Greening for Bosons

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Abstract

Throughout history, scientific advancement has been dependent upon advances in the technologies of research. However, branches of research that today rely on Research Infrastructures (RIs) such as accelerators require technological investments so large that multi-nation collaborations are required to fund them. Modern accelerator science also has massive (and increasing) energy needs, yet the very provision of secure, equitable, clean and cost effective energy is one of the greatest sustainability challenges facing society. Modern energy provision systems are fundamental to development, yet also constitute one of the greatest threats to sustainability via their contribution to environmental degradation and climate change. This paper works from a premise that any new proposal for investment in an RI should credibly demonstrate that it would deliver more value than cost to society. As our understanding of the negative impacts of energy use grows, the demonstration of overall value creation has become more complex; it must now include consideration of an RI's 'energy system footprint'. Programs to reduce the energy footprint can help address this delicate balance. This paper uses experiences in the development of the European Spallation Source (ESS) in Sweden to demonstrate how credible programs to improve the energy performance of an RI can take form.

THE REASON FOR GREENING

Research Infrastructure

We use the term "Research Infrastructure" (RI) to denote scientific facilities of such magnitude that they are comparable to other infrastructure such as airports, bridges or tunnels. Many of these facilities are based on accelerators, but there are also telescopes, supercomputers, reactors, wind tunnels, and more.

The funding of scientific RIs is also an issue that can be compared with that of bridges and airports. Such investments are often necessarily financed by governments, but are motivated by explicit expectations that the benefits they provide to society, both in the medium and long-term, far outweigh their costs. There is thus, a strong social element in the argument for investments in RIs such as particle accelerators. This social argument element includes the societal value of knowledge as a goal in itself.

Costs and Benefits of RIs

Just as each breakthrough in the crafting of lenses has paved the way for new scientific discovery with telescopes and microscopes that can see further, or 'smaller', each generation of accelerator-based RI required for the next level of knowledge needs to be more powerful. While technological improvements help ameliorate the situation, for the most part, each RI generation with increased performance also needs increased energy input – and the overall energy consumption (and operational cost) increases.

In order to attract governments to join the financing of new RIs, scientists and other proponents must successfully argue that benefits continue to (significantly) outweigh the costs. Cost/benefit assessments however, are complex; both the benefits and the costs are likely to contain a large proportion of intangible or contingent items. As positives, these can include the effects of creativity and innovation; as negatives, there may be fear of (potential) accidents, concern about radiation or simply NIMBYism. It can therefore be a difficult task to demonstrate net benefit. It is perilous to disregard stakeholder concerns however. Proponents of scientific infrastructure, often themselves scientists, may tend to undervalue risk vectors that seem irrational, or factually unfounded, such as the concerns of neighbours of the potential dangers of the research to be conducted (e.g. the 'creation of a black hole', the potential of a meltdown, etc.). Even if concerns are unfounded, they can still be real, both in the minds of neighbours, and even in law. In Swedish environmental legislation, as one example, the concerns of neighbours are considered as an 'environmental impact' and must be managed; just as emissions are.

SUSTAINABILITY

Humankind places an increasing burden on the planet. Despite our gains in efficiency, the effects of population growth and economic growth consume increasing amounts of resources [1], [2]. Scarcity of resources leads to price volatility – and to 'security of supply' challenges that are most serious for those most sensitive to price. Food, water and energy can always be produced and distributed to those who can afford them. This is not the central challenge for sustainability. A very important challenge however, is to do so for the world's poor.

Science can substantially contribute to both the knowledge needed to lower the cost of supplying life essentials, and to the growth needed for the poorest to access them. This is an important argument for investment in science. However, it is also important to recognise that an initial investment of resources to create large RIs places additional stress on supply systems. It can contribute to energy poverty by raising prices, and also competes directly for potentially scarce energy with such sectors as food production.

In addition to its highly publicized links to climate change [3], energy also plays important roles in the supply of food. World food production is dependent on energy carriers to produce and distribute chemical fertilizer, and to produce and distribute the food.. Conversely, agriculture can be used to produce useful energy forms, such as biomass and biofuel. In doing so, energy supply competes directly for land with food production.

The concept of Sustainable Development is commonly represented using three pillars: environment, economy and society. These may also be useful to understand and discuss the impact of accelerator projects both inside and outside the facility boundary. Energy is not only an environmental issue; it is most certainly a critical economic issue for the facility, as energy use is a substantial part of operating costs, and price fluctuations pose a serious threat to the planned scope of operations.

The establishment of new research infrastructure can also tangibly affect local resource markets and distribution. On the margin, use of resources for research infrastructure competes with other uses; in some areas (such as rare earths) even globally.

CASE ESS

The European Spallation Source, the world's 'brightest' neutron source is now being built in Lund, Sweden. The first cornerstone is being laid on October 9, 2014. The first neutrons are to be delivered by the end of 2019. Ramp up to full power will then continue to 2025, after which the planned lifetime is 40 years. A 5MW linear accelerator will propel bunches of 10E12 protons into a rotating tungsten target, where neutrons will be spalled from tungsten nuclei, each proton liberating around 30 neutrons [4].

The justification for a new neutron source is that neutrons are especially useful for investigating inside materials in a way that complements more common X-ray methodologies. Neutrons, by virtue of their mass, are especially sensitive to the nuclei of light atoms, such as those of organic compounds found in life sciences, and also in the energy field. Within the field of energy applications, neutrons can facilitate investigation of in many areas. Combustion processes are one example: where engines can be examined while running, and additives tested to improve efficiency. As another example, lithium ion batteries can be examined with both neutrons and X-rays. This gives a more comprehensive understanding of how ion structures change in the batteries. Similarly, neutrons are useful for fuel cell research, to understand the details of how ions interact with membranes; for hydrogen storage in metals; for the study of carbon capture and storage mechanisms; and for material structural investigations needed for photovoltaics development. Extreme materials research is yet another area: extremely heat-resistant materials can be tested for application in more efficient power plants – and neutrons can also be used to investigate the structural integrity of existing power plants. [5]

These are just a few of the possible uses of ESS in the energy arena. There are many more in life sciences, and other important research fields, such as the development of new materials. Viewed from this perspective ESS can be considered to be somewhat of a 'Swiss army knife', with many uses. It is 'workhorse' facility, applicable on technology close to market (even post market). The practical usefulness of ESS combined with its special importance for life science and energy have made it relatively easy to formulate and evaluate the 'sustainable science' case for the facility. "Science for Society" has been used as a motto throughout the history of the project.

Responsible, Renewable, Recyclable

As an energy-intensive facility in an increasingly 'resource constrained world', the ESS is committed to implementing its self-developed energy program "Responsible, Renewable, Recyclable". This requires that the facility must be energy efficient, use only renewable energy sources and will recycle its waste heat. The ESS board of directors has set firm goals for each pillar of the program.

Energy Inventory

Twice per year, ESS performs an Energy inventory to calculate the energy use in the future operations. The inventory serves the dual purposes of assessing performance in relation to baseline goals for consumption, and focusing attention on energy efficiency.

At the launch of the ESS project, there was insufficient data to perform an inventory based on the ESS design. Therefore, the first energy inventories for ESS were performed at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory in the USA, with scaling and adjustment according to known differences. These studies were vital to the early implementation of the ESS energy strategy and are a good example of the power of collaboration between facilities.

The original plans for ESS, based on a 2002 design proposal, called for an annual energy consumption of 610 GWh for a MW accelerator facility [6]. The Scandinavian bid to host ESS was based on a slimmer single-purpose version (long-pulse) and greatly increased use of superconduction; this yielding a much reduced overall demand.

Heat Recovery

To facilitate recovery and reuse of heat ejected in cooling cycles, ESS has signed an agreement with the local district heating provider (Kraftringen) that has three parts. First, ESS will be connected to the district-heating grid, an investment of 5 M€. Second, ESS will sell surplus heat to Kraftringen at a market-based rate, varying over the year. Recycling of the entire surplus heat (using heat pumps) would generate a revenue of 5M€ per year to ESS (but also involves additional power use, and costs for running heat pumps). Third, ESS will purchase heat from the grid for pre-operations and as back-up in the event of failure in internal heat supply.

The technical conditions within the agreement also concretise requirements for a significant design change for an accelerator RI. High-temperature cooling cycles are a pre-requisite, in that the district heating system requires 80°C as a supply temperature to function. This is also linked to important developments on the heat-grid side, as historic temperature requirements have been significantly higher than 80°C, especially in winter. The return temperature, which corresponds to the cooling temperature available for ESS, is around 50°C. With this design configuration, any equipment or system that generates less than 80°C, or must be cooled to below 50°C, necessitates the use of heat pumps. The greater the temperature gap, the greater is the electricity demand for the heat pumps. However, while heat pumping to facilitate recycling of low-grade heat (down to 10°C) for delivery to 80° district heating is technically feasible, under many conditions it may be economically and environmentally questionable. Therefore alternative technical pathways are worthy of examination.

In this light, heat at 40°C and below can be used in other areas such as space heating, for greenhouses, drying of biofuels, and for heating of bio-digesters or aquaculture ponds. For the ESS, a ‘hybrid-cooling regime’ supporting a food production cooling chain has been proposed. It encompasses greenhouses, fish farming and fish fodder production with yeast. A guiding principle for this is to put together a cooling chain of declining temperatures so that the heat is used efficiently. An important point is that these processes also form a nutrient loop. Hydroponic greenhouse farming can use the fish excrements as fertilizer, eliminating a major energy consumer in agricultural processes. Fish can be fed with fodder made from yeast, which can be produced on a substrate of organic waste. Thus waste heat combines with organic waste to produce new, high quality, locally produced food. A schematic of the envisioned cooling and nutrient chains is shown in Figure 1.

For ESS, the result would be similar revenue to a solution where the facility upgrades waste heat to 80°C with heat pumps, however, it involves lower costs, lower energy use and a suite of ancillary socio-economic benefits. Among other things, this system can deliver increased food security and quality, improved land and marine environment, and local economic activity.

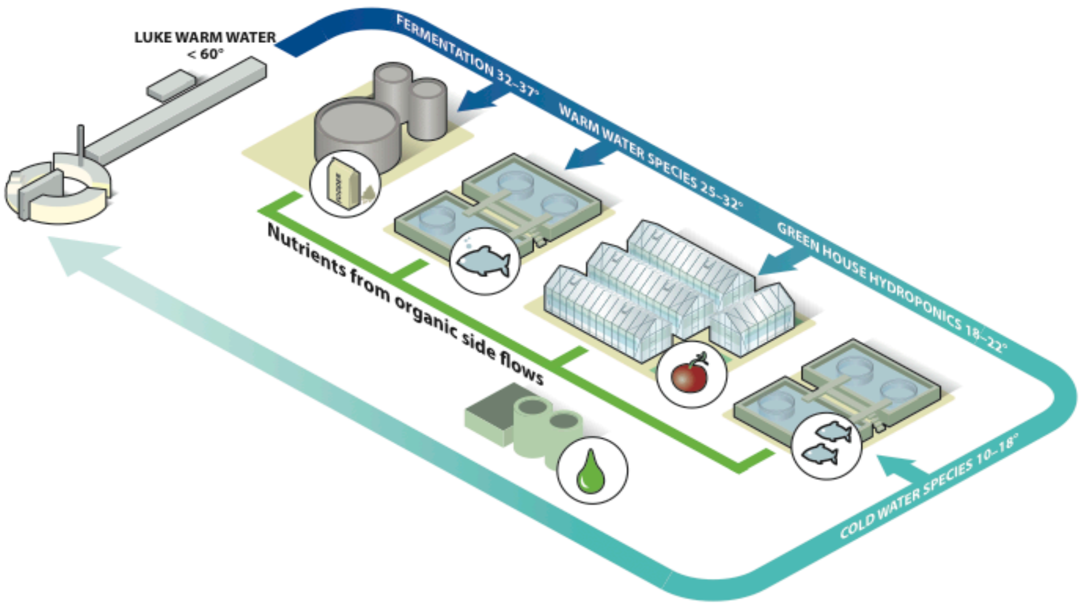

Figure 1: A ’hybrid cooling regime’ proposed for ESS. A cooling chain of declining temperatures is paired with a nutrient loop from agricultural and food waste

Remarkable and Replicable

The ‘Responsible, Renewable and Recyclable’ strategy was born out of the competition to host ESS. In order to work as a unique selling point, it was necessary to adopt a strategy that would be perceived as well beyond current best practice. In the spirit of the RRR-slogan, the solution also needed to be 'Remarkable'.

However, it must be recognized that the 'Renewable' and 'Recyclable' parts of the ESS energy strategy build on local opportunities that may not be available elsewhere. The ESS site happens to also host a wind turbine already – and even more importantly, the structure of the energy market is such that power can be traded, throughout the Nordic grid, with limited transaction costs. This helps by broadening siting options for renewable energy from the immediate surrounds, to the entire grid region. For 'Recyclable', a vital enabling factor is the existence of district heating system that already delivers a TWh/yr of heat to Lund and neighbouring areas. More broadly, ESS benefits from an environment where there is a significant demand for space heating due to a cool-temperate climate with average mid-winter daytime temperatures at approximately 0°C.

Although ESS benefits from some opportunities that are unusual in the accelerator community, there is nothing in these boundary conditions that is not equally applicable for many types of energy intensive industry in the region, of which there are a number. The ESS solutions can readily be applied in industry, i.e. the strategy is also 'Replicable'. This is an important societal benefit, delivering a significant leverage to society's investment in this RI.

The strategy as originally formulated reflected emerging social expectations for energy, that at the time were perceived as the main sustainability issue for the facility. However, as the implementation of the strategy has evolved, other sustainability issues, such as food, water, land-use and transportation have gained greater recognition, and are now explicitly included in discussions and in concrete planning.

The sustainability challenges facing ESS reflect a growing global imperative that we adjust consumption and production systems to align with a carbon and resource constrained future. These are issues that are being experienced, and increasingly addressed, by businesses worldwide [7].

COLLABORATION

Reflecting the broader applicability of a 'Responsible' energy culture throughout the RI field, the ESS, CERN and ERF (the European Association of National Research Facilities) together hosted an *Energy for Sustainable Science* workshop in Lund in October 2011. All the national laboratories of Europe, along with a number of international labs attended. The event became somewhat of a 'kick-off' for a movement focused on energy issues at large-scale research laboratories – now often referred to as 'The Grand Energy Challenge'. The ensuing network has already spawned a number of collaborative and individual efforts, many of which were presented at the second workshop, held at CERN in October 2013. The motivation underlying such activities is captured in the content of the executive summary of the 2011 gathering, where the organizing committee discusses the "*Energy Grand Challenge"* and strongly argues for an RI role in process of meeting this sustainability challenge. There were several points to this argument. A first was that RIs can be a focal point for innovation; they can both deliver groundbreaking research and provide a nurturing innovative environment. A second is that RIs, although industrial in scale, differ from industry in that they share and disseminate results, scientific advances and technological improvements, thus leveraging improvements for society. The combination of industrial scale, free(er) information dissemination and international networking also make RIs an excellent training ground for young researchers and engineers for future opportunities in industry. As a third point, RIs are often required to innovate in order to deliver the science expected of them; as such, they are natural test beds for innovative schemes of energy management [8].

Another on going European collaboration, conceived in parallel with the abovementioned workshops, is the energy efficiency work package in the EU accelerator development project 'EuCARD2'. This collaboration encompasses energy recovery, accelerator efficiency and other issues. It is especially significant because energy issues are discussed in the context of the pinnacle of accelerator development [9].

CONCLUSION

At the ESS, an energy program within this RI is now seen as a fundamental item – an 'expectation' rather than a option. Importantly, there is also evidence that this 'expectation', or 'norm' is spreading in the RI community. While we would argue that the ESS "Responsible, Renewable, Recyclable" concept is neither perfect nor universal, it provides a benchmark for future development – and is certainly useful to showcase how an energy culture both complements the traditional expectations of an RI, and prepares it for escalating stakeholder expectations in areas such as resource efficiency, and for more volatile resource markets.

As the total efficiency of accelerator systems is generally unimpressive, energy efficiency must be the primary objective of such work – and the earlier efficiency efforts are made, the greater their potential benefit. While it will likely be possible to make incremental improvements all through an RI life cycle, major improvements can usually only be made before the facility is built – utilizing the combined strength of design flexibility and buying power to define better systemic performance from the outset.

This sentence helps define our first rule of heat recycling at ESS – don't! Use efficiency efforts to avoid energy consumption and the ensuing heat creation. Then, where waste heat cannot be avoided seek to 'reuse' heat. Where options exist, deliver immediately 're-usable' heat streams – for example via high temperature cooling in a facility. As a third step examine options for the use of low-grade heat.

As the driving forces underlying a mandate for energy efficiency, low carbon energy systems, and energy price stability for RIs continue to escalate; a foundation for action now exists in the international RI community. Continued and intensified interactions between RI laboratories and projects, both in dedicated fora like the "Energy for Sustainable Science" workshop series, and in conjunction with other interactions such as this "*The 55th ICFA Advanced Beam Dynamics Workshop on High Luminosity Circular e+e- Colliders – Higgs Factory*". conference are important to continue such work. As immediate actions, it will be useful to develop clear performance indicators (and benchmarks) for parameters such as *energy delivered/energy used* to map and track progress in accelerator utilization or design, or both. Further, worldwide collaboration on accelerator efficiency can increase leverage for actors such as designers, suppliers, constructors and managers to deliver technical solutions to meet our *Grand Energy Challenge.*

Showcasing of successful projects in laboratories across the world will be an important part of helping the Science community to both understand and rise to meet such challenges.[10]

REFERENCES

[1] P. Gerland, A. E. Raftery, H. Ševčíková, N. Li, D. Gu, T. Spoorenberg, L. Alkema, B. K. Fosdick, J. Chunn, N. Lalic, G. Bay, T. Buettner, G. K. Heilig, and J. Wilmoth, "World population stabilization unlikely this century," *Science*, Sep. 2014.

[2] IPCC, "Summary for Policymakers," in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White, Eds. Cambridge, United Kingdom, and New York, NY, USA: Cambridge University Press, 2014, pp. 1–32.

[3] S. Chu and A. Majumdar, "Opportunities and challenges for a sustainable energy future," *Nature*, vol. 488, no. 7411, pp. 294–303, Aug. 2012.

[4] Steve Peggs, Ed., *ESS Technical Design Report*. European Spallation Source, 2013.

[5] *Neutrons for Global Energy Solutions 2010 Book of Abstracts*. Forschungszentrum Jülich GmbH, 2010.

[6] G. S. Bauer, F. H. Bohn, K. Bongardt, F. Carsughi, A. Claver, K. N. Clausen, I. S. K. Gardner, C. Hake, H. Tietze-Jaensch, and H. Ullmaier, Eds., *The ESS Project Volume III Technical Report*. ESS Council.

[7] WBCSD, "WATER, FOOD AND ENERGY NEXUS CHALLENGES," World Business Council for Sustainable Development, Paris, 2014.

[8] F. Bordry, T. Parker, and C. Rizzuto, "Main findings of the first joint workshop on Energy management for large-scale research infrastructures," presented at the Energy for Sustainable Science workshop, Lund, Sweden, 2011.

[9] J. Stadlmann, R. Gehring, E. Jensen, T. Parker, and P. Seidel, "Energy efficiency of particle accelerators - A networking effort within the EuCard2 program," presented at the 5th International Particle Accelerator Conference, Dresden, Germany, 2014, pp. 4016–4018.

[10] T. Parker, "Sustainable energy: Cutting science's electricity bill," *Nature*, vol. 480, no. 7377, p. 315, Dec. 2011.