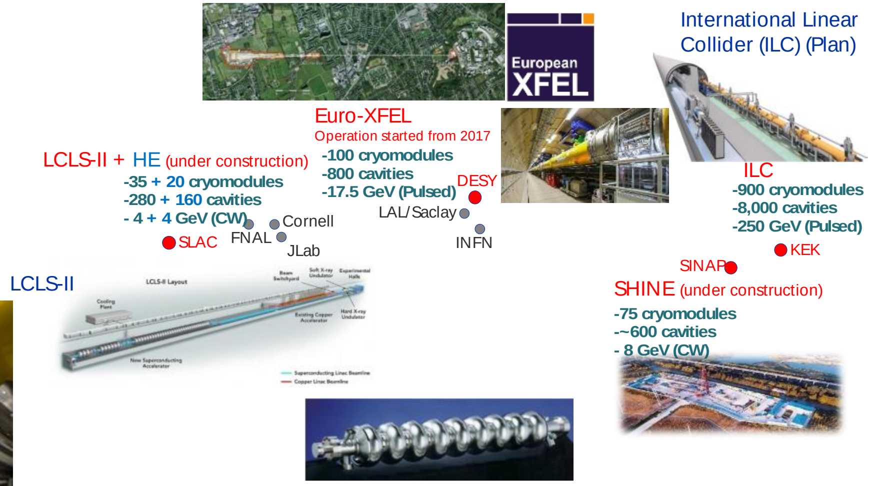
- Creating particles — Sources
  - polarized elections/positrons
- High quality beam — Damping ring
  - low emittance beams
- Acceleration — Main linac
  - superconducting radio frequency (SRF)
- Collide them — Final focus
  - nano-meter beams
- Go to — Beam dumps

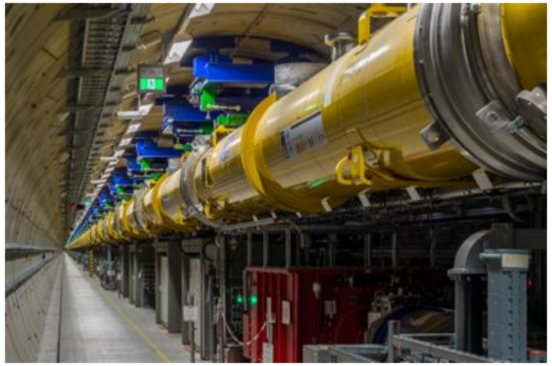
Undulator positron source



Electron driven positron source







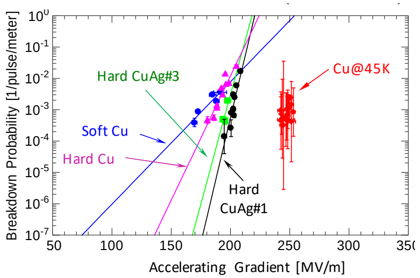
C3 studies

8 km footprint for 250/550 GeV CoM ⟹ 70/120 MeV/m

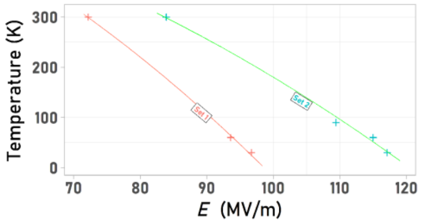
- 7 km footprint at 155 MeV/m for 550 GeV CoM – present Fermilab site

Large portions of accelerator complex are compatible between LC technologies

- Beam delivery and IP modified from ILC (1.5 km for 550 GeV CoM)
- Damping rings and injectors to be optimized with CLIC as baseline
- Reliant on work done by CLIC and ILC to make progress

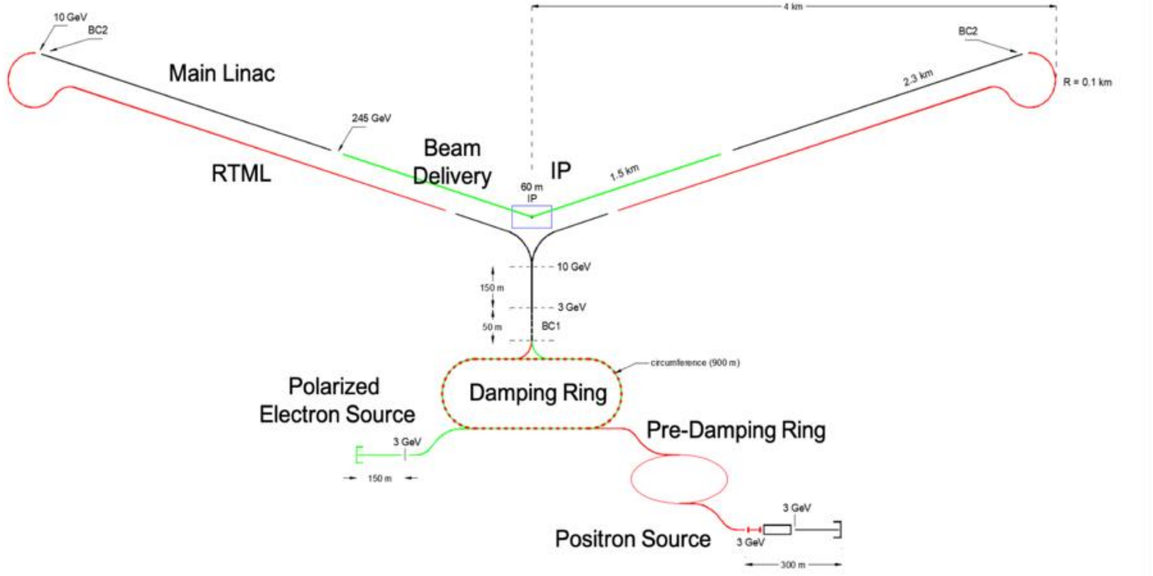


Cryo-cooled c

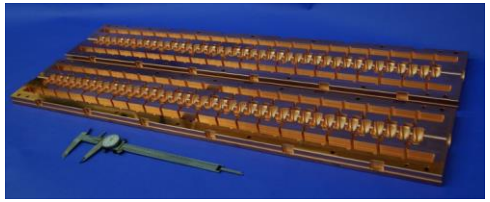


Cryo-cooled copper pulsed dc electrodes, Uppsala/CERN

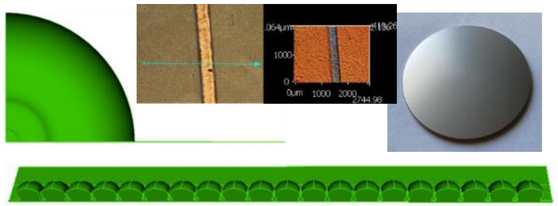
C^3 - 8 km Footprint for 250/550 GeV



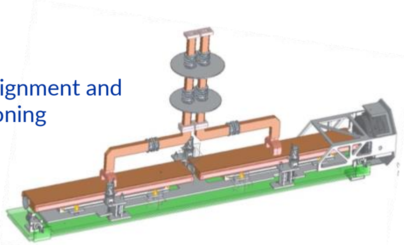
Modern Manufacturing
Prototype One Meter Structure



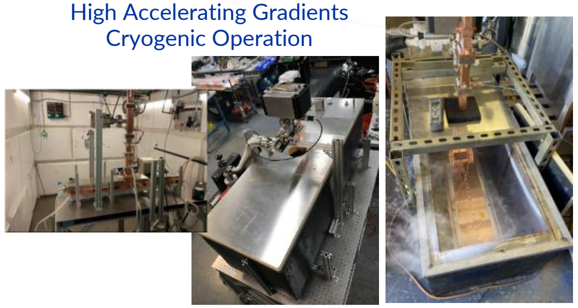
Integrated Damping
Slot Damping with NiChrome Coating



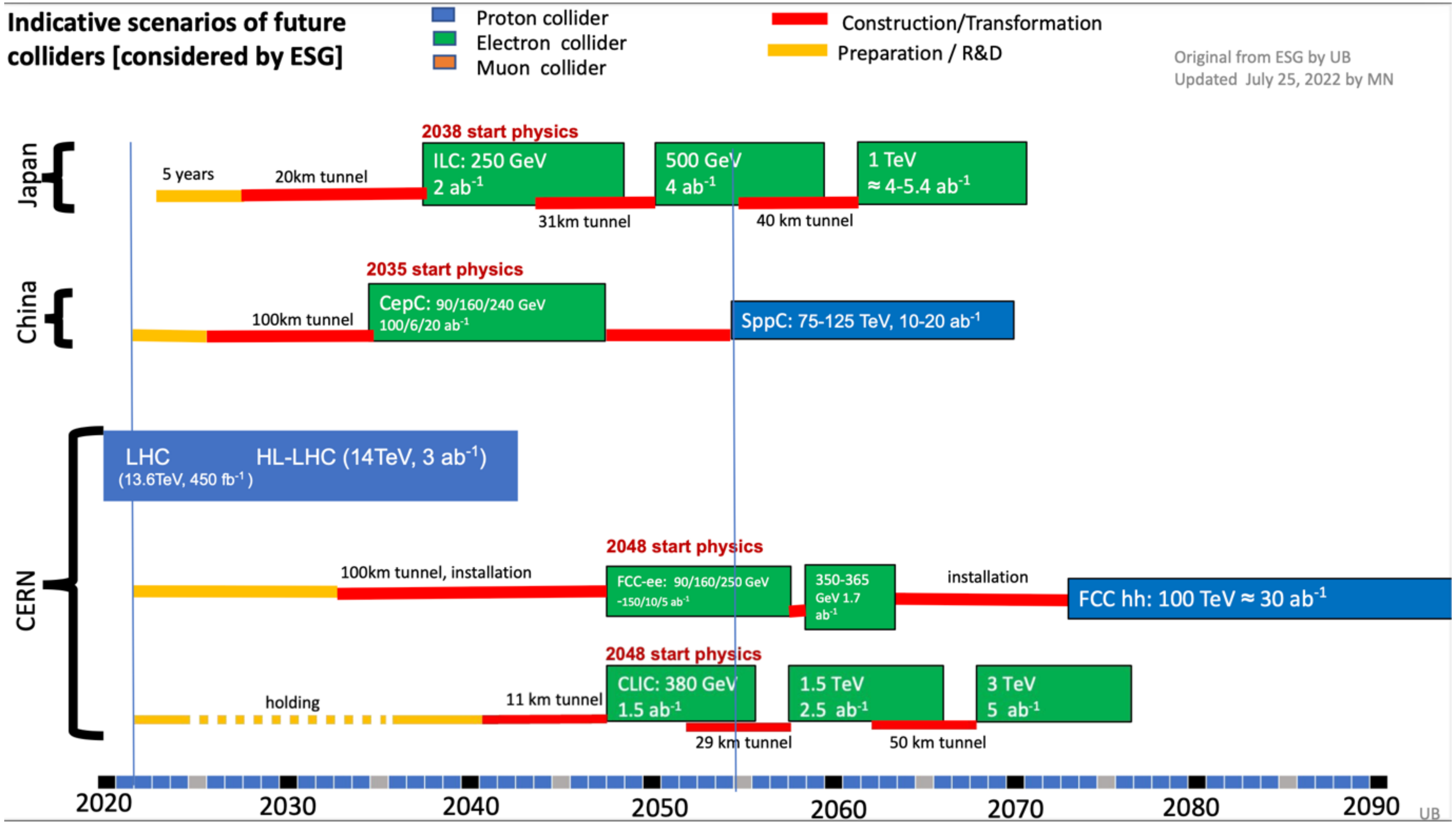
Preliminary Alignment and
Positioning



High Accelerating Gradients
Cryogenic Operation



Timelines in Snowmass Energy Frontier summary



Comments:

- Timelines are technologically limited – except the CERN projects that are linked to completion of the HL-LHC
- CEPC and ILC schedules are mature, but the projects need to pass approval processes in the near future to maintain these schedules
- A clear wish to develop options for future US sited EF colliders
- From Meenakshi Narain EF summary Snowmass

Personnel estimate and cost – Higgs factories

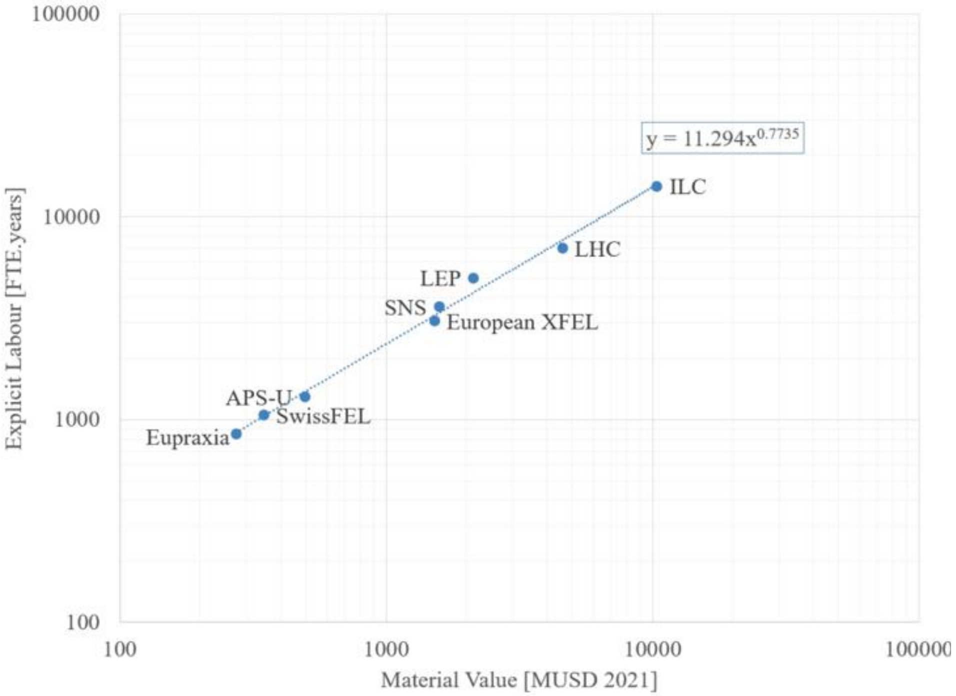


Figure 5: Explicit labor for several large accelerator projects vs. project value.

One FTEy estimated to 200kUS$

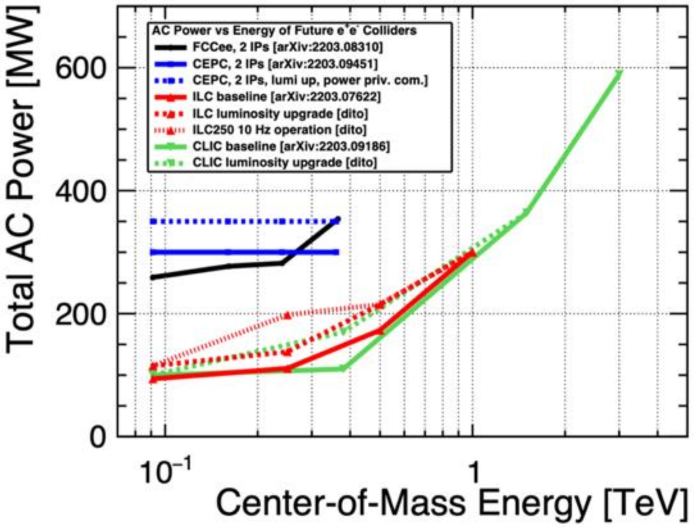
Figure 8: The ITF cost model for the EW/Higgs factory proposals. Horizontal scale is approximately logarithmic for the project total cost in 2021 B$ without contingency and escalation. Black horizontal bars with smeared ends indicate the cost estimate range for each machine.

This estimate from Snowmass process includes personnel costs (usually kept separate at CERN)

Power and energy

CERN "standard" running scenario used to convert to annual energy use

Very uncertain but MTP assumes 120 MCHF/TWh beyond 2026



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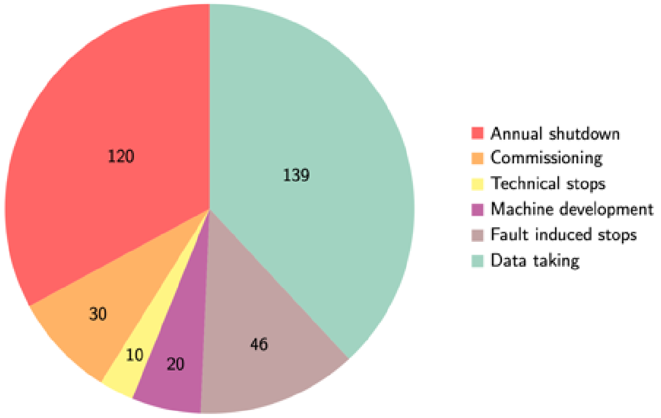
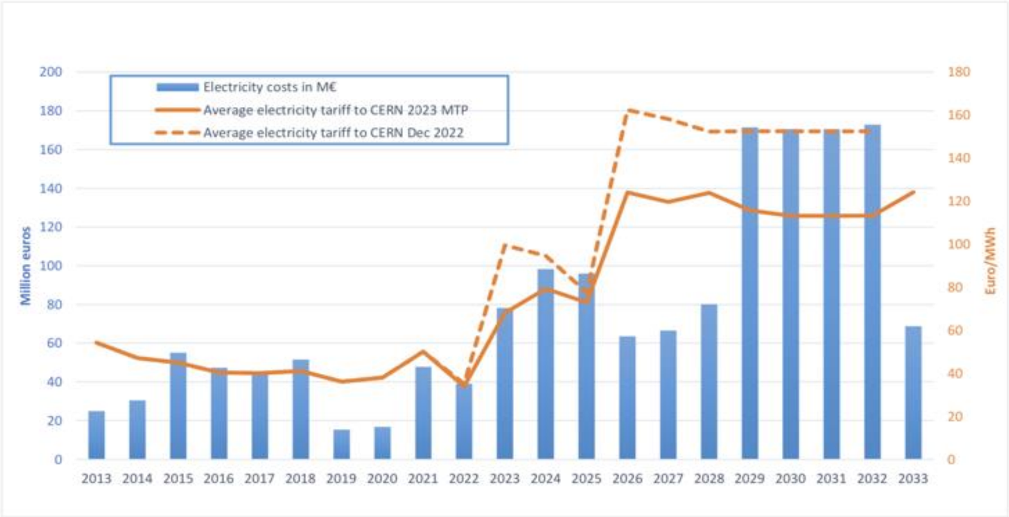




With "standard" running scenario every 100 MW corresponds to ~0.6 TWh annually (~75 MCHF)

Power optimization – examples

Design Optimisation:

All projects aim to optimize – most often energy reach, luminosities and cost. Power is becoming at least as important, maybe even compromising ultimate performance for power saving.

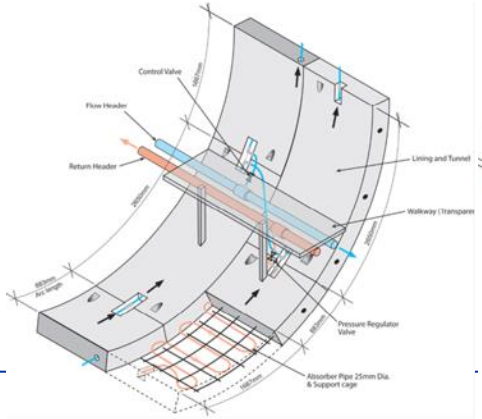
Technical Developments:

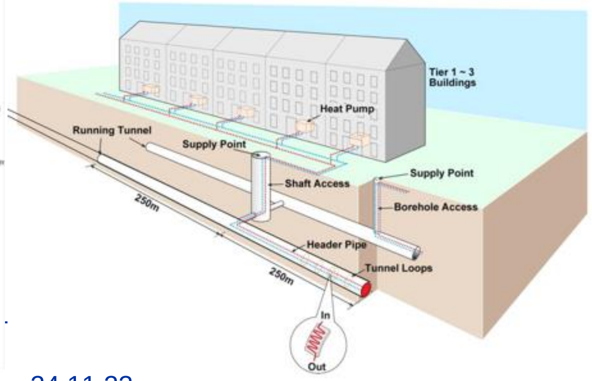
Technical developments targeting reduced power consumptions at system level high efficiency klystrons and RF systems generally, RF cavity design and optimisation, magnets (traditional SC and HTS including cryo, and also permanents magnets).

Heat recovery:

Already implemented in point 8 for LHC

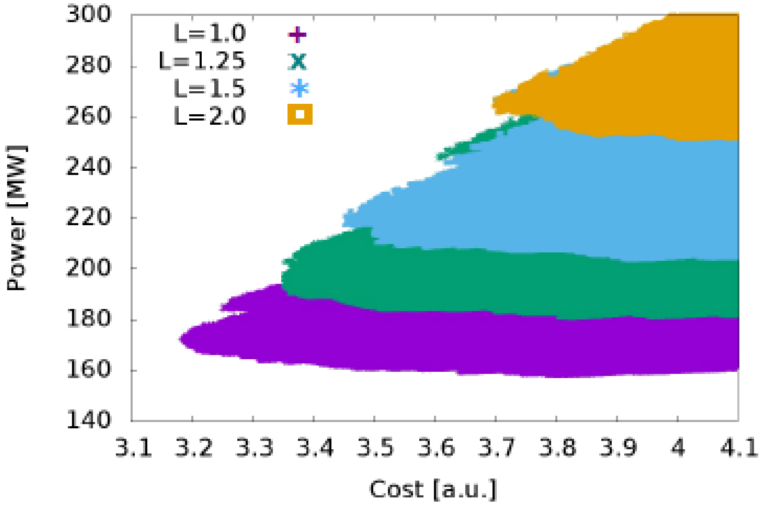
Tunnel heat recovery study by ARUP in 2022, results interesting but …

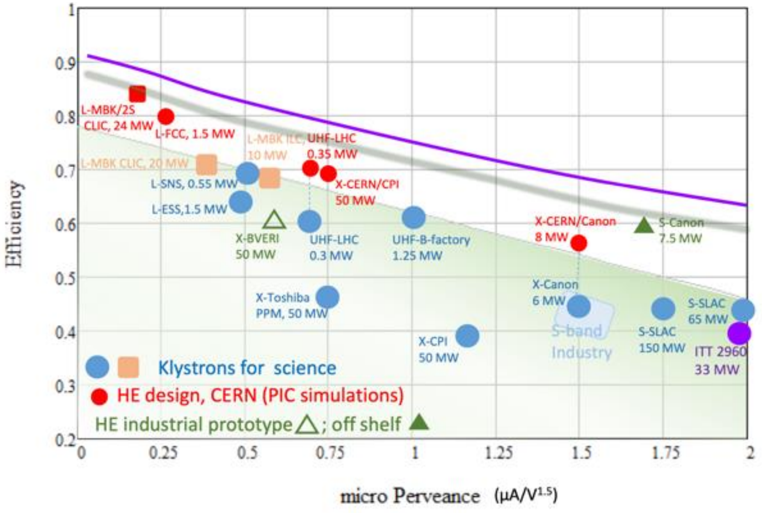




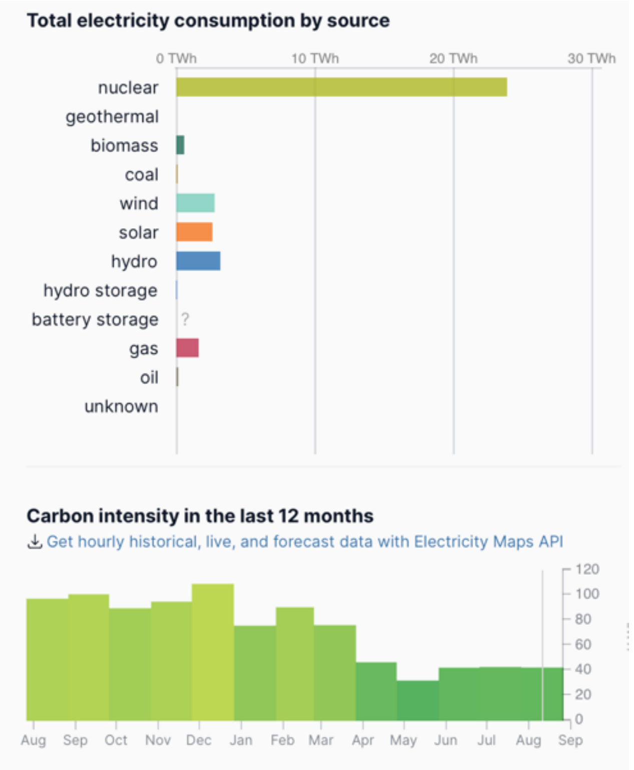
The designs of CLIC, including key performance parameters as accelerating gradients, pulse lengths, bunch-charges and luminosities, have been optimised for cost and power.

Parameter scans to find optimal parameter set, change acc. structure designs and gradients to find an optimum.

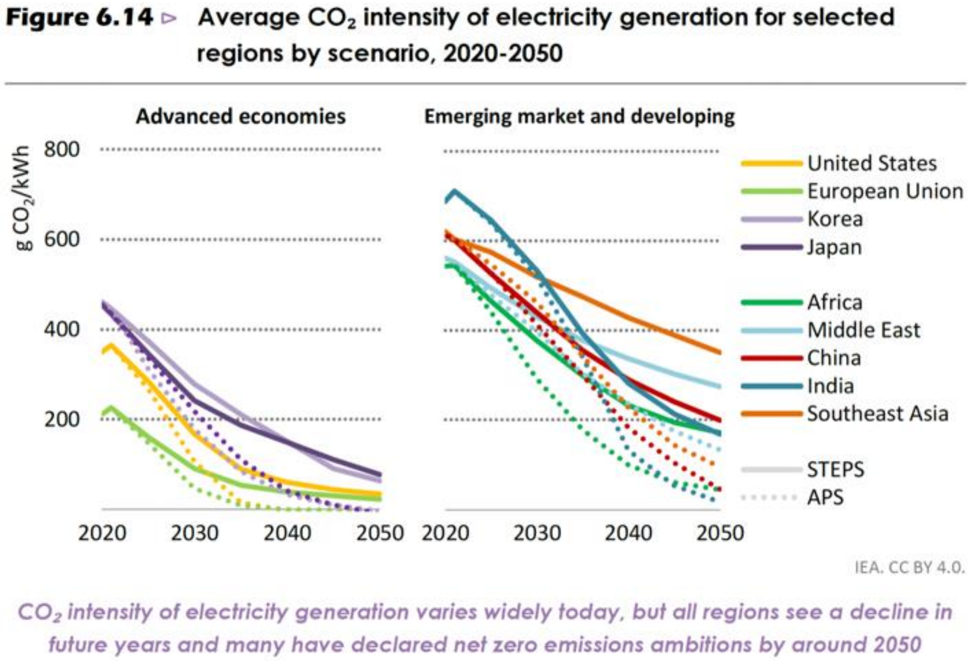




From energy to CO_2 – in 2040-2050



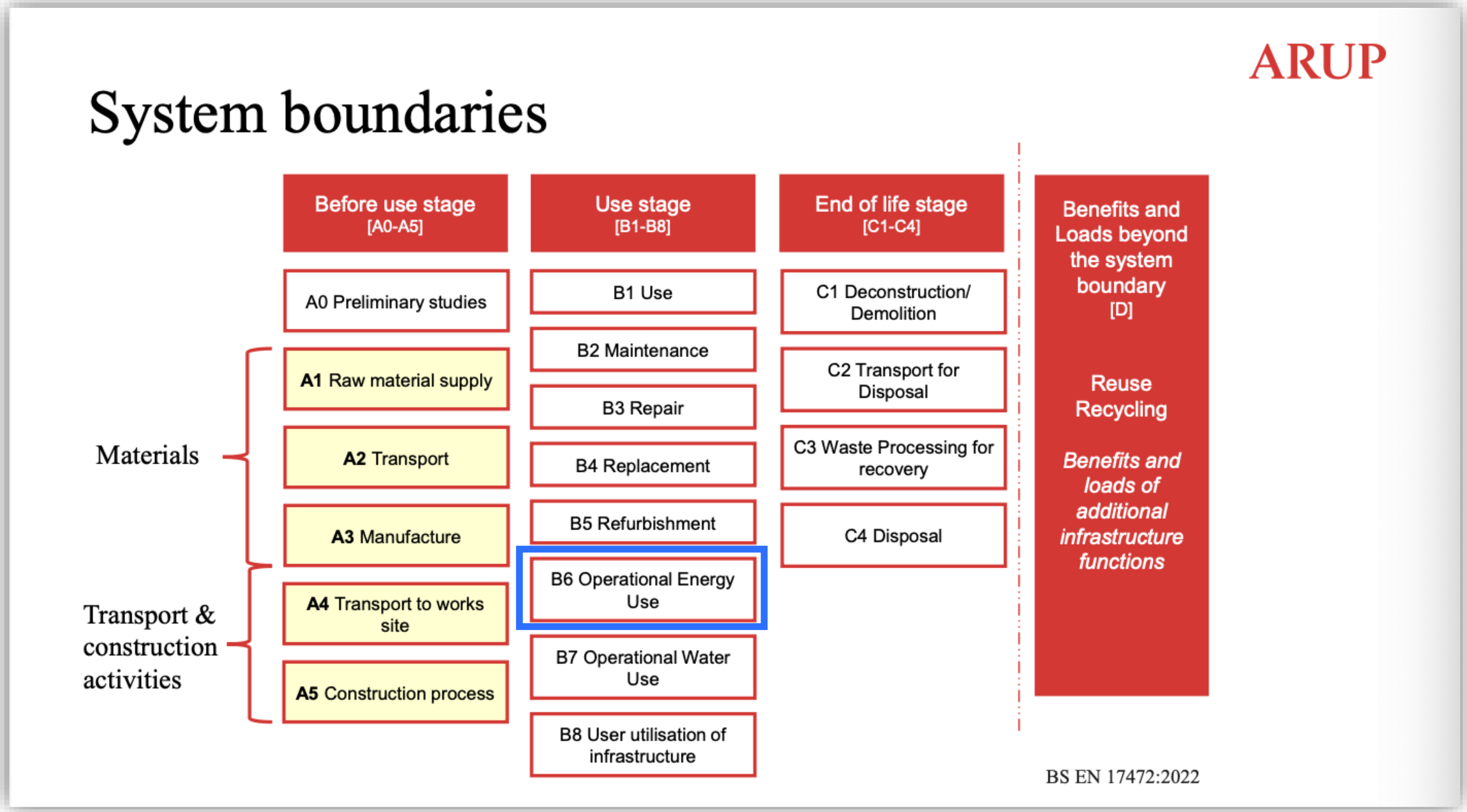
Source: https://app.electricitymaps.com/zone/FR
Contains also g/kWh per source



A rough estimate, assuming ~50% nuclear and ~50% renewables (as wind/sun/hydro): **0.6-0.8 TWh annually equals a bit less than 10 kton CO_2 equiv. annually**

(Note: this is factor ~3 below the current French summer month average)

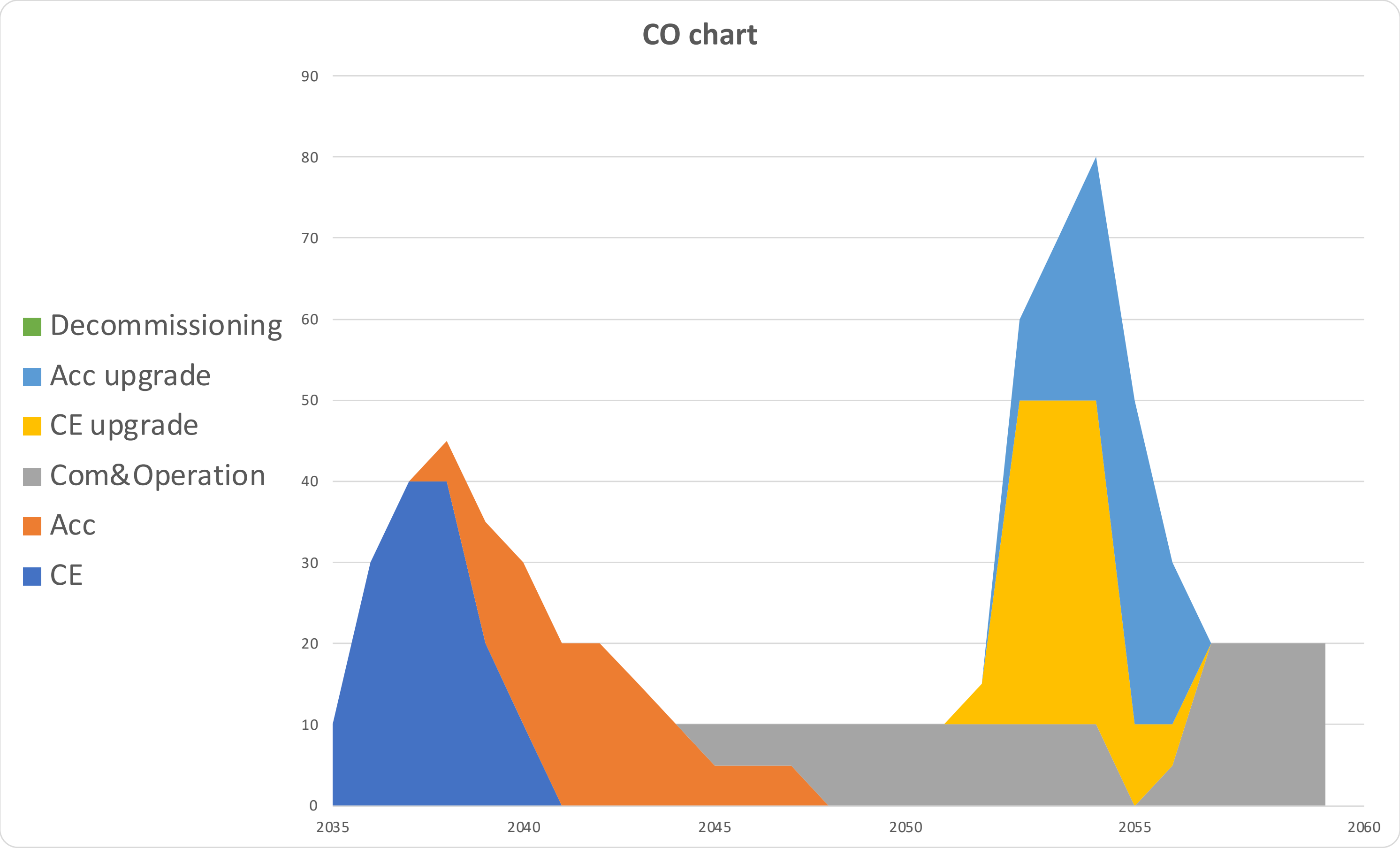
Towards a life cycle assessment



Only B6 discussed in all the slides above, now discuss A1-A5 for the CE

Plus – a LCA is not only about CO_2 of course, the metric is much more sophisticated

Towards Carbon Accounting



Main conclusion is that the initial construction emission is the hardest to reduce

Various comments/conclusions:

- CE: best industry solutions, reduce dimensions when possible
- Acc. components: material choices, responsible purchasing, technical choices in some cases
- Operation: reduce power, use green sources, base on projections for ~2050
- Upgrades: re-use if possible
- Decommission: to be understood

Much more work needed on accelerator components and decommissioning

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