8 Sustainability considerations

8.1 Introduction

Scarcity of resources, along with climate change originating from the excessive exploitation of fossil energy are ever growing concerns for humankind. Particularly, the total electric power consumption of scientific facility operations will become more important as the reliance on fossil fuels is being reduced, carbon-neutral energy sources are still being developed and a larger part of the energy consumption is converted from fossil fuel to electric power.

In our accelerator community we need to give high priority to the realisation of sustainable concepts, particularly when the next generation of large accelerator-based facilities is considered. Indeed, the much-increased performance – higher beam energy and intensity – of proposed new facilities comes together with anticipated increased electric power consumption. In the following we classify the most important development areas for sustainability of accelerator driven research infrastructures in three categories - technologies, concepts and general aspects. We suggest investing R&D efforts in these areas and to assess energy efficiency with an equal level of relevance as the classical performance parameters of the facilities under discussion.

8.2 Energy efficient technologies

Energy efficient technologies have a long history in the accelerator facilities for particle physics since often the required performance could only be reached with highly energy efficient devices such as superconducting magnets and superconducting RF cavities. Below are some items, where R&D could further improve energy efficiency.

Low loss superconducting resonators: Cryogenic losses in superconducting resonators can be significant for linacs, particularly in CW operation. The R&D on high Q superconducting resonators should be continued with high priority. Resonators using Nb3Sn-coating have shown good performance [1] and could be operated at 4.5 K. At this temperature the cryogenic efficiency is much improved, while still reasonable Q values are achieved.

Efficient radio frequency (RF) sources: For many accelerators the main power flow involves converting grid power to RF power. To improve the overall efficiency RF sources must be optimised. Efforts should be invested for efficient klystron concepts (e.g. adiabatic bunching and superconducting coils), magnetrons (mode locking) and solid-state amplifiers [2–4].

Permanent magnets: Permanent magnets don't need electrical power. As a side effect no heat is introduced which has a positive effect on the stability of a magnet lattice. Significant progress has been made with permanent magnets for light sources, and for example tunable quadrupoles for the CLIC linacs [5].

Highly efficient cryogenic systems: Another important development are efficient cryogenic systems (e.g. He/Ne refrigeration), allowing to optimise heat removal in cold systems from synchrotron radiation and other beam induced energy deposition [6].

Superconducting electrical links: Cables using High Temperature Superconductors (HTS) allow to power high-current devices from a distance with no or little losses, thus enabling to install the power converters outside of radiation areas [7].

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Use of heat pumps: Heat recovery in aquifers is often done at low temperatures with limited usefulness. But after boosting the heat to a higher temperature level using heat pumps, this waste heat can be used for residential heating.

8.3 Energy efficient accelerator concepts

Increasing the energy efficiency of accelerator components can significantly reduce energy consumption, but different accelerator concepts, especially with built-in energy recycling, has the potential to drastically reduce the energy consumption without compromising the performance.

Energy Recovery Linacs The Energy Recovery Linac (ERL) concept was first proposed in 1956 and it allows the recirculation of the beam power after the beam is used by decelerating it in the same RF structures. Using this concept for the electron and positron beam a high energy e+e- collider could be built where more luminosity can be achieved with much less beam intensity than using storage rings since the single beam collision can be much more disruptive. The much lower beam intensity then results in much less energy lost to radiated synchrotron power [8]. For a high energy collider the energy savings can amount to over a 100 MW. In view of the significant technical challenges this scheme should be studied and optimised in more detail (see Section 6).

Intensity Frontier Machines For Intensity Frontier Machines the conversion efficiency of primary beam power for example to Muon/Neutrino beam intensity is a critical parameter. With optimised target and capture schemes the primary beam power, and thus the grid power consumption, can be minimised. Similar arguments are valid for accelerator driven neutron sources [4].

Muon Collider For very high parton collision energies the Muon Collider [9] exhibits a favorable scaling of the achievable luminosity per grid power. With constant relative energy spread bunches can be made shorter at higher energies, allowing stronger transverse focusing at the interaction points. Besides other arguments this is an important reason for strengthening R&D efforts on the muon collider concept (see Section 5).

Energy Management: With an increasing fraction of sustainable energy sources like wind and solar power in the future energy mix, the production of energy will fluctuate significantly. One way to mitigate the impact of high energy physic facilities on the public grid is to actively manage their energy consumption using local storage or dynamic operation. Investigation of such concepts should be an integral part of design studies.

Accelerator Driven Systems (ADS) Accelerator driven sub-critical reactors can be used to reduce the storage time of radioactive waste (transmutation) of nuclear power stations by orders of magnitude. Such concepts would address an important sustainability problem of nuclear power. The development of high intensity accelerators for ADS has synergies with applications for particle physics or neutron sources. Another innovative accelerator-based transmutation concept using muons is proposed in Ref. [6].

8.4 General sustainability aspects

A carbon footprint analysis in the design phase of a new facility can help to optimise energy consumption for construction and operation. For cooling purposes accelerator facilities typically have significant water consumption. Cooling systems can be optimised to minimise the impact on the environment. For the construction of a facility environment-friendly materials should be identified and used preferably. The mining of certain materials, in particular rare earths, takes place in some countries under precarious conditions. It is desirable to introduce and comply with certification of the sources of such materials for industrial applications, including the construction of accelerators. A thoughtful life-cycle management of components will minimise waste. Many facilities use helium for cryogenic purposes. Helium is a scarce resource today and with appropriate measures the helium loss in facilities can be minimised.

Many of these issues are discussed at the workshop series on 'Energy for Sustainable Science at Research Infrastructures' [10].

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