ACCELERATOR R&D: RESEARCH FOR SCIENCE – SCIENCE FOR SOCIETY*

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Abstract

In September 2011 the US Senate Appropriations Committee requested a ten-year strategic plan from the Department of Energy (DOE) that would describe how accelerator R&D today could advance applications directly relevant to society. Based on the 2009 workshop "Accelerators for America's Future," (AfAF) [1] an assessment was made on how accelerator technology developed by the nation's laboratories and universities could directly translate into a competitive strength for industrial partners and a variety of government agencies in the research, defence and national security sectors. The Office of High Energy Physics (OHEP), traditionally the steward for advanced accelerator R&D within DOE, commissioned a task force under its auspices to generate and compile ideas on how best to implement strategies that would help fulfil the needs of industry and other agencies, while maintaining focus on its core mission of fundamental science investigation.

INTRODUCTION

Accelerator science and technology, along with their associated R&D programs, have a major impact on many fields in our society. The largest and most obvious is discovery science, where accelerators are used as tools and are sometimes the only option to provide the answers sought. It is natural then that the stewards of discovery science in the US—the Department of Energy Office of Science and the National Science Foundation—are major users and drivers of innovation in accelerator science and technology.

The reach of accelerators, though, extends beyond the purview of discovery science and today spans almost all aspects of our lives. Still, their impact is not readily recognized. Accelerator applications, with their potential for continued innovation, can help drive US economic competitiveness both here and abroad. Such applications were clearly identified in the 2009 AfAF workshop (organized by the DOE (OHEP), the acknowledged steward of long-term generic accelerator R&D. As part of the recommendations resulting from this workshop, accelerator applications in energy and the environment, medicine, industry, defence and security, and discovery science were identified by the fields' experts and customers as the most promising areas. A number of accelerator R&D pursuit areas that would help the US to maintain its competitive edge were singled out to help develop a coherent program.

In September 2011, in recognition of these opportunities, the Senate Appropriations Committee requested that the DOE develop a 10-year strategic plan "…for accelerator technology research and development to advance accelerator applications in energy and the environment, medicine, industry, national security, and discovery science" for accelerator stewardship by June 2012. OHEP then established the current task force, made up of representatives from the national laboratories, universities and industry, to provide input for that plan. The report [2] was published in May 2012 and the charge is in Appendix 2.

Now the accelerator community needs to address these R&D areas, feed the results back, and at the same time keep an eye on what comes next. We also need to keep current on who the customers of these technologies are and what they want and need. Publicly funded research, such as accelerator research at national laboratories, has the potential to contribute to the creation of new businesses and jobs and strengthen our economy. As of today the direct turnover in the US alone exceeds $5.5Billion, while the indirect economic impact through cargo scanning, irradiation of food, medical applications etc exceeds this number by many orders of magnitude.

In order to foster the advancement of the application of accelerator technology for issues of national importance, it is essential that new relationships be formed and nurtured between those who are empowered to develop this technology, and those who are the ultimate beneficiaries of this technology. A more "customer-focused" approach will help to ensure that the research and development program takes deliberate steps to meet user demands, rather than relying on chance or serendipity. To that end, one of the most important suggestions resulting from the work of this task force is the establishment of a steering group made up of senior leadership of the various stakeholders, supported by periodic, dedicated workshops. For example, such a meeting could involve both intra-agency and interagency program managers along with industry representatives and technical advisors in the area of accelerators and their applications.

With input from those who develop or utilize accelerators in industry and other government agencies, the task force identified a number of administrative impediments where removal would facilitate a

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stewardship program. They include the lack of easy access to existing DOE facilities and expertise, issues associated with protecting and/or sharing intellectual property, lack of infrastructure development, the insufficient availability of professional services, and lengthy processing and approval times for establishing contractual or other agreements, which must be completed prior to the initiation of work.

The DOE Office of Science and other funding agencies have an extensive variety of infrastructure that, if needed, could be made available to those who, at present, have no chance to use it or aren't aware of these resources and capabilities. Much of this infrastructure can be easily modified to accommodate the needs of industry or other agencies. To leverage its use, we can define the specific needs of all stakeholders and jointly define any required additions. In the case where demonstrations are needed, they can be based on existing expertise and facilities within individual national laboratories.

Many of the opportunities for advancing the application of accelerator technology outlined in the Accelerators for America's Future report are interdisciplinary in nature; progress requires bringing together the required expertise in accelerator technology with the expertise in the end-use of that technology. For example, progress in medical accelerator applications requires teams of accelerator technologists and medical professionals working closely together. Realizing the opportunities outlined in the AfAF Workshop report could be achieved in a competitive manner by creating Collaborative Accelerator Research Teams (CARTs). These teams would be focused on specific issues and challenges within the areas of energy and environment, medicine, industry, defence and security, and discovery science. CARTs can easily grow from the individual strengths of each national laboratory, yet integrate the strengths of other laboratories, other agencies, universities and industrial partners to best meet the technical challenges. Thus, CARTs would have a clear mission, and a limited duration, and their funding could be competitively bid through a peer-reviewed process. In addition, a road for development of the major application programs can be opened via government initiative, as is being established in some foreign countries, strongly integrating certain industries that express interest.

Finally, the task force has recognized with great satisfaction that many necessary programs identified in the AfAF) workshop already exist. Establishing a new program in HEP as an umbrella under which all of these efforts could be gathered is an appropriate step in realizing the workshop's output and has been one of the main considerations of this task force report.

BUILDING ON A STRONG FOUNDATION

The DOE Office of Science (SC) is the steward of ten national laboratories and operates or supports eight large accelerator installations across the country. Over the last five decades it has continually constructed new, cutting-edge accelerator facilities and further developed existing ones in support of specific scientific missions. Today, the Office of Science operates a suite of accelerator-based user facilities that is the envy of the world. That success would not have been possible without the investment made over many decades in both near-term, targeted, and longer-term, generic accelerator technology development.

The Office of Science's (SC) Office of High Energy Physics (HEP) maps out specific goals for advanced generic accelerator science, providing resources to the Office's accelerator research programs to improve the very technology that gives rise to science discoveries a decade or more into the future. Program stewardship and technology development are not limited, however, to HEP. These have a much broader base in the SC directorates, including Nuclear Physics (NP), Basic Energy Sciences (BES), Fusion Energy Sciences (FES) and Advanced Computing (ASCR), to name the offices most involved. Equally important, the National Science Foundation (NSF) and its university programs are major contributors, as are the laboratories working under the stewardship of the National Nuclear Security Administration (NNSA) and other defence departments.

THE SEVEN GRAND CHALLENGES

The core of the Office of Science's mission is science investigation. In order to address the "R&D Needs" of partners whose work lays outside this science mission, such as industrial companies or other government agencies, a healthy relationship between the goal to deliver science and the need to solve particular technology challenges must be cultivated.

Because of accelerator science's positive impact on other fields, one of its broad goals is developing the technology of beams to deliver transformational capabilities to meet the needs of medicine, energy, the environment, defence and security, industry and discovery science in the 21st century. We have summarized the long-term development of the field of accelerator science along seven Grand Challenges:

1. High Energy: Extend the energy reach of collider technology to probe fundamental phenomena at the multi-TeV scale
2. Beam Power: Extend the beam power and intensity reach of hadron accelerator technology to enable next-generation capabilities in fundamental physical sciences and applications in energy
3. High Gradient: Extend the capability and understanding of performance limits of radio-frequency accelerating structures and technology
4. New Acceleration Methods: Break the "radio-frequency barrier" by developing scalable next-generation acceleration methods in the 10 GeV/meter range
5. Beam Emittance: Develop tools and technologies for the manipulation of particle beam phase-space and the exploration of limitations to beam emittance

6. Brightness & Coherence: Develop concepts and technologies to extend the brightness, brilliance and coherence of photon sources to meet the challenges of 21st century materials science
7. Compact Accelerators: Develop accelerator systems to serve as compact sources of photons, neutrons, protons and ions

HEP's Advanced Accelerator R&D program (including both national laboratories and universities) addresses each of the above challenges funded through programs called "DOE R&D Program Thrust" in Fig. 1. Together with contributions from the other Offices (NP, BES, FES, ASCR), the NSF and the laboratories operated by the NNSA, the skills and resources exist to meet these Seven Grand Challenges.

The contributions of NSF, for example, connect to the challenges not only by R&D but also by promoting accelerator education, in particular when students work on operating accelerators. In a similar way, programs operated under NNSA bring accelerator development to bear on the needs of defence.

Amongst all the sponsors of the field, OHEP retains a special role in stewarding the long-range R&D for accelerators and beams. Indeed, OHEP manages by far the largest accelerator R&D portfolio, with a total yearly investment of approximately $160 million in FY11.

Connecting the Dots: Technology Developments Leading to Products

Through the development of the technologies under the DOE R&D Program Thrust areas, the DOE, NSF, NNSA and universities as well as agencies are currently addressing many of the R&D needs.

Yet at times these agencies' work to address these R&D needs goes unacknowledged because they are not a stated goal of the HEP accelerator program. The area of reliability in accelerators is a good example. When designing high-power proton accelerators for spallation neutron sources or neutrino beams, accelerator builders must obviously design and build highly reliable systems. The components developed as highly reliable subsystems become a by-product. Reliability, then, though often at the core of technology development, is thus a product of the R&D, not a program in itself. Many other examples could be mentioned. It is of concern that many of the R&D needs mentioned in [1] are either inconsistently or not explicitly outlined in the nation's accelerator program as technological goals. They become less emphasized, and researchers could eventually lose sight of them.

The unfortunate consequence is that our clients' R&D needs often go unidentified, leaving unanswered the question of how to close the gap between science "push" and application "pull". Delivering technology to those clients can become erratic and undirected.

Just as it is useful to outline the relationship between the Office of Science's science mission and accelerator R&D, it is also helpful to spell out how accelerator R&D benefits industry, medicine, energy, the environment and defence and security, That is, to show how accelerator R&D addresses needs beyond those of SC (see Fig. 1). A program that addresses these needs would not have to start from ground zero—there is a well-established foundation already. Indeed, accelerator science has a well-documented history of producing numerous technology spin-offs described for example in [2].

An optimized program would ensure that the application "pull" is fed back to the science "push" so that the application needs can be met in a more deliberate way. This circular flow would signify that our partners have a means for feeding back into both the science goals and the program thrusts. Such an arrangement would allow researchers to cater to their specific R&D needs, providing directed R&D to drive the development of accelerator technology to specific ends.

By building out the various thrust areas or providing an effective mechanism for feedback, we can facilitate and establish a productive and useful cycle of accelerator R&D, closing the circle.

Science Goal "Push"								Application "Pull"				
High Energy	Beam Power	Beam Emittance	High Gradient	New Methods	Brightness & Coherence	Compact Accelerators	DOE R&D Program Thrust	Industry	Medicine	Energy and Environment	Defense and Security	Discovery Science
●	●		●			●	Superconducting RF	●		●	●	●
●	●	●		●	●		Accelerator, Beam, Computation			●	●	●
	●	●			●		Particle Sources	●		●	●	●
●	●		●				RF Sources	●		●	●	●
	●	●			●		Beam Inst. & Controls		●		●	●
			●			●	NC High-gradient Acc. Structures	●			●	●
●				●		●	New Accelerator		●		●	●
●		●				●	Superconducting Magnets	●	●			●

Figure 1: This table shows how broad applications (right) benefit from advancements toward accelerator science's primary R&D goals, the Seven Grand Challenges (left). The DOE programmatic thrust areas, listed in the middle column, are the means by which progress in accelerator science can be delivered (and is today funded) to fields outside discovery science.

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IMMEDIATE ACTIONS ON THE ROUTE TO SUCCESS

The Accelerators for America's Future workshop identified a large number of opportunities that span the fields of energy and environment, medicine, industry, defence and security and discovery science. In addition, it identified specific R&D needs—from reliability to particle sources—that would have to be addressed to give a competitive edge to many of these applications. This chapter lists the major ideas to which a follow-up program could be directed and outlines areas where it would make sense for stakeholders to collaborate more effectively.

Encourage stakeholder engagement

OHEP, being the historical steward of long-term accelerator and accelerator-related research and development, could consider leading an accelerator working group, an oversight panel, a steering group or a Board of Stakeholders. This would involve intra-agency and interagency program managers as well as industry representatives and technical advisors in the area of accelerators

Such a stakeholder panel would change the dynamics within the DOE R&D program because it would provide a venue in which the long-term R&D programs are steered with a "customer-focused" approach guided by the question: "What do the users of accelerators and accelerator R&D outside of discovery science need in order to be successful in their areas?" This new group would not control monetary portfolios but would advise HEP and other participating agencies on 1) avoiding duplication and 2) distributing workloads and activities to maximize relevance of the program, turnaround, and progress. Individuals from the following organizations might be considered for membership: the Army Research Laboratory, Air Force Research Laboratory, AFOSR, DARPA, DTRA, EPA, Naval Research Laboratory, NCI, NIH, NNSA, NSF, Office of Naval Research, and industry and academia. As observers and sounding boards, DHS, MDA, NASA and academia could be considered. Another option with the same integrating effect would be to have a yearly higher-level meeting among leaders of the various agencies supported by annual and special workshops where program directions would be discussed and fed back to OHEP for consideration.

Engage partners by communicating capabilities and streamlining access

National laboratories, user facilities and other accelerator R&D facilities of the Office of Science would all benefit from more direct and open communication. This would include the development of simple user-friendly procedures to give customers access to national laboratory infrastructure (computing centers, test facilities and technology infrastructure) and, equally importantly, to expertise (people). This could include a provision to perform proprietary research, or at least research in access-controlled areas. In many cases the use of this infrastructure could be modelled after well-established principles for user facilities and could be represented by the National User Facility Organization (http://nufo.org/).

Several user facilities operated by the national laboratories and funded by the Office of Science have developed effective methods for allowing access to industry or other agencies. Basic Energy Sciences provides an excellent example that deals with a large variety of users and whose practices could be applied. A great deal of expertise and infrastructure is or could be of interest for industry and other agencies, but these customers have indicated that it takes too long to engage.

Streamline processes to encourage partnerships with industry

The Office of Science should work to identify, understand and resolve the concerns from industry and other agencies regarding protection of incoming and generated intellectual property or information. It would be useful to have, for this purpose and as a basis, a template applicable to all user facilities and infrastructures at Office of Science national laboratories. Such templates could cover all aspects of a contractual arrangement that is typically negotiated every time an arrangement is put in place.

An ongoing theme in discussions with potential industrial partners is the concern that intellectual property (IP) is not well-protected in current collaboration vehicles (CRADAs, WFO agreements, accelerated-use permits, licenses). Protecting incoming IP is at least as important as protecting generated IP and, if carried out to the advantage of US companies, could provide the competitive advantage needed to stay ahead. The possible methods for doing this are diverse. They could include standardized agreements, establishment of access-controlled areas, even if they are set up temporarily to different indemnity provisions, smaller or no-advance-payment requirements, or even significantly decreasing the turnaround time during negotiations.

Leverage the SBIR/STTF programs

Leveraging the SBIR/STTR funding with a specific focus on energy and environment, medicine, industry and defence and security apart from discovery science could strengthen these parts of the program, providing an easy way to direct funding towards the topical areas identified in the Accelerators for America's Future workshop.

The existing SBIR/STTR program has successfully supported many areas of accelerator R&D and has helped small businesses both with start-up funding to implement their new businesses and with access to expertise within the Office of Science laboratories. The Office of Science could consider a targeted approach with these above-listed areas in mind in the next few solicitations. The approach is especially attractive since no new funding is required, yet would still support the accelerator builders and potentially foster the establishment of new companies in this country.

Focus efforts by forming interdisciplinary teams to solve specific challenges

The Office of Science' wealth of knowledge and vast infrastructure could be channelled to establish Collaborative Accelerator Research Teams (CARTs) focused on specific challenges detailed in the Accelerators for America's Future workshop. OHEP with its stewardship program and the other directorates through their national laboratories could direct their capabilities to tackle issues in the areas of energy and the environment, medicine, industry, defence and security and discovery science. The interdisciplinary Teams, drawing from national laboratories, other agencies, industry and universities, would have a clear mission, a limited duration and would be competitively bid.

Establish a Program in Applied Accelerator Technology

The Office of Science could establish a program with the purpose of bringing industry, laboratories and universities together to foster the application of accelerator technology in energy and the environment, industry, medicine, defence and security and discovery science.

A program could address specific challenges discussed in the Accelerators for America's Future report. It would provide a specific funding line at the same time, similar to the other eight "DOE R&D Program Thrusts."

Ensure the accelerator workforce of tomorrow by expanding educational programs

The particle accelerator workforce would significantly benefit from an extension and addition of education programs to what is currently available. Workforce development for particle accelerator R&D has traditionally been a major emphasis of the Office of Science, in particular at HEP, and of the NSF, in particular the Physics Division. Though close contacts between universities and national laboratories exist, the Office of Science could help involve more universities in accelerator education programs. A greater integration with industry into educational programs would be beneficial.

While many students have been supported by various programs of the Office of Science and by NSF, recruiting offices at many laboratories still report a shortage of accelerator physicists and engineers whenever job postings appear. The NSF has provided an essential part of the US accelerator education at universities with operating accelerators. Cornell's program for co-op students in industry, the NSF's GOALI program, and the US Particle Accelerator School (USPAS) internship program are steps in this direction.

Explore opportunities for enabling the development of hadron therapy

The medical community would benefit from a discussion of how the current R&D program could help on the route to National Resources for Hadron Beam Medical Facilities. The Office of Science could develop a stepwise implementation plan for providing beams, developing beams and beam delivery systems for a cost-efficient production of such a facility.

Medical applications of accelerators include treatment either as a monotherapy or combined with surgery and/or chemotherapy. Over the last decade, proton therapy has been developed to the point that fifteen medical centers using it in the US are in operation or under construction. Other countries are building up this capability and US industry is successfully competing in this market. Light-ion beam applications are still in the development stage.

Consider incorporating laser R&D for accelerator applications into the research portfolio

The Office of Science could consider providing a home for laser R&D under its auspices. An enabling technology, lasers have become an integral part of accelerators and provide tremendous potential for new methods of acceleration, for miniaturization of accelerators and as part of accelerator systems.

Lasers are instrumental in every aspect of accelerator physics and application. They are used to generate and diagnose particle beams, to pump and probe matter and to act as a direct driver for advanced acceleration processes. As such they could become enabling tools for compact accelerators, for medical accelerators, for very high-gradient, high-energy accelerators and as drivers for a new generation of light sources or colliders. Today the fast development of lasers is largely driven by industry, defence and other applications, but the specific technological needs for lasers driving accelerators are rarely taken into account. A dedicated program as part of the accelerator R&D portfolio would cover all these aspects and integrate well with the needs in the areas of energy and the environment, medicine, industry, defence and security and discovery science, as well as with the needs of user facilities.

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