The New Charge for Non-Fusion-Energy FES Applications

James W. Van Dam
on behalf of
Fusion Energy Sciences

U.S. DEPARTMENT OF ENERGY

Office of Science

Presented to FESAC
March 12, 2015

New Charge: The WHAT

Charge from Congress

- **Explanatory statement accompanying the FY 2015 enacted budget appropriation (Public Law 113-325):**
  - *The agreement further directs the Office of Science to submit to the Committees on Appropriations of the House of Representatives and the Senate not later than 180 days after enactment of this Act a report on the contribution of fusion energy sciences to scientific discovery and the development and deployment of new technologies beyond possible applications in fusion energy.*

Charge to FESAC

- **Charge letter to FESAC from Acting Director of the Office of Science (February 4, 2015):**
  - Consider a wide range of connections between research performed through the FES portfolio and other scientific disciplines and technological applications.
  - Applications beyond fusion energy will naturally focus on the curiosity-driven research areas of the FES portfolio (e.g., basic plasma science, low temperature plasma, space and astrophysical plasma, etc.) but may also involve spin-offs from anywhere in this portfolio.
  - Consider scientific and technical applications of fusion and related plasma science to other branches of science.
  - Consider contributions to new scientific developments and technologies beyond possible applications in fusion energy related, but not limited, to areas such as energy and the environment, materials science, medical diagnostics and treatment, biology, national security, and industry.
  - Comment on how well the contributions of FES are advancing the interests of society and meeting its needs, and ensuring the Nation’s competitiveness in the physical sciences and technology.

New Charge: The WHY

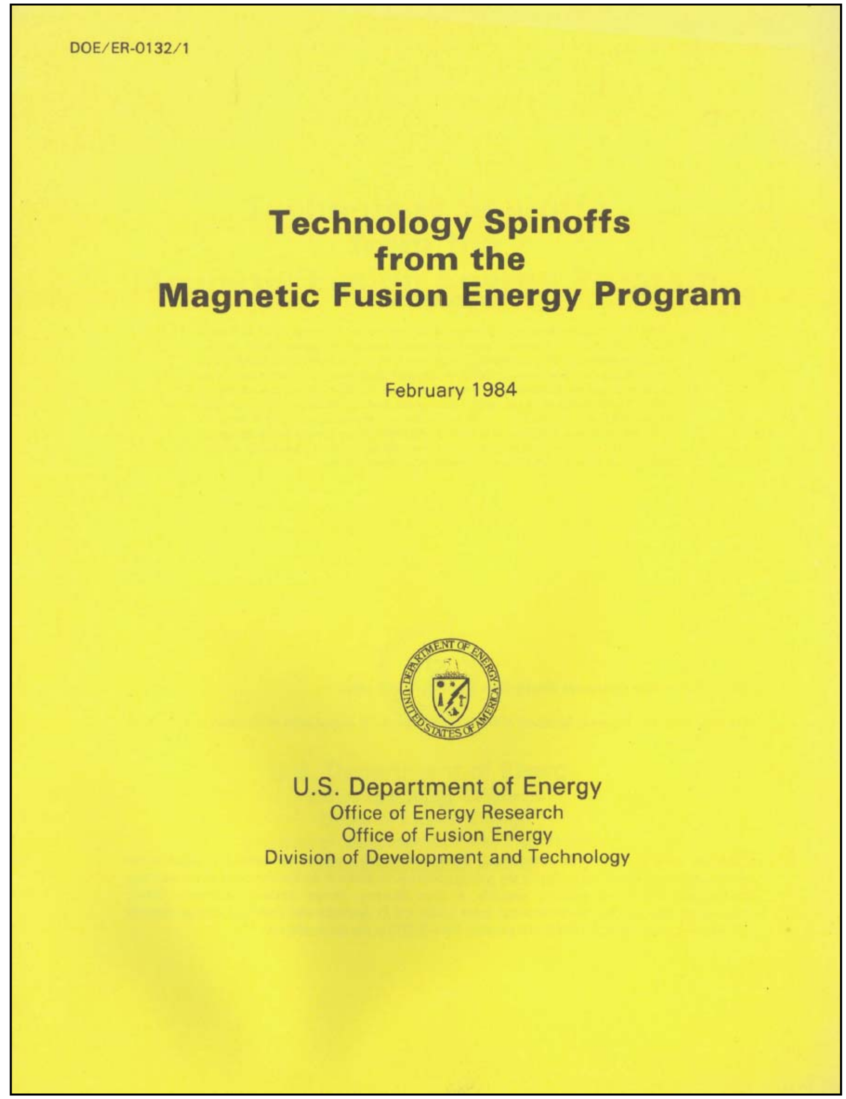
- Possible political considerations
- Regardless, this is a opportunity for our field to describe our broader impacts, connections to other fields of science, and benefits and applications to society

New Charge: The HOW

- Previous examples in fusion energy sciences field
- Examples in other scientific fields

FES previous example #1

- ***Technology Spinoffs from the Magnetic Fusion Energy Program*** (DOE/OER/OFE report, February 1984)
  - Computers
  - Man-machine interface
  - Metal forming
  - Isotope separation
  - Electrical welding
  - Astronomy
  - Ultraviolet sources
  - Electric power



DOE/ER-0132/1

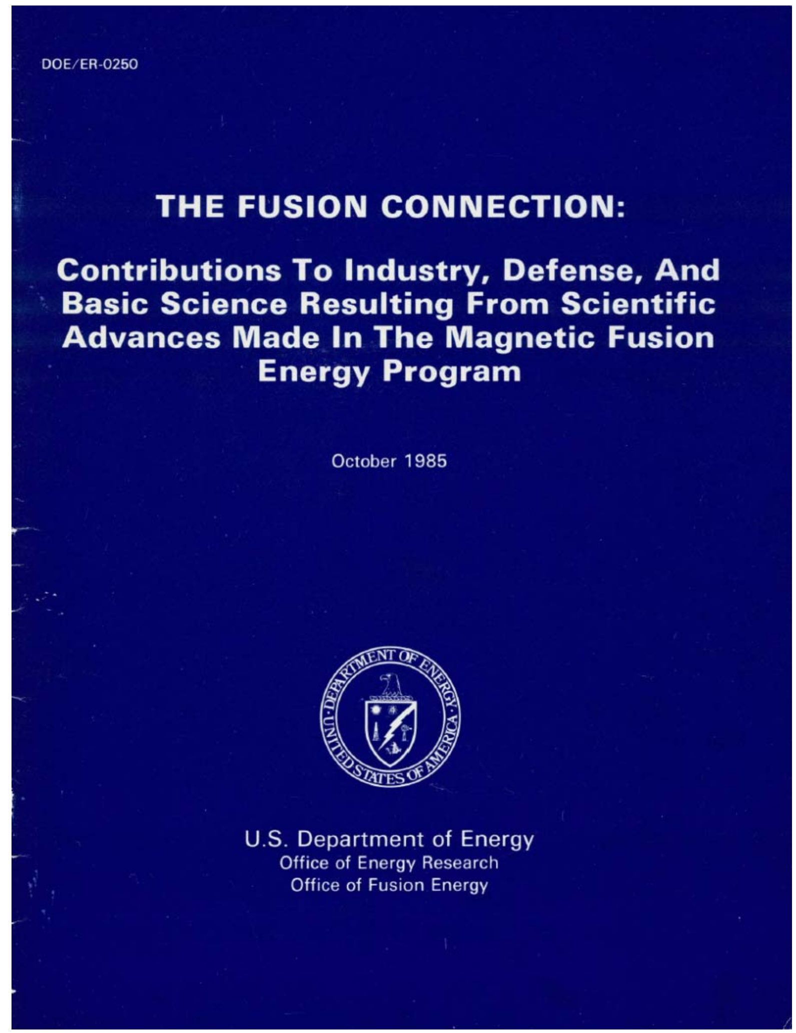
Technology Spinoffs
from the
Magnetic Fusion Energy Program

February 1984

U.S. Department of Energy
Office of Energy Research
Office of Fusion Energy
Division of Development and Technology

FES previous example #2

- ***The Fusion Connection*** (DOE/OER/OFE report, 1985)
  - Contributions to Industry, Defense, and Basic Science Resulting from Scientific Advances Made in the Magnetic Fusion Energy Program



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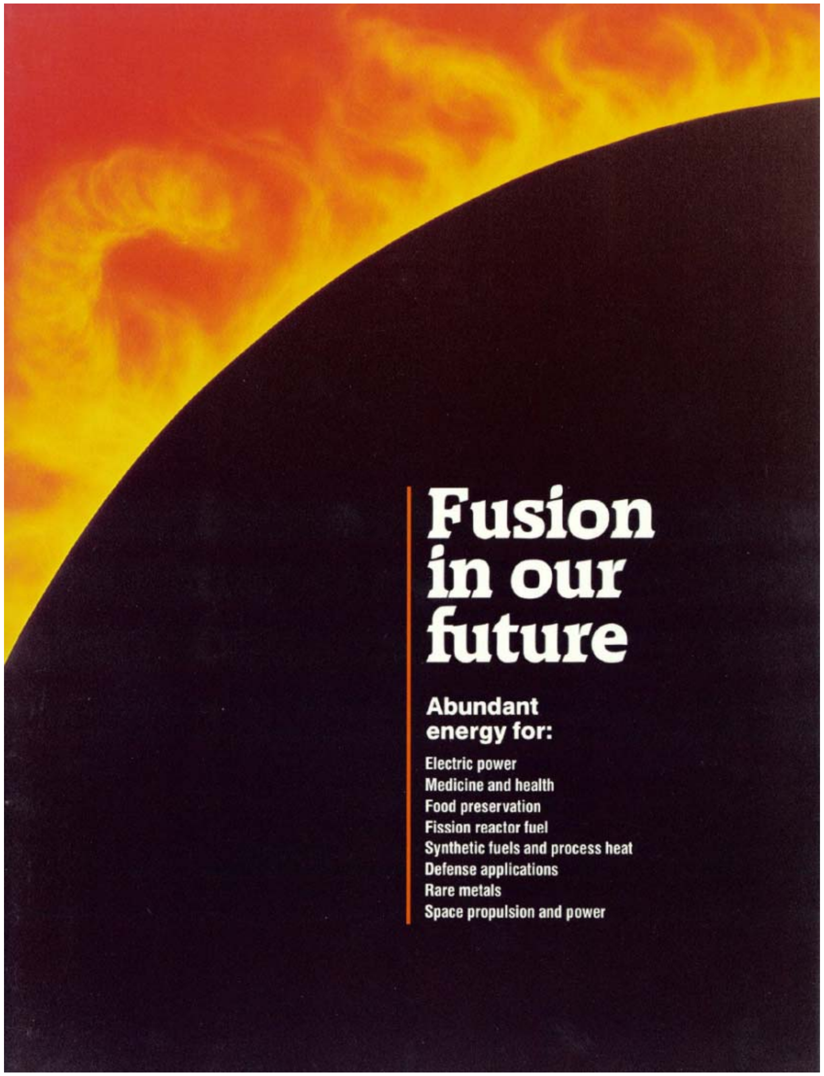
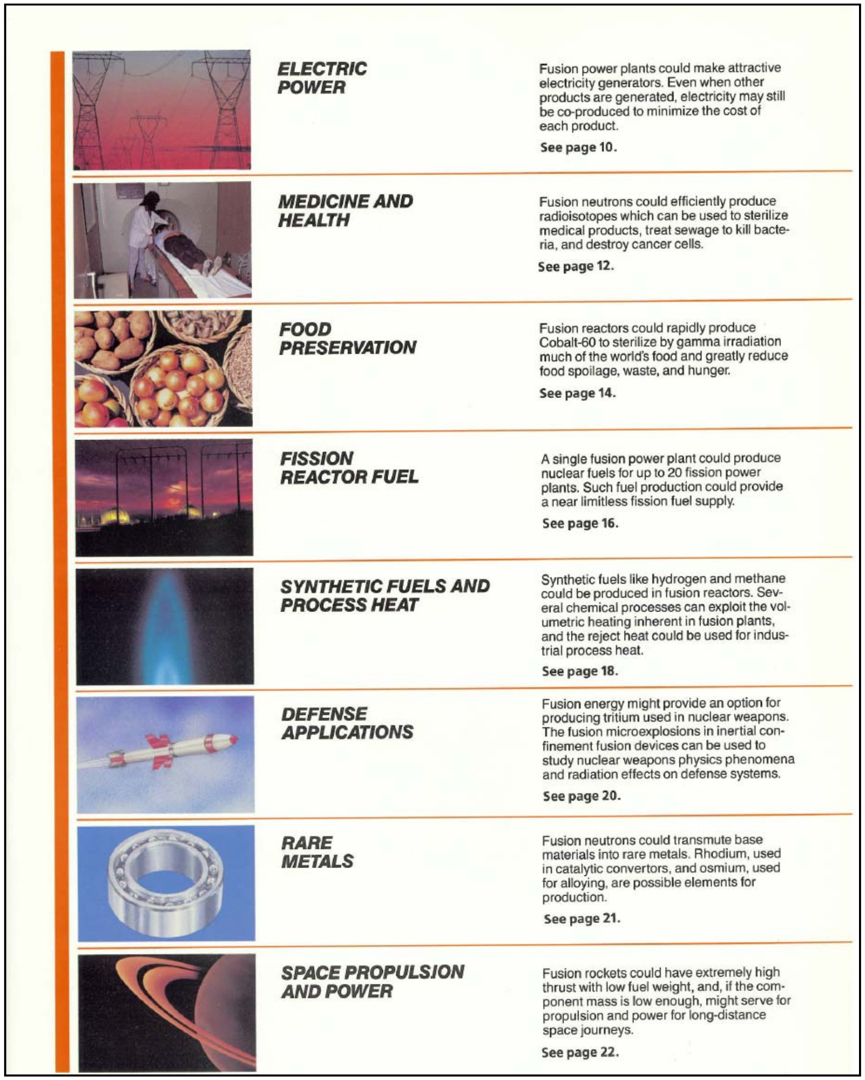
FES previous example #3

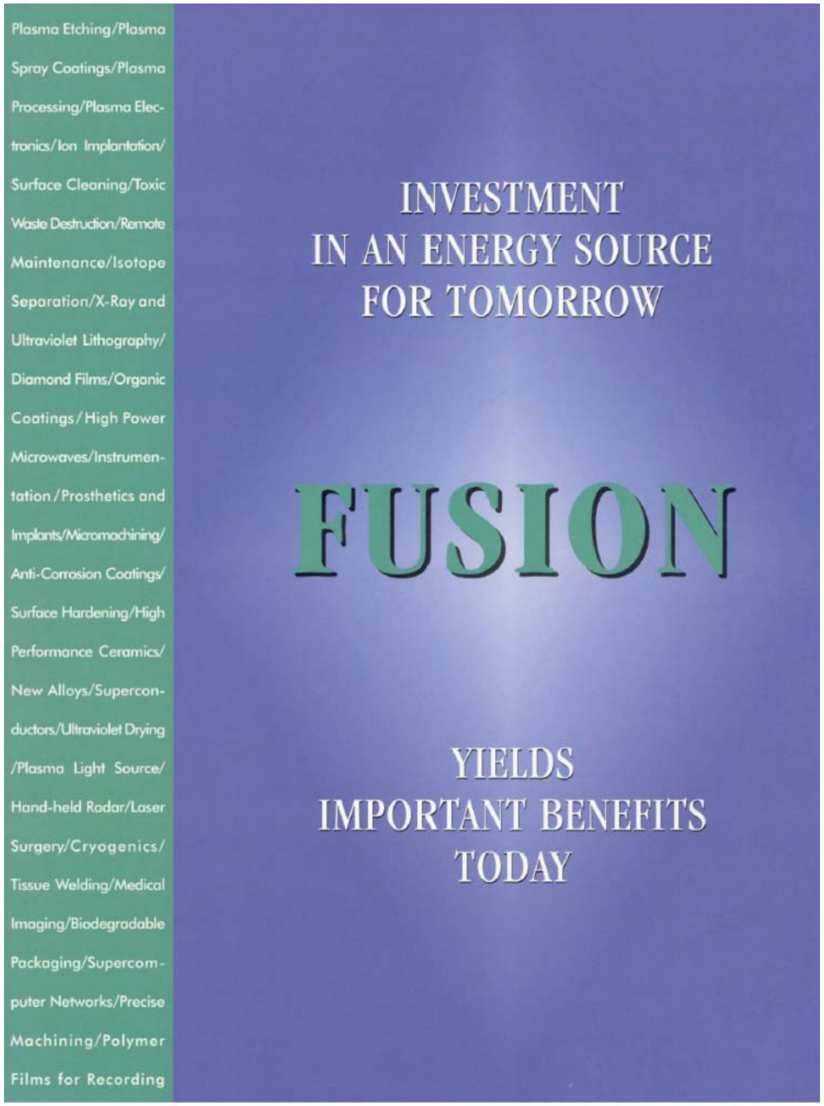


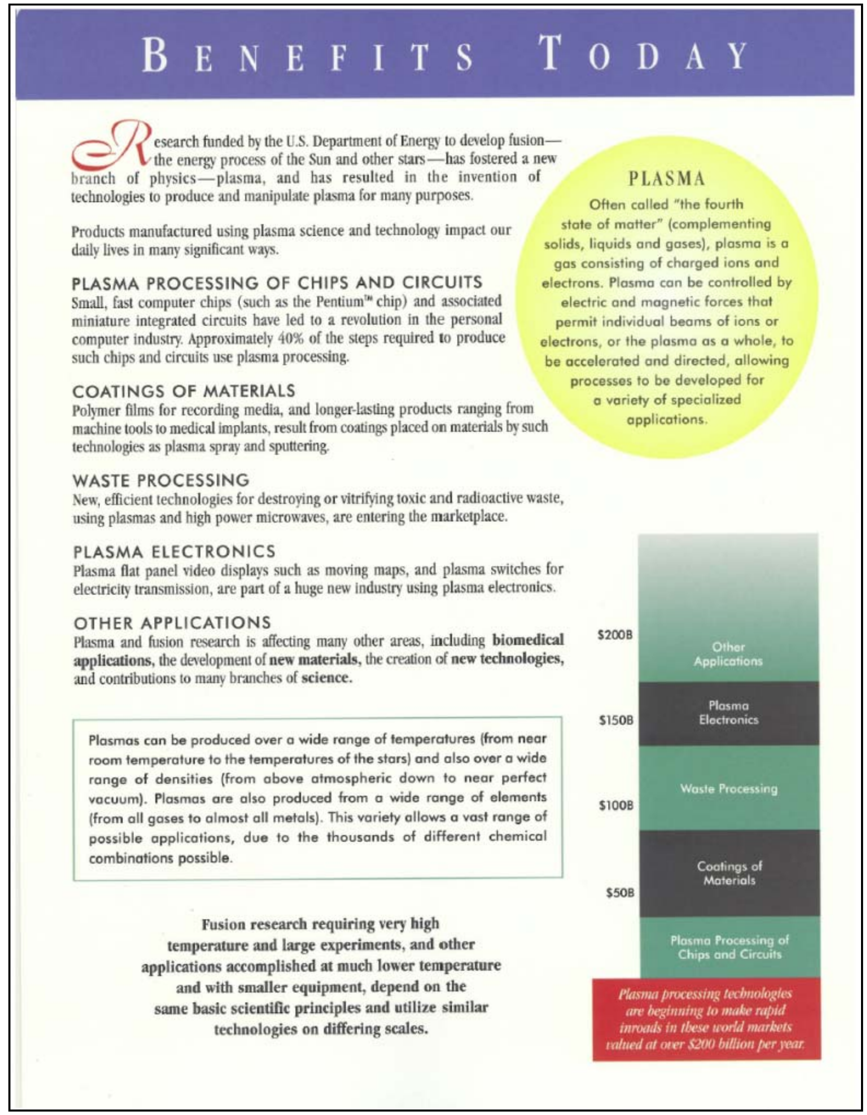


ELECTRIC POWER	Fusion power plants could make attractive electricity generators. Even when other products are generated, electricity may still be co-produced to minimize the cost of each product. See page 10.
MEDICINE AND HEALTH	Fusion neutrons could efficiently produce radioisotopes which can be used to sterilize medical products, treat sewage to kill bacteria, and destroy cancer cells. See page 12.
FOOD PRESERVATION	Fusion reactors could rapidly produce Cobalt-60 to sterilize by gamma irradiation much of the world's food and greatly reduce food spoilage, waste, and hunger. See page 14.
FISSION REACTOR FUEL	A single fusion power plant could produce nuclear fuels for up to 20 fission power plants. Such fuel production could provide a near limitless fission fuel supply. See page 16.
SYNTHETIC FUELS AND PROCESS HEAT	Synthetic fuels like hydrogen and methane could be produced in fusion reactors. Several chemical processes can exploit the volumetric heating inherent in fusion plants, and the reject heat could be used for industrial process heat. See page 18.
DEFENSE APPLICATIONS	Fusion energy might provide an option for producing tritium used in nuclear weapons. The fusion microexplosions in inertial confinement fusion devices can be used to study nuclear weapons physics phenomena and radiation effects on defense systems. See page 20.
RARE METALS	Fusion neutrons could transmute base materials into rare metals. Rhodium, used in catalytic convertors, and osmium, used for alloying, are possible elements for production. See page 21.
SPACE PROPULSION AND POWER	Fusion rockets could have extremely high thrust with low fuel weight, and, if the component mass is low enough, might serve for propulsion and power for long-distance space journeys. See page 22.

(General Atomics, 1989)

FES previous example #4(a)





BENEFITS TODAY

Research funded by the U.S. Department of Energy to develop fusion—the energy process of the Sun and other stars—has fostered a new branch of physics—plasma, and has resulted in the invention of technologies to produce and manipulate plasma for many purposes.

Products manufactured using plasma science and technology impact our daily lives in many significant ways.

PLASMA PROCESSING OF CHIPS AND CIRCUITS
Small, fast computer chips (such as the Pentium™ chip) and associated miniature integrated circuits have led to a revolution in the personal computer industry. Approximately 40% of the steps required to produce such chips and circuits use plasma processing.

COATINGS OF MATERIALS
Polymer films for recording media, and longer-lasting products ranging from machine tools to medical implants, result from coatings placed on materials by such technologies as plasma spray and sputtering.

WASTE PROCESSING
New, efficient technologies for destroying or vitrifying toxic and radioactive waste, using plasmas and high power microwaves, are entering the marketplace.

PLASMA ELECTRONICS
Plasma flat panel video displays such as moving maps, and plasma switches for electricity transmission, are part of a huge new industry using plasma electronics.

OTHER APPLICATIONS
Plasma and fusion research is affecting many other areas, including **biomedical applications,** the development of **new materials,** the creation of **new technologies,** and contributions to many branches of **science.**

PLASMA
Often called "the fourth state of matter" (complementing solids, liquids and gases), plasma is a gas consisting of charged ions and electrons. Plasma can be controlled by electric and magnetic forces that permit individual beams of ions or electrons, or the plasma as a whole, to be accelerated and directed, allowing processes to be developed for a variety of specialized applications.

Plasmas can be produced over a wide range of temperatures (from near room temperature to the temperatures of the stars) and also over a wide range of densities (from above atmospheric down to near perfect vacuum). Plasmas are also produced from a wide range of elements (from all gases to almost all metals). This variety allows a vast range of possible applications, due to the thousands of different chemical combinations possible.

Fusion research requiring very high temperature and large experiments, and other applications accomplished at much lower temperature and with smaller equipment, depend on the same basic scientific principles and utilize similar technologies on differing scales.

$200B
$150B
$100B
$50B
Other Applications
Plasma Electronics
Waste Processing
Coatings of Materials
Plasma Processing of Chips and Circuits

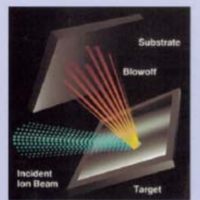
Plasma processing technologies are beginning to make rapid inroads in these world markets valued at over $200 billion per year.

(Prepared by Argonne National Lab and Fusion Power Associates for DOE, 1996)

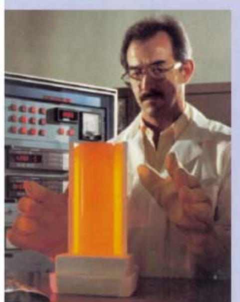
FES previous example #4(b)

COATINGS AND FILMS

Many commercial materials require coatings to reduce corrosion or to provide thermal protection. Plasma spray and intense ion beam technologies permit rapid deposition of uniform coatings on large, complex objects, such as turbine blades of aircraft engines. These technologies are also used for depositing diamond coatings on cutting tools and electronic circuits and for depositing polymer films on recording media. The estimated world market for coating technologies exceeds $50 billion a year.



Ion Beam Coating Technology: Los Alamos National Laboratory


Vitrified Ceramic: Oak Ridge National Laboratory

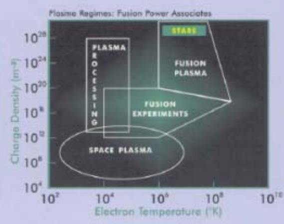
WASTE PROCESSING

The disposal and/or destruction of toxic waste is a massive societal problem. Burning or chemical processing of such waste often results in the production of additional toxic material. Plasma can be used to melt solid waste and transform it into solid, non-leachable glass or ceramics. Plasma and beam technologies can be used to decompose toxic molecules in a gas. Mixed (radioactive and toxic) waste is being processed by plasma torches. Cryogenic and microwave technologies, developed for fusion research, are also being used for efficient cleaning of surfaces, e.g., removal of paint from aircraft. The estimated world market for toxic waste processing alone exceeds $50 billion a year.

PLASMA ELECTRONICS

Plasma electronics covers the range from plasma flat panel displays to arc-switching devices used in the power generation and transmission industry. Plasma flat panel displays permit compact, high quality full-color, full-motion videos, such as moving maps for transportation navigation. Arc-switching technologies improve efficiency and reduce maintenance costs in the electric power industry. The estimated world market for these applications exceeds $40 billion a year.


Full-color, full-motion video, plasma flat panel monitor: Photonics Imaging, Inc.

Plasma Regimes: Fusion Power Associates


CONTRIBUTIONS TO SCIENCE

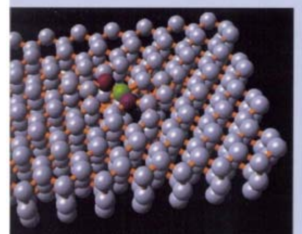
The development of plasma science has impacted many other areas of science, including astro, solar and magnetospheric physics; atomic physics; lasers; nonlinear dynamics and chaos; and numerical computation and modeling. Fusion researchers have pioneered in the field of supercomputer networking.

The fundamentals of plasma science, and the technologies required to study plasmas, underlie the many practical applications coming into use today, and eventually will lead to fusion as an energy source for tomorrow.

PLASMA PROCESSING OF CHIPS AND CIRCUITS

The speed of computer chips and integrated circuits is increased, and their size reduced, if plasma processes are used instead of chemical processing in their production. This has resulted in powerful computers becoming available to the average citizen. Advances in plasma technologies continue to reduce the size and cost of these products. The estimated world market for high performance chips and circuits exceeds $30 billion a year.


Pentium™ Chip Processing: Intel Corporation

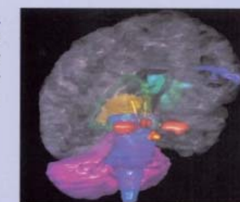

Synthetic Diamond: San Diego Supercomputer Center

NEW MATERIALS

Plasma and ion beams are used as the source of ions which, when implanted in the surface of materials, can result in new properties, such as increased hardness, decreased friction, increased smoothness, increased fatigue life, etc. Applications range from machine tools, ball bearings, and automotive components, to implants and prosthetics. Plasma and microwave technologies are also used to greatly reduce the time required to process high performance ceramics, itself a $5 billion a year industry. Plasmas alter the normal pathways through which chemical systems evolve from one stable state to another, thus providing the potential to produce materials with properties that are not attainable by any other means. Materials, including carbon fiber composites, that are more resistant to thermal shock have been developed due to the requirements of high temperature plasma experiments.

BIOMEDICAL APPLICATIONS

A wide range of medical applications can trace their origins to plasma and fusion research, from magnets used in magnetic resonance imaging (MRI) to tomography and interferometric imaging first developed to diagnose plasma experiments. Laser surgery and tissue welding, and their associated computerized controls and interpretive diagnostics, also have connections to fusion research.


Medical Imaging: San Diego Supercomputer Center

Plasma light bulb: Fusion Lighting, Inc.


NEW TECHNOLOGIES

Fusion and plasma research has opened up a wide range of new technologies and applications. High efficiency ultraviolet and visible light sources, emitted from plasmas, are in use for rapid drying of special inks, coatings, and adhesives, as well as for lighting large areas with reduced energy consumption. For example, the visible light from a golf-ball-sized plasma produced by microwaves, yields as much light as 250 one-hundred watt bulbs at a fraction of the corresponding energy consumption.

Fusion scientists developing high speed digitizers for diagnosing laser-produced plasma, have applied the technology to a new radar device, with a cost of about $20. These devices, which can fit in the palm of the hand, have many applications such as low cost surveillance systems and sensors.

FES previous example #5

- ***Summary of Opportunities in the Fusion Energy Sciences Program*** (FESAC, 1999)
  - Chapter 4: Near-Term Applications
    - Microelectronics and flat panel displays
    - Materials and manufacturing
    - Environmental applications
    - Biomedical and food-safety applications
    - Plasma propulsion

Summary of
Opportunities in the
Fusion Energy Sciences Program

Prepared by the
Fusion Energy Sciences Advisory Committee
For the
Office of Science of the U.S. Department of Energy

U.S. DEPARTMENT OF ENERGY
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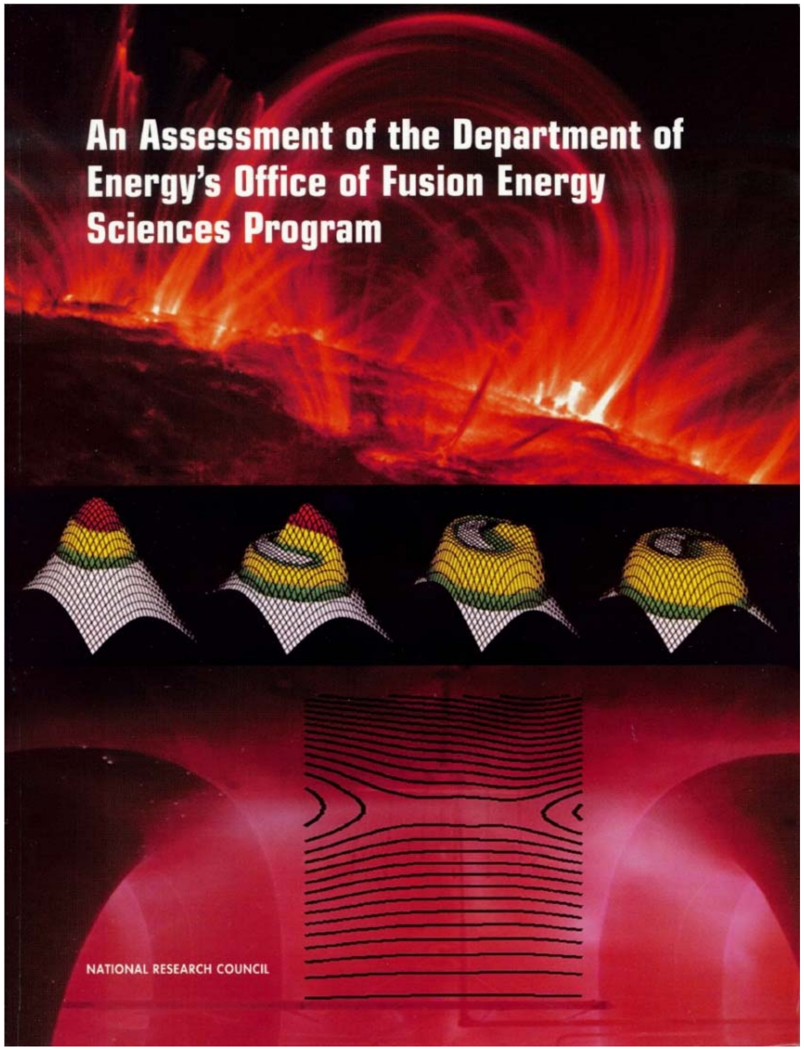
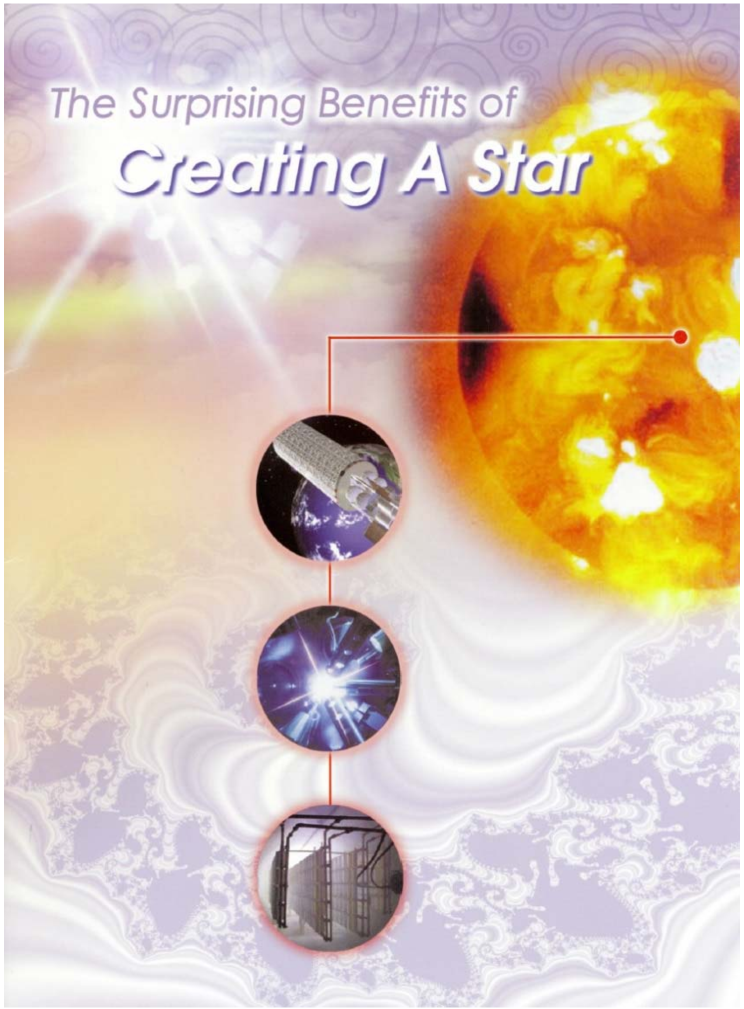
FES previous example #6

- FuSAC report (NRC, 2001)
  - Chapter 4: <u>Interactions of the Fusion Program with Allied Areas of Science and Technology</u>



FES previous example #7



Spinoffs

TECHNOLOGY
Semiconductor Manufacturing
Large area plasma etching and deposition
Extreme Ultra Violet Lithography (EUVL)
Thin film deposition EUV masks
Precision EUV optical elements
X-ray microlithography
Direct write e-beam array using nanotube electron field emitters
Ion implantation
Plasma HDTV display panel

Space Propulsion
Hall thrusters
RF drive (VASIMR Project)

Waste Remediation
Plasma torch
Waste glassification
Cryopellet ablation
Isotope separation
Microwave spallation of contaminated surfaces
Plasma-assisted catalyst
High Sensitivity Continuous Emission Monitor (CEM) for metals in stack gas

Material Processing
Laser peening
Ion beam surface modification
Microwave sintering
Enhanced Plasma Chemical Vapor
Deposition (EPCVD)
Optical material manufacturing
Rapid crystal growth
Laser machining

Pulsed Power & Power Conversion
IGBT power conversion units for trains, buses, and earth movers
Microwave Impulse Radar (MIR)
Power generation, transmission, storage, conditioning, surge limiting, & motors

Superconductivity
Nuclear Magnetic Resonance (NMR)
Superconducting cyclotrons for isotope production and neutron radiography
Superconducting synchrotrons for X-ray lithography
Magnetic separation of materials (e.g., clay)
Magnetic Resonance Imaging (MRI)

Medical/Health
Laser cavity drilling
Medical isotope separation (laser/rf)
Tissue welding
X-ray catheter
Continuous glucose monitor
Opto-acoustic laser system for blood clot emulsification
Dental imaging
Grain sterilization & milk pasteurization
Magnetic Resonance Imaging (MRI)

SCIENCE
Laboratory Astrophysics
Simulation of Supernova Instabilities
Simulation of radiatively cooled jets
Dense matter (metallic hydrogen)
Planetary science of giant planets and brown dwarf stars

Diagnostics
X-ray spectrometer
Laser anemometer
High-dynamic-range high-speed streak cameras

Code Development
Turbulence
Astrophysics
Nonlinear Dynamics
Chaos Theory

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- ***The Surprising Benefits of Creating a Star*** (Oct 2001)
  - 17-page brochure; published by GA (R. Callis, editor)

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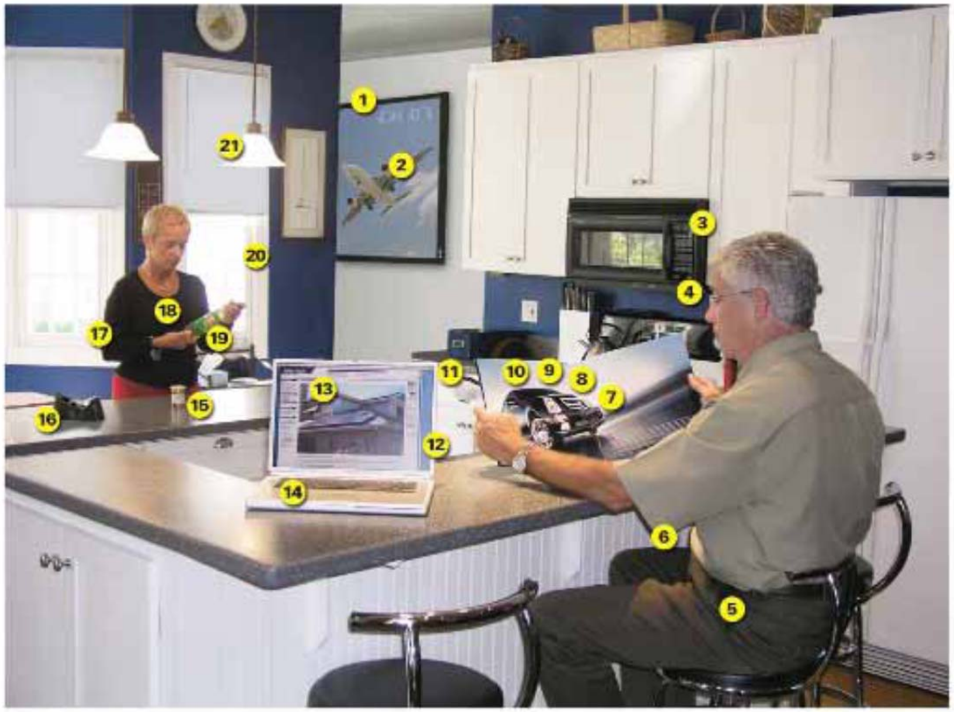
FES previous example #8



01—Plasma TV
02—Plasma-coated jet turbine blades
03—Plasma-manufactured LEDs in panel
04—Diamondlike plasma CVD eyeglass coating
05—Plasma ion-implanted artificial hip
06—Plasma laser-cut cloth
07—Plasma HID headlamps
08—Plasma-produced H_2 in fuel cell
09—Plasma-aided combustion
10—Plasma muffler
11—Plasma ozone water purification
12—Plasma-deposited LCD screen
13—Plasma-deposited silicon for solar cells
14—Plasma-processed microelectronics
15—Plasma-sterilization in pharmaceutical production
16—Plasma-treated polymers
17—Plasma-treated textiles
18—Plasma-treated heart stent
19—Plasma-deposited diffusion barriers for containers
20—Plasma-sputtered window glazing
21—Compact fluorescent plasma lamp

Plasmas in the Kitchen

Plasmas and the technologies they enable are pervasive in our everyday life. Each one of us touches or is touched by plasma-enabled technologies every day. Products from microelectronics, large-area displays, lighting, packaging, and solar cells to jet engine turbine blades and biocompatible human implants either directly use or are manufactured with, and in many cases would not exist without, the use of plasmas. The result is an improvement in our quality of life and economic competitiveness.

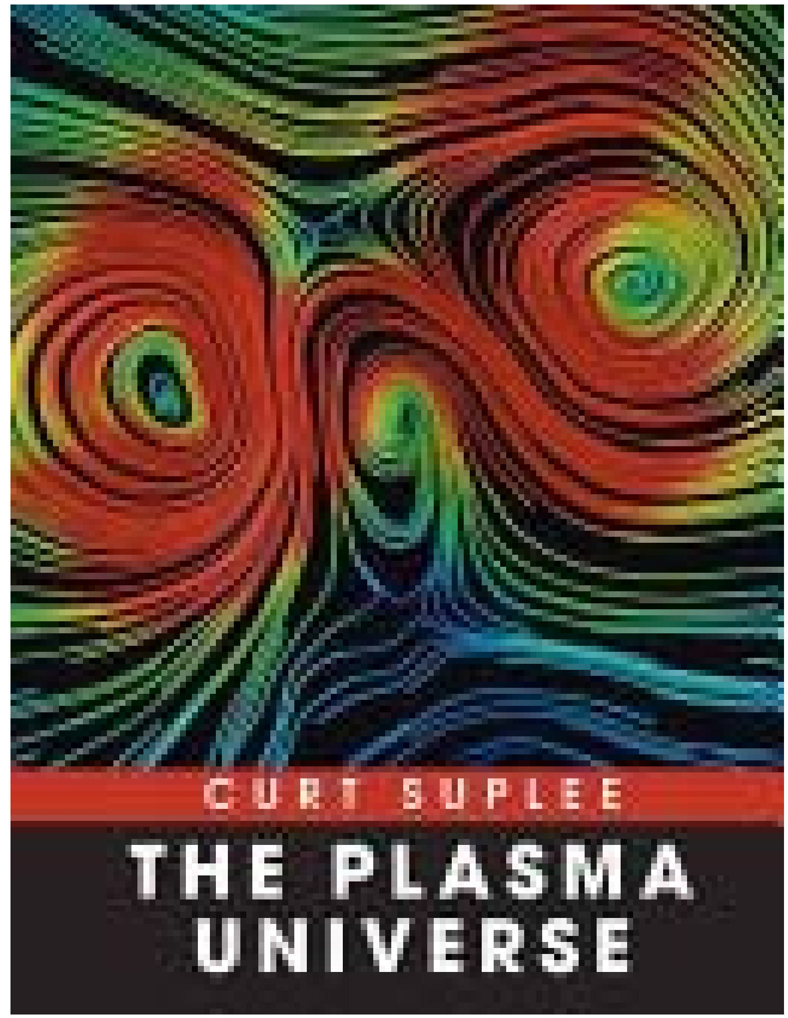
[borrowed from talk by M. Kushner]

Low Temperature Plasma Science (DOE workshop report, 2008):
Chap 1: <u>Science Challenges and Societal Benefit</u>

FES previous example #9

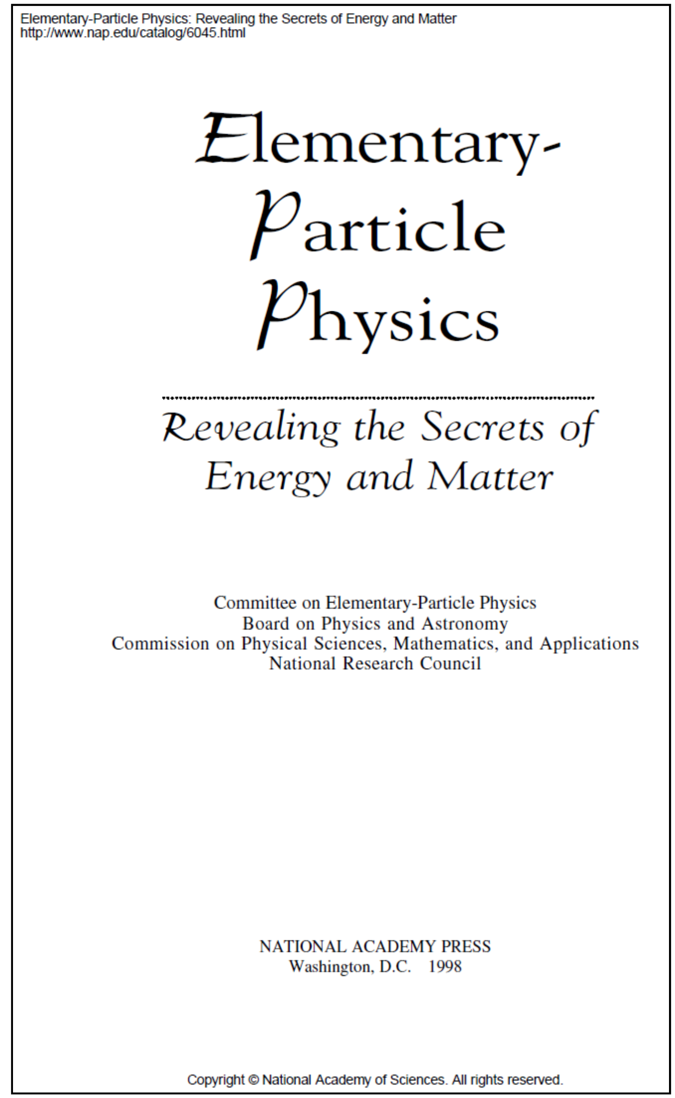
- ***The Plasma Universe***, by Curt Suplee (Cambridge University Press, 2009, 88 pp)
  - Chapter 6: Putting Plasmas to Work
    - A plasma to read by
    - Walls of light
    - Withdrawal and deposits
    - Plasmas and human health
    - When push comes to shove

- Publication was sponsored by APS-DPP for its semi-centennial annual meeting (Nov 2008)
  - Edited by A. Bhattacharjee
  - Copyrighted by APS-DPP



High Energy Physics example #1

- **"Interactions with and Connections to Other Branches of Physics and Technology"** (14 pp, Chapter 9 of NRC/NAS report, 1998)
  - Cosmology
  - Astrophysics
  - Nuclear physics
  - Atomic physics
  - Condensed-matter physics
  - Fluid dynamics
  - Mathematics and computational physics



Elementary-Particle Physics: Revealing the Secrets of Energy and Matter
http://www.nap.edu/catalog/6045.html

Elementary-Particle Physics

Revealing the Secrets of Energy and Matter

Committee on Elementary-Particle Physics
Board on Physics and Astronomy
Commission on Physical Sciences, Mathematics, and Applications
National Research Council

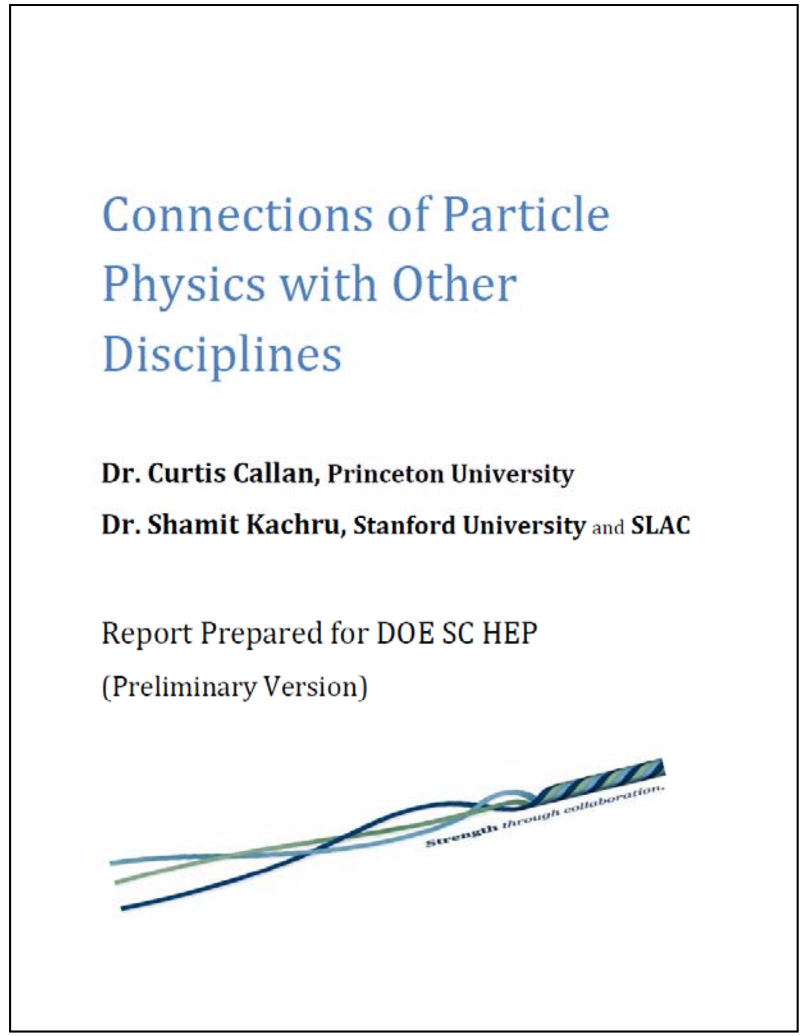
NATIONAL ACADEMY PRESS
Washington, D.C. 1998

High Energy Physics example #2

- ***Accelerators for America*** (symposium report, 2010)
  - Energy & environment
  - Industry
  - Medicine
  - National security
  - Discovery science

High Energy Physics example #3

- **HEP Science Connections & Partnerships Overview** (2013)
  - Non-HEPAP task force charged to update the 1998 NRC report (especially in the neglected areas of climate research, biosciences, economics, and national security)
  - Draft report: ***Connections of Particle Physics with Other Disciplines*** (C. Callan and S. Kachru, Feb 2014)



Connections of Particle Physics with Other Disciplines

Dr. Curtis Callan, Princeton University

Dr. Shamit Kachru, Stanford University and SLAC

Report Prepared for DOE SC HEP

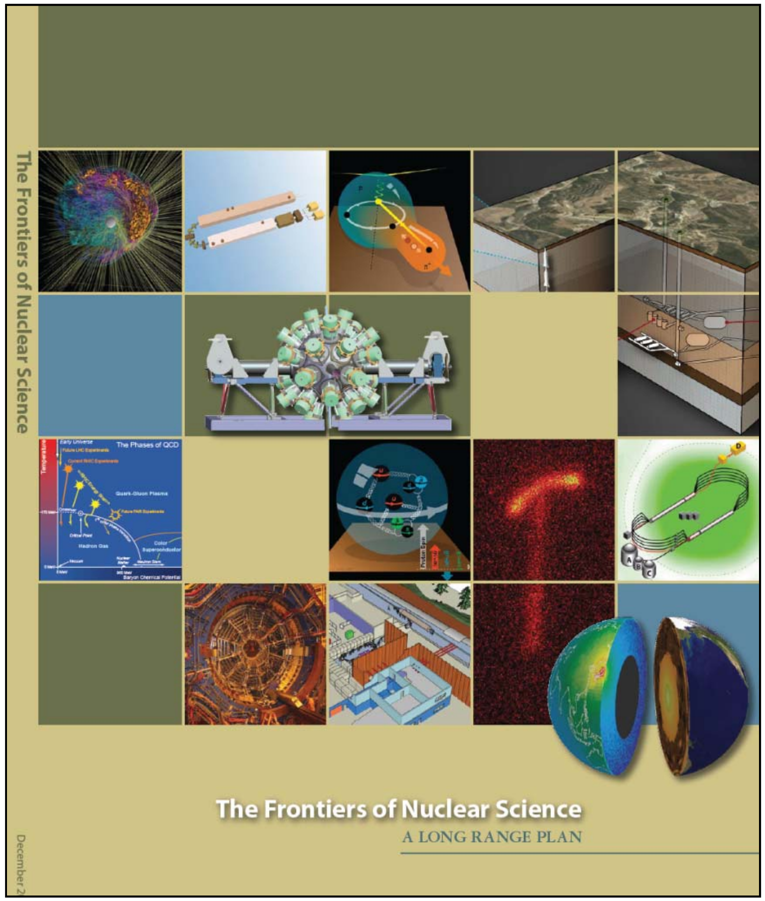
(Preliminary Version)

Nuclear Physics example #1

- ***Opportunities in Nuclear Science: A Long Range Plan for the Next Decade*** (NSAC report, 2002)
  - Chapter 4, Section 4: <u>Impacts and Applications</u>

Nuclear Physics example #2

- ***The Frontiers of Nuclear Science: A Long Range Plan*** (NSAC report, 2007)
  - Chapter 5: The Broader Impacts of Nuclear Science
  - Connections to other fields; applications



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Nuclear Physics example #3

- ***Nuclear Physics: Exploring the Heart of Matter*** (NRC/NAS decadal report, 2012)
  - Chapter 3: Societal Applications and Benefits
  - Sidebar highlights:
    - Diagnosing cancer with PET
    - The Fukushima event—a nuclear detective story
    - Nuclear crime scene forensics

Nuclear Physics: Exploring the Heart of Matter

Nuclear Physics

Exploring the Heart of Matter

Committee on the Assessment of and Outlook for Nuclear Physics

Board on Physics and Astronomy

Division on Engineering and Physical Sciences

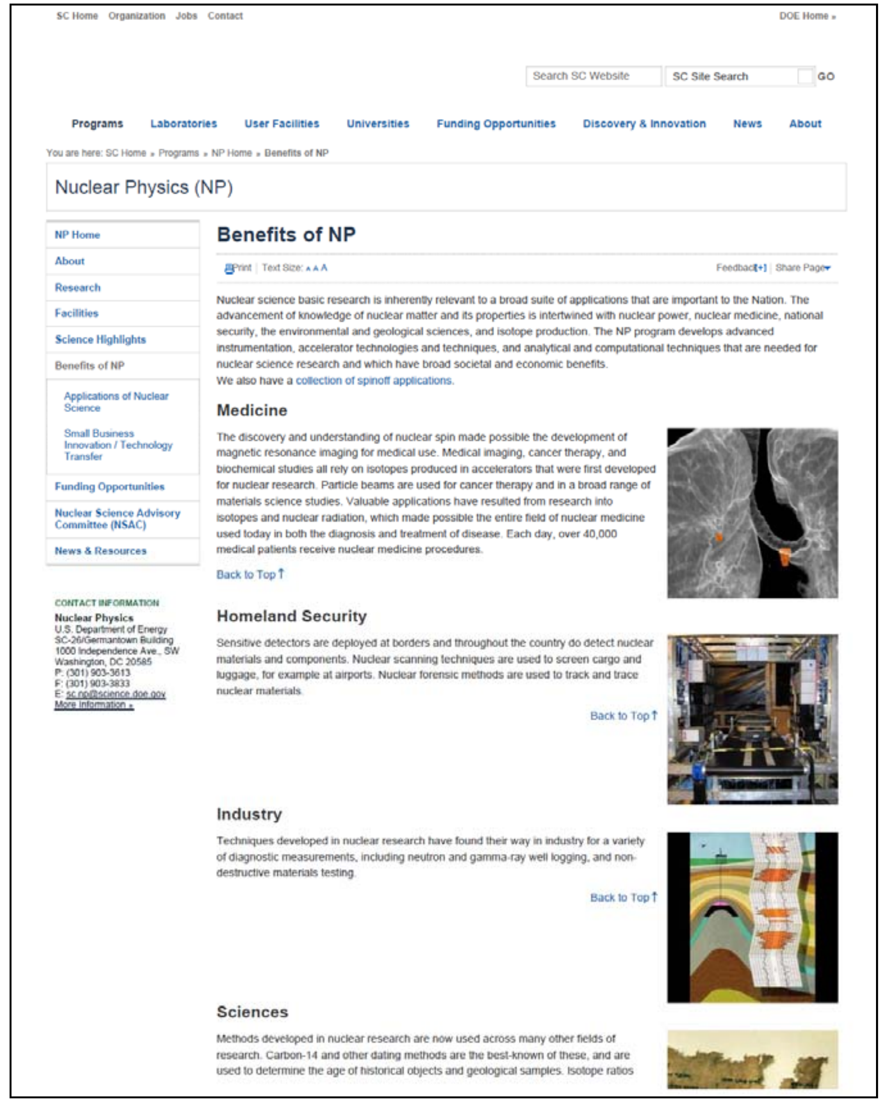
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

Nuclear Physics example #4

- Dedicated page (***Benefits of NP***) and subpage (***Applications of Nuclear Science***) on the Office of Nuclear Physics web site

- Examples from
  - Medicine
  - Homeland security
  - Industry
  - Sciences
  - Workforce development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Nuclear Physics (NP)

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E: sc.np@science.doe.gov
More Information »

Benefits of NP

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Nuclear science basic research is inherently relevant to a broad suite of applications that are important to the Nation. The advancement of knowledge of nuclear matter and its properties is intertwined with nuclear power, nuclear medicine, national security, the environmental and geological sciences, and isotope production. The NP program develops advanced instrumentation, accelerator technologies and techniques, and analytical and computational techniques that are needed for nuclear science research and which have broad societal and economic benefits.
We also have a collection of spinoff applications.

Medicine

The discovery and understanding of nuclear spin made possible the development of magnetic resonance imaging for medical use. Medical imaging, cancer therapy, and biochemical studies all rely on isotopes produced in accelerators that were first developed for nuclear research. Particle beams are used for cancer therapy and in a broad range of materials science studies. Valuable applications have resulted from research into isotopes and nuclear radiation, which made possible the entire field of nuclear medicine used today in both the diagnosis and treatment of disease. Each day, over 40,000 medical patients receive nuclear medicine procedures.

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Homeland Security

Sensitive detectors are deployed at borders and throughout the country do detect nuclear materials and components. Nuclear scanning techniques are used to screen cargo and luggage, for example at airports. Nuclear forensic methods are used to track and trace nuclear materials.

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Industry

Techniques developed in nuclear research have found their way in industry for a variety of diagnostic measurements, including neutron and gamma-ray well logging, and non-destructive materials testing.

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Sciences

Methods developed in nuclear research are now used across many other fields of research. Carbon-14 and other dating methods are the best-known of these, and are used to determine the age of historical objects and geological samples. Isotope ratios

New Charge: The WHEN

- **Congressional language**: 180 days after FY 2015 budget enactment
  – Dec 10, 2014 + 180 days = ~ June 10, 2015

- **Extension**: Possible to request this

New Charge: The WHO

- Charge will be addressed by a subcommittee
  - Being set up by FESAC chair, in consultation with FES
- Input will be solicited from the entire FES community