SUSTAINABILITY STUDIES FOR LINEAR COLLIDERS

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Two large electron-positron linear colliders are currently being studied as potential future Higgs-factories, the International Linear Collider (ILC) in Japan, and the Compact Linear Collider (CLIC) at CERN, Switzerland. The former is based on Super-Conducting 1.3 GHz RF technology and will start operation at 250 GeV (with length ~20.5km) centre-of-mass energy and the latter is based on room temperature 12 GHz copper RF structures starting at 380 GeV (~11.5km). The initial luminosities are in both cases estimated to be around $1.5\cdot10^{34}$ $cm^{-2}s^{-1}$, but either facility would be upgradable in energy and luminosity as part of a longer-term electron-positron collider programme. The facilities are extensively documented in (1) and (2).

Linear colliders rely on low emittance high intensity beams created in damping rings and ultimately being focussed to the nano-meter level at the collision point. Although very large facilities, ILC and CLIC have many common features, challenges, and proposed solutions with existing or planned Free Electron Laser Linacs and, for injector and damping rings, the Synchrotron Light Sources worldwide. ILC can be implemented rather quickly starting construction around ~2026, CLIC is an option for a post LHC accelerator at CERN and is being developed with this timescale in mind.

Sustainability has become a prioritized goal in planning and implementation of future large accelerators. Both linear collider projects, collaborating in many areas, have extensively studied novel design and technology solutions to address power efficiency and reduce the environmental impact of the facilities. The sustainability considerations, in addition to the more traditional cost concern and need for developing core technologies, are today the primary R&D drivers for the projects.

Concerning energy consumption, the ILC power consumption has been estimated to 110 MW at 250 GeV and CLIC to 170 MW at 380 GeV. The ILC numbers are optimised while the CLIC numbers might still have a 10-15% potential for improvement. Turning these power numbers into yearly energy consumption gives estimates in the range of 600-800 GWh. As a reference CERN uses around 1.2 TWh of electricity yearly.

To achieve these numbers several dedicated studies have been conducted to control and reduce the power consumption, in parallel with studies considering the environmental impact of the facilities in a wider sense. Many of these studies are widely applicable and generally relevant for future accelerator facilities. Among these are:

— The designs of ILC and CLIC, including key performance parameters as accelerating gradients, pulse lengths, bunch-charges and luminosities, have been optimised for cost but also increasingly focussing on reducing power consumption.

— Technical developments targeting reduced power consumptions at system level, primary examples are developments of high Q and high gradient SC cavities (3), high efficiency klystrons (4), and super conducting and permanents magnets for damping rings and linacs. In many cases these studies are equally applicable and relevant for other accelerator facilities, and cover a wide range of possible installations.

— Local impact studies of establishing ILC as a new laboratory in the Tohoku region in Japan (5). These studies focus on establishing a "thermal eco-community", utilizing excess heat for agriculture and fishery. Other elements are use and production of local materials for construction, also utilizing waste heat, reducing the ecological footprint, use and development of local infrastructure benefitting the entire community, availability of "green" energy and other key resources for establishing a new large laboratory, etc. Implementing CLIC in a tunnel below the existing LHC ring at CERN have similar challenges but can also benefit from the fact that the LHC accelerator was already constructed in this area.

— The possibility of making use of the fact that the linear colliders are single pass, i.e. the beams and hence power are needed "shot by shot", possibly allowing to operate in daily or weekly time-windows when power is available in abundance from suppliers and costs are reduced (2). Seasonal operation is already being used for energy cost reasons.

— Estimating the renewable power that can be made available for running the colliders by investing for example 10% of the overall construction costs in solar and wind energy capabilities, again profiting from the fact that single pass colliders can quickly adapt to changes in energy output from such sources (2).

— Technical solutions for recovering energy losses in all parts of the accelerator, to be reused for acceleration and/or for use in the local area (homes, industry) near the facility.

In many cases the studies mentioned are still on-going and the programme for further work will also be presented. The studies above provide some possible answers that can help to construct sustainable future accelerator facilities, but a full analysis of the start to end environmental impact including carbon footprints will still need to be done for ILC and CLIC.

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