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DIFFUSION OF WASTE TECHNOLOGIES AND ITS POTENTIAL IMPACT ON RESEARCH AND DEVELOPMENT

A. L. RIVERA

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Chemical Technology Division
Waste Management Technology Center

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A. L. Rivera

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DIFFUSION OF WASTE TECHNOLOGIES AND ITS POTENTIAL IMPACT ON RESEARCH AND DEVELOPMENT

A. L. Rivera

ABSTRACT

The concept of waste technology diffusion as a driving force in research and development (R&D) planning is discussed. Technology diffusion is presented as a mechanism that supports the definition of R&D needs and priorities. The greatest barriers to continuing innovation are waste technology diffusion and uncertainty over performance. Consequently, there is no substitute for real-life demonstrations in high-leveraged applications. This technology demonstration phase is critical in the formulation of the issues, questions, and priorities to be addressed by technology R&D activities.

1. INTRODUCTION

The rapid expansion of environmental regulations has stimulated a growth in the hazardous waste management industry. Business opportunities exist for companies that can provide products and services which assure generators that their hazardous wastes are properly managed. Licensed commercial treatment, storage, and disposal (TSD) facilities offering services that provide off-site management have emerged. In addition, waste management services such as transporters and brokers have emerged to complement the services provided by TSD facilities.

Generators of hazardous waste, particularly the small quantity generators, will be turning increasingly to outside specialists for TSD services as they attempt to comply with the increasing requirements of federal and state regulations. The management of hazardous waste generated $1.3 billion to $2 billion in 1983 and was projected to reach $5 billion in 1988.[1] This growth in the waste management industry could support the increase in the diffusion of waste technologies.

Most of the technology portfolio of the hazardous waste industry that is presented in Table 1 has evolved under different industrial contexts. The development of technology has been characterized by

Table 1. Waste technology codes used to report the handling of hazardous wastes in a facility which has interim status or a permit.

Storage methods ("S" codes)	Treatment methods ("T" codes): Thermal	Chemical	Physical[a]	Physical[b]	Biological	Disposal methods ("D" codes)
S01 Container (barrel, drum, etc.)	T06 Liquid injection incinerator	T19 Absorption mount	T35 Centrifugation	T48 Absorption - molecular sieve	T67 Activated sludge	D79 Underground injection
S02 Tank	T07 Rotary kiln incinerator	T20 Absorption field	T36 Clarification	T49 Activated carbon	T68 Aerobic lagoon	D80 Landfill
S03 Waste pile	T08 Fluidized bed incinerator	T21 Chemical fixation	T37 Coagulation	T50 Blending	T69 Aerobic tank	D81 Land treatment
S04 Surface impoundment	T09 Multiple hearth incinerator	T22 Chemical oxidation	T38 Decanting	T51 Catalysis	T70 Anaerobic lagoon	D82 Ocean disposal
S05 Other (specify details)	T10 Infrared furnace incinerator	T23 Chemical precipitation	T39 Encapsulation	T52 Crystallization	T71 Composting	D83 Surface impoundment (to be closed as a landfill)
	T11 Molten salt destructor	T24 Chemical reduction	T40 Filtration	T53 Dialysis	T72 Septic tank	D84 Other (specify details)
	T12 Pyrolysis	T25 Chlorination	T41 Flocculation	T54 Distillation	T73 Spray irrigation	
	T13 Wet air oxidation	T26 Chlorinolysis	T42 Flotation	T55 Electrodialysis	T74 Thickening filter	
	T14 Calcination	T27 Cyanide destruction	T43 Foaming	T56 Electrolysis	T75 Trickling filter	
	T15 Microwave discharge	T28 Degradation	T44 Sedimentation	T57 Evaporation	T76 Waste stabilization pond	
	T16 Cement kiln	T29 Detoxification	T45 Thickening	T58 High gradient magnetic separation	T77 Other (specify details)	
	T17 Lime kiln	T30 Ion exchange	T46 Ultrafiltration	T59 Leaching		
	T18 Other (specify details)	T31 Neutralization	T47 Other (specify details)	T60 Liquid ion exchange		
		T32 Ozonation		T61 Liquid-liquid extraction		
		T33 Photolysis		T62 Reverse osmosis		
		T34 Other (specify details)		T63 Solvent recovery		
				T64 Stripping		
				T65 Sand filter		
				T66 Other (specify details)		

[a] Separation of components

[b] Removal of specific components

well-defined, product-driven technical requirements, resulting in desirable technology performance characteristics. The current regulatory requirements are not expressed in terms of performance objectives and criteria. As the regulations begin to evolve into performance-based standards for technology assessment, the diffusion phase of most waste technologies is expected to function as a technology demonstration arena for identifying the questions and priorities for long-term R&D in waste technology innovation.

Because the greatest barriers to continuing innovation are waste technology diffusion and uncertainty over performance, there is no substitute for real-life demonstrations in high-leveraged applications. Indeed, unless the waste technology promises a great improvement, it is unlikely to even be tried.

Diluting the effort of technology innovation by aiming at several potential applications, or seeking refinements of properties without a specific application in mind, is an invitation to failure. To get the learning curve to work, we have to get on it.

This report describes the innovation process and presents the hazardous waste technology diffusion phase as a framework for waste technology R&D management. This diffusion phase provides the field data for defining the R&D needs and priorities that could revitalize the technology innovation process in waste management.

2. TECHNOLOGY DIFFUSION AS AN ELEMENT OF INNOVATION

2.1 OVERVIEW OF THE TECHNOLOGY INNOVATION PROCESS

It is clear that throughout the 1980s, competitive advantage, new product development, new markets, productivity, and profitability will all be tied directly to technology.[2-4] The industrial winners in this era of economic imbalance and escalating competition will be those firms that seize and exploit technology as a corporate strategic weapon and as an asset that can be effectively managed in support of business and corporate strategy. Waste technology can be viewed as an asset of the waste industry in protecting the environment from the newly generated

waste and for the cleanup of the multitude of sites contaminated with hazardous and radioactive waste from past practices. Management of this critical asset could result in a competitive waste technology industry and the protection of the environment.

But, what is technology management? To borrow a definition from Peter Drucker's book, Technology Management and Society, technology is, quite simply, know-how. Innovation, as distinct from an invention or technical prototype, refers to the technology actually being used or applied for the first time. Waste technology development is aimed at a specific component of a waste stream. However, the performance of such technology depends on this waste component of interest as well as on the other components of the waste stream. Because no two waste streams are completely similar, the potential for technology innovation is enhanced. This uniqueness of nuclear and chemical waste makes the combination of waste technology and waste stream a potential area for innovation and a critical factor in technology diffusion. Some of the technologies listed in Table 1 could be selected on the basis of performance and costs and applied in solving a given waste problem. Some of the technologies are complementary in the sense that they are combined to perform as components of waste systems designed to achieve a desirable waste management performance objective.

The panorama of technological change that has occurred since the turn of the century is characterized by three distinct types of technology innovations, as shown in Table 2. For the foreseeable future, technology innovation in waste management will be a combination of the complex systems and a nuts-and-bolts type of innovation.

The process of waste technology innovation can be modeled, as shown in Fig. 1.[5] The nuts-and-bolts innovation can be carried out from conception to implementation within a single organization. Waste technology innovation of the waste systems type tends to draw on contributions from multiple organizations.

Successful innovations begin with a new idea that involves the recognition of technical feasibility and demand. At this point in time, there exists a current state of the art, or inventory of technical knowledge, on which the estimate of technical feasibility is based. At

Table 2. Three distinct types of waste technology innovations

Innovation type	Description
Waste systems	Thorough, long-range planning that ensures that the needed technologies will be available and demonstrated and that they will fit together when the final implementation stage is reached.
Radical technological breakthrough	A major radical breakthrough in technology that turns out to change the whole character of the waste industry.
Nuts-and-bolts	Focusing on technology improvement, waste form improvement, cost reduction, and quality control. This sort of innovation is more ultimately paced by economic factors than is innovation of the systems type or the breakthrough type.

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TECHNOLOGY DIFFUSION AND R&D AS ELEMENTS OF THE PROCESS OF TECHNOLOGY INNOVATION

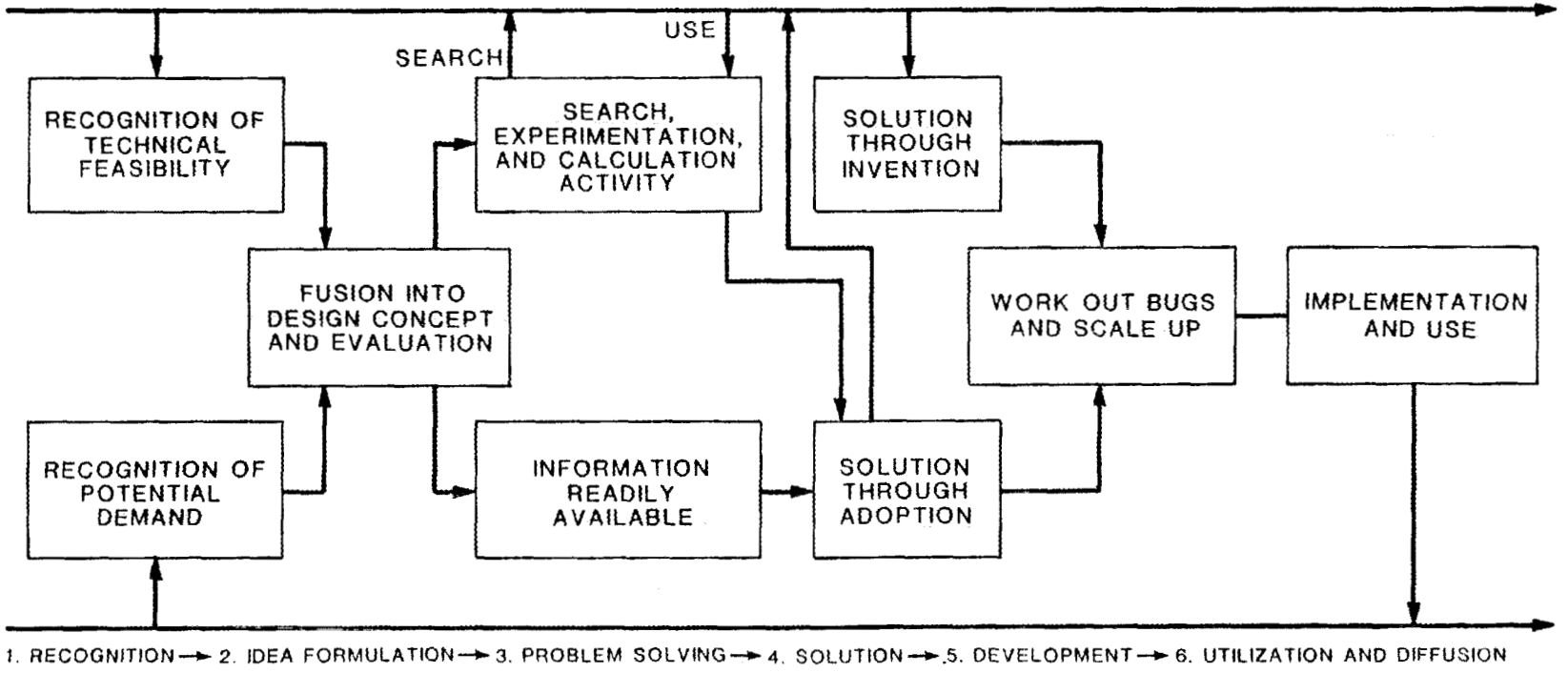

Fig. 1. Model of the innovation process.

some time, there is a current state of social and economic utilization in which the innovator can recognize an existing or potential demand.

The next stage is idea formulation, which consists of the integration of a recognized demand and a recognized technical feasibility into a design concept. Part of the idea formulation stage is really evaluation. The design concept functions as the mechanism for the identification and formulation of a problem on which it is worth committing resources to work.

The problem-solving stage then follows. In some instances, the information necessary for the solution is readily at hand in the state of the art; in others, R&D and inventive activity are called for. If problem solving is successful, a solution, often in the form of an invention, is found, and this knowledge passes into the state of the art once the patent protection is ensured. Alternatively, the problem may be solved by the adoption of an invention or other input from this pool of technical art. In this case, the ultimate technical change becomes, simply, an innovation by adoption. Some of the treatment technologies shown in Table 1 fit into this category.

Whether the solution, invented or adopted, verifies the technical feasibility and demand which were originally recognized or focuses on a modified problem with somewhat different objectives, uncertainty still remains. At this point, the development stage begins. The innovator attempts to resolve uncertainties with respect to market demand and the problems of scaling up production. **Innovation is never really achieved until the technology is introduced into the actual market, the waste management system and performance are demonstrated, or cost reductions are realized.**

Diffusion is the spreading of the innovation throughout a social system. This final stage in the innovation process occurs when the solution is first utilized and diffused into the market place. Some of the uncertainties present at the design-concept stage have been reduced, but the risks - in terms of investment - have increased. In the case of the adopted innovation, the uncertainties are less and the risks can be more accurately evaluated, which, of course, accounts for the popularity of this form of innovation.

In general, the technology innovation process as described in this section could take anywhere from 10 to 20 years (Fig. 2). Solution by adoption could shorten this time. However, the diffusion stage appears to be the limiting phase.

2.2 KEY FACTORS AFFECTING THE RATE OF DIFFUSION OF WASTE TECHNOLOGIES

As shown in Fig. 3, the key factors affecting the rate of diffusion of waste technologies are (1) the rate of implementation of new regulations, (2) public acceptance, (3) project financing, (4) the nature of future regulations, (5) mobile technologies, and (6) incentives for innovative technologies. In a 1983 study, the Office of Technology Assessment (OTA) identified three factors that could affect the rate of diffusion of waste technologies (Table 3).[6] These factors operate by diminishing the incentives for technology development and diffusion. The ban on land disposal of hazardous waste and the application of the best demonstrated available technology (BDAT) policy will induce a movement for innovative technologies in the waste treatment area. Table 4 summarizes some of the options presented by the OTA study to promote alternatives to land disposal of hazardous waste at the state level.

Public acceptance of waste systems is another factor delaying the diffusion of waste technologies. European countries have integrated centralized hazardous waste treatment facilities into broad national hazardous waste management systems.[7] The ability of the northern European countries to build and operate such sophisticated facilities in well-planned waste management systems is not simply because they are more advanced technically. Rather, the development of these facilities is dependent upon the broad acceptance of public ownership and public intervention. Public intervention has been critical in four important areas: (1) amassing the capital for construction, (2) planning the waste management system, (3) subsidizing the rate structure for operations, and (4) regulating and stabilizing the waste stream market.

Another concept used by European countries is that of creating authorities that are financed by a mix of investments from local communities, state governments, and private industry. This approach

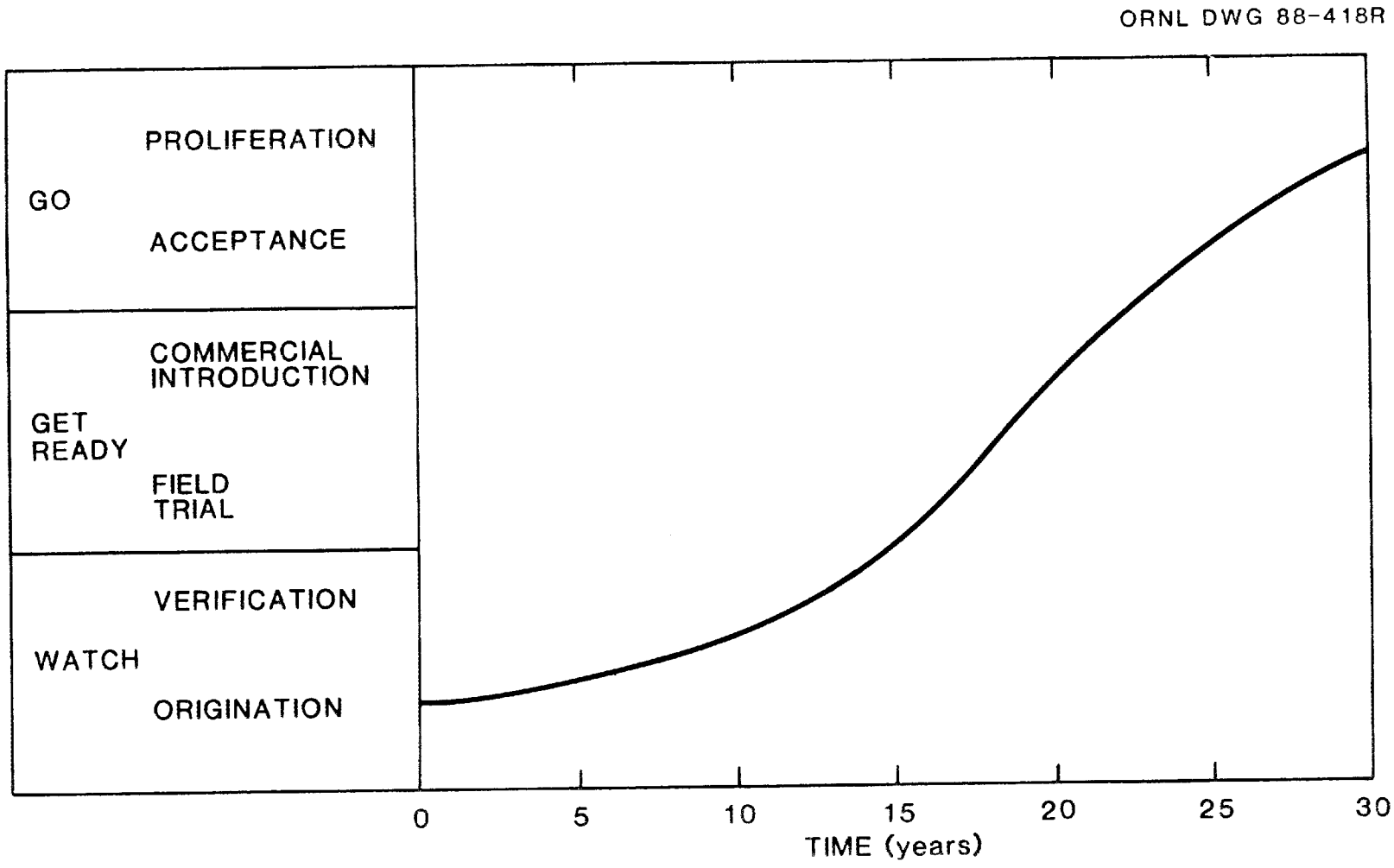

Fig. 2. Generalized path and timing of technology development.

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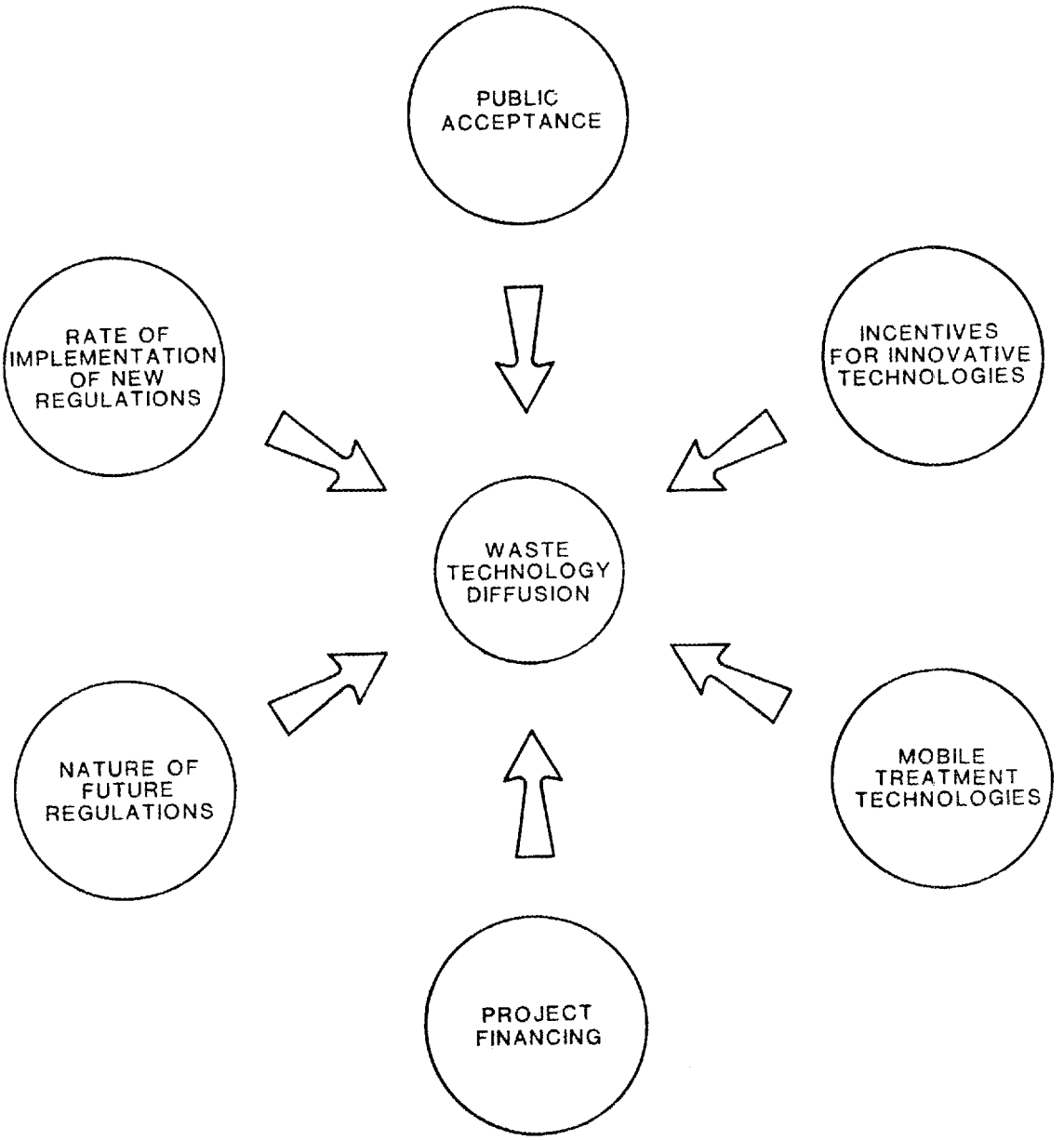

Fig. 3. Key factors with potential of affecting the diffusion rate of waste technologies.

Table 3. Summary of the Office of Technology Assessment's findings on the federal-state hazardous waste program

Finding	Impact on technology innovation
Delays in implementation of regulations	An incentive for some firms to not seek effective and economic measures to dispose of hazardous waste.
Continued use of inadequate waste technologies	Continued reliance on landfilling and other land disposal methods that have proven inadequate to contain hazardous wastes.
No incentive for innovative technologies	Need to provide the necessary incentives for promoting the use of alternative waste treatment or destruction technologies.

Table 4. Summary of state options for encouraging alternatives to land disposal of hazardous waste

State	Fee structures	Tax incentives	Bonds	State ownership	State waste management plan	Regulatory exclusions	Fast track permitting	R&D programs	Land burial restrictions
Alabama	X								
Alaska									
Arizona	X			X					X
Arkansas	X								
California	X				X			X	X
Colorado									
Connecticut	X					X			
Delaware									
Florida	X		X						X
Georgia		X	X	X					
Hawaii									
Idaho									
Illinois	X	X	X					X	X
Indiana	X	X	X			X			
Iowa									
Kansas	X						X		
West Virginia	X								
Wisconsin	X	X							
Wyoming									

provides for distributing responsibility, sharing authority, raising capital, and encouraging cooperation. In the current political climate of the United States, it is unlikely that public ownership will be readily adopted. An increasing level of American public intervention could provide the basis for such policy models in the United States.

Project financing was an innovative technique developed about a decade ago to meet the need for large-scale, energy-related projects requiring vast capital outlays and prolonged construction periods. Based on this historical background, it is possible to envision the same concepts applied to high-technology, high-capital-cost hazardous waste disposal facilities.[8] The basic credit criteria include:

- The project must involve a proven technology.
- The operation must be flexible.
- The supply of hazardous waste must be reliable.
- The operator must be able to demonstrate expertise.
- Risk sharing should be distributed among a pool of project users.
- Detailed, credible cash-flow projections should be introduced.
- A sound capital structure must be established.
- The users should be sponsors of the project.
- Contracts between the user and the project should spell out the user's obligations in the event that additional capital funds are needed.
- Postclosure liability should be addressed.

As a result of the congressional mandates contained in the Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act, many hazardous wastes will soon be banned from any type of land disposal. This regulatory bias against land disposal and the inevitable difficulties associated with siting new facilities may impair the ability to respond to the increasing demand for disposal capacity. If the waste industry faces a shortage of disposal capacity, it is anticipated that the unit cost of disposal will increase dramatically. Waste minimization could also result in increased unit costs of disposal as the waste industry attempts to recover the fixed costs of operations and the profit margins. As a result, alternative treatment technologies must be developed to safely manage and dispose of those wastes in the future. Diffusion of these technologies could be favored due to these economic incentives.

The nature of environmental regulations is anticipated to change in the future. The current trend in the development of regulations is for the use of risk assessment methodologies to establish health-based standards. These standards become ultimate goals of the regulatory system. In practice, a technology-based standard becomes the operational limits. This difference between the health-based standard and the technology-based standard creates a **technology gap.** This gap provides the incentive for investments in technology development. The risks of technology investments are reduced if the regulatory system is willing to endorse the technology and recommend it as a BDAT. In addition, this gap also represents an uncertainty for investment in fixed facilities based on technologies with a projected useful life of 20 to 30 years. Technological change can increase the financial risk in investing in these fixed facilities.

The presence of economies of scale associated with fixed facilities always leads to a cost advantage for the large-scale waste management firm (or firms that can share activities) over small-scale firms. It is assumed that large-scale waste management firms have the most efficient facilities, distributions systems, service organizations, or other functional activities for their size. Technological change may penalize these large-scale firms if facilities designed to reap scale economies are also more specialized and less flexible in adapting to new technologies.

An expanding capability in the hazardous waste industry, with potential for enhancing technology diffusion and supporting technology R&D programs, is offered by the mobile treatment technology. The market for this service has been in part stimulated by the demand for remedial actions at abandoned hazardous waste sites and the regulatory bias against land disposal. For example, the use of commercial mobile incinerators has the advantages of eliminating the use of capital costs and reducing the costs and risks associated with transportation of hazardous waste. The mobile technology reduces the investment risk associated with fixed facilities as a result of technological change.

One factor delaying the diffusion of the mobile technology is the time delay caused by the current permitting process. A recent development to improve this process was made on January 15, 1986, by a petition from the Hazardous Waste Treatment Council (HWTC) to EPA to establish a Portable Treatment Permitting Program under RCRA. The petition requests that the agency utilize two permitting mechanisms for treatment technologies which can be brought to the plant of a hazardous waste generator or any other site which needs cleanup: (1) permit by rule and (2) the consolidated statewide permit. These two options will expedite the permitting process for portable treatment technologies and expand national treatment capacity at the earliest possible dates.

3. THE ROLE OF R&D IN UNCERTAINTY REDUCTION

The main objective of technology R&D is to provide data for reducing the uncertainties in a decision-making process to more accurately evaluate the benefits, costs, and risks of implementing a proposed technological alternative. The types of data, both numerical and nonnumerical, needed in the management of hazardous waste are summarized in Table 5.[6]

The regulators need data on facilities to (1) effectively regulate them, (2) monitor compliance with the regulations, (3) select fruitful areas for R&D, and (4) perform actions required under CERCLA.

The physical and chemical characteristics of waste strongly influence the technologies that are used for its treatment. Important physical characteristics include its form — solution, solid, or sludge. Important chemical characteristics include its origin — organic or inorganic. Waste can be further characterized as acid or alkaline, concentrated or dilute. Each characteristic influences the combinations, sequences, costs, and performance of treatment and disposal options. Because of the chemical and physical diversity of waste, treatment and disposal alternatives are diverse. No single treatment and disposal process can be considered exclusively appropriate or technically correct.

Table 5. Types of data needed in the management of hazardous waste

Type of data	Description
Environmental (E)	Characterize the nature of the environment that is exposed to the waste. The data incorporate biological, ecological, geological, meteorological, and chemical characteristics, as well as all relevant transport mechanisms.
Waste (W)	Characterize a given waste. It is desirable that these data pertain to individual waste constituents and to the waste as a whole. Two types of waste characteristics are recognized: (1) physical and chemical characteristics: state (solid, liquid, gas, solution, or suspension in a liquid such as water), viscosity, density, flashpoint, corrosiveness, organic or inorganic, elements, compounds, mixtures, concentrations, chemical degradability, reactivity in ambient environments, reactivity in waste streams; and (2) biological characteristics: toxicity (including genetic effects), nature of hazard, hazard level, persistence, degradability, tendency toward bioaccumulation, fate in humans and the environment.
Facility (F)	Characterize a single facility involved in the generation, storage, recovery, treatment, or disposal of hazardous waste. These data include location, operating characteristics, input-output waste characteristics, and the nature of environmental and human exposure to hazardous constituents associated with the facility.
Technology (T)	Characterize the typical performance and costs of available management technologies (e.g., landfills, injection wells, incinerators).
State (S)	Represent the overall activity of all facilities in the state.
National (N)	Represent the overall activity of all facilities in the nation.

As a result of this decision process, waste management decision/policy makers are beginning to realize that a systems engineering approach is needed in the implementation of cost-effective, regulator-approved, technical solutions to waste management problems. A systems engineering framework for waste technology management is shown in Fig. 4.

Five fundamental questions concerning waste systems are presented as building blocks for waste technology management using a systems engineering approach:

1. What is the worth of a particular waste system?
2. Should it be built or maintained at all?
3. How should it be structured and organized?
4. How should it be controlled?
5. What are the reasonable values of costs and time for producing or maintaining it?

The framework presented in Fig. 4 suggests that the operation and control of future waste systems will be based on three critical procedures: (1) comprehensive waste acceptance criteria, (2) quality assurance, and (3) waste certification. This waste system operation and control scenario will provide performance-based requirements for waste technology management.

4. CONCLUSIONS

The following concluding observations have been drawn from this brief study of technology diffusion and its potential impact on waste technology R&D.

1. The evolution of the waste industry technology portfolio is being driven primarily by technology diffusion.
2. Innovation is never really achieved until the technology is introduced into the actual market or waste system and performance is demonstrated or cost reductions achieved.
3. The greatest barrier to continuing innovation are waste technology diffusion and uncertainty over performance. There is no substitute for real-life demonstrations in high-leveraged applications.

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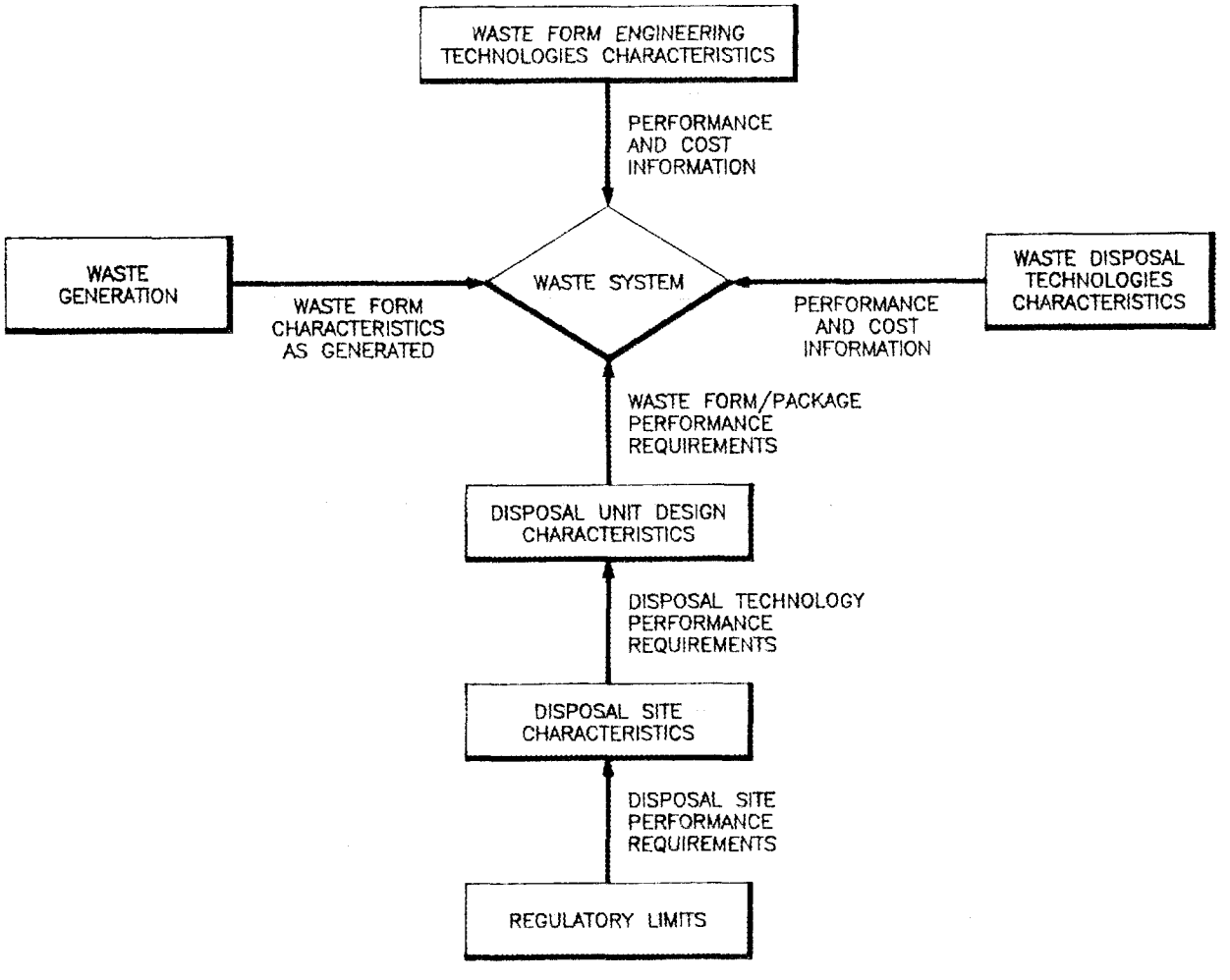

Fig. 4. Systems engineering framework for waste technology management.

4. There is a need for a systems engineering approach to waste technology management. This methodology offers a sound framework for managing the technology innovation process.

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