# Snowmass 2021, Letter of Interest:
# Fostering the development of energy efficient and sustainable technologies and concepts for accelerator driven research infrastructures.

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Scarcity of resources, along with climate change originating from the excessive exploitation of fossil energy are ever growing concerns for humankind. In our accelerator community we should give high priority to the realization 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 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. With this letter of interest, we suggest investing R&D efforts in these areas and to assess energy efficiency with equal level of relevance as the classical performance parameters of the facilities under discussion.

## 1. Energy efficient technologies

**Low loss superconducting resonators**: Cryogenic losses in s.c. resonators can be significant for linacs, particularly in CW operation. The R&D on high Q s.c. resonators should be continued with high priority. Resonators using $Nb_3Sn$-coating have shown good performance [1] and could be operated at 4.5K. At this temperature the cryogenic efficiency is much improved, while still reasonable Q values are achieved.

**Efficient 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 optimized. Efforts should be invested for efficient klystron concepts (e.g. adiabatic bunching and s.c. coils), magnetrons (phase and frequency control) and solid-state amplifiers [2][3][8].

**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 [4].

Another important development are **efficient cryogenic systems** (e.g. He/Ne refrigeration), allowing to optimize heat removal in cold systems from synchrotron radiation (FCC-hh) and other beam induced energy deposition [9].

**Superconducting electrical links** utilizing HTS cables allow to power high-current devices from the distance with no or little losses, thus enabling to install the power converters outside radiation areas [5].

**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.

**Short term energy storage:** In cycling booster accelerators as needed for an e+/e- collider or the muon collider, the energy contained in the fields of the magnets is significant but typically lost over one cycle. With adequate short term storage systems the overall energy loss can be minimized, e.g. [6].

## 2. Energy efficient accelerator concepts

The **Energy Recovery Linac** concept allows recirculation of the beam power after collision, while e+/e- collision parameters significantly better than those of a ring collider are achievable [7]. In view of optimizing beam dynamics, complexity and cost this scheme should be studied and optimized in more detail.

For **Intensity Frontier Machines** the conversion efficiency of primary beam power for example to Muon/Neutrino beam intensity is a critical parameter. With optimized target and capture schemes the primary beam power, and thus the grid power consumption, can be minimized. Similar arguments are valid for accelerator driven neutron sources [8].

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 IP). Besides other arguments this is an important reason for strengthening R&D efforts on the muon collider concept.

**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 HEP facilities on the public grid is to actively manage their energy consumption using local storage or dynamic operation. Investigation of such concepts should be integral part of design studies.

**Accelerator driven subcritical reactors** can be used to reduce the storage time of radioactive waste (transmutation) of nuclear power stations significantly. Such concepts would address an important sustainability problem of nuclear power. The development of suited high intensity accelerators has synergies with applications for particle physics or neutron sources. Another innovative accelerator-based transmutation concept using muons is proposed in [10].

## 3. General sustainability aspects [11]

A **carbon footprint analysis** in the design phase of a new facility can help to optimize energy consumption for construction and operation.

For cooling purposes accelerator facilities typically have significant **water consumption**. Cooling systems can be optimized to minimize the impact on the environment.

For the construction of a facility **environment friendly materials** should be identified and used preferably. A thoughtful **lifecycle management** of components will minimize 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 minimized.

## 4. References and Workshops:


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[3] ARIES Workshop on Energy Efficient RF, Ångström Laboratory (2019), https://indico.uu.se/event/515/

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[7] V.N. Litvinenko, T. Roser, M. Chamizo-Llatas, Physics Letters B 804 (2020) 13594

[8] Workshop on Efficiency of Proton Driver Accelerators, PSI (2016), http://indico.psi.ch/event/Proton.Driver.Efficiency.Workshop

[9] recent papers: https://iopscience.iop.org/journal/1748-0221/page/extraproc46, for a comparison of collider concepts see arXiv:2007.15684

[10] Y. Mori et al, Intense Negative Muon Facility with MERIT ring for Nuclear Transmutation, JPS Conf. Proc., 011063 (2018), https://doi.org/10.7566/JPSCP.21.011063

[11] 5th Workshop Energy for Sustainable Science at Research Infrastructures, PSI (2019), https://indico.psi.ch/event/6754/