U.S. Department of Energy
Office of Accelerator R&D and Production

Review of Accelerator Technologies in the U.S.

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Office of Accelerator R&D and Production

ILC Workshop on Potential Experiments (ILCX2021)
October 26-29, 2021

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v. 1.1 10/25/2021

Nearly half of SC's nearly 33,500 users* perform research at an accelerator-based facility


Linac Coherent Light Source


Advanced Light Source


Advanced Photon Source


National Synchrotron Light Source II


Stanford Synchrotron Radiation Light Source


Spallation Neutron Source


Fermilab Accelerator Complex

Relativistic Heavy Ion Collider


ATLAS


Facility for Rare Isotope Beams


FACET Beam Test Facility


BNL Accelerator Test Facility


Continuous Electron Beam Accelerator Facility


DIII-D


NSTX-U

Accelerator Science & Technology (AS&T) is the foundation of these world-leading scientific instruments

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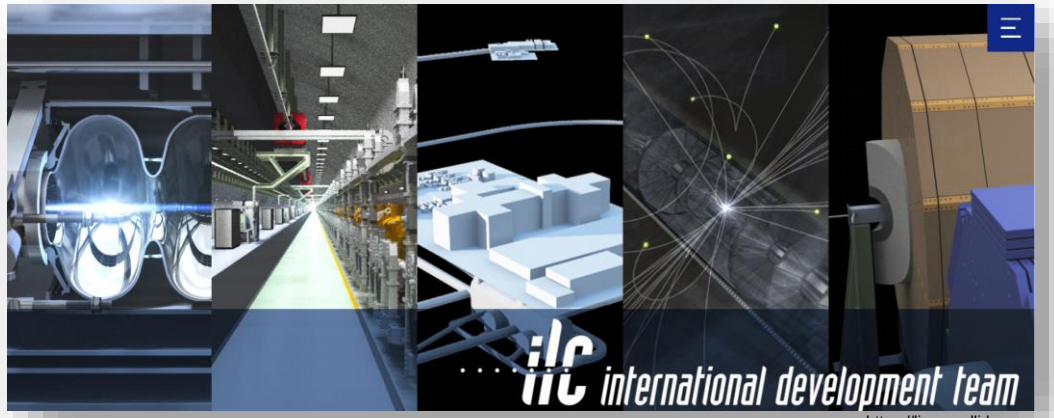
* In FY 2020, COVID reduced the number of users coming to physical facilities significantly.
Pre-COVID numbers (FY 2019): 19,337 users (**54%** of 35,771 total SC users) were at accelerator-based SC facilities.

Next generation facilities will increasingly need the close collaboration of institutions and funding sources

https://lcls.slac.stanford.edu/lcls-ii/partnerships

https://cds.cern.ch/record/2655225/plots

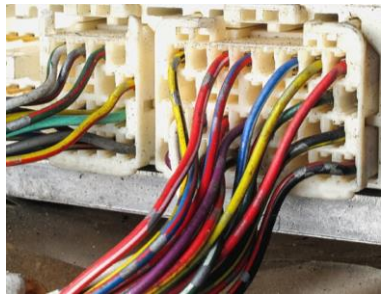
http://news.fnal.gov/wp-content/uploads/2019/07/cryomodules-lcls-ii-tunnel.jpg



https://linearcollider.org

AS&T use in Commercial and Industrial Products

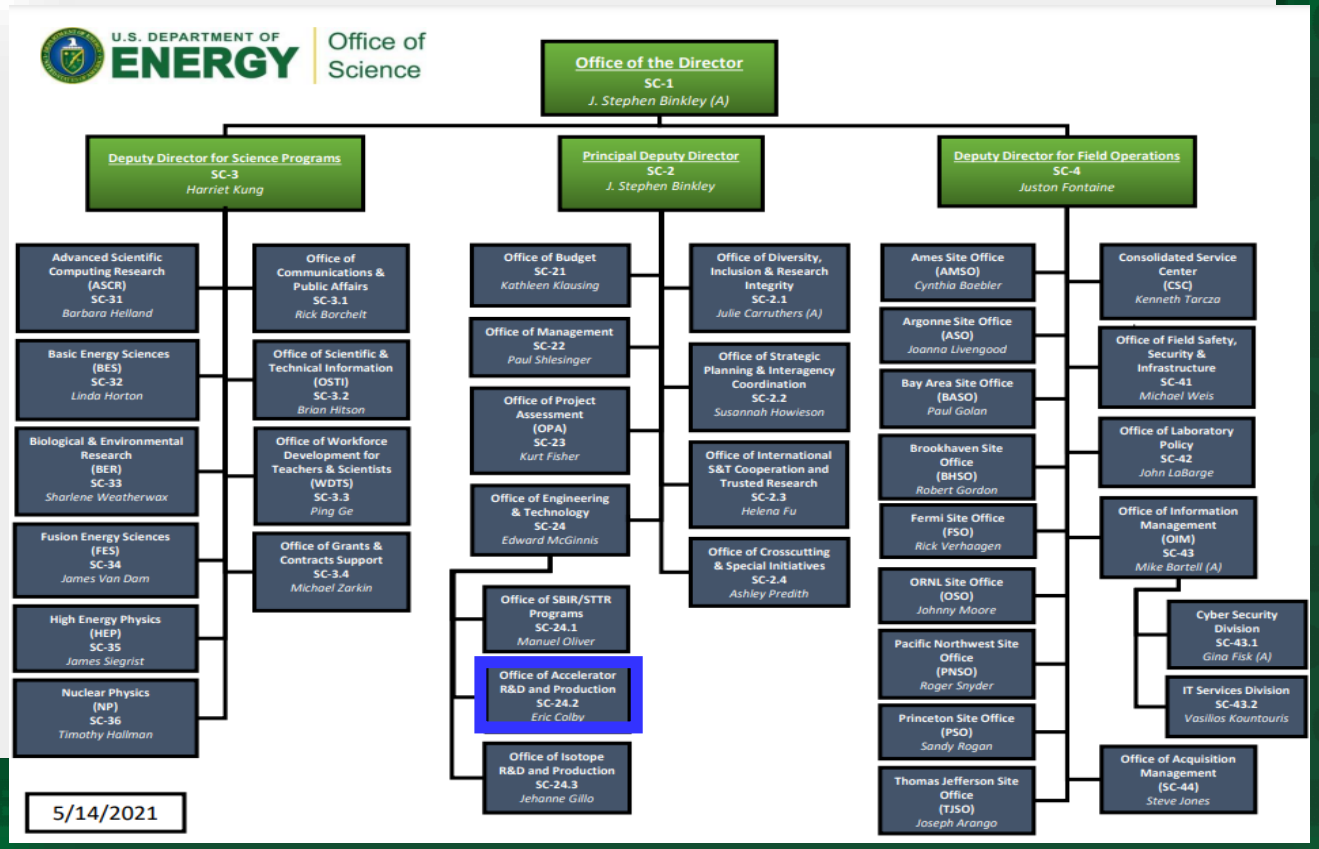
- **Economic impact of accelerators**
  - $300B worth of semiconductors are treated annually with ion implanters [3]
  - $85B worth of materials (tires, insulation, heat-shrink tubing) are processed annually with e-beam systems [4]
  - In 2012, approximately 70 companies worldwide sold more than 1,100 new accelerators with a combined market value of $2.2B [2]
  - As of 2014, an estimated 42,200 accelerators are in operation worldwide [1]
    - 64% Industrial use [~6% CAGR]
    - 33% Medical use [~9% CAGR]
    - 3% Basic research [~0.9% CAGR]
- **Accelerators are an underdeveloped tool for manufacturing with significant potential**
  - Very specific, controllable, deeply penetrating source of heat (e.g., as used in e-beam welders)
  - Flexible, controllable source of ionizing radiation (e.g., as used to drive certain chemistries)
- **The worldwide market is saturating, with the U.S. increasingly shut out due to cost**
  - Analysis [3] indicates that the accelerator industry is in the declining growth rate period typical of a mature industry, with the market projected to reach 95% saturation in the next 15-30 years



[1] A.P. Chernyaev, S. M. Varzar, Phys. At. Nucl. **77** (10), p. 1203-15 (2014).
[2] R. Hamm, M. Hamm, Industrial Accelerators and their Applications, World Scientific, (2012).
[3] M. Florio, A. Bastianin, P. Castelnovo, NIM A, **909** 21-26 (2018).
[4] Industrial Radiation with Electron Beams and X-rays, published by the IIA, (2011).

Establishment of ARDAP

- ARDAP* (SC-24.2) was established April 12, 2020 in recognition of the central importance of accelerators and related technologies to the current and future scientific capabilities stewarded by SC programs. Activities will be tightly integrated with those in BES, FES, HEP, and NP.
  - 8/1/2020 – Marion White joins ARDAP part time, focusing on workforce issues.
  - 10/11/2021 – Bruce Carlsten joins ARDAP, focusing on strategical planning and technology production.
- FY 2022 – first statutory authorization and appropriation.



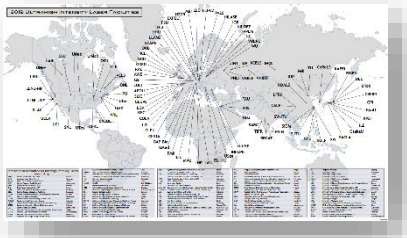
and Laser

* ARDAP = Office of Accelerator R&D and Production

Mission of Accelerator R&D and Production

- **Mission: Ensure a robust pipeline of next-generation Accelerator Science & Technology to support physical sciences research and provide technology advances and industrial strength that position the U.S. to lead the world for decades to come.**

- ARDAP will fulfill this mission by:
  - Maintaining a strategic picture of AS&T* needs and worldwide competition,
  - Facilitating coordination of Programmatic AS&T R&D investments across SC,
  - Investing in selected cross-cutting AS&T areas,
  - Providing a system engineering perspective for SC facility projects,
  - Supporting workforce development, when needed,
  - Maturing key AS&T technology and developing capable U.S. vendors,
  - Transitioning accelerator technology to broader uses.



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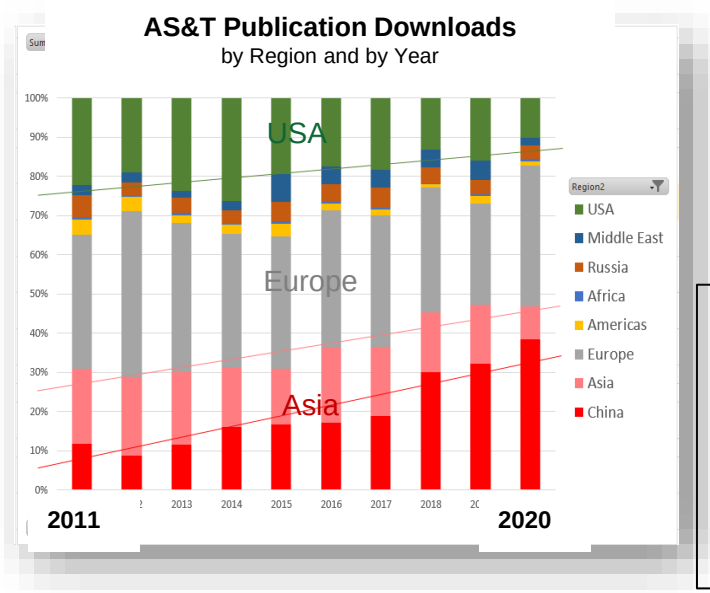
*AS&T = Accelerator Science & Technology

SC Long-Term Accelerator R&D funding has declined sharply during the last decade

Since 2011, SC AS&T R&D funding has declined **55% in absolute terms,** and **70% relative to the total cost of R&D, Operations, and Construction**

- The U.S. has
  - Lost leading accelerator scientists
  - Lost leading vendors
- The U.S. now
  - Buys more than half of all AS&T technology offshore
  - Competes internationally for workforce
- The U.S. will
  - Fall behind in research facilities
  - Lose the lead in physical sciences



Impact:
1 in 4 AS&T papers downloaded from Web of Science in 2011 was from the U.S.

In 2020 that has shrunk to less than **1 in 8**.

The Accelerator Science & Technology Initiative is formulated to help address this

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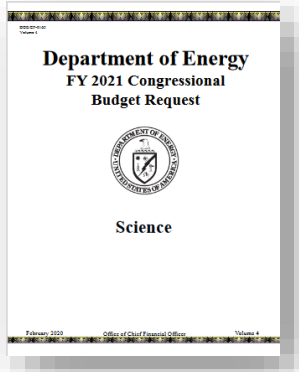
12,193 AS&T publications analyzed 2011-2020 from Web of Science database.
Analysis date: 5/11/2020; schema: topic="Accelerator" AND ("electron" OR "proton" OR "ion") binned by geographic region

Office of Science Research Initiatives



- Are High-priority, interdisciplinary challenges
- Originate typically within SC
  - Some originate at the Administration level, such as QIS and AI/ML
- Are typically multi-year
- Involve multiple SC-Programs
- Appear explicitly in DOE's Budget Narrative
  - FY 21: Strategic Accelerator Technology Initiative (SATI)
    - Started in FY 2021
    - $13.5M
  - FY 22: Accelerator Science & Technology Initiative (ASTI)
    - Continues SATI in FY 2022, and hopefully beyond
    - *Request: $40.7M*

FY2021 Research Initiatives

New

- Data and Computational Collaboration with NIH
- Next Generation Biology
- Rare Earth/Separation Science
- Revolutionizing Polymer Upcycling
- Strategic Accelerator Technology Initiative
- U.S. Fusion Program Accelerator program

Ongoing

- *Artificial Intelligence and Machine Learning
- Biosecurity
- Exascale Computing
- DOE Isotope
- Microelectronics Innovation
- *Quantum Information Science

***IoTF**: AI/ML, AM, QIS, 5G, biotech.

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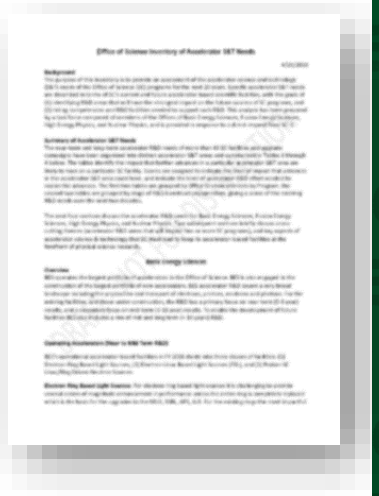
Accelerator Science & Technology Initiative



The Accelerator Initiative has grown out of an assessment of AS&T needs and an analysis of suppliers that was completed by BES, FES, HEP, and NP.

Five primary technology areas are strategically important for SC facilities

1. **Advances in superconducting accelerator systems, including SRF, SC magnets, and cryogenic engineering.**
2. **Beam physics and high-fidelity computer modeling & control, including better diagnostics, (AI/ML-based) control systems, advanced focusing, and beam cooling techniques.**
3. **Advances in high intensity electron, proton, and ion sources, also including megawatt-class targets for secondary particle sources.**
4. **Higher average power radiofrequency and ultrafast laser sources, including power handling devices, and high accuracy x-ray optics.**
5. **High-risk high-reward R&D in advanced materials, particle sources, beam dynamics, acceleration techniques, and other advanced topics.**

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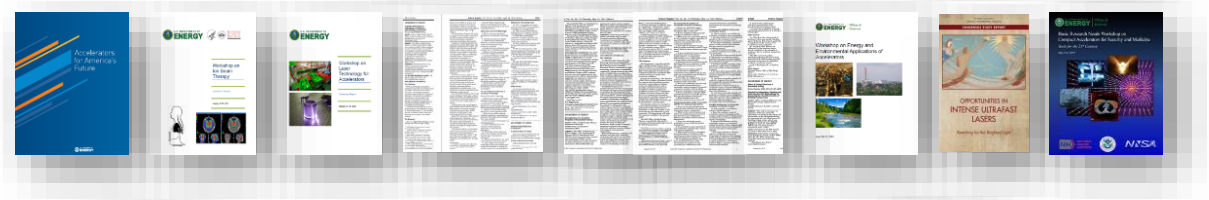
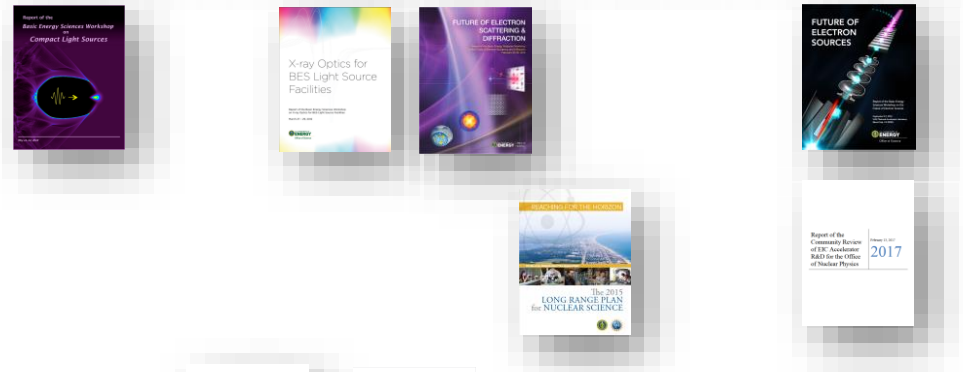
Prioritizing Accelerator R&D with the Community's Help

- High Energy Physics
  - P5, GARD Panel, Roadmaps; Snowmass 2021*

- Accelerator Stewardship
  - BRNs, RFIs, NAS



- Basic Energy Sciences
  - BRNs and Workshops



- Nuclear Physics
  - LRP and Panel

- Fusion Energy Sciences
  - Prioritization Panel, LRP, and NAS Decadal

Snowmass 2021

Office of Science

ARDAP's early efforts are aimed at information gathering

A substantive input process has started that will result in an AS&T investment strategy for the next 10-20 years:

- **Identifying high-level goals**
  - Plans for DOE's major facilities and future facility construction
  - Plans for other USG facilities
- **Analyzing domestic capability and plans**
  - Near- and long-term AS&T advances and actions needed
    - Virtual site visits to key institutions
    - Data calls, roundtables, RFIs, workshops (virtual)
    - Workforce and development pipelines
- **Analyzing international capabilities and plans**
  - Capabilities and plans for scientific facilities, AS&T R&D, and industrialization
- **Studying technology transfer examples through case studies**
  - Examples of public-private-partnerships, organizations, ecosystems, …

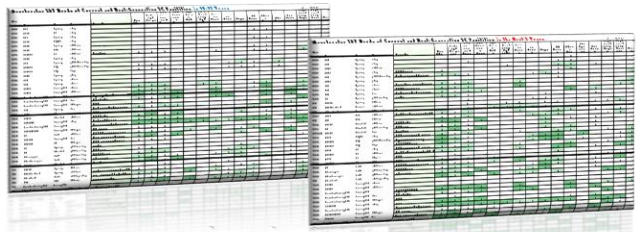
Charting a future for accelerator technology

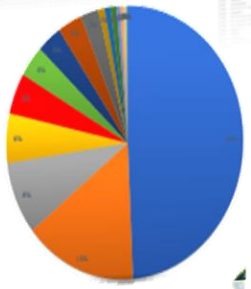
- ***Inventory of R&D Needs for DOE Facilities***
  - *Completed in 2018, refreshed in 2020*
  - What are the facilities of the next decade
  - What AS&T R&D is needed and when

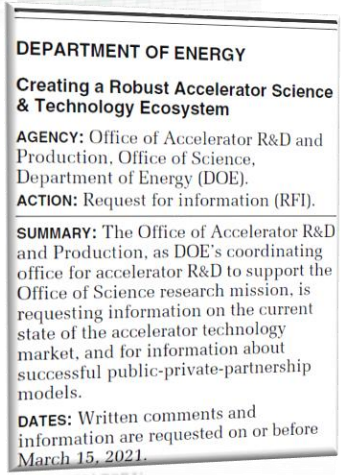
- ***AS&T Supplier Survey***
  - *December 2020*
  - What critical AS&T was purchased, from whom, and how much
  - Covered current projects and recent operations

- ***Request for Information on Creating a Robust AS&T Ecosystem***
  - *January 2021*
  - Status and Future of the Market
  - Workforce Development
  - Models for Technology Transfer
  - Defining an Optimal Federal Role

- ***Office of Science Roundtable on Supply Chain Risk Mitigation for Scientific Facilities and Tools***
  - *November 2021*
  - Covering **all** technologies used for physical science R&D
  - Procurement issues, market conditions, potential mitigation strategies







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Creating a Robust Accelerator Science & Technology Ecosystem

AGENCY: Office of Accelerator R&D and Production, Office of Science, Department of Energy (DOE).

ACTION: Request for information (RFI).

SUMMARY: The Office of Accelerator R&D and Production, as DOE's coordinating office for accelerator R&D to support the Office of Science research mission, is requesting information on the current state of the accelerator technology market, and for information about successful public-private-partnership models.

DATES: Written comments and information are requested on or before March 15, 2021.

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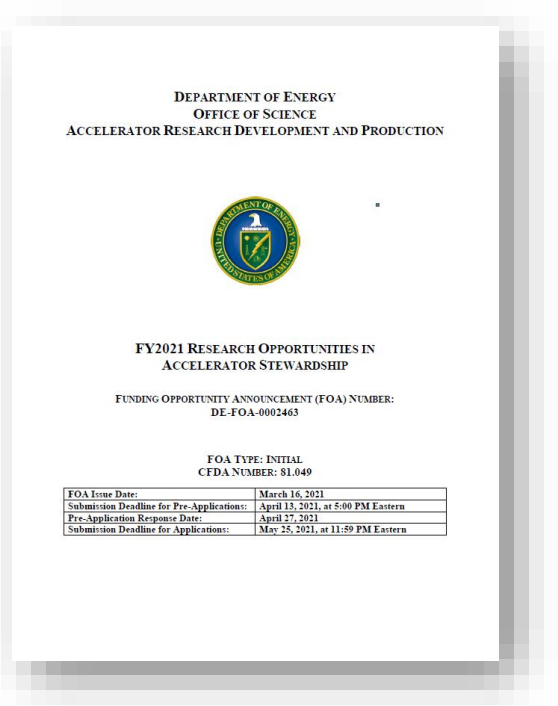
Accelerator Technology Business Sector Strategic Plans

[Accelerator Stewardship Program]

- Funding for one-year, team-led* studies, awarded by peer review process to provide deeper-dive strategic information and community building in critical accelerator technology areas



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ACCELERATOR RESEARCH DEVELOPMENT AND PRODUCTION

FY2021 RESEARCH OPPORTUNITIES IN ACCELERATOR STEWARDSHIP

FUNDING OPPORTUNITY ANNOUNCEMENT (FOA) NUMBER:
DE-FOA-0002463

FOA TYPE: INITIAL
CFDA NUMBER: 81.049

FOA Issue Date:	March 16, 2021
Submission Deadline for Pre-Applications:	April 13, 2021, at 5:00 PM Eastern
Pre-Application Response Date:	April 27, 2021
Submission Deadline for Applications:	May 25, 2021, at 11:59 PM Eastern

Five Critical Technology Areas:

- Superconducting accelerator systems
  - Superconducting radiofrequency accelerators
  - Superconducting wire, cable, and high-field magnets
  - Cryogenic systems — Funded in FY2021
- Beam physics and diagnostics
- Particle sources
- Power sources and optics (both rf and laser) — Funded in FY2021
- Advanced technologies (materials, novel concepts)

Required Analysis:

1. Define the optimal public/private partnership including participants, management, technologies to transfer, funding mechanisms, and management of quality and IP.
2. Analyze the pathway to production at market scale.
3. Analyze and project the market for this technology.
4. Describe any workforce needs.
5. Describe any other factors to the market success of this technology sector (e.g., regulatory issues)

- Next call for proposals in early CY 2022

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*Teaming requirement: (1) a technically leading institution, (2) multiple industrial companies, (3) a business school or consulting firm.

Ensuring a Robust AS&T Ecosystem

- **There is renewed interest in strengthening domestic suppliers of critical technologies**
  - Superconducting RF accelerator manufacture
  - Superconducting high-performance wire and cable manufacture
  - Advanced manufacturing and cost reduction
- **A market co-development approach is needed**
  - Expansion of markets for critical accelerator technologies is needed to support the domestic supplier base or supplier gains will be temporary
- **Workforce development must be a coordinated part of the picture**
  - New technologies, new skillsets, and increased worldwide demand
- **A large collider can be the trigger that spawns an industry**
  - As happened with the Tevatron, the industrialization of high-quality NbTi superconducting cable facilitated the growth of the commercial MRI/NMR industry

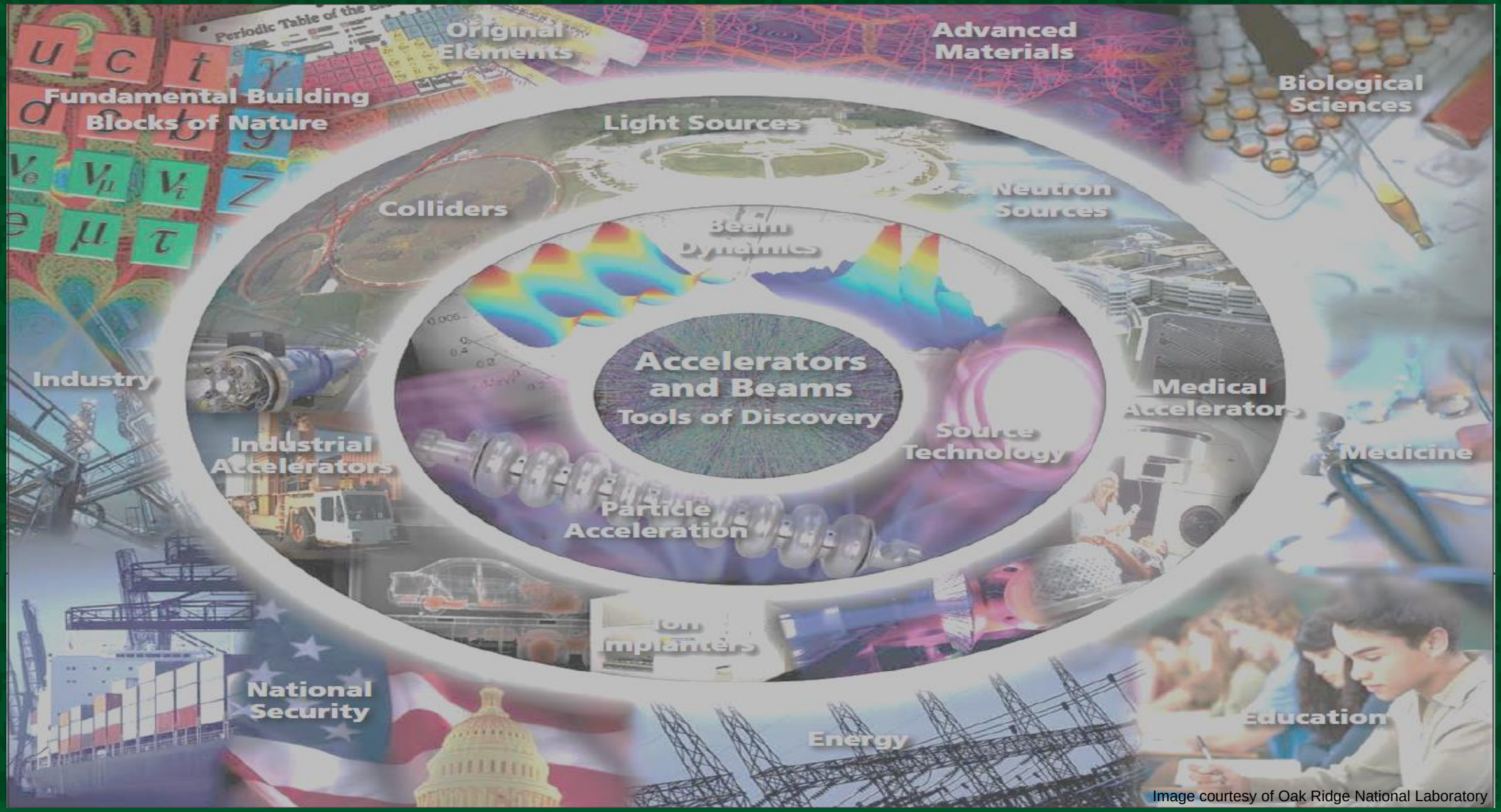

Image courtesy of Oak Ridge National Laboratory