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Development of a Comprehensive Environmental Technologies List for the U.S. Department of Energy

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INTRODUCTION

Upon completion of the National Energy Strategy of 1991, the U. S. Department of Energy (DOE) initiated a periodic review of its technology research and development (R&D) program. DOE began this review process to ensure that maximum national benefit is gained from federal investment. One main goal of the review is to align DOE's R&D projects with national priorities. The following six priorities (not in any order) were identified by the administration as national goals to be considered for assessing R&D activities that would be included in the Fiscal Year 1996 Budget[1]:

1. A healthy, educated citizenry;
2. Job creation and economic growth;
3. World leadership in science, mathematics, and engineering;
4. Improved environmental quality;
5. Harnessing information technology; and
6. Enhanced national security.

DOE's Office of Policy was assigned the task of evaluating R&D activities, and in 1992, developed a method for assessing energy technologies. An energy technologies taxonomy was developed as the focal point of the assessment process. The energy technologies taxonomy consisted of 12 technology groups (e.g., coal and related technologies, fusion energy and related technologies, renewable energy and related technologies), 75 technology areas (e.g., advanced coal liquefaction, inertial fusion energy technology, high temperature solar systems), and 300 subtechnologies (e.g. biological liquefaction, photon implosion, central receiver heliostat). Three working groups were established to assess contributions of these energy technologies in achieving three strategic goals: energy security, economic growth, and environmental quality, respectively. Each working group evaluated technologies based on potential benefits (e.g., improves preparedness for potential oil supply disruptions, stimulates economic performance and competition, and reduces the emissions of greenhouse gases) and risks (e.g., technological, economic, and societal)[2]. In 1993, the three working groups reported their rankings to DOE based on this benefit and risk analysis[3,4,5].

With lessons learned through the initial assessment of energy technologies and with a new vision outlined in DOE's new strategic plan[6], the Office of Policy determined that assessment of R&D activities should extend beyond energy technologies and consider all DOE technology R&D programs, including environmental and dual-benefit defense programs. Of particular importance is the consideration of how well environmental technology R&D activities support the paradigm shift toward sustainable development. Sustainable development, defined in the Clinton Administration's Report titled *Technology for a Sustainable Future*[7] as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," is dependent on effective environmental technologies. The importance of environmental technologies is echoed in DOE's Strategic Plan in which one specific goal is stated as: "By the Year 2005, [DOE will] be a leading Federal Agency in environmental technology development focused on the Nation's needs.[8]"

LISTING ENVIRONMENTAL TECHNOLOGIES

Before initiating the assessment process, DOE's Office of Policy commissioned the authors to develop an environmental technology list. DOE requested that the list be comprehensive (i.e., the maximum possible environmental technology areas of national interest be represented) and recommended that it should include energy technologies from the energy technology taxonomy that have a clear overall benefit to the environment. As a first step in creating the list, environmental technologies were defined as "technologies that advance sustainable development by reducing risk, enhancing cost effectiveness, improving process efficiency, and creating products and processes that are environmentally beneficial or benign" (note that the word technology is intended to include hardware, software, systems, and services)[9].

Environmental technologies were listed within a hierarchy of technology definitions and relationships. The list was organized with three hierarchal levels: (1) technology categories, of which there are four; (2) technology areas, of which there are forty; and (3) representative technologies, of which there are more than one hundred. The ranking of technologies would occur at the second level, that is, on the technology areas. The four general environmental technology categories were obtained from the Administrations's Report *Technology for a Sustainable Future*[10] and are:

1. *Monitoring and Assessment* technologies that establish and monitor the condition of the environment;

2. *Avoidance* technologies that reduce or eliminate the production of environmentally hazardous substances;

3. *Remediation and Restoration* technologies that render harmful or hazardous substances harmless after they enter the environment and improve ecosystems that declined due to naturally induced or anthropogenic effects; and

4. *Control* technologies that reduce the hazard from substances before they enter the environment.

The resulting environmental technology list is shown in Table 1. In this table, technology areas are numbered in two columns, A and B. Technologies numbered under column B are energy technologies considered by the authors to have an overall benefit to the environment. Technologies listed under column A are to be assessed exclusively as environmental technologies. Energy technologies are categorized in a separate energy technologies list and column B numbers correspond directly to numbering in that list.

Technology areas and representative technologies were grouped based on information from several sources to facilitate a thorough assessment of future research programs. These sources are listed below.

Environmental Technologies Industry and Global Markets - A Supplement to Environmental Technologies Export: Strategic Framework for U.S. Leadership[11]. This report outlines the background and issues supporting the national strategy which was developed to deploy U.S. Government resources most effectively to increase environmental technologies exports.

U.S. Department of Energy Office of Environmental Restoration and Waste Management, Office of Technology Development: A National Program[12]. This FY 1993 report summarizes significant programmatic information relevant to activities within DOE's Office of Technology Development Program for Research, Development, Demonstration, Testing, and Evaluation (RDDT&E).

U.S. Department of Energy Office of Environmental Management: Technology Catalogue[13]. This catalogue provides performance data on developing environmental technologies for scientists and engineers.

U.S. Department of Energy Crosscut Matrices and Program Inventory Sheets for FY 1994[14]. These sheets detail most major research programs within DOE.

Environmental Technologies from the Department of Energy's Facilities in Oak Ridge, Tennessee[15]. This document contains fact sheets that summarize technology projects sponsored by the DOE's Office of Technology Development.

Technology Transfer 94[16]. This DOE document communicates opportunities available to U.S. industry and academic institutions to work with DOE and its national laboratories.

Technology and Task Descriptions[17]. This document by the National Defense Center for Environmental Excellence lists descriptions of environmental technologies.

Environmental Technology Initiative: FY 1994 Program Plan[18]. A report that identifies the U.S. Environmental Protection Agency's (EPA) initial priority areas for environmental technologies and funding research into innovative environmental technology R&D.

Remediation Technologies Screening Matrix and Reference Guide[19]. This reference guide and screening matrix are designed to help project managers, scientists, and engineers in determining remediation alternatives and identify technologies for remedial action.

Environmentally Conscious Manufacturing Technology in Federal Facilities and the Private Sector[20]. A paper describing the Pollution Prevention Program, specifically Environmentally Conscious Manufacturing, and the associated technologies being developed by DOE and other agencies.

CONCLUSION

The environmental technologies list represents a comprehensive general register of current environmental technology areas. From this list, technology areas may be assessed and ranked by expert working group panelists in terms of benefits and risks. These rankings may then be used as an aid to decision makers who need to optimize resource allocations and plan a R&D portfolio that best supports sustainable development. Note that the list and subsequent ranking process are just two of many tools that decision makers would use for planning purposes. The establishment of final priority would remain the responsibility of national policy makers.

Updates of the environmental technologies list would be required periodically to ensure that major technology areas are represented. Additional adjustment may be required in terms of the general categories in which the technologies are grouped based on changing national priorities and advancing technologies. Despite the need or use, the list needs to be dynamic to remain useful in any decision making process.

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Table 1. Environmental Technologies List

Number[1]		Technology Area	Representative Technologies
A	B		
Monitoring and Assessment			
1		Advanced air monitoring	Air quality boundary monitoring for VOCs Continuous emissions monitors for hazardous air pollutants Microwave plasma analyzer for real-time off-gas analysis Miniature elastic backscattering lidar
2		Advanced radon monitoring and assessment	Transport of radon in buildings Physical/chemical reaction of radon progeny in air
3		Advanced sensors and controls	Advanced fiber-optic sensor systems Spectroelectrochemical sensors Neutron activation logging system SEAMIST membrane liner Laser raman spectroscopy for tank waste characterization
4		Remote sensing systems	Broadband Electromagnetics X-ray fluorescence
5		Non-invasive geophysical characterization technologies	Seismic imaging High resolution infrared imaging Electromagnetic imaging used to characterize buried waste High speed digital and computed tomography
6		Real time field characterization	Cone penetrometer On-site infrared analysis Real time surface water analysis The colloidal borescope Portable acoustic wave sensor Absorptive stripping voltametry

[1] Technology areas are numbered in two columns, A and B. Technologies numbered under column B are energy technologies considered to have an overall benefit to the environment. Energy technologies are categorized in a separate energy technologies list. Column B numbers correspond directly to numbering in that list. Technologies listed under column A are to be assessed exclusively as environmental technologies.

Table 1. Environmental Technologies List (continued)

Number[1]		Technology Area	Representative Technologies
A	B		
Monitoring and Assessment (continued)			
7		In-situ soil and groundwater monitoring	In-situ secondary ion mass spectroscopy analysis Directional drilling Sonic drilling Microbial monitoring Soil surface monitoring using long-range alpha detector
8		Robotics in characterization and monitoring applications	Light-duty utility arm system for tank characterization
9		Advanced air dispersion modeling	Fine particle modeling and statistical research Ozone assessment models Research in visibility reduction Wet and dry deposition modeling Atmospheric flow in complex terrain
10		Global climate change / greenhouse gas effects research	Atmospheric radiation measurement program and dynamics Ocean CO_2 transfer research Earth CO_2 history research Plant/microbial CO_2 fixation research Ecosystem research
11		Advanced soil and groundwater contaminant plume transport models	Integrated data modeling and prediction tools
12		Advanced tank remediation models	Transuranic extraction (TRUEX) model
13		Advanced risk assessment methods	Epidemiology and health surveillance

[1] Technology areas are numbered in two columns, A and B. Technologies numbered under column B are energy technologies considered to have an overall benefit to the environment. Energy technologies are categorized in a separate energy technologies list. Column B numbers correspond directly to numbering in that list. Technologies listed under column A are to be assessed exclusively as environmental technologies.

Table 1. Environmental Technologies List (continued)

Number[1]		Technology Area	Representative Technologies
A	B		
Avoidance			
	24-25	Fusion Energy	Magnetic fusion energy technologies Advanced inertial fusion reactor technologies
	19-21	Fission energy	Advanced light water and other fission reactors Improved fission fuel cycles
	32	Biomass fuels	Gaseous fuels Ethanol, methanol and diesel fuels from biomass Improved production and harvesting technologies Improved plant species Improved biomass combustion processes
	29-31 and 33-36	Other renewable energy sources	Advanced photovoltaic technologies High-temperature solar systems Improved wind energy technologies Ocean energy Geothermal energy Municipal solid waste energy
	12	Industrial gas fueled turbine systems	Ultra-high efficiency turbines
	14, 16, and 17	Advanced coal systems	Improved coal combustion systems Advanced coal gasification Coal fueled heat engines
	26-28	Hydrogen production, transport, storage and use technologies	Hydrogen fuel cells Hydrogen fueled internal combustion engines Improved electrolysis of water Hydrogen from biomass Improved LH2 liquification/transport/storage

[1] Technology areas are numbered in two columns, A and B. Technologies numbered under column B are energy technologies considered to have an overall benefit to the environment. Energy technologies are categorized in a separate energy technologies list. Column B numbers correspond directly to numbering in that list. Technologies listed under column A are to be assessed exclusively as environmental technologies.

Table 1. Environmental Technologies List (continued)

Number[1]		Technology Area	Representative Technologies
A	B		
Avoidance (continued)			
	37-42	Efficiency and energy conservation technologies in commercial and residential building	Solar building heating/cooling Improved daylighting Electric lighting improvements Efficient appliances Improved HVAC Advanced building materials and envelopes
	48-52	Efficiency and energy conservation in industrial process	Improved sensors and controls Advanced industrial combustion processes Advanced process heating and cooling Industrial cogeneration Improved electric drives
	55-63	Advanced transportation technologies	Improved auto and truck systems Electric, hybrid and alternative fueled vehicles Intelligent vehicle/highway systems Increased efficiency in air and ground mass transportation Transportation demand reduction
	64-68	Advanced electricity conversion technologies	Advanced conversion techniques Utility fuel cell conversion Electricity storage technologies Advanced transmission and distribution technologies
14		Environmentally conscious manufacturing methods	Chlorinated and CFC solvent replacement Laser and other dry process cleaning of surfaces Polymer replacements Near net shape forming Plasma spray coating

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Table 1. Environmental Technologies List (continued)

Number[1]		Technology Area	Representative Technologies
A	B		
Avoidance (continued)			
15		Stratospheric ozone protection technologies	CFC replacement with HCFCs
16		In-process recycling (zero discharge of pollutants)	Waste acid detoxification reclamation of metals Gas and dust recovery systems Advanced recovery of residues Zero discharge electroplating
17		Life cycle assessment	
18		Oil spill avoidance	Improved oil collection systems Improved oil tanker designs
19		EMF exposure avoidance technologies	
20		Advanced ecological impact avoidance technologies	Improved aquatic life protection technology
21		Environmental education programs	K-12 outreach programs Graduate and postdoctoral fellowships

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Table 1. Environmental Technologies List (continued)

Number[1]		Technology Area	Representative Technologies
A	B		
Remediation and Restoration			
22		Contaminated soil and groundwater containment techniques	Cryogenic (frozen soil) barriers Viscous liquid physical barriers Hydraulic diffusion barriers Chemical barriers Horizontal barriers
23		Advanced in situ soil and groundwater decontamination technologies	In situ bioremediation In situ magnetic separation In-situ chemical and electrochemical treatment In situ vitrification In situ thermal treatment In situ air stripping Advanced DNAPL restoration techniques
24		Permeable filter barrier technologies	Chemically enhanced barriers Biological filters Slurry walls
25		Innovative soil washing techniques	
26		Advanced tank remediation technologies	Flowable grout skin barriers Biological destruction of tank waste
27		Robotics technologies used in remediation and restoration	Integrated log reach arm systems for tank remediation
28		Oil spill mitigation	Biological treatment technologies
29		Innovative technologies for facility transitioning, decommissioning and final disposition	Advanced concrete decontamination and dismantlement Advanced metal decontamination and dismantlement

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Table 1. Environmental Technologies List (continued)

Number[1]		Technology Area	Representative Technologies
A	B		
Control			
30		Advanced waste stabilization and retrieval technologies	Arc melter vitrification Polymer encapsulation Sulfur polymer cement Cryogenic retrieval
31		Efficient waste separation and pretreatment processes	Innovative radionuclide separation technologies In situ magnetically-assisted chemical separation Soil washing Titanate ion exchange Pyrochemical treatment processes Innovative chemical separation
32		Advanced waste destruction technologies	Innovative thermal processes with closed loop off-gas systems Molten salt oxidation Chemical and electrochemical oxidation processes Advanced wet oxidation techniques Biological treatments
33		Robotics in waste management applications	Robotics remote excavation system Robotics drum opening and emptying system
34		Innovative waste minimization technologies	Biodegradable consumer goods packaging Remanufacturing of used hardgoods Composting Use/conversion of post-consumer wastes Advanced municipal waste incineration techniques Minimization of industrial process wastes

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Table 1. Environmental Technologies List (continued)

Number[1]		Technology Area	Representative Technologies
A	B		
Control (continued)			
35		Nuclear waste management	Permanent nuclear waste repository Monitored retrievable storage Improved waste separation and processing Dry cask storage Improved mixed waste management In-reactor actinide burning Advanced waste disposal and storage forms
36		Advanced air pollution control technologies - stationary sources	NO_x control by hybrid technologies
37		Improved control of transportation emissions	Lean-burn catalysts Improved evaporative emissions control Diesel exhaust cleanup technologies After-treatment for particulate matter and NO_2
38		Advanced water treatment technologies	Aerobic/anaerobic treatment of wastewater Treatment systems for removal of multi-contaminants
39		Greenhouse gas mitigation technologies	CO_2 well injection Oceanic disposal of CO_2 Improved plant/microbial enzymes for CO_2 CO_2 recovery and reuse Landfill methane extraction and recovery
40		Coal preparation and effluent technologies	Low rank coal benefication processes Microbial desulfurization Coal pre-combustion cleaning and treatment Ceramic filtering of particulate matter Alkali metals removal Flue gas scrubber systems

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