Accelerators for America's Future

U.S. DEPARTMENT OF ENERGY

Accelerators for Industry

Today in the United States many thousands of particle accelerators are at work across an extraordinary spectrum of fields from basic research to industry. Around the world, industry both uses accelerators for a multitude of applications and designs and manufactures accelerators for research and industrial uses. Innovations in accelerator technology beget new applications and vice versa, each reinforcing the other and building the potential for future industrial and scientific uses for accelerators.

Worldwide, hundreds of industrial processes use electron-beam and ion-beam accelerators. Electron-beam applications center on the modification of material properties. They provide technology for the cross-linking of polymers, for surface treatment, and for pathogen destruction in medical sterilization and food irradiation. Ion-beam accelerators, which accelerate heavier particles, find extensive use in the semiconductor industry in chip manufacturing and in hardening the surfaces of materials such as those used in artificial joints. Industry is also pursuing the manufacture and application of superconducting radio-frequency, or SRF, accelerators. These SRF accelerators presently find use mainly in basic research and defense applications.

Private-sector organizations are the principal developers of industrial electron-beam and ion-beam accelerators and of their many successful industrial applications in markets that have evolved over decades. Government-funded national laboratories are the major developers and main users of SRF accelerators, with private-sector involvement in supplying SRF cavities, klystrons, couplers and cryogenic components.

Crosslinking of polymers by an electron beam, as in this Illinois plant, improves heat resistance of coatings for wire and cable.
Photo: Reidar Hahn, Fermilab

Around the world, industry both designs and manufactures accelerators for research and industrial uses and uses accelerators for a multitude of applications.

A Rhodotron, a commercial electron-beam accelerator for industrial applications including sterilization of medical devices
Image courtesy of IBA

To take advantage of the significant potential to increase existing markets and to develop new accelerator applications for all three technologies, both industry and government will need to address critical barriers to expansion. Electron-beam accelerators, for example, could replace thermal processes in the curing of inks and coatings, with energy savings and benefit to the environment. However, concerns about reliability and financing make customers wary of changing to a new accelerator process from a familiar thermal one. Similar concerns block the development of applications for waste water and flue-gas treatment. A cost-sharing government-industry partnership for long-term demonstrations would reduce risk and open up potential markets for accelerator technology.

Several national-laboratory programs have SRF accelerator components in the procurement pipeline, but U.S. industry currently lacks the capacity to produce the required quantities on the estimated schedules. As the only major U.S. customer for SRF technology for the next five years, the government must integrate industry into SRF programs, as Japan and Europe have done, in order to prepare U.S. industry for the cost-effective manufacture of key SRF accelerator components to meet government procurement schedules. Without a major government-supported industrialization effort, most of these procurements will go offshore.

Two factors retard the growth of accelerator technologies for industry. First, there is a need for more Department of Energy engagement in technology exchanges within existing organizations, and for workshops and other regular interactions with industry. Small companies often lack R&D resources and need ways to address their R&D needs while protecting intellectual property. Second, high risk makes customers hesitant to switch from existing processes to particle accelerator-based technologies. Government support for user facilities and demonstrations could go far to establish the value of accelerators in saving energy and preserving the environment.

Industrial applications of accelerator technology comprise the areas of electron-beam, ion-beam and SRF technology. Other applications of accelerated electrons, not discussed in this section, include scanning electron microscopy, electron-beam welding, and medical diagnosis and treatment.

Electron beams

There are approximately 1700 high-current, industrial electron-beam accelerators producing tens of billions of dollars of value-added products in diverse market areas worldwide.

The largest industrial use of electron-beam accelerators is for the modification of polymers by cross-linking, the formation of three-dimensional chemical links between adjacent polymer segments. Cross-linking renders materials insoluble in solvents that would dissolve non-cross-linked materials. Surface curing with low-energy electron beams (70 to 300 keV) is the fastest-growing market segment because of the improved energy efficiency of these high-speed processes and their environmentally friendly elimination of volatile organic solvents from the manufacturing process. Uses include cross-linking of the polymers for insulation on electrical wires and for heat-shrinkable tubing for protecting wire and cable connections, making these products more flame retardant for automotive under-hood wiring and other applications.

Cross-linking of heat-shrinkable films, most widely used in food packaging, makes up a large share of the electron-beam market. Such films extend the shelf life of meat, produce, poultry and dairy products and provide tamper-resistant packaging. The major producer of cross-linked packaging uses more than 125 industrial electron-beam accelerators in its global manufacturing operations.

Cross-linked closed-cell polyethylene foam cushions the interior of automobile roof liners and door panels. The tire industry uses electron-beam processing to partially cure the rubber stock to stabilize tire cord placement and to produce better-balanced tires. The manufacture of heat tracing systems and polymeric switches uses cross-linked conductive polymers.

Electron-beam curing of inks, coatings and adhesives eliminates the use of volatile organic compounds, enabling manufacturers to attain high production speeds with minimal energy consumption and reduced environmental impact. In these applications, "green" electron-beam technology yields as much as a 90 percent reduction in power consumption compared to conventional thermal drying and curing.

The manufacture of hydrogels for wound and burn treatment employs electron-beam technology. High-energy electron beams and x-rays derived from electron-beam systems sterilize medical equipment. Ionizing radiation eliminates food-borne pathogens, such as *E. coli*, *Salmonella* and *Listeria*, from meats, poultry and other food products, and disinfects grains and spices. A small number of service centers around the world use electron beams for food irradiation. Widespread public mistrust of food irradiation constitutes a significant barrier to expansion. However, the cumulative cost to Americans of foodborne illnesses is $152 billion annually, according to a 2010 Georgetown University study. The Centers for Disease Control and Prevention estimate that there are 76 million cases of food-related illness in the U.S. each year, resulting in 5000 deaths and 325,000 hospitalizations. Increased emphasis on food safety and growing concerns over the safety and supply of the radioactive isotope ^{60}Co, are likely to stimulate demand for food irradiation using electron beams and x-rays derived from high-energy, high-power electron-beam accelerators.

Other industrial uses for electron-beam technology include degradation of polytetrafluoroethylene, or Teflon, for manufacturing micronized lubricants; grafting of filter membranes and battery separators; and enhancement of polyethylene water pipes. The use of electron beams to treat seeds and soil shows promise for increasing crop yields.

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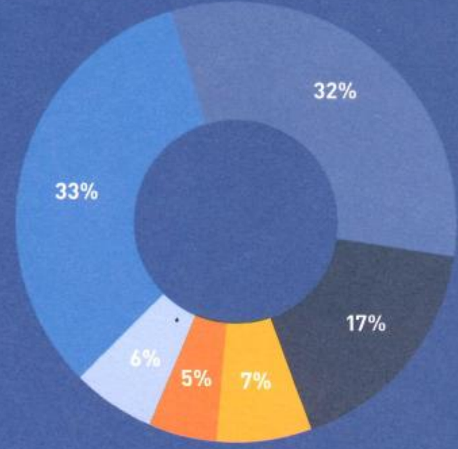
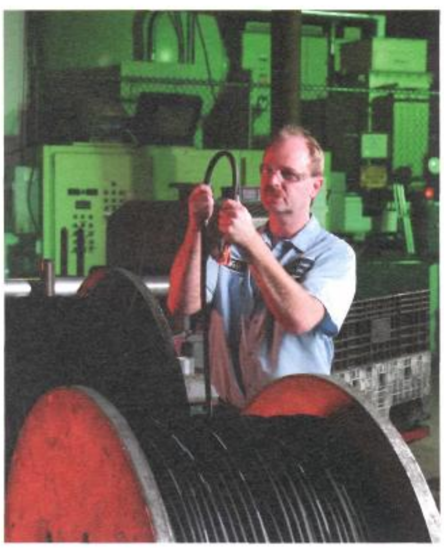


Markets for industrial electron beams total $50 billion per year.

Image source: IAEA Working Material on Industrial Electron Beam Processing

Converting metal-coating facilities to electron-beam technology could realize a 95 percent savings in power demand.



Coated cables at Electron Beam Technologies, Inc. in Kankakee, Illinois
Photos: Reidar Hahn, Fermilab

NEEDS, OPPORTUNITIES AND TECHNOLOGIES

Energy, the environment and electron beams

Industrial electron-beam processing has the potential to conserve energy in industrial processes, to remediate stack gas emissions from fossil-fueled power plants, to purify drinking water, and to disinfect and detoxify municipal and industrial waste water. The Energy and Environment chapter of this report discusses these applications in more detail.

Metal coatings

While it can be difficult to quantify the cumulative environmental impact of low-energy electron-beam processes such as the curing of printing inks, coatings, adhesives and laminations, it is easier to calculate the effects for a narrower market segment, the metal coating industry. Based on U.S. Environmental Protection Agency projections, the U.S. has about 80 facilities that apply coatings to steel or aluminum to make approximately 1.8 trillion square meters of precoated metals for fabricating rain gutters, appliance housings, metal doors, and outdoor panels for metal buildings. These facilities currently use thermal processes consuming approximately 166 megawatts of power just to dry the coatings. Converting these facilities to electron-beam technology could realize a 95 percent savings in total power demand. Electron-beam curing would also enable these facilities to comply with the U.S. EPA directives to attain the Maximum Achievable Control Technology, or MACT, for reduction of emissions of volatile organic compounds.

Electron beams and acid rain

Currently, coal-fired generating plants meet nearly half the total annual U.S. electric power demand of about 4000 terawatt-hours. Appropriately sized electron-beam accelerators at larger plants could significantly reduce the acid-rain-forming emissions they produce. Small-scale experiments in Japan and a full-scale demonstration plant in Poland have shown that electron-beam treatment of nitrogen and sulfur oxides eliminates about 90 percent of both these emissions. Other technologies, such as the use of scrubbers, cannot cost-effectively eliminate nitrogen oxides. Injection of ammonia into flue gas before electron-beam treatment causes the ammonia to react with these gaseous wastes and converts them into saleable fertilizer. Supported by the International Atomic Energy Agency in the mid-1990s, the full-scale Polish electron-beam flue-gas treatment facility cost approximately $25 million.

The typical electron-beam power requirement is one percent of the electric power output of the plant. Meeting the entire U.S. need would require about 2500 megawatts of electron beam power. Even with a beam power of 500 kilowatts for each accelerator, this would generate a demand for some 5000 accelerators using current technology. Adopting electron-beam technology in the U.S. would require building and operating a full-scale facility to demonstrate feasibility and cost effectiveness to power companies.

Water treatment

Electron-beam treatment can disinfect and decontaminate both waste water and drinking water. Projects in Boston and in Miami-Dade County, Florida, funded by the National Science Foundation, have shown the feasibility of disinfecting municipal waste water with relatively low doses of electron-beam treatment. Further NSF project studies at the Miami-Dade facility have shown that electron-beam treatment can break down water-borne organic toxins such as halogenated hydrocarbons. An existing full-scale facility in Korea uses electron beams from an accelerator provided by Russia's Budker Institute to break down residual dyes from a fabric plant before discharge into a river.