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Strive towards sustainability

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Exacerbated by the impacts of climate change and the recent energy crisis, concentrated efforts towards more sustainable research have become matters of urgency, in particular for large-scale accelerator complexes and light sources.

Towards the end of 2022, several large-scale research infrastructures had to cut down operation time due to an increase in the cost of electricity. The Large Hadron Collider's yearly technical stop was moved up by two weeks, and the machine's operation was reduced by 20% for 2023[1]. The Elettra synchrotron in Trieste, Italy, and its free-electron laser FERMI had to halve user beam time in the first semester — a fate shared by many other light sources.

Immediate actions to alleviate the situation are limited, as long-term planning is required for large-scale facilities. Therefore, it's not surprising that sustainability — mainly in terms of reduced power consumption and carbon footprint — was an important topic at this year's International Particle Accelerator Conference.

One point towards making research facilities more sustainable is the move towards greener energy. In this regard, the SESAME light source in Allan, Jordan, is a trailblazer. The facility has its own solar power plant (pictured) and was the world's first large accelerator complex, whose power stems only from renewable energy sources. Others followed suit: the HZB in Berlin, Germany, that operates the BESSY II synchrotron secured their full electricity needs with renewable energy, saving up to 17,400 tonnes of CO_2 per year compared to 2018.

Another issue is increasing the energy efficiency of accelerator complexes. Improvements of the injectors of the Large Hadron Collider have greatly reduced the overall energy consumption; for example, a powering scheme introduced a few years ago reduced the Super Proton Synchrotron's energy consumption by 40 GWh per year. For comparison, the whole canton of Geneva consumes around 3,000 GWh per year. Similarly, by integrating

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the previously separate SPring-8 synchrotron with the SACLA X-ray free-electron laser in Sayo, Japan, the power consumption was reduced by five MW — roughly an electric locomotive's power output. But this is not the end of the road. With future upgrades, these and many other facilities aim to substantially reduce their energy consumption.

Apart from measures directed at improving the sustainability of the research infrastructure, such as water and waste management, a few main themes concerning accelerator technology have emerged. The actual particle acceleration occurs in superconducting radiofrequency cavities. For bulk niobium, this requires operation at 2 K and thus cooling with superfluid helium. Increasing the operation temperature to around 4.5 K would result in substantial energy savings. One direction that's being explored is superconducting thin films on bulk copper for radiofrequency cavities, which also have the potential to achieve higher accelerating gradients and thus to enable more compact machines.

The bending and focusing of the accelerated particle beams relies on different magnets. For the future BESSY III synchrotron, electromagnets are estimated to amount to an annual energy consumption exceeding 5 GWh, which could be reduced by 80% by installing permanent magnets as dipole and quadrupole magnets[2]. But this does not necessarily make them a more sustainable choice. Permanent magnets often involve rare-earth elements; their mining not only has a substantial carbon footprint but also impacts the people living on the land[3].

A clever way to make linear accelerators more sustainable is through energy recovery. The idea is rather simple: instead of dumping two accelerated particle beams after colliding them, why not recover the beam energy? The principle of an energy recovery linear accelerator was first demonstrated in 1987 — enabled by superconducting radiofrequency technology. A recent experiment at the S-DALINAC machine demonstrated saving up to 87% of the consumed beam power in its main linear accelerator[4].

In the design of large-scale facilities, performance is weighted against cost. Factoring in sustainability parameters, such as CO_2 emission from energy use or the embodied CO_2, increases the level of complexity and changes the optimization. For the proposed Compact Linear Collider and the International Linear Collider, a life cycle assessment estimated the environmental footprint. Such assessments provide the accelerator community with guidelines for the planning of more sustainable large-scale projects.

Apart from considering the impacts of accelerators on climate change and making the research infrastructures more sustainable, they can contribute to sustainability as well. For example, pollutants in wastewater can be reduced through irradiation with electron beams. By switching from normal conducting to superconducting radiofrequency technology, electron beam irradiation could become more cost efficient and competitive with other treatment methods[5].

Sustainability is an all-encompassing issue, from research facilities to the code used to analyse data[6]. And it's much broader than considering electrical power consumption and carbon footprints. Striving towards sustainability requires a holistic understanding of the multiple and connected impacts on the environment — including the people that live in it.

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