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Contact : RIKEN SPring-8 Center

Addr.: 1-1-1 Kouto, Sayo-cho, Sayo-gun, Hyogo 679-5148 JAPAN
Tel : +81-(0) 791-58-2800
https://www.riken.jp/en/research/labs/rsc

The perspective of Future Circular Collider (FCC) Project - from the view of technological innovation -

IN BRIEF.
Accelerator science and technology have continually contributed to making human society more convenient and prosperous through technological innovation. By highlighting the technological innovations expected throughout the Future Circular Collider (FCC) project, we recognize the project's value as a catalyst for innovation.
Technological innovations are essential to the success of the FCC project, particularly with regard to the performance of superconducting technologies, including high-temperature superconductors (HTSs). Such breakthroughs have the potential to pave the way for unexpected "green innovations." This mirrors how recent high-performance HTS magnets have paved the way for compact tokamak fusion reactors, which promise future zero-carbon dioxide (CO_2) green power generation technologies.
Looking back at the history of accelerator science and technology reveals that the more ambitious and challenging the goals, the more likely innovative technologies are to emerge and overcome them. As mentioned earlier, the ambitious FCC project is expected to not only drive foreseeable advances in superconducting technology, but also develop new technologies that will significantly contribute to building a circular economy.

High-Energy Physics Experiments Drove Accelerator Science and Technology

The history of particle accelerators began in the 1930s with the invention of the Cockcroft-Walton accelerator, which used high-voltage direct current. Around the same time, the cyclotron was invented. It used radiofrequency electric fields and a constant magnetic field to accelerate particles repeatedly in a spiral path. The goal was to conduct nuclear spallation experiments using particles with even higher energies, which at the time were performed using alpha particles from naturally occurring radioactive nuclei.
From the 1950s to 1970s, high-performance synchrotrons were developed that could overcome the effects of special relativity to accelerate particles to higher energies. This breakthrough made it possible to accelerate protons and electrons to high energy levels, leading to the successive discovery of new particles and laying the foundations for the "Standard Model" describing elementary particles and their interactions.
Since the 1970s, the advent of colliders, which can achieve much higher collision energies than fixed-target experiments, has opened up new frontiers in high-energy physics.
The intellectual curiosity to more precisely understand the nature of the matter making up our world has driven the continuous evolution of accelerator systems aimed at increasing collision energies in experiments.

Numerous Technological Innovations Brought by Human Intellectual Curiosity

The following four examples introduce innovations that may emerge as high-energy physics overcomes various challenges and pushes the boundaries of the energy frontier. The crucial point is that a strong desire for advanced technology is the driving force behind innovation.

- Synchrotron radiation (SR) sources exploiting new frontier of science and driving industrial innovation:

Synchrotron radiation (SR) is light, such as X-rays, generated when the trajectory of accelerated charged particles is deflected by a magnetic field. SR was first discovered in a ring accelerator. SR sources are widely used in material, medical, and biological sciences as well as in industrial applications, attracting attention as a means of green innovation to achieve sustainable development goals.
For an easy-to-understand example, consider how synchrotron radiation contributed to Professor Kitagawa's research. Susumu Kitagawa, along with Richard Robson and Omar M. Yaghi, was awarded the Nobel Prize in Chemistry 2025 for discovering and applying Metal-Organic Frameworks (MOFs). MOFs are porous, three-dimensional metal-organic structures with customizable functions. These functional compounds are capable of storing liquids and gases as guest molecules. In the future, they are expected to be used as high-density storage systems, particularly for carbon dioxide (CO_2) and hydrogen. To achieve this, Professor Kitagawa devised the concept of "soft porous crystals" which can switch between adsorption and desorption by external stimuli.
Using the SPring-8, a third-generation SR source in Japan, he visualized how gas molecules are adsorbed within MOFs, quantified their properties, and used this information to enhance the MOFs' performance. Initially, no one knew how the gas molecules were arranged within the MOFs. Analysis of powder X-ray diffraction data obtained using SPring-8's high-brightness X-rays revealed the answer.

- Superconducting magnet technology supporting a wide range of social needs:

Superconductivity is a pivotal technological innovation that emerged from the quest to increase the energy of colliding particle beams. Practical superconducting magnet technology, which uses liquid helium to generate ultra-strong magnetic fields, is used in many aspects of our daily lives. One prominent example is the medical field, where superconducting magnets are a core component of magnetic resonance imaging (MRI) scans, which are now indispensable for public health. Additionally, this technology is essential for particle beam therapy facilities, which are crucial for cancer treatment, and for medical isotope production, because it enables these facilities to maintain a compact footprint.
The European Organization for Nuclear Research (CERN) plans to implement advanced, loss-free high-current electrical connections using MgB_2, which operates at liquid hydrogen temperatures (~20 K), for the High-Luminosity Large Hadron Collider project. The use of high-temperature superconductors (HTS) for manufacturing electromagnets in the Future Circular Collider (FCC) project is also being considered. The high magnetic fields enabled by HTS technology reduce the size and cost of devices and further performance improvements

are expected to contribute to a more convenient life in the future.

- World Wide Web (WWW), which contributed the Internet spread over the society:

The World Wide Web (WWW), software that allows users to share information on local servers via the internet, was invented in 1989 by Dr. Timothy John Berners-Lee while he was working at CERN. By the end of 1990, he and his colleagues had developed the necessary tools and published the world's first website from CERN. In April 1993, WWW-related technologies were released to the public as free software. This invention contributed to the rapid spread of the internet and formed the basis of today's internet-based society.
CERN developed the WWW because a system was needed to allow researchers around the world to easily share and access vast and complex experimental data and literature, regardless of the type or location of the computer, so they could collaborate and advance the scientific project efficiently. This made it possible to collectively identify related documents and information via hyperlinks and share information located on servers around the world via the Internet. This technology contributed to the Internet's widespread use in people's daily lives, dramatically improving convenience.

- Particle acceleration technology contributing to Industry applications:

High-efficiency particle acceleration technology is widely used throughout society. It is used in the medical field for cancer treatments, as well as for producing radioisotopes. It is also used for non-destructive testing of infrastructure, modifying materials, and evaluating them. Novel accelerator-based light sources are being developed for next-generation semiconductor manufacturing. The development of compact accelerators that can serve as X-ray or neutron sources is advancing rapidly. This development is driven by the critical global need to address the aging of public transportation infrastructure, such as bridges and roads. These accelerators are used to assess the internal deterioration of concrete and the structural integrity of large-scale infrastructure, enabling the formulation of appropriate mitigation measures.

What We Expect from the FCC Project

The first expectation is the academic dimension, in which researchers from around the world collaborate to advance the pursuit of universal knowledge. We anticipate that the project will yield the intended physics outcomes. This success will build upon the know-how, technology, and experience accumulated at CERN.
The second expectation is the role that international collaboration plays in fostering mutual understanding among researchers through discussion. This serves as a deterrent against futile conflicts. In today's world, plagued by ceaseless conflict, CERN's principle of "Science for Peace" is exactly what is needed. We hope the FCC project will serve as a bridge of peace, connecting nations through the pursuit of knowledge.
The third expectation is the technological innovations that will emerge during the process of striving to achieve this challenging goal. We also look forward to the impact of FCC construction on accelerating the development of practical technologies that reduce carbon footprints. For example, commercializing construction materials with low carbon footprints such as "green concrete", could yield significant benefits for society. Similarly, the FCC project involves large-scale underground tunnels, so the disposal of excavated soil is likely to become an environmental issue. It is hoped that the project will proactively consider environmentally conscious approaches to excavated soil transformation and recycling.

Conclusion

The most significant point to highlight is that the goals of the FCC project are rooted in a shared intellectual quest common to all of humanity: to understand the fundamental nature of matter and, by extension, the universe itself including dark matter. These objectives transcend national borders, attracting researchers from around the globe and fostering large-scale international collaboration. Deepening mutual understanding through this kind of cooperation is a vital step toward peace. Furthermore, history has shown that when talent and passion unite behind a common purpose to pursue challenging intellectual endeavors, numerous obstacles are overcome and groundbreaking technological innovations are achieved. Given that the FCC project is a continuation of this high level of intellectual activity, we can confidently anticipate further revolutionary innovations.
The FCC project is expected to consume roughly the same amount of electricity as the current Large Hadron Collider (LHC), or between 1.1 and 1.8 terawatt-hours (TWh) per year. The

French electricity grid, which is already ~98% carbon-free, will supply this power. Therefore, proceeding with the FCC project will not result in a significant increase in greenhouse gas emissions.