STRATEGIC INDUSTRY ANALYSIS: BIOTECHNOLOGY IN THE WASTE TREATMENT INDUSTRY

PREPARED FOR
INDUSTRY, SCIENCE AND TECHNOLOGY CANADA

SECOR INC.
OCTOBER 1989

TABLE OF CONTENTS

The Market

In North America, expenditures on cleaning up water and solid waste pollution were estimated at approximately $U.S. 56 billion in 1988: $U.S. 51 billion in the United States and $U.S. 5 billion in Canada. This expenditure includes both capital and operating costs. North American expenditures on air pollution control were about $U.S. 38 billion; however, no significant biotechnology applications were found in air pollution control. Consequently, this particular part of the pollution control market was excluded from further consideration.

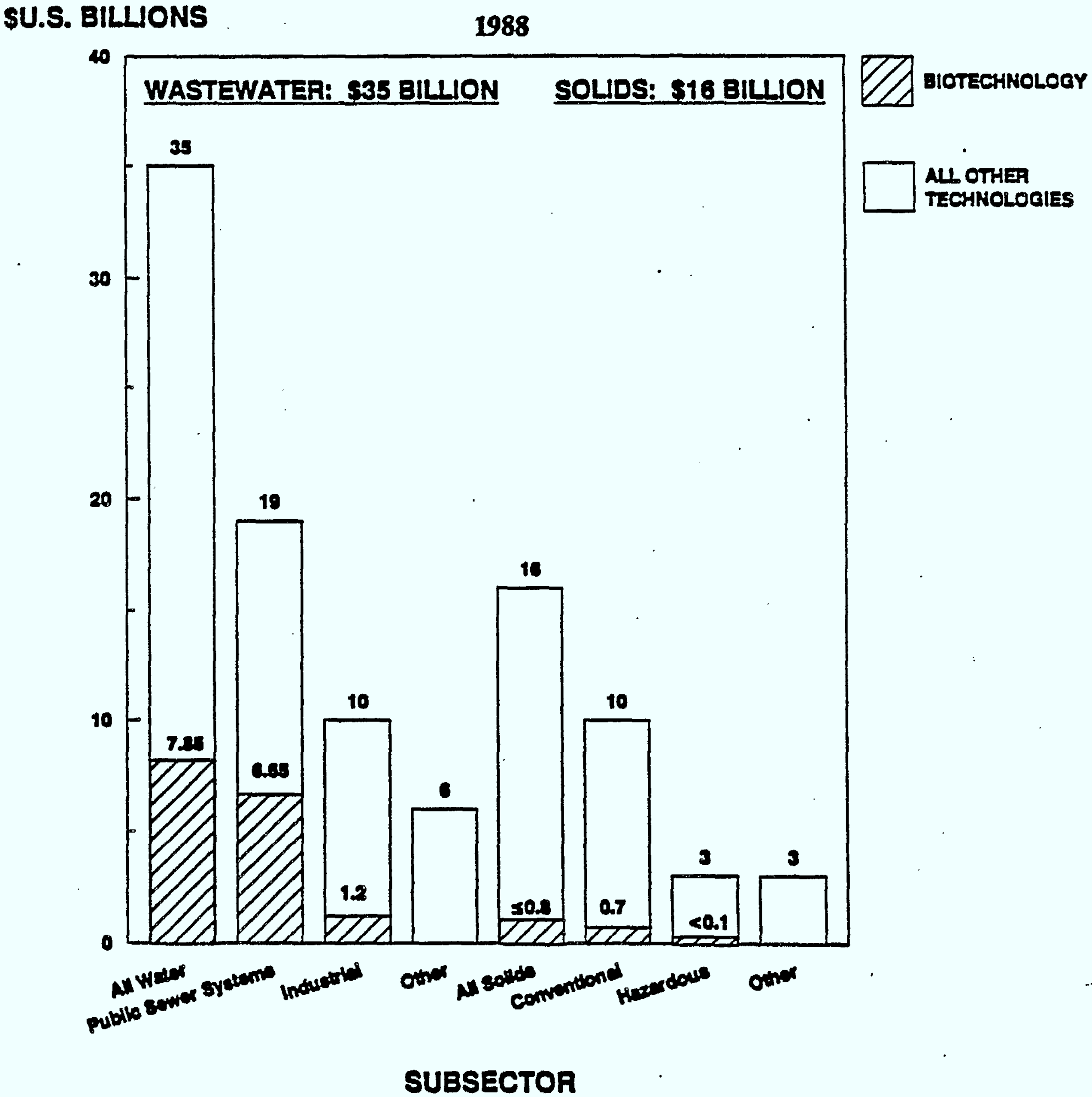
Public money predominates in the effort to control pollution. Approximately 60% of all U.S. expenditures or about $U.S. 30 billion are from public funds. In water pollution control expenditures, public money accounts for two out of every three dollars spent. Of the $U.S. 21 billion spent by the private sector, industry spends some $U.S. 9 to $11 billion on internal measures to control pollution. As a major chemical producer put it: "We handle most of our wastes ourselves". Consequently, commercial hazardous waste companies handle less than 5% of the wastes generated.

Public sewer systems are the largest market, accounting for $U.S. 19 billion or 37% of all pollution control spending on water and solid waste. Industrial expenditures on water pollution control are around $U.S. 10 billion. "Other" expenditures, for example, groundwater protection programs and measures directed at non-point sources amount to $U.S. 6 billion.

Solid waste pollution control expenditures are around $U.S. 16 billion, or approximately 31% of all pollution control spending on water and solid waste. Conventional waste, such as municipal garbage, accounts for most of this expenditure, about $U.S. 10 billion. Spending on hazardous waste, including site remediation amounts to approximately $U.S. 3 billion while other, unspecified spending is also $U.S. 3 billion.

In 1988, it is estimated that biotechnology accounted for approximately $8.6 billion or about 17% of total spending on cleaning up water and solid waste pollution. As the following graph shows, this spending is overwhelmingly concentrated in the wastewater area, public sewer systems in particular.

Biotechnology's share of annual spending on facilities investment and operations United States 1988



Market Growth

The largest market, water pollution control, is also the slowest growing market. In the United States, although total expenditures have marginally increased in constant dollars over the 1975 to 1985 period, growth in capital expenditures has slowed. Capital spending is down 30% for industrial facilities and 22% for public sewer systems. By the same measure, Canadian capital expenditures on public sewer systems declined 39%. In effect, the great capital investment in water pollution control was made in the 1970s, in both the public and private sectors. Consequently, new capital expenditures will decline in real terms to the turn of the century. However, operating expenditures for the huge base of installed systems are increasing.

Conventional waste disposal expenditures, such as those for municipal garbage, will expand in step with GNP or slightly more to the year 2000. Site remediation, driven largely by public funding, will continue to expand rapidly. Hazardous waste treatment, especially on-site services, is expected to grow the fastest of all.

Demand Drivers

Regulation is the basic impetus behind spending on pollution control. Regulation is stronger in the United States where there has historically been an adversarial relationship between government and industry. Furthermore, Canadian regulatory powers are shared between the provincial and federal governments, a less effective arrangement than in the U.S. where power is concentrated in the Environmental Protection Agency (EPA).

Public opinion is an underlying force which is interpreted through government and focussed and expressed through regulations. Companies are also affected directly by public opinion. In a consumer society where marketing and public image count, companies are more conscious of avoiding public outcries over their pollution record. Finally, companies are also confronted with environmental regulations through the actions of surrogate regulators like banks and insurance companies.

These institutions insist that companies producing wastes meet regulations as a condition for getting loans and insurance.

Cost is a factor in moderating efforts to reduce pollution. Expenditures to meet regulatory standards are dollars which are not available to invest in the basic business. Furthermore, in North American business, all capital investments are viewed in a more short-sighted manner. This stems from our higher interest rate structure which demands that all investments pay out quickly to the bottom line. Because of this, companies will do what they must to meet regulatory demands and some of consumers' expectations, not more.

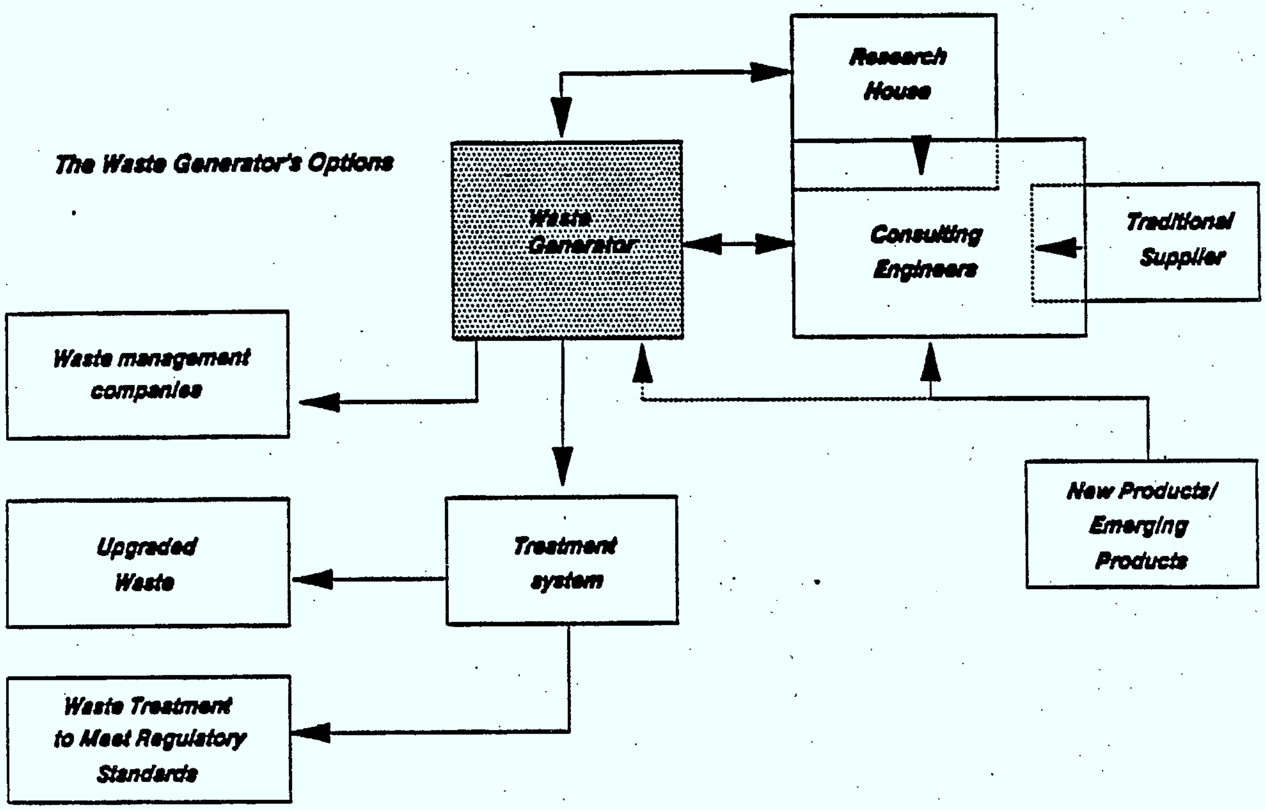
In the United States, specific regulatory measures have been essential in helping to develop new waste treatment technology. For example, the EPA has established the Superfund Innovative Technology Evaluation (SITE) program. The overall goal is to carry out a program of research, evaluation, testing, development and demonstration of alternative or innovative treatment technologies for the clean-up of Superfund sites in order to maximize the use of alternatives to land disposal.

Industry Structure and Dynamics

The environmental biotechnology industry is smaller, more fragmented and less developed than its counterparts in the pharmaceutical or agricultural sectors for example. Amongst dedicated biotechnology companies in the United States, only 1% focus on waste treatment and disposal. Even amongst the larger established companies which undertake R&D in biotechnology, only 2% concentrated on waste treatment and disposal.

The companies in the waste treatment industry can be thought of as comprising six strategic groups: the research houses, the consulting engineers, traditional equipment suppliers, suppliers of new and emerging products, the waste generators themselves and the waste treatment companies. How these players interact to provide waste treatment is depicted in the following figure.

INTERACTIONS AMONG KEY STRATEGIC GROUPS



In the mature industry of wastewater treatment, biotechnology companies concentrating on research are newcomers operating at the margins of the industry. Most of these research houses are young companies with under ten employees and variable financial resources from year to year. Some are university spin-offs and some have shifted from contact research work to developing products.

Because wastewater treatment involves a process engineering approach to adapt mostly proven technologies to users' needs, consulting engineers are central players in this industry. Their activities also tend to overlap with those of the research houses and those of traditional equipment suppliers to the industry. For example, both SNC and Lavalin have developed their own bioreactors. Because the consulting engineers play numerous roles to meet the wastewater generators' needs: e.g., develop designs, screen vendors, act as general contractors, they wield considerable decision-making power. Since they bear the technical responsibility, they also tend to be very conservative. This combination of conservatism and decision-making power tends to frustrate the entry of suppliers of new and emerging products. These companies offer products ranging from new strains of bacteria to sophisticated equipment such as digestors and bioreactors, generally focussing on very specific niches. Some do contract research to help pay some of their product development costs.

The waste generators themselves are typically large resource-based concerns like mining or pulp and paper companies. They will often have their research departments work on in-house solutions to waste problems and are interested in biotechnologies as an economic solution to upgrade or treat their wastes.

The situation with solid and hazardous wastes is different. Where the waste generators do not take care of the wastes themselves, they typically rely on the waste management corporations. In this sector, the top eight companies presently hold around 15% of the market. This degree of concentration is expected to increase. First, the industry giants, companies like Waste Management Inc. and Browning Ferris have been diversifying and making acquisitions. They are broadening the scope of their services, adding biotechnology capabilities where these offer a more economic solution. Second, there is a growing tendency for such companies to develop multiple technology capabilities. In some segments, such as site remediation, having a range of skills can be crucial in winning contracts. Third, government agencies responsible for environmental problems and major industrial customers are attracted to larger companies because they believe such companies have the resources to be reliable partners in projects that can take years to complete. Fourth, rising regulatory standards for waste treatment are forcing companies to invest more in equipment, management and assets like laboratories and landfill sites.

Technology and Technology Sources

Biotechnology must compete with other technologies to serve the $U.S. 56 billion North American market. On a broad range of criteria, from the ability to handle process upsets to reliability and cost, Arthur D. Little ranks biotechnology fourth out of five waste treatment technologies. Biotechnologies were ranked ahead of thermal treatment but behind physical, chemical and land disposal methods. Biotechnologies' greatest strength lies in their operational reliability. Unlike some other technologies, such as thermal, biosystems are largely on-line when needed. On the other hand, biotechnologies' two greatest weaknesses are seen as their inability to adapt easily to changes in input and the need for operator intervention to control the process.

Biotechnology research in the waste treatment industry tends to come primarily from public sources. Private research is fragmented and underfunded. These facts give rise to the following problems. First, capital is unavailable to bring innovations to market. Although funding is generally available at the laboratory scale and to a lesser degree at the pilot scale, all industry participants pointed to a lack of funding for demonstration projects as the greatest barrier to implementing biotechnology in industry. Second, industry and universities are still learning how to work with each other in joint research. They have different interests which must be accommodated. Third, Canada is not competitive in protecting intellectual property. Companies urge extension of the Patent Act to all aspects of biotechnology: processes are particularly difficult to protect.

Conclusions

In terms of market size, wastewater treatment presents the greatest opportunities for biotechnology. Biotechnology-based treatments account for approximately 35% of all capital expenditure on public wastewater treatment in the United States, and around 12% in the manufacturing sector. The operating expenditures of this huge public and private base of facilities amount to over $U.S. 14 billion annually in the United States alone.

In the faster growing market of hazardous waste treatment including site remediation, biotechnology's share is estimated to be under 5%. As biotechnology develops, this share will increase; however, site remediation in particular poses a mix of problems, from explosion and fire hazards to radioactive materials, pesticides and inorganics. Consequently, a broad range of technologies will be required to cope with these problems. For the treatment of hazardous wastes in industry, biotechnology has a very small share. For example, microbial treatment currently represents a $U.S. 5 million market. At this point, no biotechnology treatments are clearly commercially established. In conventional waste management, few new applications are foreseen for biotechnology. Currently, biotechnology in the form of microbial treatment, composting and landfarming represents about a 7% market share of annual capital and operating expenditures in conventional waste treatment, or about a $700 million annual market.

Biotechnology's most attractive opportunities lie in the municipal wastewater treatment sector. In particular, the interrelated problems of sludge disposal, dewatering and contamination by heavy metals present opportunities where biotechnology may find extensive application. Conventional sludge disposal techniques involve the use of landfill sites. However, heavy metal contamination imposes limits on how much sludge can be applied per unit area. With the North American problem of limited landfill sites, this makes the continued use of current sludge disposal techniques problematic, unless the political problems in siting new landfill capacity can be resolved.

Presently there are a considerable number of publicly funded research projects underway in the areas of sludge biodegradation and heavy metals removal. These projects range from the conversion of sewage sludge into oil and bioadsorption of heavy metals to sludge degradation processes and metal lixiviation from sludge.

Finally, bioreactors in municipal and industrial wastewater treatment represent a second area of potential application of biotechnology. Much opportunity appears to exist from the selection and development of improved microbial strains. Process control is a second area for significant improvements in bioreactor performance. In the area of bioreactor control, publicly funded projects include computer controls for activated sludge processes, automated monitoring and control strategies, and modelling and control of bioprocesses among others.

The potential health risks to waste treatment workers from airborne infections and skin adsorption could lead to a much greater emphasis on computer control and automation. Together with the development of improved microbes, this new degree of process control and automation would eliminate biotechnology's two greatest weaknesses : the need for operator intervention and the inability to adapt easily to changes in input.

I
INTRODUCTION

INTRODUCTION

This study was undertaken on behalf of Industry, Science and Technology Canada. The objective was to assess the opportunities for biotechnology in the waste treatment industry. The methodology comprised a review of existing literature along with industry contacts in both Canada and the United States. Our contacts in Canada were guided by the "1988 Canadian Biotechnology Industry Sourcebook". Our contacts in the United States centered on publicly-owned companies applying biotechnology in the waste treatment field. The study was finalized through consultations with industry participants to verify the tentative conclusions which were developed in the final phase of the study.

This document is divided into nine chapters. This first chapter serves to introduce the study briefly and put the work into context. In the second chapter, we outline the size of the market for the waste treatment industry. Chapter three looks at the underlying forces which tend to increase the demand for waste treatment services. The fourth chapter looks at the structure of the Canadian waste biotreatment industry as indicated by contacts with companies listed in the Canadian Biotechnology Industry Sourcebook. This look at industry structure is extended in the following two chapters: in chapter five, with an overview of where biotechnology fits in with the publicly-held companies; in chapter six, with a sample of what some of the smaller, privately-held companies are doing under the innovative "SITE" program in the U.S. The seventh chapter summarizes how biotechnology measures up to other technology options available to industry for treating waste. Chapter eight examines the public sources of waste biotreatment technology in Canada. In the ninth chapter, we summarize the outlook for biotechnology and its most promising applications in the waste treatment industry.

II
MARKET SIZE

The United States is the world's largest, best-documented market. In 1986, pollution abatement expenditures were estimated at some $ U.S. 74 billion

- This includes both capital and operating expenditures. Internal corporate expenditures are accounted for as well.

- At first glance, air pollution is the largest market; however, anti-pollution devices installed on cars and trucks represent the lion's share.

- The water pollution market is the largest: more than twice the size of either the solid waste or the non-vehicle air pollution market.

- The solid waste market includes site remediation.
  - as of 1989, the EPA had identified some 1,200 sites in the United States.

UNITED STATES
ESTIMATED POLLUTION ABATEMENT EXPENDITURES
(U.S. $ BILLIONS)
1986

SECTOR		$		(%)
AIR		30		(41)
Vehicular	20		(27)	
non-vehicular	10		(14)	
WATER		30		(41)
SOLIDS		14		(19)
TOTAL*		74		(100)

* *Totals may not add because of rounding*
Source: SECOR, based on data from the U.S. Bureau of Economic Analysis.

WATER POLLUTION

Water pollution abatement expenditures amounted to approximately $ U.S. 30 billion in 1986.

- Public sewer systems are the largest market, accounting for some 55% of all expenditures
  - over half of this is capital spending on facilities.
- Although industrial operations represent a smaller share of the market, their spending is much more concentrated on operations.

WATER POLLUTION ABATEMENT EXPENDITURES
UNITED STATES
1986

SECTOR	$ U.S. (000,000)		(%)
PUBLIC SEWER SYSTEMS		16,300	(55)
Facilities	8,800		
Operations	7,500		
INDUSTRIAL		9,300	(31)
Facilities	3,300		
Operations	6,000		
OTHERS*		4,300	(14)
TOTAL		**29,900**	**(100)**

* *Include non-point sources not shown separately*

Source: SECOR, based on U.S. Bureau of Economic Analysis data

In the manufacturing sector, industrial capital expenditure for wastewater treatment totalled $U.S. 975 million in 1985. Biosystems spending represented 12% of this outlay.

- The bulk of biosystems expenditures (64% in 1984, 55% in 1985) were in the chemical and petroleum industries.

- Textiles, food, chemicals and petroleum represent the highest percentage of capital spending on biosystems.

MANUFACTURING CAPITAL EXPENDITURES ON WASTEWATER TREATMENT
UNITED STATES
(U.S. Millions)
1984-1985

INDUSTRY	BIOSYSTEMS		TOTAL		BIOSYSTEMS/ TOTAL		DIFFERENCE
	1984	1985	1984	1985	1984	1985	1984-1985
Food	8.3	11.7	56.3	62.9	15%	19%	+4%
Textile	7.0	8.8	40.2	39.9	17%	22%	+5%
Paper	5.5	8.4	74.2	85.2	7%	10%	+3%
Chemical	**41.7**	**43.2**	**196.9**	**238.7**	**21%**	**18%**	**-3%**
Petroleum	**14.9**	**22.6**	**120.5**	**125.3**	**12%**	**18%**	**+6%**
Primary metals	1.2	1.8	46.5	45.1	2%	4%	+2%
Fabricated metals	0.8	4.5	41.8	45.1	2%	10%	+8%
Electric equipment	1.5	1.8	40.6	47.6	4%	4%	0%
Electric utilities	4.2	13.3	96.9	97.0	4%	14%	+10%
Coal mining	3.2	3.3	106.9	110.1	3%	3%	0%
Other	N/A	N/A	75.1	78.5	N/A	N/A	N/A
TOTAL	**88.3**	**119.4**	**895.9**	**975.4**	**10%**	**12%**	**+2%**

Source: Business Development Service, "Watermark 85 - January 1985 Survey and Forecast", Feb. 1985

WATER POLLUTION : CANADIAN EXPENDITURES ON EQUIPMENT

About $ 455 million is spent annually in Canada for water and wastewater treatment equipment. If trends continue toward more stringent industrial and municipal wastewater requirements, this figure could rise to almost $ 600 million by 1992[(1)].

- Total annual equipment expenditures in Canada for municipal treatment systems are estimated at about $ 275 million[(1)].

- Industrial expenditures on water pollution control equipment are estimated at $ 100 million[(1)] annually. An additional $ 80 million is spent on water treatment[(2)].

ANNUAL WATER AND WASTEWATER EQUIPMENT EXPENDITURE
CANADA
($000,000)
1989

Source	Expenditure
Municipal	275
Industrial	100
Other	80
Total	**455**

(1) *Source: B.A. Fenton, Science Council of Canada, Water Resources Equipment Industry: Opportunitites for Research and Manufacturing, Jan. 1989.*

(2) *Source: W.M. Glenn, Corpus Information Services, "Jobs and the Environment: Some Preliminary Number Crunching," Alternatives 14(3) (1987), 25.*

WATER POLLUTION : GROWTH RATE OF ABATEMENT EXPENDITURES

Water pollution abatement, in both the public and industrial sectors, is a mature market. Total spending on facilities and operations has increased, on average, at less than 1% over the period 1975 to 1985. By way of comparison, the annual GNP growth rate over this period was 3.3%, in constant dollars.

- In spite of slow growth, particularly in capital spending on industrial facilities, the market is still immense.

- Spending on operations has increased, reflecting the huge base of installed facilities.

WATER POLLUTION ABATEMENT EXPENDITURES
IN CONSTANT (1982) DOLLARS ($000,000)
UNITED STATES
1975 - 1985

YEAR	TOTAL (Capital & Operating)	INDUSTRIAL Facilities	INDUSTRIAL Operations	PUBLIC SEWER SYSTEMS Facilities	PUBLIC SEWER SYSTEMS Operations
1985	24,770	2,941	5,042	6,990	5,946
1984	23,257	2,900	4,795	6,387	5,649
1983	21,543	2,811	4,509	5,551	5,475
1982	21,199	3,080	4,022	6,148	5,156
1981	21,984	3,259	4,180	6,882	4,880
1980	24,647	3,725	4,081	8,942	4,694
1979	26,470	4,013	4,222	9,758	4,583
1978	26,631	4,277	3,934	10,090	4,392
1975	22,840	4,200	2,950	8,977	3,428
TEN YEAR AVERAGE GROWTH RATE IN PER CENT	0.85	-3.0	7.1	-2.2	7.3

Source: U.S. Bureau of Economic Analysis

WATER POLLUTION :
FUTURE GROWTH OF PUBLIC ABATEMENT EXPENDITURES

Capital expenditures on public wastewater treatment facilities will decline from current (1988) levels over the next 20 years.

- The estimated capital investment in facilities to meet fully the needs of the United States' population was $ U.S. 67.9 billion as of January, 1988.
  - In 2008, this is expected to increase to $ U.S. 83.5 billion (in constant 1988 dollars). The $ U.S. 15.6 billion difference represents additional needs to serve population growth.
- If spending to meet all identified needs were realized over the next twenty years, this would translate to an annual facilities expenditure of some $ 5 billion. Capital expenditures in 1985 were some $ U.S. 7 billion.
- The installed base will grow, but more slowly than in the past.

TOTAL NEEDS FOR PUBLICLY-OWNED WASTEWATER TREATMENT FACILITIES (BILLIONS OF 1988 DOLLARS)
UNITED STATES
1988 - 2008

YEAR	TOTAL NEEDS ($)	INDEX: 1988 = 100
2008	83.5	123
1988	67.9	100

Source: "1988 Needs Survey Report to Congress", EPA, Feb. 1989
The estimates are based on "grant-eligible" categories of needs. For example, 39 States which participated in the survey submitted separate estimates for an additional $ U.S. 15.9 billion in needs which did not meet the criteria of the survey.

WATER POLLUTION : CONSTRUCTION EXPENDITURES IN CANADA

In Canada, the total value of construction work purchased for sewage systems, disposal plants and connections has declined steadily from 1975. However, new treatment plant construction opportunities exist in Quebec. In 1978, Quebec embarked on a program to improve water and wastewater treatment services.

- Recently, le Conseil des ministres du Québec, voted to spend some $1.5 billion, in total, over the next three years for urban wastewater treatment facilities. This reflects "catch-up" spending. Quebec will constitute the largest market for municipal treatment equipment in Canada for at least the next 5 years[1].

- It is assumed that by 1992, Ontario will make up 50% of the market for industrial treatment facilities[1].

TOTAL VALUE OF CONSTRUCTION WORK PURCHASED IN CANADA FOR SEWAGE SYSTEMS, DISPOSAL PLANTS AND CONNECTIONS (1982 CONSTANT DOLLARS, $ 000,000) 1975-1985

Year	Expenditures[2]
1985	674
1984	695
1983	705
1982	754
1981	733
1980	810
1979	868
1978	922
1975	1,099

Sources:(1) *B.A. Fenton, Science Council of Canada, Water Resources Equipment Industry: Opportunities for Research and Manufacturing, Jan. 1989.*

(2) *Statistics Canada, cat. 64-201, June 1985.*

Investment in secondary and advanced treatment systems, which together represent the best opportunities for biotechnology are expected to increase from 35% to 38% of the total capital investment required in public wastewater treatment systems.

NEEDS FOR PUBLICLY-OWNED WASTEWATER TREATMENT FACILITIES (BILLIONS OF 1988 DOLLARS) UNITED STATES 1988

NEEDS CATEGORY	CURRENT NEEDS $	(%)	NEEDS IN 2008 $	(%)
Secondary Treatment	20.2	(30)	26.8	(32)
Advanced Treatment	3.9	(6)	5.0	(6)
Sub-Total*	24.1	(36)	31.8	(38)
Infiltration/Inflow Correction	2.9	(4)	2.9	(3)
Replacement/Rehabilitation	3.7	(5)	3.7	(4)
New Collector Sewers	10.9	(16)	13.8	(17)
New Interceptor Sewers	9.9	(15)	14.9	(18)
Combined Sewer Overflows	16.4	(24)	16.4	(20)
TOTAL*	**67.9**	**(100)**	**83.5**	**(100)**

* *Totals may not sum to 100% because of rounding*

Source: 1988 Needs Survey Report to Congress, EPA, Feb. 1989.

The number of secondary and advanced treatment facilities will need to be expanded from their current level of 12,000 to 15,000 to meet fully the currently documented needs under the Clean Water Act.

- This would mean an expansion in design capacity from about 31,575 MGD to 42,107 MGD or an increase of some 33%.

NUMBER OF FACILITIES
1988 ACTUAL VS NEEDED
UNITED STATES

LEVEL OF TREATMENT	# OF FACILITIES		DIFFERENCE	
	ACTUAL	NEEDED	#	DESIGN CAPACITY, MGD
Secondary	8,536	9 659	1,123	2,903
Greater than Secondary	3,412	5,293	1,881	7,629
Sub-Total	11,948	14,952	3,004	10,532
Less than Secondary	1,789	48		
No Discharge*	1,854	2,363		
Other	--	11		
TOTAL	**15,591**	**17,374**		

* *Most are pond systems which dispose of their total inflow by evaporation, by percolation to groundwater, or through reuse, e.g. spray irrigation.*

The known breakdown by process type to meet fully 1988 documented needs is presented below.

- Additional biological treatment needs and sludge treatment of a biological nature represent some 7,700 process installations or fully 28% of the over 27,000 process installations which are required.

EXPECTED PROCESS NEEDS BY TYPE
UNITED STATES
1988 ACTUAL VS NEEDED

TYPE OF TREATMENT	1988 ACTUAL	NEEDED	DIFFERENCE #
BIOLOGICAL TREATMENT			
Stabilization Ponds	5,165	6,449	1,284
Aerated Lagoons	1,575	2,367	792
Total Containment Ponds	867	1,017	150
Aquaculture/Wetlands/ Marsh Systems	5	21	16
Trickling Filter	2,260	2,365	105
Rotating Biological Contactor	448	725	277
Sequencing Batch Reactor	1	2	1
Activated Sludge	3,591	4,284	693
Activated Sludge/ Extended Aeration	2,082	2,858	776
Oxidation Ditch	937	1,353	416
Biological Nitrification	1,007	2,053	1,046
Biological Denitrification	49	85	36
Biological Phosphorous Removal	28	37	9
Other Biological Treatment	39	65	26
Land Treatment System	985	1,445	460
Sub-Total	19,039	25,126	6,087
SLUDGE TREATMENT			
Aerobic Digestion	3,710	4,800	1,090
Anaerobic Digestion	3,628	4,072	444
Composting	77	126	49
Sub-Total	7,415	8,998	1,583
OTHER SLUDGE TREATMENT	10,791	13,156	2,365
SLUDGE DISPOSAL	10,255	12,054	1,799
PRELIMINARY OR PRIMARY TREATMENT	18,345	22,108	3,763
PHYSICAL/CHEMICAL TREATMENT	15,912	23,657	7,745
NON-CENTRALIZED COLLECTION/TREATMENT	379	879	500
MISCELLANEOUS	16,098	19,681	3,583
TOTAL	**98,234**	**125,659**	**27,425**

Source: "1988 Needs Survey Report to Congress", EPA, Feb. 1989.

SOLID WASTES

Solid waste is classified into hazardous and non-hazardous materials as follows:

- A solid waste is hazardous if it exhibits any of the following characteristics:
  - ignitability
  - corrosivity
  - reactivity
  - toxicity

  Industry produces over 200 million tons[1] annually of hazardous wastes in the U.S.

- A solid waste is not hazardous if it is:
  - household waste
  - agricultural waste used as fertilizer
  - from the extraction, beneficiation and processing of ores and minerals (including coal)
  - fly ash, bottom ash, slag and flue gas and emission control waste from fossil fuel combustion
  - drilling fluid associated with oil, gas and geothermal energy exploration, development and production

  Municipal wastes, for example, amount to over 150 million tons annually in the U.S.

(1) Souce: "Hazardous Materials Management Markets" SRI International, Fall 1987.

The conventional waste management market in the United States is valued at some $U.S. 10.5 billion in 1989, exclusive of the collection and transportation costs involved.

- The market breakdown by treatment method is shown in the following table.

CONVENTIONAL WASTE MANAGEMENT MARKET
UNITED STATES
($U.S. 000,000)
1989

Treatment method	$	(%)
Containment	5 750	(55)
- largely landfill		
Waste-to-Energy	2 010	(19)
Recycling	1 870	(18)
Treatment	840	(8)
Sub-total	10 470	(100)
Collection/Transportation	12 000	---
TOTAL	22 470	---

Source: "The Huge Conventional Waste Management Business", Business Communications Company Inc., May 1989. Cost basis includes construction, engineering and operating costs.

With some exceptions, this market has limited opportunities for biotechnology. Containment and recycling alone represent almost three-quarters of the expenditures.

- CONTAINMENT
  - Is largely dominated by landfill operations. In fact, landfill handles an estimated 81% of all non-hazardous solid waste
    - geomembranes and geotextiles constitute the high technology portion of this market.
- RECYCLING
  - Presently, accounts for an estimated 11% of the hazardous waste stream
    - well-known examples include aluminum cans and newspapers
    - over 15% of U.S. households and commercial establishments will be participating in some kind of recycling program by 1999.
- WASTE-TO-ENERGY
  - This market includes incineration (for energy recovery) and landfill methane recovery projects
    - the use of biotechnology may enhance methane gas production.
- WASTE TREATMENT
  - Includes incineration (not-for-energy-recovery), microbial treatment, composting and landfarming
    - the fastest growing market will be incineration, mainly because of an increased need for the destruction of infectious or medically suspect wastes
    - the remaining three sectors represent a $U.S. 700 million market in 1989. However, this overlaps somewhat with the sludge treatment activities covered in the previous section on water pollution.

The recycling and waste-to-energy segments are forecast to grow at real rates in excess of 10% to 1994. The waste treatment segment, in contrast, is expected to grow to $U.S. 820 million in 1994 or some 3% annually.

The commercial hazardous waste sector had revenues of approximately $U.S. 2.3 billion in 1986, including site remediation work; however, it is important to note that this figure does not include private industry's own internal expediture of $U.S. 8 to 10 billion on hazardous waste/wastewater spending.

- Public sector spending under the Superfund program to clean up inactive waste sites accounts for more than half of this market.
- Industry's purchase of waste management services is largely for the treatment of ongoing waste streams.

THE HAZARDOUS WASTE CONTROL INDUSTRY
UNITED STATES
1986

Sector		$U.S. (000,000)	(%)
Private Industry		1 000	(44)
- on-site work	360		
Public		1 250	(56)
TOTAL		**2 250**	**(100)**

Source: "1987 UPDATE - Hazardous Waste Control Industry Outlook", WTL & Co. Management Consultants.

HAZARDOUS WASTES : SOURCE BY SECTOR

The hazardous waste market is concentrated in relatively few industrial sectors. In fact, nearly 80% of the estimated annual industrial expenditures for hazardous waste management is concentrated in only 4 industry groups.

INDUSTRY CONCENTRATION OF THE HAZARDOUS WASTE MANAGEMENT MARKET UNITED STATES 1986

Major Industry Group	Estimated Expenditures[1] $U.S. (000,000)	(%)	Estimated waste generation[2] (000,000) metric tons	(%)
CHEMICALS AND ALLIED PRODUCTS, e.g.	2 010	(29)		
- Industrial Organic Chemicals			48	(19)
- Industrial Inorganic Chemicals			42	(16)
- Agricultural Chemicals			20	(8)
- Alkalies and Chlorine			4	(2)
PRIMARY METALS, e.g.	1 337	(20)		
- Blast furnaces			24	(9)
FABRICATED METAL PARTS, e.g.	1 040	(15)		
- Gray Iron Foundries			11	(4)
- Steel Wire			4	(2)
RUBBER AND PLASTICS PRODUCTS, e.g.	971	(14)		
- Misc. Plastics			9	(4)
- Rubber, Plastic Hose			6	(3)
- Plastics, Resins	—	—	5	(2)
Sub-Total*	5 358	(78)	173	(69)
TOTAL	**6 860**	**(100)**	**259**	**(100)**

* *May not add because of rounding*

1 *Source: "Hazardous Materials Management Markets" SRI International, Fall 1987. These figures include industry's own internal expenditures.*

2 *Source: Apogee Research*

The commercial hazardous waste treatment industry is expected to grow at a 20 to 25% annual rate.

- "The recent flood of new legislation and continually shifting standards for compliance have put most companies in a state of flux. Virtually every manufacturer is re-evaluating or implementing new hazardous waste management practices"[1]

- EPA estimates put the commercial hazardous waste treatment industry's volume at under 5% of the total quantity of hazardous waste generated.

  - a one percentage point increase in the 5% share handled could add as much as $U.S. 1.5 billion by 1991

  - on-site work is expected to grow fastest of all.

- The site remediation market will grow at about 10% annually

EXPECTED GROWTH OF THE HAZARDOUS WASTE CONTROL MARKET
UNITED STATES
($U.S. 000,000)
1986-1991

Sector	1986		1991	
	$	(%)	$	(%)
Private Industry	1 000	(44)	3 000	(60)
- On-site work	360	(16)	2 500	(50)
Public				
- Site remediation	1 250	(56)	2 000	(40)
TOTAL	**2 250**	**(100)**	**5 000**	**(100)**

Source: "1987 Update - Hazardous Waste Control Industry Outlook", WTL & Co. Management Consultants, 1987.

1 *"Hazardous Materials Management Markets" SRI International, Fall 1987.*

Hazardous waste has been largely disposed through conventional means up to the mid - 1980s. However, traditional disposal practices like landfill, deepwell injection and surface impoundment are on the decline. By 1990:

- Incineration is expected to grow by over 200%
  - destruction of wastes by classic incineration technology is well known and commercially established.

- Advanced recovery of useful materials will grow by more than 100%
  - solvent recovery is often cost-effective
  - similar efforts with metals have not yet gained commercial acceptance.

- Treatment, a broad category which includes many technologies, biotechnology among them, is expected to grow on the order of 50%
  - historically, treatment has occurred with simple reactions like oxidation, reduction and precipitation.

COMMON HAZARDOUS WASTE DISPOSAL METHODS
UNITED STATES
MID - 1980S

Method	Approximate use (per cent of total waste)
Aqueous Treatment	(30)
Deep Well Injection	(20)
Landfill	(20)
Surface Impoundment	(15)
Solvent/Oil recovery	(10)
Incineration	(5)
TOTAL	(100)

Source: "Hazardous Materials Management Markets", SRI International, Fall 1987.

Currently, spending on high technology treatment of hazardous wastes amounted to some $U.S. 215 million in 1988 or roughly one-tenth of the commercial hazardous waste treatment market.

- Biological treatment of wastes with naturally occurring and genetically enhanced organisms includes hundreds of processes, but none are yet clearly commercially established.
  - microbial cultures represent about a $U.S. 5 million market, or some 2% of the high technology sector.
  - slow growth to about a 3% share of the high technology market is forecast to 1998.
- Membrane separation is the original high technology hazardous waste treatment.
  - ultrafiltration, microfiltration, reverse osmosis and electrodialysis will be the fastest growing subsector.
- High technology containment consists of sophisticated landfill techniques including multiple geotextile and geomembrane layers along with leachate gathering and characterization networks.
  - in-situ vitrification is an example of an entirely new technique.
- Advanced incineration utilizes techniques like plasma arc, infrared, fluidized bed, etc.
- Advanced chemical treatment includes processes like supercritical oxidation and hydrogen peroxide treatment.

The market value of these high technology segments is outlined on the following page.

THE HIGH TECHNOLOGY HAZARDOUS WASTE TREATMENT MARKET
UNITED STATES
1988-1998

Sector	1988		1998	
	$	(%)	$	(%)
Chemical	120	(56)	259	(50)
Containment	60	(28)	162	(31)
Membrane	19	(9)	72	(14)
Incineration	11	(5)	9	(2)
Microbial	5	(2)	14	(3)
TOTAL	**215**	**(100)**	**516**	**(100)**

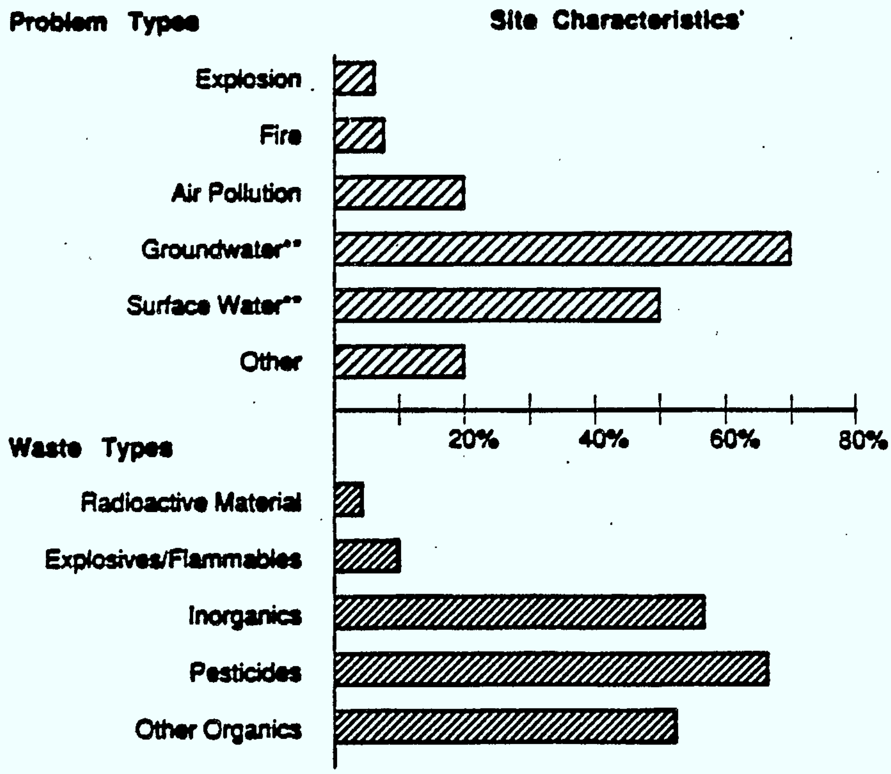
Source: *"Hazardous Waste Control: Advanced Waste Treatment Technology", Business Communications Co. Inc., July 1988*

Site remediation, the most mature segment in the hazardous waste treatment business, is served by major established international companies like Chemical Waste Management, International Technology and Browning-Ferris.

- Although these companies have used many basic techniques like hydrogeological engineering and containment, they are increasingly considering advanced technologies.

- The complex and multifaceted nature of site remediation dictates that a broad range of technologies will be required to cope with the many problems and waste types encountered.

THE COMPLEX PROBLEMS OF SITE REMEDIATION



*Totals exceed 100% because many sites had numerous types of problems and wastes.
**Contamination of potentially potable water supplies.

Source: SRI International

AIR POLLUTION

The air pollution control market, contrary to that of solid waste and wastewater does not present any significant opportunities for biotechnology.

- "In the treatment of both liquid and solid wastes there are significant opportunities for biotechnology... The possibilities for using biological systems to control atmospheric pollution, in contrast, are rather limited."[1]

- No evidence was found in either the public or private firms researched of significant applications of biotechnology to air pollution.

- Outside of automotive applications, sales of air pollution control equipment are estimated at some $U.S. 2 billion in 1988. This will grow to some $U.S. 8 billion by 1995.[2] Flue gas desulphurisation equipment to reduce acid rain is a major factor in this growth.

- Other significant parts of the air pollution control equipment market include, among others:

  - industrial and agricultural waste burning
  - municipal incinerators
  - hospital incinerators
  - liquid incinerators in the chemical and petrochemical industry
  - high speed printing plants re: Volatile Organic Carbon (VOC) emissions
  - semiconductor plants: scrubbers for wafer fabrication facilities.

- Very few biotechnological solutions are being developed by Canadians to solve atmospheric pollution problems.

  - Biofilters already exist mainly to control odor problems. These filters use peat and bacteria. Tourbières Premier CDN from Quebec works on that product.
  - Some biotreatment to recover sulfate from stacks has been patented though not yet commercialized, by Coastech Research B.C.

---

(1) U.S. Office of Technology Assessment, Commercial Biotechnology: An International Analysis.

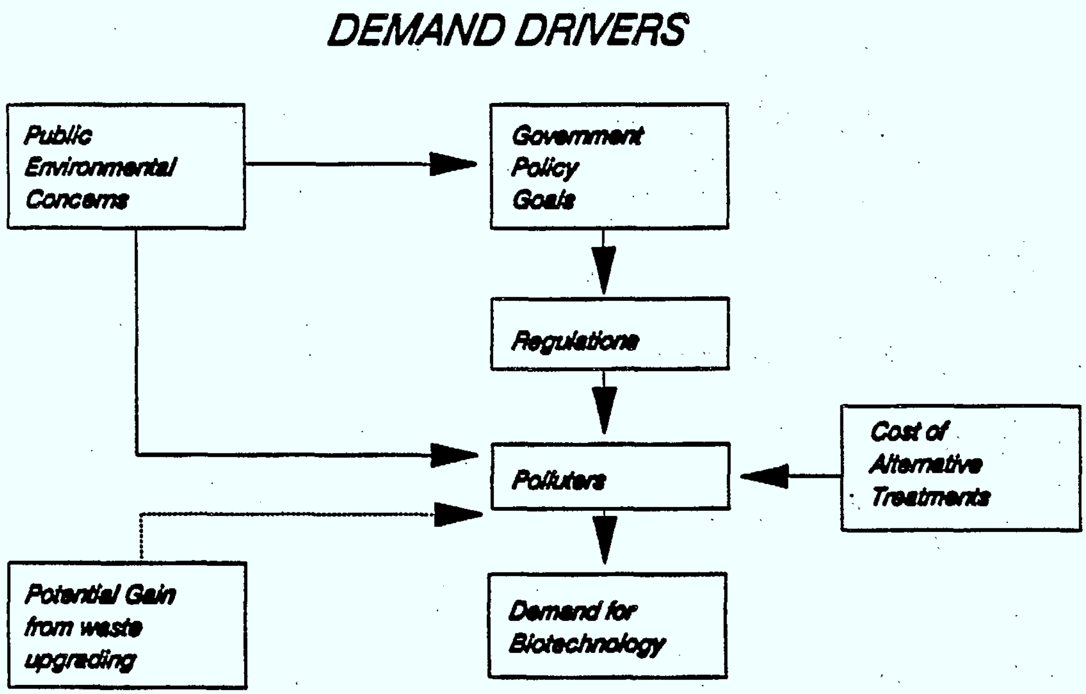
(2) "The Air Pollution Control Market in the 1990s", International Journal of Air Pollution Control and Waste Management, March 1988.

III
DEMAND DRIVERS

Demand for biotechnological solutions to pollution problems can be stimulated by factors such as public policies, cost of other types of waste treatment, corporate policies and regulation.

- Both corporate policies and regulation are influenced by public environmental concerns.

- Industrial process improvement through waste upgrading could also be a demand driver, to a lesser extent.



The principal effects of these demand drivers are detailed in the following pages.

1. REGULATIONS

The entire field of pollution control is driven primarily by government regulation. In general, waste generators only clean up as much as they have to; therefore, incentives to improve current systems come mostly from tightening the rules. Proper enforcement of regulations is also essential to drive industry towards better environmental practices.

- Industry is waiting for guidelines - it doesn't want to invest in cleaning up to a certain level if the government is then going to say that it wasn't properly done.

- In general, U.S. Federal and State regulations are stricter than those in Canada, where new federal and provincial legislation has yet to cause concrete changes in corporate and municipal behavior.

- Banks and Insurance companies tend to act as "surrogate" regulators.

  - They insist that waste producers meet environmental standards that are on the books as a condition for obtaining loans or insurance coverage.

- Basically, two types of legislation can act as demand drivers: health and safety regulations and environmental regulation.

1. REGULATIONS : THE UNITED STATES

There are 5 principal Acts which comprise the American regulatory framework:

a) Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)

b) Clean Water Act

c) Resource Conservation and Recovery Act (RCRA)

d) Toxic Substances Control Act

e) Clean Air Act

The essence of these five Acts is summarized in the following pages.

a) The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) authorizes the Federal government to respond to spills and other releases of hazardous substances, as well as to leaking hazardous waste dumps.

- Hazardous substances are identified under:

  - the Resource Conservation and Recovery Act (RCRA)
  - the Clean Water Act
  - the Clean Air Act
  - the Toxic Substances Control Act

  or, are designated by the EPA.

- The Superfund Amendements and Reauthorization Act of 1986 (SARA) amends the CERCLA by directing the EPA to establish the "Superfund Innovative Technology Evaluation (SITE) Program".

  - The overall goal of the SITE Program is to "carry out a program of research, evaluation, testing, development, and demonstration of alternative or innovative treatment technologies..."

  - Specifically, the goal of the program is to maximize the use of alternatives to land disposal in cleaning up Superfund sites.

b) The Clean Water Act establishes as its objective the restoration and maintenance of the chemical, physical and biological integrity of the Nation's waters. The Act has been termed a technology forcing statute because of its rigorous requirements which demand the achievement of increasing levels of pollution abatement.

- One major part of the Act consists of authorizing Federal financial assistance for municipal sewage treatment plant construction. In 1982, the Clean Water Bill committed $U.S. 18 billion over nine years to new sewage treatment plants.

  - the 1987 amendements also encourage States to undertake groundwater protection activities as part of their overall nonpoint pollution control efforts. Federal financial assistance totaling $U.S. 400 million is provided to support demonstration projects and actual control activities.

- The other major part consists of regulatory requirements which apply to industrial and municipal dischargers.

  - The Act requires pollutant cleanup by no later than March 1989, generally demanding use of the best available technology that is economically achievable. Extensions of up to two years are available for industrial sources utilizing innovative or alternative technology.

c) The Resource Conservation and Recovery Act (RCRA):

- Amendments in 1984 concerning hazardous and solid waste represent a radical departure from the RCRA approach by establishing a strong presumption against land disposal. The Congress called for a ban on the land disposal of most untreated hazardous wastes by 1990[(1)].

- Performance-based treatment standards have to be established for the majority of waste streams[(1)].

- Approaches to defining wastes as hazardous or non-hazardous will be revised and improved[(1)].

d) The Toxic Substances Control Act (TSCA) was designed to provide EPA, among other things, with authority to control unreasonable risks of chemicals already known, or as they are discovered.

- To eliminate unreasonable risks, EPA can use powers such as limiting the volume of production or concentration, or control disposal methods.

e) The Clean Air Act is designed to protect health and the environment by limiting and reversing the pollution of ambiant air through reductions of individual pollutants at source. Strategically, the Act revolves around health-based National Ambiant Air Quality Standards (NAAQS).

- NAAQS sets limits on pollution levels in outdoor air. The seven major pollutants are sulphur oxides, total suspended particulate matter, nitrogen oxides, carbon monoxide, photochemical oxidants (ozone), hydrocarbons and lead.

(1) Source: Waste Age, May 1988

1. REGULATIONS : CANADA

Water pollution:

Water pollution control falls under federal jurisdiction when it is a matter of urgent national concern, otherwise water quality is managed by federal-provincial agreements.

Main federal legislation:

- Canada Water Act
- International Boundary Waters Treaty Act
- Canadian Environmental Protection Act (CEPA)
- Fisheries and Ocean Act

  - The St-Lawrence Action Plan is a new federal-provincial program of $110 million (over 5 years) which aims at the reduction of 90% of the toxic effluents released in the St-Lawrence River by 50 big polluters.

Hazardous Wastes:

Hazardous wastes are mainly controlled by provincial jurisdiction except for questions concerning their transportation, and the storage of wastes containing PCBs. Products listed in Schedule I of CEPA fall under both federal and provincial jurisdiction (see Appendix).

Main federal legislation:

- Canadian Environmental Protection Act (CEPA)
- Transportation of Dangerous Goods Act

There is significant variation in the extent to which provinces have developed and implemented hazardous waste management regulations. The trend is towards greater regulation and waste minimization.

The Canadian Council of Resource and Environment Ministers (CCREM) are preparing a Hazardous Waste Action Plan. This reflects increasing public concern with dangerous waste.

Quebec and Ontario have the toughest regulations for toxic wastes.

Solid Wastes:

Solid waste management is mostly controlled by provincial administration except for transportation matters which fall under CEPA, and sludge which also falls under federal jurisdiction.

Main federal legislation:

- Canadian Environmental Protection Act

Agricultural utilization of sludge in Canada comes under both federal and provincial jurisdiction. The sale of sludge and sludge-based products as fertilizers and soil amendments is within the purview of the Fertilizers Act administered by Agriculture Canada.

Air pollution:

Atmospheric emissions of substances listed in Schedule I of CEPA fall under both federal and provincial jurisdiction. Other emissions are regulated by provincial authorities.

Main federal legislation:

- Canadian Environmental Protection Act (CEPA)

1. REGULATIONS : CANADA ...

The new Canadian Environmental Protection Act (1988) concerns human health and environmental protection regarding any pollution caused by toxic substances. This Act allows the federal government to rule toxic substances from "cradle to grave". It is the strongest federal law that can act as a demand driver for waste treatment.

- It falls under the responsibility of Environment Canada and Health and Welfare Canada.

- It establishes guidelines, objectives and regulations to prevent contamination of water, soil and air and to solve existing pollution problems such as waste sites.

- CEPA covers substances as broadly defined as any distinguishable kind of organic or inorganic matter, whether animate or inanimate, and includes chemical products, biotechnology products and mixtures contained in effluents, emissions or wastes.

- Investigations and inspections to enforce the law have already started in certain areas.

- Offences and punishment are much stronger than the ones provided by the old environmental law. Pollutors can be fined up to one million dollars daily and even more if they made profits from pollution.

- The following federal acts have been merged into CEPA:

    - Clean Air Act
    - Department of the Environment Act
    - Environmental Contaminants Act
    - Ocean Dumping Control Act

1. REGULATIONS : CANADIAN VS AMERICAN

Even with the new Canadian Environmental Protection Act, Canadian legislation is still behind its American counterpart. In fact, no Canadian department has the power of the U.S. Environmental Protection Agency.

- In Canada, the power is not centralized like in the United States. Jurisdiction is often assumed by the federal and provincial levels, creating conflicting situations. In terms of waste management, provinces have more say than federal authorities.

- Though CEPA was promulgated in 1988, much work is still needed before it is completely enforced.

- Historically, Canadian environmental regulations have been less effective because no mechanisms were applied vigorously to enforce the laws.

2. PUBLIC ENVIRONMENTAL CONCERNS

Growing awareness over pollution issues drives biotechnology development indirectly through its double impact on regulations and corporate policies.

- Regulations are made up in response to pressure from electors who are concerned by environmental problems.

- Public concern also drives companies conscious of their image to elaborate policies taking the environment into account.

3. PUBLIC POLICY GOALS

Government policies can strongly influence biotechnology development by providing or creating a proper set of tools. Such tools can consist of research funding, tax credits, trade policies, legislation, and the like. But, biotechnology has to be given high priority to become successful.

- The following examples illustrate some provincial initiatives in research funding:

  - At the Alberta Research Council, the use of biotechnology in waste treatment applications is a major goal for the 1990's. They see this whole area of research as characterized by technology push, rather than market pull.

  - The B.C. Science Council through its SPARKS Program[1] has set up a Biotechnology Committee which is looking at a proposal to fund the establishment of a biotechnology center. Waste treatment is identified as a research priority for the next 5 years.

---

(1) SPARKS PROGRAM: Strategic Planning and Applied Research Knowledge Program

2. PUBLIC ENVIRONMENTAL CONCERNS...

- The Ontario Premier's Council Technology Fund supports this type of research mainly through contributions to the University Research Incentive Fund.

- Here are a few industry comments about public policy goals:

  - Does Canada really want to make it a priority? If so, why is BIOQUAL only a network to facilitate communication and co-operation, lacking other resources?

  - Attention must be given to coordinating actions from the different federal departments involved in biotechnology. Actions undertaken must converge in the same direction.

  - Consultation with experts from academia and industry is essential to formulate this direction.

4. COST OF OTHER TREATMENTS

Waste generators and public organizations undertaking pollution control operations favour the most economical solution available to solve an environmental problem, given that it meets the regulations.

- Since compliance with environmental regulation in order to solve a waste problem translates into a compulsory expense, waste generators tend to keep it at the lowest level using the most cost-effective technology.

- Biotechnology offers an economic solution. In 1985, biotreatments ranged from $15 - $30/ton, relatively inexpensive compared with thermal treatment averaging $100/ton.

IV
INDUSTRY STRUCTURE

In general, the environmental biotechnology sector is smaller, more fragmented and less developed than the leading pharmaceutical and agricultural biotechnology sectors.

- In 1988, 13.8% (30) of Canadian firms involved in biotechnology had their most marked interest in waste treatment, up from 7% (8) in 1986[1].

- 8% ($13.1 million) of biotechnology R & D expenditures and 5.4% (80.5) of biotechnology R & D researchers were involved in the waste treatment field in 1988[2].

PROFILE OF BIOTECHNOLOGY R&D IN WASTE TREATMENT
CANADA

1986 VS. 1988

	1988	**1986**
Number of Canadian Biotechnology firms with marked interest in waste treatment	30 (13.8%)	8 (7%)
Biotechnology R&D in waste treatment		
- R&D spending	$ 13.1 million (8%)	N/A
- R&D personnel	80.5 people (5.4%)	N/A

(1) *Source: "1988 Canadian Biotechnology Industry Sourcebook"*
(2) *Source: Idem*

In the United States, as in Canada, R&D efforts in the environmental sector are also less than in the health care and agricultural sectors.

- Only 1% of the total number of dedicated biotechnology companies focus primarily on waste disposal/treatment R&D.
- Within the large, diversified, established companies this figure reaches 2%.

AREAS OF PRIMARY R&D FOCUS BY BIOTECHNOLOGY COMPANIES UNITED STATES

Research area	Dedicated biotechnology companies # (%)	Large, established companies # (%)
Human therapeutics	63(21%)	14(26%)
Diagnostics	52(18%)	6(11%)
Chemicals	20(7%)	11(21%)
Plant agriculture	24(8%)	7(13%)
Animal agriculture	19(6%)	4(8%)
Reagents	34(12%)	2(4%)
Waste disposal/treatment	3(1%)	1(2%)
Equipment	12(4%)	1(2%)
Cell culture	5(2%)	1(2%)
Diversified	13(4%)	6(11%)
Other	31(18%)	0(0%)
Total	**276(100%)**	**53(100%)**

Source: Office of Technology Assessment, New Developments in Biotechnology - Report No. 4 U.S. Investment in Biotechnology, Summary, July 1988.

Based on contacts with the companies listed in the 1988 Biotechnology Source Book, there are six key actors in the waste biotreatment industry. The strategic groups comprised by these actors and their most important characteristics are summarized in the following table:

STRATEGIC GROUPS

TYPE	TYPICAL CHARACTERISTICS
Research houses Example: B.C. Research	• most established after 1980; typically fewer than 10 employees • few financial resources resulting in a variable number of employees from year to year • some are university spin-offs • some shift from contract research work to making actual products
Consultants Example: Groupe SNC	• well-established companies, typically large; often play a leading role in exports • also smaller specialized firms • services: engineering and/or environmental consulting • rather conservative since they bear the technical responsibilty • play numerous roles to meet clients' needs: develop architectural designs, screen vendors, make equipment purchases, act as general contractors, etc
Waste management corporations Example: Waste Management Inc.	• established companies broadening the range of their services with biological technologies, where these offer a more economic solution

STRATEGIC GROUPS

TYPE	TYPICAL CHARACTERISTICS
Waste Generators Example: Large mining or manufacturing company	• large companies, typically involved in pulp & paper and mining sectors • interested in biotechnologies as an economic solution to upgrade or treat their wastes • will often have their research division develop in-house solutions to their own problems
Traditional suppliers Example: Degremount Infilco	• supply packaged systems such as complete waste water systems • have the know-how to design customized systems
New products/ emerging products Example: Microbe Inc.	• focus on development and applications of new knowledge and techniques to products generally for very specific higy technology niches • earn some revenues from contract research to support their long term product development interests • products range from strains of microorganisms to sophisticated equipment such as digestors and bioreactors

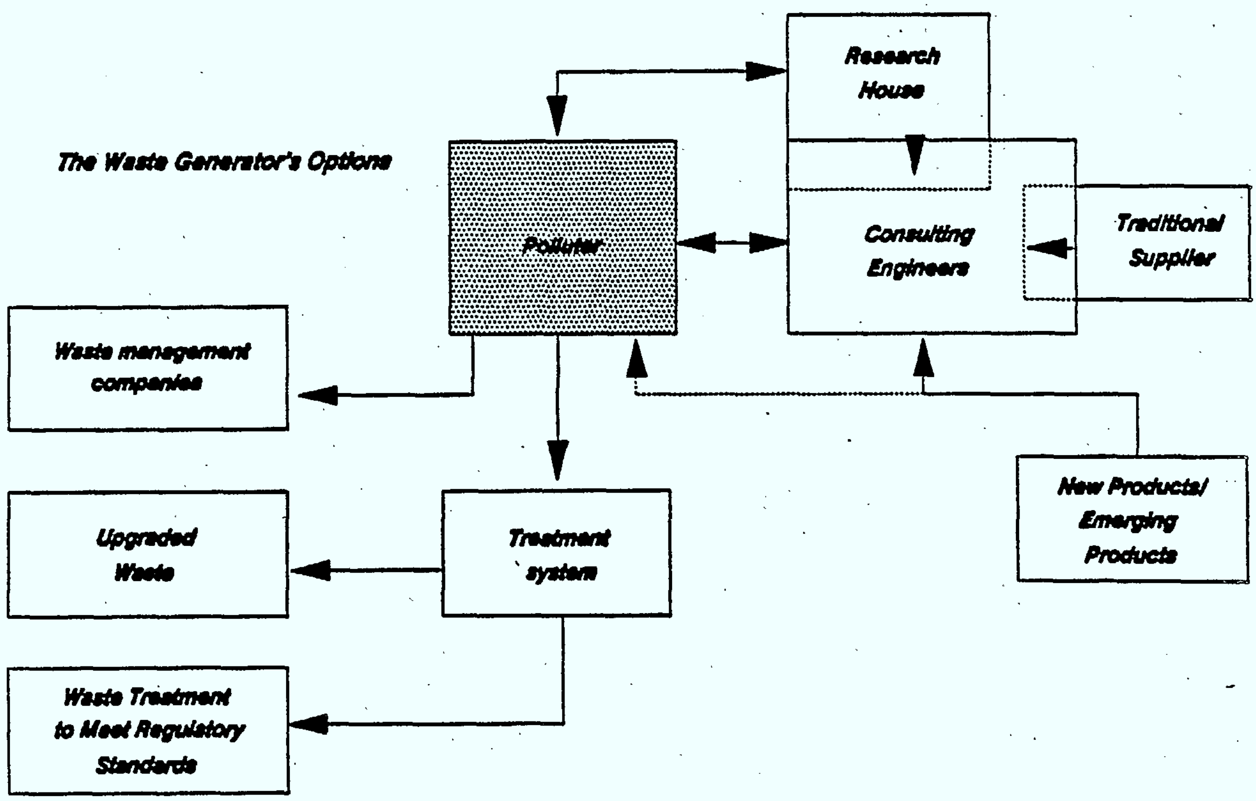
The interaction of the six strategic groups to deal with pollution problems is illustrated in the following figure.

- Waste generators seek solutions to solve their waste problems. They can use the services of a waste management company to eliminate it or call upon consulting firms which will conceive a system to treat and/or upgrade the waste.

- Consulting firms are at the center of all the interactions: sharing research interests with research houses, designing facilities that traditional suppliers will put together, bringing some emerging products on the market.

  - Consulting firms tend to overlap with research houses and traditional suppliers e.g. SNC's bioreactor and T.W. Beak's research activities.

INTERACTIONS AMONG KEY STRATEGIC GROUPS



Research houses, emerging product firms and consultants are the most numerous players at this stage of the Canadian industry's development.

- Even though research houses outnumber the other categories, the revenues generated by them are fairly low, mostly under $1 million.
- Consultants (for the major part consulting engineers) generate the bulk of the revenues.

KEY STRATEGIC GROUPS

TYPE	NUMBER	TOTAL SALES $ (000,000)
Research houses	17	13 (1)
Emerging product firms	11	69
Consultants	11	98 (2)
Waste generators	5	N/A
Traditional suppliers	2	12.5
Waste Management Companies	1	30
PARTIAL TOTAL	**47****	**222.5**

(1): Total of 12 firms
(2): Total of 10 firms

* *Compiled from "1988 Canadian Biotechnology Industry Sourcebook.*
** *Totals 47 instead of 58 listed in the Sourcebook - after checking of information with most companies named in the Sourcebook, p.17.*

V
PROFILES OF PUBLIC COMPANIES

INTRODUCTION

The following analysis is based on American public companies which are in the waste treatment business.

- Of these companies, at least seven are employing biotechnology to some degree. These seven companies are profiled in the following pages.

PUBLIC COMPANIES INVOLVED
IN BIOTECHNOLOGY WASTE TREATMENT
UNITED STATES

- Groundwater Technology Inc.
- Westinghouse
- Environmental Diagnostics
- Waste Management Inc.
- Laidlaw
- International Technology Corp.
- Cambridge Analytical Associates

SUMMARY : BIOTECHNOLOGY VS OTHER TECHNOLOGIES

Though most of these seven public companies offer some kind of biological solution, other types of treatments are being used much more extensively.

- *Biological technologies*
  - Conventional biological treatments like land farming and composting are the most popular biotreatments.
  - Some companies are recovering methane gas from landfill sites.
  - Bioreclamation technology is showing some growth and is practiced by several companies.
    - For International Technology Corp., bioreclamation is even the source of four patents
    - Cambridge Analytical Associates has a whole division concentrating on bioremediation
    - Groundwater Technology uses mostly bioreclamation as a solution to site remediation.
- *Other technologies*
  - Disposal and incineration are the principal technologies offered.
    - Disposal technologies include deep well injection, disposal cells and landfills
    - Incineration is a promising technology. Sophisticated incinerator units have been developed by Rollins, International Technology and Westinghouse.

- *Market outlook*

  - Very few public firms are in the wastewater treatment market.

  - Trends seem to favor very strongly on-site vs off-site remediation for hazardous waste contaminated sites.

    - The NIMBY syndrome (Not-in-my-back-yard) is a strong hurdle to permanent treatment installations

    - All of the public companies described in the following pages have developed some kind of expertise in site remediation

    - International Technology Corp. put its hazardous waste facilities up for sale, intending to concentrate on expanding its site clean-up efforts

    - Many companies have obtained substantial contracts to clean up Superfund sites.

  - The giants have not entered the bioremediation field because of competitive concerns. They are moving cautiously because they are waiting to see the efficiency of new biotreatments.

  - Overall, the Superfund site decontamination program is actually the best market opportunity for biological treatment applications.

COMPANY PROFILE : GROUNDWATER TECHNOLOGY INC.

This is an international corporation providing integrated, full-service environmental solutions to companies that produce, or use hazardous materials. The basic business consists of cleaning up petroleum related soil and groundwater contamination for oil companies, among others.

Environmental services

Tests for contaminants, risk assessment, design and implementation of corrective programs, equipment manufacturing, consulting.

Technologies

- Biological: bioreclamation
- Other: air stripping, hydrocarbon pump

Revenues

1988 = $66.1 M (US);   1987 = $37.1 M (US)

COMPANY PROFILE : WESTINGHOUSE

Westinghouse is an international company. Its principal markets include TV and radio broadcasting, electronic systems, financial services, environmental services, and the industrial construction and electric utility industries.

Environmental services

Westinghouse has entered the waste field through acquisitions of S&ME/Haztech and Aptus. S & ME/Haztec Inc is a company that offers environmental and geotechnical engineering, hazardous waste clean-up, asbestos abatement, petroleum product recovery and geographic information data bases. The acquisition complements corporate capabilities in the clean-up of hazardous wastes. Aptus expands Westinghouse's capabilities in the transportation and destruction of hazardous wastes. In two years, Westinghouse's backlog for waste-to-energy plants has grown from zero to $1 billion.

Technologies

- Biological: land farming, bioreactors (activated sludge, fixed film), composting treatment with forced air conditions.

- Other: thermal - O'Connor Combustor, Plasma Arc Pyrolysis, Electric Pyrolyzer, Shirco Infra-Red Incinerator, Slagging Rotary Kiln Incinerators, mobile wastewater treatment equipment.

Revenues

1988 = $12,500 M (US); 1987 = $11,332 M (US)

This company's core is in the agricultural biotechnology area. EDI manufactures proprietary diagnostic kits for agricultural, clinical and environmental purposes. The company also sells culture media, animal blood products, reagents and other biomedical products and supplies.

Environmental services

The company offers environmental testing for toxic waste clean-up sites. Potential markets are in contaminated water/soil analyses, industrial analysis and underground leak detection.

Technologies

- No waste treatment offered

Revenues

1987 = $2 M (US); 1986 = $1.5 M (US)

Waste Management Inc. is an international provider of solid and hazardous waste management services. In addition the company provides street sweeping services, portable lavatories and related services and mobile office services. Through other subsidiaries, Waste Management supplies lawn care and pest control services.

Environmental services

Solid wastes: collection, transfer, resource recovery and disposal;
Medical wastes: collection, treatment and disposal;
Construction of wastewater facilities and operation of waste-to-energy facilities;

Through its Chemical Waste Management subsidiary (the largest hazardous waste management service in the U.S.) it provides: transportation, treatment, resource recovery disposal, hazardous waste site remediation services, radioactive waste management services.

Technologies

- Biological: methane gas recovery from landfills
- Other: sanitary landfills for solid waste;
  for chemical waste: disposal cell, deep well injection, incineration, distillation, evaporation and separation, chemical oxidation and reduction, chemical precipitation of heavy metals, hydrolysis, neutralization.

Revenues (in Canadian dollars)

Total: 1988 = $4254 M
Solid wastes: $3403.2 M
Hazardous wastes: $ 805.8 M
- transportation: $ 114.9 M
- treatment, resource recovery and disposal: $610.9 M
- special services (including site remediation): $125.0 M

Laidlaw is the third largest waste services company and the largest school bus operator in North America. Over 70% of the company's operating assests are in the United States.

Environmental services

Solid waste collection is the most important operation of the waste service division. Other services include: chemical waste collection, solid and chemical waste disposal, solid and chemical waste transfer stations, resource recovery, recycling, wastewater treatment facilities, clean-up of chemical spills, clean-up of hazardous waste facilities.

Technologies

- Biological: composting, gas recovery in landfills, land treatment
- Other: landfills, liquid injection, incineration.

Revenues

Total:	1988 = $1,182 M (US)	1987 = $ 892 M (US)
Waste services:	1988 = $ 617 M (US)	1987 = $ 481 M (US)
• commercial & industrial:	1988 = $ 305 M (US)	1987 = $ 270 M (US)
• transfer & disposal:	1988 = $ 116 M (US)	1987 = $ 62 M (US)
• residential:	1988 = $ 107 M (US)	1987 = $ 99 M (US)
• chemical wastes:	1988 = $ 89 M (US)	1987 = $ 51 M (US)

IT is an environmental management company providing services in three business areas: risk control services, environmental projects and environmental services.

Environmental services

The company put its hazardous waste facilities up for sale, concentrating on on-site remediation, the fastest growing market in the environmental sector. Biotechnology continues to be a key development focus for the company.

Technologies

- Biological: bioreclamation (source of four patents for IT); anaerobic bioreactor systems for dealing with organically contaminated liquid waste streams.
- Other: hybrid thermal treatment systems (modular transportable incinerator); solidification/stabilization; landfill cell construction; synthetic cap installation; thermal separation unit (in development).

Revenues

Environmental Projects[1]:	1988 = $140.4 M (US)	1987 = $99.6 M (US)
Environmental Services:	1988 = $ 52.9 M (US)	1987 = $43.8 M (US)
Risk Control Services:	1988 = $ 16.2 M (US)	1987 = $12.2 M (US)

(1) The Environmental Projects Division is the group mostly involved in waste treatment.

CAA provides environmental analysis and consulting services for the identification, measurement and management of hazardous and non-hazardous chemical wastes. CAA is also developing and commercializing processes to treat hazardous wastes at the site of contamination.

Environmental services

CAA is organized in two divisions, the Bioremediation Systems Division and the Environmental Services Division. The first one concentrates on analytical activities, while the second one offers site remediation services for contaminants such as chlorinated solvents, petroleum hydrocarbons and coal tar.

Technologies

- Biological: application of naturally occurring microorganisms; pumped groundwater treatment by bioreactors or activated carbon; in-situ aquifer remediation by re-circulation of groundwater; in-situ forced aeration treatment and composting of excavated soils; land treatment; in-situ soil treatment with off-gases being treated with biological filters or other methods.
- Other: catalytic destruction; soil vapor extraction for volatile compounds; direct chemical oxidation; neutralization; activated carbon.

Revenues

Environmental Services Division:	1987 = $5.0 M (US)	1986 = $3.5M (US)
Bioremediation Systems Division:	1987 = $1.0 M (US)	1986 = $0.3M (US)

VI
PRIVATE COMPANIES' ACTIVITIES

The following pages describe different biotreatments that were demonstrated within EPA's Site Program by six private companies. This chapter does not intend to cover all emerging technologies in the United States, but rather give examples of what is being done[1,2].

1. Colorado School of Mines

Wetlands-based treatment technology:

This concept uses natural geochemical and biological processes inherent in a man-made wetland ecosystem to remove and accumulate metals from influent waters. The processes that play a role in the wetlands system include filtration, ion exchange, adsorption, absorption accumulation by plants and microbes, and precipitation through geochemical and microbial oxidation and reduction.

Waste applicability:

The treatment is suitable for acid mine drainage from metal or coal mining activities. These wastes typically contain high metal concentrations and are acidic in nature.

---

(1) For information concerning biotreatments in Canadian technology, we invite the reader to consult -The 1988 Canadian Biotechnology Industry Sourcebook, by the Ministry of State for Science and Technology.

(2) In appendix, the reader will find two lists of American companies commercializing biotechnology with applications to waste treatment.

2. Detox Inc

Submerged fixed-film bioreactor:

This system relies on aerobic microbial processes to metabolize contaminants present in a liquid waste stream. It consists of an above ground fixed-film reactor, supplemental nutrient storage tank and pump, sump tank with pump, cartridge filter and final activated-carbon filter. The bioreactor is operated on a one-pass, continuous-flow basis.

Waste applicability:

Groundwater and industrial process waters. Also applicable to lagoon and/or pond waters. Readily biodegradable compounds such as methyl ethyl ketone and benzene can be treated along with other organic chemicals such as chlorobenzene.

Inoculation of microorganisms into reaction tank:

The essence of this biotechnology involves the adaptation of naturally occurring microorganisms to perform specific biodegradation of targeted organic hazardous wastes. Once these microbes are adapted, the process involves the accelerated growth of these microorganisms and their inoculation into the contaminated soil or the slurry tank in which the waste is contained. Nutrients and catalysts are added over time when necessary to enhance the microbial activity. Subsequent inoculations of microorganisms may be necessary. The process involves the slurrying of a contaminated soil with water in an open top agitated tank.

Waste applicability:

Suitable for treating liquids, sludges and soils. Currently microorganisms have been developed to biodegrade the following organic contaminants: PCBs, pentachlorophenol, creosote, oil, phenolics, PAHs, chlordane and myrex.

3. Motec Inc

Liquid-solid contact digestion technology:

This technology involves organic wastes which are placed in a high energy environment and solubilized into the aqueous phase, thus allowing microorganisms to degrade or detoxify organic constituents. The system uses two or three portable tank digesters or lagoons. The portable system has three phases: (1) Primary Contact or Mixing Phase, (2) Primary Digestion Phase, and (3) Polishing Phase.

Waste applicability:

Halogenated and non-halogenated organic compounds, PCBs, dioxins and pesticides. This technology has been demonstrated on liquids, sludges and soils with high organic concentrations.

4. Biotrol Inc.

Aqueous treatment system:

Remediation approach based on the use of specific microorganisms as the sole treatment agent for the biodegradation of toxic organic compounds in groundwater. The microbiological system degrades the organic contaminants via immobilized film bioreactor units without leaving residual intermediate compounds. These units can be based on either aerobic or anaerobic conditions.

Waste applicability:

Groundwaters contaminated with organic compounds, such as pentachlorophenol and creosote from wood-treating chemicals, gasoline or other fuels' hydrocarbons, pesticides, halogenated aliphatic solvents, alcohols, phenolic and PNA wastes from coal gasification processes, and effluent from pulp and paper mills. This technology is also applicable for the removal of certain inorganic compounds such as nitrates.

5. Zimpro/Passavant Inc.

Powdered activated carbon treatment (PACT):

The PACT process was developed for the treatment of wastewaters from both industrial and municipal sources. Powdered activated carbon for physical adsorption is added to the active biomass in the aeration basin. Out of the basin, excess solids are removed from the system by wasting a portion of the solids from the clarifier or thickener. The PACT system can be used with a wet air oxidation unit.

Waste applicability:

Municipal and industrial wastewater containing organic pollutants. The technology has been applied to industrial wastewater including: chemical plant wastes, coke oven flushing liquors, contaminated groundwater, dye production wastewater, food processing wastes, pharmaceutical wastes, and refinery and synthetic fuel wastes.

6. Biorecovery Systems Inc.

AlgaSORB™ sorption process:

This process is designed to remove heavy metal ions from aqueous solutions and is based upon the natural, very strong affinity of the cell walls of algae for heavy metal ions. AlgaSORB™ functions as a biological ion-exchange resin.

Waste applicability:

AlgaSORB™ will remove only heavy metal ions from aqueous solutions.

VII
TECHNOLOGY OPTIONS

TECHNOLOGY OPTIONS AS SEEN BY THE USERS

Users face many options to solve their waste problems and biotechnology is one tool among others. Biotechnology solutions are seen as partial answers; i.e. they are used in support of other solutions. The following table summarizes the advantages and disadvantages to biotechnology approaches.

BIOTECHNOLOGY : PROS AND CONS IN WASTE MANAGEMENT

ADVANTAGES	DISADVANTAGES
• ability to treat wastes on site - cuts transportation costs and risks	• doesn't work well under low temperatures
• minimum disruption of sites - in cases of site remediation	• needs dilute conditions
• can be used as polishing step with other techniques	• specificity of microorganisms - needs mixed microflora
• faster than certain physical methods	• site specific technology
• biosystems are not energy intensive	• biodegradation not applicable to all contaminants
	• black box syndrome
	• biosystems are fragile - can die if not properly maintained

These pros and cons are discussed on the following pages:

BIOTREATMENTS - ADVANTAGES

1. **Ability to treat wastes on site**

Cuts out transportation costs and eliminates risk underlying that operation.

- For example, even the simple collection of municipal garbage amounts to over half of the total cost of dealing with these solid wastes.

2. **Minimum disruption of sites**

- Since waste can be treated on site, there is no need to dig up and haul away anything unless there are some "untreatable" contaminants in the site.
- Little disruption is caused by operations such as addition of oxygen and pumping water through the contaminated area in order to dilute the waste for biological treatment.

3. **Faster than certain other methods**

Air stripping or carbon adsorption can take up to 50 years, while bioreclamation is in the one, two or three year time frame.

4. **Use as polishing step with other methods**

- Importance of looking at biotechnology in combination with other technologies - it is shortsighted to focus on individual tools.
- Final step that gets rid of trace contaminants and achieves permanent degradation of wastes.

5. **Biosystems are not energy intensive**

Microorganisms can work at ambiant temperatures, especially the aerobic species.

- vs, for example, oxidation through incineration.

BIOTREATMENTS - DISADVANTAGES

1. **Temperature**

At temperatures below 50° F, the metabolism of microorganisms slows significantly. This means that in northern countries, biodegradation processes are seasonal unless the installation is heated.

2. **Dilute conditions**

Microbes can assimilate waste in an aqueous system only. They work better when contaminants are diluted.

- They work best when there are a few tens to a few thousands of ppm of pollutants in soil or water.
- Large molecules are often insoluble.
- As industries are using less water, effluents are becoming much more concentrated, creating problems for biological systems.

3. **Specificity of microorganisms**

No one microbe does the job alone; usually a complex mixture of microflora is required. The more complex the component, the more complex the microbial population has to be to handle it.

4. **Black box syndrome**

- The main problem is getting industry people to understand how systems work and how to operate them properly - 85% of biological treatment system failures are due to human error rather than system problems.
- Companies using biosystems must hire specialists to keep the systems working properly.

5. Fragility of biosystems

- Standard microbial products can have shelf-life problems.
- Toxic effluents can poison the biomass, creating problems to reactivate the microflora.
- Biosystems will not survive if not fed properly.

6. Site specific technology

Hydrogeological factors can limit the use of bioremediation methods.

7. Biodegradation not applicable to all contaminants

Not all contaminants are susceptible to biodegradation; for example, metal contaminants, cyanide complexes, radioactive wastes or inorganic substances.

- Very large complex molecules do not exist in nature; therefore, bacteria generally lack enzymes that can degrade them.

OVERALL RANKING OF TREATMENT TECHNOLOGIES

Waste treatment technologies can be ranked on the seven criteria indicated below. Overall, biological technologies are ranked fourth out of five. Physical technologies are ranked first, followed by chemical and disposal technologies.

- Biological systems are rated superior, overall, only to thermal treatment systems.

Scoring summary

TECHNOLOGIES	abnormal events	normal events	input flexibility	operational flexibility	operational reliability	technical reliability	cost	TOTAL SCORE
BIOLOGICAL								60
Activated sludge	19	12	7	3	9	9	5	64
Anaerobic digestion	19	8	10	3	7	9	5	61
Fluid bed contactor	19	12	7	3	7	7	5	60
Land treatment	8	7	11	8	9	9	3	55
Activated sludge/powdered act. carbon	19	12	7	3	9	9	5	64
Rotating biol. contactor	19	12	7	3	7	9	5	62
Trickling filter	19	12	7	3	7	7	5	60
Waste stab. pond	8	11	7	8	9	9	3	55
PHYSICAL								75
Air stripping	19	12	7	8	9	9	8	72
Carbon adsorption	28	12	7	8	9	9	3	76
Resin adsorption	28	12	7	8	9	9	3	76
Centrifugation	31	10	11	8	7	9	8	84
Dissolved air flotation	22	7	10	8	7	9	5	68
Electrodialysis	31	12	10	8	0	12	8	81
Emulsion breaking	22	14	10	8	9	9	5	77
Evaporation	19	11	7	8	9	13	5	72
Filtration	28	10	11	8	7	9	8	81
Floc./sedimentation	28	14	11	8	7	9	3	80
Reverse osmosis	31	12	10	8	0	12	8	81
Solidification	31	10	11	8	9	9	3	81
Solvent extraction	8	10	10	8	9	10	3	58
Steam stripping	19	12	7	8	9	7	5	67
Ultrafiltration	25	12	10	8	0	12	8	75

(Continued...)

Scoring summary (Continued...)

TECHNOLOGIES	abnormal events	normal events	input flexibility	operational flexibility	operational reliability	technical reliability	cost	TOTAL SCORE
CHEMICAL								70
Chemical oxidation	8	8	10	8	9	7	5	55
Chemical reduction	25	8	7	8	9	7	5	69
Dehalogenation	8	10	7	8	9	7	3	52
Ion exchange	31	12	11	8	9	12	8	91
Precipitation	28	14	11	8	9	9	8	87
Neutralization	28	14	7	8	9	13	8	87
Wet air oxidation	8	11	11	3	0	11	8	52
THERMAL								48
Fluidized bed incin.	8	7	11	3	0	11	5	45
Liquid injection	8	7	11	5	7	11	5	54
Pyrolysis	8	7	11	3	0	11	5	45
Rotary kiln incin.	8	7	12	3	0	11	5	46
DISPOSAL								66
Geologic isolation	25	10	11	8	9	12	3	78
Deep well injection	8	14	11	5	7	9	8	62
Engineered landfill	11	10	11	8	9	9	5	63
Warehouse storage	8	10	11	8	9	12	3	61
MAXIMUM SCORE	35	14	13	8	9	13	8	100

Source: Arthur D. Little of Canada Ltd: Technologies and systems for treatment and disposal of special wastes in Ontario.

Biological systems' comparative strength lies in their operational reliability.

- Their two[1] weakest points are
  - their inability to adapt easily to changes in input
  - their relatively higher need for operator intervention to control the process (technical reliability)

RANKING OF TREATMENT TECHNOLOGIES BY INDIVIDUAL CRITERIA

TECHNOLOGIES	abnormal events	normal events	input flexibility	operational flexibility	operational reliability	technical reliability	TOTAL SCORE
PHYSICAL	1st	1st	3rd	1st	4th	3rd	1st
CHEMICAL	2nd	2nd	4th	2nd	3rd	4th	2nd
DISPOSAL	4th	2nd	2nd	3rd	1st	2nd	3rd
BIOLOGICAL	3rd	4th	5th	4th	2nd	5th	4th
THERMAL	5th	5th	1st	5th	5th	1st	5th

Source: *see Appendix*

(1) *In terms of unit costs which are not presented in the table, biological treatments score fairly well.*

Wastewater treatment is a classic bioprocess which is open to further technological improvements.

- The major treatment steps and their respective purposes are outlined in the following table.
- Processes similar to these are also used in the treatment of industrial wastewater.

MICROBIAL TREATMENT OF NON-TOXIC WASTES IN PUBLICLY-OWNED WASTEWATER TREATMENT PLANTS

TREATMENT STEP	PURPOSE
Primary Processing • typically a physical settling/ separation process	- to remove solids from wastewater for: • disposal, or • digestion (to reduce their volume)
Secondary Processing • typically in a large open basin with natural microbes and some kind of forced aeration	- to degrade dissolved organic compounds
Tertiary Processing • can involve a range of processes from chemical precipitation and separation from phosphorous and nitrogen, to sand filtration, detention ponds or biological filters	- to further remove dissolved compounds, e.g. phosporous & nitrogen
Sludge Digestion • typically an anaerobic process	- to achieve a combination of four objectives: • to reduce the total solids volume requiring disposal • to reduce the odour • to reduce the number of pathogenic organisms • to recover methane gas

Source: U.S. Office of Technology Assessment, Commercial Biotechnology: An International Analysis.

Some specific opportunities for biotechnology-based improvements in wastewater treatment are discussed below.

1. Solids separation

- *Flocculation*

Synthetic polymers which have been used in recent years with promising results are both toxic and expensive. Therefore for both safety and economic reasons, biologically derived flocculants could be very desirable.

- *Advanced separations technology*

The many technologies in this class include advanced filtration materials, membranes and centrifuges. In Canada, advanced separation technology is dominated by foreign firms. Research needs are primarily in materials development including separations membranes and application.

2. Biological reactor design

Reactor designs using fixed - or floating - bed techniques show excellent promise of higher biological efficiencies. These designs are generally patented.

3. Sludge dewatering

Because much of the water retained in sludge is probably held in polymeric matrixes composed of cellulosics, fats, polysaccharides, and proteins, partial degradation of these matrixes by using some enzyme combination should release it. For certain potentially useful enzymes, techniques for economic, high-yield production will have to be developed using microbial strains. Presently, thermal conditioning is an alternative which is used for sludge dewatering.

4. Sludge elimination

Sewage sludge is a by-product of the wastewater treatment processes used to render industrial and municipal wastewaters less harmful to the environment. Canada alone produces 500,000 tonnes of sludge annually. An interesting solution has been developed by the Wastewater Technology

Center to convert the substance into fuel oil. The next step will be the full-scale demonstration of the process, if sufficient funding can be made available.

5. Control of organic micropollutants

Their removal could be improved by the use of enzymes that are capable of polymerization. Development of this process requires one or more of the following biotechnological developments.

- microbial strain improvement and process development programs using known polymerizing enzyme-producing microbial strains.
- identification of microorganisms that produce these enzymes in high yield.
- genetic manipulation of a microorganism to produce high levels of these enzymes.

Another approach is to develop microorganisms that will better degrade these contaminating compounds.

6. Control of heavy metal contamination

Heavy metals can have detrimental effects on the operation and performance of biological processes used in wastewater treatment.

- one potential approach to solving the problems of heavy metal contamination involves the use of metallothioneins (proteins having a high affinity for various heavy metals). This process could be used not only for decontamination of waste streams from any industrial process, but also for extraction and concentration of metals by the mining industry. However, specificity is usually the major stumbling block. An alternative approach is to use resins to absorb metals.

BIOTECHNOLOGY APPLICATIONS TO SITE REMEDIATION

Biotechnology is projected to play a low to moderate role in site remediation where organic compounds are the principal contamination problem.

- Where organics are involved, the only treatment methods forecast to have moderate to extensive use were both physical methods:
  - carbon absorption for aqueous streams
  - sedimentation/filtration

- Stripping is forecast to have moderate use and thermal oxidation and carbon absorption for gases are expected to have low to moderate use.

FUTURE USE OF SELECTED TECHNOLOGIES

Evaluation criterion	Biological treatment	In-Situ biodegradation
Applicability	Moderate to broad for organic compounds	Limited to special situations for organic compounds
Effectiveness	Can reduce migration; some leakage likely	Can reduce migration; some leakage likely
Confidence	Well-proven; long-term effectiveness high	Limited experience; used in other applications
Capital cost	Low	Medium
Capital cost/ Operating & Maintenance	Capital cost lower than O & M	Capital cost higher than O & M
Projected level of use	Moderate	Limited

Source: Hazardous Materials Management Markets, SRI

Because of their toxicity, developing biotechnological approaches for effective treatment of toxic wastes may be difficult. A specific microorganism or enzyme will probably have to be developed for each different compound. Development of such enzymatic processes would probably involve an extensive research effort, and only very hazardous toxic wastes would justify this degree of effort.

- In general, toxic wastes in dumps or lagoons are likely to be more amenable to biological treatment than those that have been widely dispersed. Dumps and lagoons have the advantage of presenting a reasonable, high concentration of a particular type of compound or family of compounds at a specific site. Thus, the feasibility of developing a very specific treatment process tailored to both the waste to be detoxified and the environment in which it is found is increased.

- For more widely distributed wastes, even if biological methods for detoxification are developed, it may be impossible to apply them effectively.

Microbial populations will adjust to the presence of a toxic compound and eventually achieve some degree of efficiency in its decomposition. This phenomenon probably represents the selection of mutant microorganisms that are able to both tolerate and degrade the toxic compound. In the case of certain toxic wastes, it may be possible to accelerate this mutation by the use of certain techniques.

- In traditional **chemostat selection**, the natural microbial populations present in samples collected from or near the waste disposal sites are grown continuously over several months in the presence of steadily increasing concentrations of the relevant toxic compound, in order to increase the selective pressure for the growth of the mutant microorganisms.

- In a more modern version of chemostat selection, **plasmid-assisted molecular breeding**, laboratory strains of microorganisms that contain plasmids encoding enzymes involved in the degradation of toxic compounds are added to the chemostat to stimulate exchanges of genes from other plasmids in other microorganisms.

- **r-DNA** technology can also be used to transfer the ability to degrade the offending compounds to a different microbial host.

- **Bioremediation** consists in increasing the natural population of microbes at a contaminated site. This is achieved by providing the site with proper environmental conditions which will stimulate the population's growth.

Current applications of biotechnology to waste management rely on naturally occurring microbes. Although there is practically no difference between naturally mutating organisms and mutations induced in laboratories, the application of genetic engineering to the waste management field remains some years away. Here below are the reasons which underly this trend.

- The main reason evoked is the fear of regulatory barriers related to environmental release of genetically engineered microorganisms (GEMs).

- "Even GEMs will adapt to their environment, so if environmental conditions are not sufficiently controlled, the GEMs will adapt to their new situation"(1).

- "Why have all the qualities in one organism when you can have just four different ones; natural consortiums are more effective"(2).

- "GEMs may be ready 5-10 years down the line but there are problems that must be dealt with now"(3).

- Because degradation of a toxic compound usually involves a complex and often uncharacterized series of reactions, it has generally been preferable to let nature select for the proper genetic combination rather than to attempt to construct it *de novo* in the laboratory.

---

(1) Quote from R. Laughton - Pollutech Ltd.
(2) Quote from D. Forrester - Gemini Biochemical Research Inc.
(3) Quote from R. Brouzes - Alcan Aluminium.

VIII
TECHNOLOGY SOURCES

Biotechnology research in the waste treatment field tends to come primarily from public sources. Private research is fragmented and underfunded.

- Public research in Canada is the subject of this chapter. The list of institutions and research projects presented is not meant to be comprehensive; it is a quick overview of efforts in the field to give an idea of some of the initiatives which are being undertaken.

- Private research initiatives are covered in similar fashion in chapters 5 and 6 where the activities of a sample of public and private companies are sketched out.

GOVERNMENTAL SOURCES OF TECHNOLOGY[1,2]

1. National Research Council (NRC)

1.1 Biotechnology Research Institute (BRI)

- Detoxification of contaminated soils
  - microbiological & enzymatic aspects
  - *pre-treatment of soils contaminated with chlorinated organic compounds (Sanivan)
  - *bioreactor development for in-situ soil treatment (Sanivan - Centre St-Laurent)
- Industrial wastewater treatment
  - anaerobic reactor for dairy industrial effluents (SNC-Polytechnique)
  - captors for wastewater stations (Sherbrooke Univ.)
  - *anaerobic reactor for pulp and paper effluents (Paques Lavalin - NRC biol. sciences)
  - pulp & paper effluent upgrading (Domtar)

1.2 Biological science division

- Anaerobic digestion of pulp & paper effluents
- Pulp & paper toxicity characterization (Paques Lavalin - BRI)

2. Environment Canada

2.1 Wastewater Technology Centre (WTC)

WTC acts as a sort of financial broker, securing funds from other agencies with similar research interests to fund R&D projects.

- Development of biological processes to address municipal and industrial water pollution problems
  - activated sludge systems
  - *computer controls for biological processes (Canviro Consultants)
- Anaerobic treatment of concentrated wastewaters
  - automated monitoring and control strategies
  - pulp & paper wastewaters

(1) Establishments appearing in brackets collaborate to the project.
(2) Technologies preceded of this symbol (*) offer good commercial potential.

2.1 Wastewater Technology Centre (continued)

- Conversion of sewage sludge to oil and char
  - negotiations for the licensing of the technology

- Land farming
  - Organic contaminants in municipal sludge applied to agricultural land
  - Industrial waste constituents applied to soil

- In-situ bioremediation of soils containing chlorinated organic compounds

2.2 St-Lawrence Centre

The Centre acts as a technology transfer centre by promoting cooperation among various partners working to control toxic discharges into the river.

- Technological Development Division
  - budget: $ 37 million (over 5 years)
  - no research at the Center, but contracted out
  - actual areas of interest:
    - anaerobic bioreactor for global effluent treatment
    - soil decontamination (McGill Univ.)

3. Agriculture Canada

3.1 Land Resource Center

- Microbial degradation of pesticide residues in soil - genetic work (Univ. of Ottawa - Ceiba Geigy)

* - Composting technology using peat
  - with fish residues (Univ. of Moncton, Aquaterre, Centre de recherche pour le développement de la tourbe)
  - with other wastes such as: manure, pulp sludge (Centre de sylvichimie de l'Outaouais)

3.2 Animal Research Center

- Composting liquid manure with peat

3.3 Centre de recherche et de développement sur les aliments

This governmental facility is a research center but also acts as a technology transfer center

* - Upgrading of whey to obtain aromas as propionic acid Université du Québec à Montréal (UQAM)

* - Upgrading of agricultural wastes (ungraded vegetables) (Lassonde)

4. Energy, Mines and Resources Canada

- Canada Centre for Mineral and Energy Technology (CANMET): Extractive Metallurgy Laboratory

  *• recovery of metallic selenium from smelter effluents

  *• degrading of de-icing fluids

  *• biological process for mitigation of acid mine drainage

  • removal of organic floatation reagents from tailing water

  • bioadsorption to recover uranium from waste streams (McMaster Univ. - Denison Mines)

UNIVERSITY SOURCES OF TECHNOLOGY[1,2]

1. Western Ontario

- anaerobic digestion of pulp & paper effluents (Kosaric - biochemical eng.) up-flow sludge blanket reactor
  coll: BRI-NRC
- algae detoxification of industrial effluents - heavy metals, chlorinated hydrocarbons (Kosaric - biochemical eng.)
- microbial de-emulsification (Kosaric - biochemical eng.)
- fermentation of cheese whey and lignocellulosic wastes to obtain alcohol (Kosaric - biochemical eng.)

2. McGill

- Unique gene fusion biosensors to detect toxic agents and characterize their mechanisms of toxicity (DuBow - microbiology)
  * NSERC strategic grant $ 203,400
- degradation of oil, kerosene and light petroleum fractions (microbiology)
- animal waste treatment (agricultural eng.)
- microbial biomass for recovery of nuclear fuel and toxic metals (chemical eng.)
- bioreactor design (chemical eng.)
- biosorbents (chemical eng.)
- biodegradation of polyaromatic hydrocarbons (PAHs) in soils under denitrification conditions (civil eng.)
- polymers in sewage treatment (civil eng.)
- composting crop residues for soil conservation and nutrient supply

3. Laval

- Biotreatment of municipal water using immobilized bacteria and algae systems (de la Noue - biology)
  * NSERC strategic grant $ 205,566
- Treatment and upgrading of swine manure with micro-algae systems (de la Noue - Centre de recherche en nutrition)
- Manure composting on farms (Karam - sc. agriculture et alimentation)
- Fixed-film multi-stage aerobic fermentor (de la Noue - Centre de recherche en nutrition)
- Land reclamation of mine tailings (Karam - Centre de recherche en aménagement et développement)

---

(1) *Contact person and research facility are indicated in brackets when known*

(2) *This symbol (*) indicates Natural Sciences and Engineering Research Council (NSERC) strategic grants.*

3. **Laval (continued)**

- Heavy metal mobility in soils treated with residual sludge (Karam - sc. agriculture et alimentation)
- Bacterial lixiviation of metallic sulphurs (Guay - medecine & microbiology)
- Ferri-cyanid degradation (Guay - medecine & microbiology)
- Biodegradation and upgrading of fish waste (Karam & Parent - sc. agriculture et alimentation)
- Biodegradation and upgrading of industrial and forest wastes (Karam - sc. agriculture & alimentation)
- Solar biotechnologies used in effluent upgrading and treatment (Lavoie, Serodes & de la Noue - civil & chemical eng.)

4. **Waterloo**

- Membrane-based separation process: pulsed-electric field-enhanced, cross-flow ultrafiltration of proteins solutions (Robinson - chemical eng.)
  * NSERC strategic grant $ 141,995
- Degradation of phenolic compounds in wastewater using activated carbon treatment and low temperature microorganisms (biology & civil eng.)
- In-situ reclamation of organic contamination in soil using fungal organisms (biology & civil eng.)

5. **École Polytechnique**

- Inverted fluidized bed bioreactors (Chavarie & Ramsay - BIOPRO Laboratory)
  coll.: BRI
- Biotech process design - Computer assisted design (CAD) (Chavarie & Paris - BIOPRO Laboratory)
- Systems engineering: bioprocesses, modeling and control (Perrier - BIOPRO Laboratory)
- Biotech process development to decontaminate hydrocarbon impregnated soils (Rouleau & Normandin - BIOPRO Laboratory)
- Laminar flow aerobic bioreactor over biomass fixed to synthetic textiles (Mayer & Normandin - BIOPRO Laboratory)
- Sequencing batch reactor technology optimization (Mayer & Normandin - BIOPRO Laboratory)

5. **École Polytechnique (continued)**
   - Determination of parameters used for wastewater system design (Mayer & Normandin - BIOPRO Laboratory)
   - Biological & chemical treatment of Kraft effluents (Archibald, Brière & Arcand - civil eng.)
   - Decantation control in wastewater systems using activated sludge (Desjardins & Brière - civil eng.)

6. **Alberta**
   - Anaerobic biological degradation of hazardous organic chemicals (Hrudey - civil eng.)
   - Powdered activated carbon study (Smith - civil eng.)
   - Role of support media in enhancing anaerobic biotreatments of phenolics (Hrudey - civil eng.)
   - Anaerobic microbial degradation of phenols applied to wastewater treatment (Fedorak - microbiology)

7. **Université du Québec**
   - UQAM
     - Biomass upgrading (wood residues, crop wastes, manure) by fermentation to produce animal food and ethanol (Dubeau - biology)
     - Sludge biodegradation in poultry slaughterhouses (Smoragiewicz - Boutard biology & physics)
     - Composting of urban wastes (Smoragiewicz - biology)
     - Biodegradation of residual sludge in wastewater stations (Smoragiewicz - biology)

   - INRS
     - Metal lixiviation from sludge
       coll: Société québécoise d'assainissement des eaux, Centre St-Laurent, CQVB
     - Sludge valorization for agriculture & forestry purposes
     - Thermophilic biological process for the treatment of agricultural wastes
     - Control system to operate activated sludge in wastewater treatment
     - Biolixiviation of oil contaminated soils
       coll: Sodexem International

7. **Université du Québec (continued)**
   - Institut Armand Frappier
     - Aromatic compound biodegradation by methanogenic fermentation
     - Development of a thermophilic aerobic treatment for swine manure (Beaudet, Bisaillon & Ishaque)
     - Anaerobic filter to improve effluent waste from septic tank (Bisaillon, Beaudet & Rollin)
     - Anaerobic treatment for thermomechanical pulp effluents (Bisaillon, Beaudet & Paquet)
     - New septic tank system incorporating a bioreactor and geotextiles (Bisaillon)
     - PCB anaerobic degradation (Bisaillon)
     - Lignin biotransformation in high value chemical products (Chabal, Ishaque & Couillard)
     - Cellulose biodegradation by fungal-like bacterias (Kluepfel)

8. **Sherbrooke**
   - Bacterial strain development for the biodegradation of crustacean shells for sugar extraction (biology)
   - Biodegradation of organic solvant fumes (Beerly - chemical eng.)
   - Improvement and control of textile sludge degradation processes (Jolicoeur - chemistry)
   - Control methods for anaerobic fermentation of dairy wastes (Jolicoeur - chemistry)
     coll: BRI & Agropur
   - Resistance to intoxication of activated sludge in municipal wastewater treatment (Jolicoeur - chemistry)
   - Revegetation of mining tailings with municipal sludge (Jolicoeur - chemistry)

9. **Manitoba**
   - Toxicity of sulphides in anaerobic waste treatment (Oleszkiewicz - civil eng.)
     * NSERC strategic grant $ 75,660

10. **Carleton**
    - Development of chloroaromatic degrading bacteria for ground and surface water treatment (Wyndham - biology)
      * NSERC strategic grant $ 184,870

11. **British Columbia (UBC)**
    - Optimization of phosphorus removal and sludge stabilization for domestic sewage (Oldham - civil eng.)
      * NSERC strategic grant $ 260,660

12. **Concordia**
    - Biomass conversion to industrial chemical products

13. **Dalhousie**
    - Bacterial lixiviation of minerals

14. **Laurentian**
    - Bacterial lixiviation of minerals

15. **McMaster**
    - Bioadsorbants to recover uranium from waste streams

1. Centre de recherche industrielle du Québec (CRIQ)

CRIQ has the mandate to promote technological development in small and medium-sized firms. CRIQ's biotechnology laboratory offers a variety of services to firms in the agrifood, forestry and chemical products business.

Research project:

- Peat biofilters for organic solvant biodegradation in the flexography and paint industries

2. Centre québécois de valorisation de la biomasse (CQVB)

CQVB is a Quebec government corporation that promotes R&D into the utilization of biomass as a raw material for commercial goods. The centre has no research teams but has concluded the following R&D agreements with associate laboratories.

- Recovery processes for lignocellulosic materials and natural macromolecules (Univ. of Sherbrooke)
- Solid fermentation and mushroom production (Laval Univ.)
- Applied microbiology and bioprocess engineering and systems R&D (BIOPRO Laboratory; École Polytechnique de Montréal)
- Production of peat-based biological substrates (Premier Enterprises CDN)

3. Ortech International (formerly Ontario Research Foundation)

Formerly a Crown Corporation, Ortech is now a private non-profit research society.

- Enhanced recovery of energy from municipal industrial solid waste
- Industrial waste treatment using rotating biological contactors
- Industrial waste treatment using aerobic and anaerobic digesters
- Leachate treatment using RBC and anaerobic digesters
- Concentration of metals from metalbearing wastewaters using biological reactors

3. Ortech International (continued)

- Landfarming of papermill sludge
- Composting of municipal organic solid wastes
- Experimental in-situ groundwater and soil remediation
- Mineral recovery using microbial leaching
- Development of hyperferm process for more economic production of ethanol from waste biomass
- Recovery and biodegration of phenols from exhaust gases using Chemdisk™ rotating biological disk
- Biodeterioration and biodegradation of materials
- Biofouling: causes and prevention

4. Alberta Research Council

This research facility has a biotechnology section. Dr. Allen Jones is working on some manure application in agriculture.

IX
CONCLUSIONS

In 1988, total North American expenditures on cleaning up water and solid waste pollution are estimated at some $56 billion: about $U.S. 51 billion in the United States and some $5 billion in Canada.

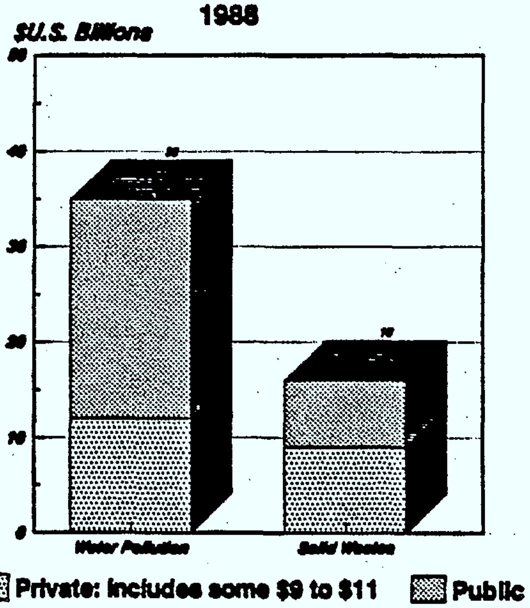
- This includes substantial internal expenditures by industry; for example, in the U.S., industry spends some $U.S. 9 to 11 billion in this way.

  - Commercial hazardous waste treatment companies handle less than 5% of the wastes generated.

  - "We handle most of our wastes ourselves".
    E.I. du Pont de Nemours & Co.[1]

- Public money predominates in pollution abatement spending on water and solid waste. It accounts for almost 60% of total expenditures in the U.S.

THE UNITED STATES WATER AND SOLID WASTE POLLUTION ABATEMENT MARKET 1988



Source: EPA

(1) *Corporate Environmental Dept., Du Pont, New York*

Breaking down total spending into the markets it represents for suppliers is complicated by industry's significant internal expenditures. Total spending, based on EPA data and American market studies, is presented below:

- Public sewer systems represent the greatest share of expenditures, fully 37%.
  - This is almost double the share that either industrial wastewater spending or conventional solid waste spending represents.
- Spending on hazardous waste, including site remediation, is the smallest market, representing only 6% of all expenditures.

EXPENDITURES BY SECTOR ON WATER AND SOLID WASTE POLLUTION ABATEMENT
UNITED STATES
($U.S. BILLIONS)
1988

SECTOR		$		(%)
WATER		35		(69)
Public Sewer Systems	19		(37)	
Industrial	10		(20)	
Other, unspecified	6		(12)	
SOLID WASTE		16		(31)
Conventional	10		(20)	
Hazardous, including site remediation	3		(6)	
Other, unspecified	3		(6)	
TOTAL*		51		(100)

Source: EPA and data from Chapter 1

MARKET GROWTH

Wastewater treatment is the most mature market. In real terms, after inflation, new capital investment is not expected to grow from today's levels. Conventional solid waste treatment and hazardous waste treatment, including site remediation will fare better; however, in terms of absolute size, wastewater treatment is an enormous market.

- New spending on industrial wastewater treatment facilities has declined some 30% in constant dollars, over the decade 1975-1985.

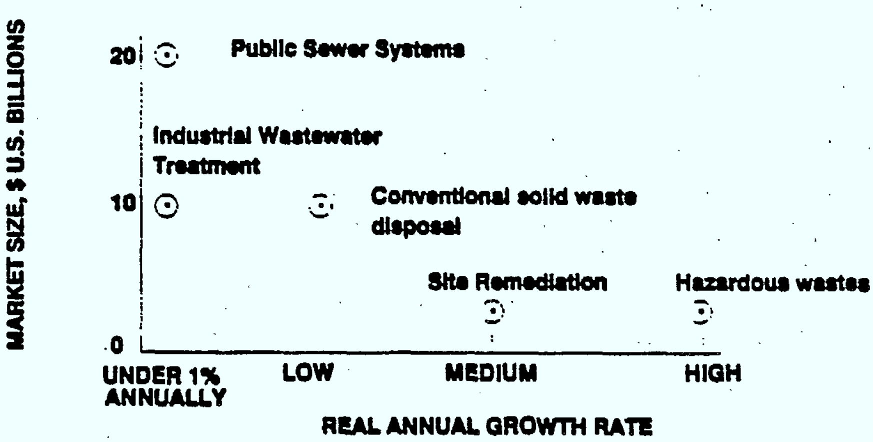
- New spending on public sewer systems declined by about 12% over the same period.

- Conventional solid waste management is expected to grow somewhat above GNP growth rates over the coming decade: about 4% yearly, on average, to 1999.

- Site remediation, driven largely by public funding, is expected to exceed this growth, breaking into the double digits.

- Hazardous waste treatment, especially on-site services, is expected to grow the fastest of all. Some estimates put the hazardous waste business to hit 20% growth.

RELATIVE MARKET GROWTH RATE AND SIZE
UNITED STATES



BIOTECHNOLOGY'S SHARE

Measured by its share of spending on facilities, biotechnology's greatest share is in the most mature markets: public sewer systems and industrial wastewater treatment.

- Biotechnology's share is greatest in municipal wastewater treatment where biotechnology's greatest weakness - the inability to adapt easily to changes in input - is much less of a factor.

- Biotechnology's share of spending on facilities in industry is considerably less: some 12%.
  - This share is highest in industries like chemicals and textiles: around 20%.
  - Biotechnology's share is least in industries like metals and coal mining.

BIOTECHNOLOGY'S SHARE OF FACILITIES INVESTMENT
UNITED STATES
($ BILLIONS)

SECTOR (YEAR)	FACILITIES INVESTMENT TOTAL	BIOTECH	(%)
Publicly-owned wastewater treatment facilities (1988)	9	3.2	(35)
Manufacturing, wastewater treatment facilities (1985)	0.98	0.12	(12)

Source: Chapter 1

In the conventional solid waste treatment market, biotechnology's share is small, measuring 7% of annual construction, engineering and operating costs. The situation is less clear in the rapidly evolving hazardous waste treatment market. Here, high technology treatments overall have about an 8% market share.

- The conventional solid waste treatment market is dominated by the technologies of landfill, waste-to-energy and recycling.
  - Biotechnology, in the form of microbial treatment, composting and landfarming, represents a 1989 expenditure of some $U.S. 700 million.
- In hazardous waste treatment, including site remediation, biotechnology's share is estimated to be under 5%.

BIOTECHNOLOGY'S SHARE OF SPENDING IN CONVENTIONAL SOLID WASTES AND COMMERCIAL HAZARDOUS WASTE UNITED STATES ($U.S. MILLIONS)

	$		
SECTOR (YEAR)	TOTAL	BIOTECH	(%)
CONVENTIONAL WASTE:			
Annual Expenditures on Construction, Engineering and Operations (1988)	10,000	700	7
COMMERCIAL HAZARDOUS WASTE: Industry Revenues (1986)	2,250	--	--
- All High Technology (1988)	215	--	--
. Microbial Cultures		5	--

Source: Chapter 1

Biotechnology-based improvements that are applicable to public water treatment systems will very likely be applicable to the industrial sector because processes used in both types of wastewater treatment facilities are similar. Both consulting engineering firms and operators of major municipal waste treatment systems confirmed the following needs in decreasing order of importance :

- **Sludge elimination, dewatering and heavy metal contamination are three key interrelated problems.**

  - Solids disposal is problematic.

    The volume, compared with municipal garbage, is not an issue; however, in any land application, such as sanitary landfill, a large land base is required to reduce the concentration of sludge components like nitrogen and heavy metals to safe levels. Alternative disposal methods run up against the same problem, e.g.:

    - composting still requires a land base sufficiently large to reduce the metals concentration to an acceptable level.

    - incineration yields ash with an even higher metal concentration. In fact, some ashes must be chemically treated to lower the metals content. Furthermore, incineration presents an air pollution problem because of metal and acid emissions.

  - Insufficient sludge dewatering complicates disposal

    Disposal of liquid sludge at sanitary landfill sites is, at best, messy. Reducing the water content would result in lower trucking costs, easier landfill operations and lower energy costs in the case of incineration.

    - if dry enough, sludge could be used directly as topsoil.

- **Biological reactors**

  - The need for improvements in this area is seen as secondary to the problem of sludge. Furthermore, the microbes themselves are seen as the key to better biological reactors.

    - there is a need to find more strains of microbes which are specifically suited to particular wastes

    - reactors with multiple microbial strains, operated in a controlled sequence to favour the growth of each strain in turn is one example of the creative use of microbes coupled with better process control

    - the development of vastly improved process control through sophisticated computer software is a must which will solve one of biotechnology's major weaknesses: the need for operator intervention.

  Such developments will increase the performance levels of biological reactors across the board.

- **Solids separation**

  - This is not seen as a particular problem; however, existing primary systems do require a large land area.

- **Control of organic micropollutants**

  None of the respondents saw this as an issue. Should such pollution arise, removal at the source is seen as the solution.

  - Furthermore, much stricter regulation on what industries are allowed to dump to municipal sewers is seen as having a double-barrelled effect on the waste treatment industry:

    - improving the performance of municipal plants

    - achieving far more cost-effective treatment by dealing with industrial wastes at the source, i.e. regulatory changes are the key, not technological progress

The foregoing ranking of opportunities in wastewater treatment could be affected by developments in the following areas:

- **Landfill**

  In North America, sufficient landfill capacity is in short supply.

  - the problem is political: landfill operations are unwelcome in most communities

  - therefore, cost competitive technological solutions to sludge elimination, dewatering and heavy metal contamination will likely continue to find a growing market.

- **Regulation**

  Industries legally dispose of many process wastes to municipal sewer systems, rather than treating them.

  - the resulting complex waste stream reduces the efficiency and effectiveness of municipal wastewater treatment
  - society would be better served at a lower total cost by treating these wastes at source

  Regulations specifying treatment at source would stimulate demand for improved technologies and advanced bioreactors in particular.

- **Risk assessment**

  Municipal operators are beginning to consider the potential health effects of working with sewage.

  - infection by air-borne organisms and skin adsorption are the biggest concerns
  - the application of computerized control, artificial intelligence and more automated processes are seen as potential solutions.

  Furthermore, industrial operators express similar concerns.

PUBLIC RESEARCH INITIATIVES IN THE AREAS OF OPPORTUNITY

Following are a few examples of publicly funded research in the areas of opportunity identified. This list is illustrative only.

- **Sludge elimination, dewatering and heavy metal contamination:**
  - Wastewater Technology Centre
    - sludge dewatering
    - conversion of sewage sludge to oil
    - organic contaminants in municipal sludge applied to agricultural land.
  - INRS
    - metal leaching from sludge
    - sludge upgrading for agricultural and forestry purposes
  - Université de Sherbrooke
    - improvement and control of textile sludge degradation processes
    - vegetation of mining tailings with municipal sludge
  - Université Laval
    - heavy metal mobility in soils treated with residual sludge

- **Biological reactors**

1) Microbial strain development :

- Carleton University
  - development of bacteria for degrading chlorinated aromatics in ground and surface water

- Biotechnology Research Institute
  - microbial & enzymatic aspects of contaminated soil detoxification

2) Process Engineering :

- École Polytechnique (Biopro Laboratory)
  - inverted fluidized bed bioreactors
  - biotechnology process computer assisted design
  - systems engineering : bioprocesses, modeling and control
  - laminar flow aerobic bioreactor over biomass fixed to synthetic textiles
  - optimization of sequential batch reactor technology
  - determination of parameters used for wastewater system design

- Biotechnology Research Institute
  - anaerobic reactor for dairy industrial effluents
  - anaerobic reactor for pulp and paper effluents

- Wastewater Technology Centre
  - automated monitoring and control strategies for anaerobic treatment of concentrated waters.

Biotechnology is projected to play a low to moderate role in site remediation since biotreatments are competing with other methods. The following situations define the context in which biotechnology will find most of its applications within the hazardous waste market segment.

- where organic compounds are the principal contamination problem
- where in-situ treatment is needed
- where the contaminated site presents a reasonable concentration of the same compound or the same family of compounds

- Among the different types of biotreatments that can be offered, the ones that can answer these specific needs will be more popular

  - speed of treatment

  - low costs
  - input flexibility (variety of wastes that can be handled)

OPPORTUNITIES FOR BIOTECHNOLOGY : SOLID WASTE

This market represents limited opportunities for biotechnology. This sector is dominated by other solutions such as landfilling, recycling and incineration. But biotechnology can still play a role in waste upgrading, methane gas recovery and composting.

- **Methane gas recovery**

  Although the effective anaerobic treatment of solid wastes is more a problem of engineering than of biotechnology, there is a possibility that enzymes added to the waste could improve the efficiency of this treatment.

- **Waste upgrading**

  Microbial treatment can contribute to upgrade organic wastes such as forestry or agricultural wastes into value-added products (e.g. aromas, fertilizers, etc...)

- **Composting**

  More efficient methods to obtain compost should be sought after and could then fill two needs : eliminating wastes and replacing chemicals by natural products in response to growing environmental concerns.

APPENDICES

- 1 -

SPECIAL WASTE TREATMENT TECHNOLOGIES
DETAILED RANKING BY INDIVIDUAL CRITERIA

TECHNOLOGY COMPARISON: NORMAL OPERATIONS

- Most biological technologies don't require any special equipment to operate except for anaerobic digestion and land treatment.

- Most biological technologies have batch discharges during normal operations, which can be analyzed prior to discharge. While there is still a discharge to the environment, wastes which are not up to standards can be sent to further treatment prior to any discharge.

Scoring for normal events objective

	Offsite discharge	Special equipment	Total	Comments
Possible Scores				
Excellent	7	7	14	None; none
Good	5	7	12	Batch discharge; safety monitoring
Fair	4	3	7	Continuous discharge; personal safety equipment (e.q. respirator)
Technologies				
BIOLOGICAL				
Activated sludge	5	7	12	Batch; none
Anaerobic digestion	5	3	8	Batch; supplied air during maintenance
Fluid bed contactor	5	7	12	Batch; none
Land treatment	4	3	7	Continuous; respirator
Activated sludge/ powdered act. carbon	5	7	12	Batch; none
Rotating biol. contactor	5	7	12	Batch; none
Trickling filter	5	7	12	Batch; none
Waste stab. pond	4	7	11	Continuous; none

(Continued...)

Scoring for normal events objective (continued...)

	Offsite discharge	Special equipment	Total	Comments
Technologies				
PHYSICAL				
Air stripping	5	7	12	Batch; none
Carbon adsorption	5	7	12	Batch; none
Resin adsorption	5	7	12	Batch; none
Centrifugation	7	3	10	None; protective clothing
Dissolved air flotation	4	3	7	Continuous; protective clothing
Electrodialysis	5	7	12	Batch; none
Emulsion breaking	7	7	14	None; none
Evaporation	4	7	11	Continuous; none
Filtration	7	3	10	None; protective clothing
Floc./sedimentation	7	7	14	None; none
Reverse osmosis	5	7	12	Batch; none
Solidification	7	3	10	None; protective clothing
Solvent extraction	7	3	10	None; respirator during maintenance
Steam stripping	5	7	12	Batch; none
Ultrafiltration	5	7	12	Batch; none
CHEMICAL				
Chemical oxidation	5	3	8	Batch; protective clothing
Chromium reduction	5	3	8	Batch; protective clothing
Dehalogenation	7	3	10	None; protective clothing
Ion exchange	5	7	12	Batch; none
Precipitation	7	7	14	None; none
Neutralization	7	7	14	None; none
Wet air oxidation	4	7	11	Continuous; none
THERMAL				
Fluidized bed incin.	4	3	7	Continuous; respirator during maintenance
Liquide injection	4	3	7	Continuous; respirator during maintenance
Pyrolysis	4	3	7	Continuous; respirator during maintenance
Rotary kiln incin.	4	3	7	Continuous; respirator during maintenance
DISPOSAL				
Geologic isolation	7	3	10	None; protective clothing
Deep well injection	7	7	14	None; none
Engineered landfill	7	3	10	None; protective clothing
Warehouse storage	7	3	10	None; protective clothing

Source: Arthur D. Little of Canada Ltd: Technologies and systems for treatment and disposal of special wastes in Ontario.

TECHNOLOGY COMPARISON: ABNORMAL EVENTS

Biological technologies are ranked 3rd because they are susceptible to the following undesirable consequences:

- Possibility of uncontrolled gaseous emissions; exposure to on-site personnel prior to emergency response.
- Possibility of release of large quantity of contaminants during flood in excess of design flood; exposure not preventable (for land treatment and waste stabilization ponds).

Scoring for abnormal events objective

	Onsite release	Onsite consequences	Offsite release	Offsite consequences	Total
Possibles scores					
Excellent	9	7	11	8	35
Good	5	-	5	-	
Fair	2	4	0	2	8
Technologies					
BIOLOGICAL					
Activated sludge	2	4	5	8	19
Anaerobic digestion	2	4	5	8	19
Fluid bed contactor	2	4	5	8	19
Land treatment	2	4	0	2	8
Activated sludge/ powdered act. carbon	2	4	5	8	19
Rotating biol. contactor	2	4	5	8	19
Trickling filter	2	4	5	8	19
Waste stab. pond	2	4	0	2	8

(Continued...)

Scoring for abnormal events objective (Continued...)

	Onsite release	Onsite consequences	Offsite release	Offsite consequences	Total
Technologies					
PHYSICAL					
Air stripping	2	4	5	8	19
Carbon adsorption	2	7	11	8	28
Resin adsorption	2	7	11	8	28
Centrifugation	5	7	11	8	31
Dissolved air flotation	2	7	5	8	22
Electrodialysis	5	7	11	8	31
Emulsion breaking	2	7	5	8	22
Evaporation	2	4	5	8	19
Filtration	2	7	11	8	28
Floc./sedimentation	2	7	11	8	28
Reverse osmosis	5	7	11	8	31
Solidification	5	7	11	8	31
Solvent extraction	2	4	0	2	8
Steam stripping	2	4	5	8	19
Ultrafiltration	5	7	5	8	25
CHEMICAL					
Chemical oxidation	2	4	0	2	8
Chromium reduction	2	4	11	8	25
Dehalogenation	2	4	0	2	8
Ion exchange	5	7	11	8	31
Precipitation	2	7	11	8	28
Neutralization	2	7	11	8	28
Wet air oxidation	2	4	0	2	8
THERMAL					
Fluidized bed incin.	2	4	0	2	8
Liquid injection	2	4	0	2	8
Pyrolysis	2	4	0	2	8
Rotary kiln incin.	2	4	0	2	8
DISPOSAL					
Geologic isolation	2	4	11	8	25
Deep well injection	2	4	0	2	8
Engineered landfill	2	7	0	2	11
Warehouse storage	2	4	0	2	8

Source: Arthur D. Little of Canada Ltd: Technologies and systems for treatment and disposal of special wastes in Ontario.

TECHNOLOGY COMPARISON: OPERATIONAL FLEXIBILITY

This criterion measures the ability to schedule waste treatment as needed.

- All of the physical technologies and most of the chemical and disposal technologies are batch processes whereas many of the biological and thermal treatments must be operated continuously.

Scoring for operational flexibility objective

	Type of operation	Comments
Possible scores		
Excellent	8	Batch
Good	5	Semi-continuous
Fair	3	Continuous
Technologies		
BIOLOGICAL		
Activated sludge	3	Continuous
Anaerobic digestion	3	Continuous
Fluid bed contactor	3	Continuous
Land treatment	8	Batch
Activated sludge/ powdered act. carbon	3	Continuous
Rotating biol. contactor	3	Continuous
Trickling filter	3	Continuous
Waste stab. pond	8	Batch

(Continued...)

Scoring for operational flexibility objective
(Continued...)

	Type of operation	Comments
Technologies		
PHYSICAL		
Air stripping	8	Batch
Carbon adsorption	8	Batch
Resin adsorption	8	Batch
Centrifugation	8	Batch
Dissolved air flotation	8	Batch
Electrodialysis	8	Batch
Emulsion breaking	8	Batch
Evaporation	8	Batch
Filtration	8	Batch
Floc./sedimentation	8	Batch
Reverse osmosis	8	Batch
Solidification	8	Batch
Solvent extraction	8	Batch
Steam stripping	8	Batch
Ultrafiltration	8	Batch
CHEMICAL		
Chemical oxidation	8	Batch
Chromium reduction	8	Batch
Dehalogenation	8	Batch
Ion exchange	8	Batch
Precipitation	8	Batch
Neutralization	8	Batch
Wet air oxidation	3	Continuous
THERMAL		
Fluidized bed incin.	3	Continuous
Liquid injection	5	Semi-continuous
Pyrolysis	3	Continuous
Rotary kiln incin.	3	Continuous
DISPOSAL		
Geologic isolation	8	Batch
Deep well injection	5	Semi-continuous
Engineered landfill	8	Batch
Warehouse storage	8	Batch

Source: Arthur D. Little of Canada Ltd: Technologies and systems for treatment and disposal of special wastes in Ontario.

Operational reliability addresses the likelihood that the technology will not be available for use when it is needed. It is measured by the amount of downtime expected.

- Most biotreatments have low to moderate downtimes compared to thermal technologies where frequent downtime is expected.

Scoring for operational reliability objective

	Down time	Comments
Possible scores		
Excellent	9	Low (0-5%)
Good	7	Moderate (5-20%)
Fair	0	High (over 20%)
Technologies		
BIOLOGICAL		
Activated sludge	9	Low
Anaerobic digestion	7	Moderate
Fluid bed contactor	7	Moderate
Land treatment	9	Low
Activated sludge/ powdered act. carbon	9	Low
Rotating biol. contactor	7	Moderate
Trickling filter	7	Moderate
Waste stab. pond.	9	Low

(Continued...)

Scoring for operational reliability objective (Continued...)

	Down time	Comments
Technologies		
PHYSICAL		
Air stripping	9	Low
Carbon adsorption	9	Low
Resin adsorption	9	Low
Centrifugation	7	Moderate
Dissolved air flotation	7	Moderate
Electrodialysis	0	High
Emulsion breaking	9	Low
Evaporation	9	Low
Filtration	7	Moderate
Floc./sedimentation	7	Moderate
Reverse osmosis	0	High
Solidification	9	Low
Solvent extraction	9	Low
Steam stripping	9	Low
Ultrafiltration	0	High
CHEMICAL		
Chemical oxidation	9	Low
Chromium reduction	9	Low
Dehalogenation	9	Low
Ion exchange	9	Low
Precipitation	9	Low
Neutralization	9	Low
Wet air oxidation	0	High
THERMAL		
Fluidized bed incin.	0	High
Liquid injection	7	Moderate
Pyrolysis	0	High
Rotary kiln incin.	0	High
DISPOSAL		
Geologic isolation	9	Low
Deep well injection	7	Moderate
Engineered landfill	9	Low
Warehouse storage	9	Low

Source: Arthur D. Little of Canada Ltd: Technologies and systems for treatment and disposal of special wastes in Ontario.

Ease of operation and also type of monitoring and control system required are the measures of technical reliability. Technologies are assumed to be easier to operate if they incorporate fewer operations and control parameters. Processes with automatic controls are assumed to be more reliable than those that rely on operator intervention for normal control.

- Biological treatments score very well since they are simple to operate; but they need periodic monitoring.

Scoring for technical reliability

	Ease of operation	Type of monitoring	Total	Comments
Possible Scores				
Excellent	6	7	13	Simple; automatic
Good	6	6	12	Moderately complex; continuous w/operator support
Fair	4	3	7	Complex; periodic
Technologies				
BIOLOGICAL				
Activated sludge	6	3	9	Simple; periodic
Anaerobic digestion	6	3	9	Simple; periodic
Fluid bed contactor	4	3	7	Complex; periodic
Land treatment	6	3	9	Simple; periodic
Activated sludge/ powdered act. carbon	6	3	9	Simple; periodic
Rotating biol. contactor	6	3	9	Mod. complex; periodic
Trickling filter	4	3	7	Complex; periodic
Waste stab. pond	6	3	9	Simple; periodic

(Continued...)

Scoring for technical reliability (Continued...)

	Ease of operation	Type of monitoring	Total	Comments
Technologies				
PHYSICAL				
Air stripping	6	3	9	Simple; periodic
Carbon adsorption	6	3	9	Simple; periodic
Resin adsorption	6	3	9	Simple; periodic
Centrifugation	6	3	9	Simple; periodic
Dissolved air flotation	6	3	9	Simple; periodic
Electrodialysis	6	6	12	Mod. complex; continuous w/support
Emulsion breaking	6	3	9	Simple; periodic
Evaporation	6	7	13	Simple; automatic
Filtration	6	3	9	Mod. complex; periodic
Floc./sedimentation	6	3	9	Mod. complex; periodic
Reverse osmosis	6	6	12	Mod. complex; continuous w/support
Solidification	6	3	9	Simple; periodic
Solvent extraction	4	6	10	Complex; continuous w/support
Steam stripping	4	3	7	Complex; periodic
Ultrafiltration	6	6	12	Mod. complex; continuous w/support
CHEMICAL				
Chemical oxidation	4	3	7	Complex; periodic
Chromium reduction	4	3	7	Complex; periodic
Dehalogenation	4	3	7	Complex; periodic
Ion exchange	6	6	12	Mod. complex; continuous w/support
Precipitation	6	3	9	Simple; periodic
Neutralization	6	7	13	Simple; automatic
Wet air oxidation	4	7	11	Complex; automatic
THERMAL				
Fluidized bed incin.	4	7	11	Complex; automatic
Liquide injection	4	7	11	Complex; automatic
Pyrolysis	4	7	11	Complex; automatic
Rotary kiln incin.	4	7	11	Complex; automatic
DISPOSAL				
Geologic isolation	6	6	12	Mod. complex; continuous w/support
Deep well injection	6	3	9	Mod. complex; periodic
Engineered landfill	6	3	9	Mod. complex; periodic
Warehouse storage	6	6	12	Mod. complex; continuous w/support

Source: Arthur D. Little of Canada Ltd: Technologies and systems for treatment and disposal of special wastes in Ontario.

TECHNOLOGY COMPARISON: INPUT FLEXIBILITY

This criterion measures the types of wastes which can be handled by a given technology.

- Biological technologies are generally the most limited in terms of wastes handled - land treatment being the most polyvalent - whereas thermal and disposal technologies are the most versatile.

Input flexibility

TREATMENT AND DISPOSAL OF SPECIAL WASTES (PROVEN TECHNOLOGIES) (& ENVIRONMENTALLY ACCEPTABLE)	BIOLOGICAL	. Activated sludge	. Anaerobic digestion	. Fluidized bed contactor	. Land application	. PACT (activated carbon)	. Trickling filter	. Rotating biological contactor	. Waste stabilization ponds	. Other biological
1. Organic sludges & still bottoms					●					
2. Solvents & organic solutions										
3. Oils & greases										
4. Oil & water mixtures					●					
5. Organic & oily residues					●					
6a. Metal solutions & residuals										
6b. Metal sludges & residuals										
7. Misc. chemicals & products										
8. Paint & organic residuals										
9. Aqueous solutions with organics						●				●
10. Anion complexes										
11. Sludges & inorganic residuals										
12. Pesticides & herbicide wastes										
13. PCB wastes										
14. Clean up residuals										

TREATMENT AND DISPOSAL OF SPECIAL WASTES (PROVEN TECHNOLOGIES) (& ENVIRONMENTALLY ACCEPTABLE)	PHYSICAL	. Air stripping	. Carbon adsorption	. Centrifugation	. Dissolved air flotation	. Electrodialysis	. Emulsion breaking	. Evaporation	. Filtration	. Flocculation/sedimentation	. Reverse osmosis	. Solidification	. Solvent extraction	. Steam stripping	. Ultra filtration
1. Organic sludges & still bottoms				●						●					
2. Solvents & organic solutions				●			●								
3. Oils & greases															
4. Oil & water mixtures				●	●		●								
5. Organic & oily residues				●	●					●			●		
6a. Metal solutions & residuals				●				●	●	●	●				●
6b. Metal sludges & residuals				●					●	●		●			
7. Misc. chemicals & products				●						●					
8. Paint & organic residuals										●					
9. Aqueous solutions with organics		●	●	●	●						●		●	●	
10. Anion complexes															
11. Sludges & inorganic residuals				●					●	●	●				
12. Pesticides & herbicide wastes															
13. PCB wastes													●		
14. Clean up residuals															

TREATMENT AND DISPOSAL OF SPECIAL WASTES (PROVEN TECHNOLOGIES) (& ENVIRONMENTALLY ACCEPTABLE)	CHEMICAL	. Chemical oxidation	. Chromium reduction	. Dehalogenation	. Ion exchange	. Neutralization	. Precipitation	. Wet air oxidation	THERMAL	. Fluidized bed incineration	. Liquid injection incineration	. Pyrolysis	. Rotary kiln incineration	DISPOSAL	. Geologic isolation	. Deep well injection	. Secure engineered landfill	. Warehouse storage
1. Organic sludges & still bottoms								●		●	●	●	●					
2. Solvents & organic solutions										●	●		●					
3. Oils & greases										●	●		●					
4. Oil & water mixtures								●		●			●					
5. Organic & oily residues								●		●		●	●					
6a. Metal solutions & residuals		●	●		●	●	●											
6b. Metal sludges & residuals														●				
7. Misc. chemicals & products										●			●					
8. Paint & organic residuals								●		●			●					
9. Aqueous solutions with organics								●		●	●		●					
10. Anion complexes		●																
11. Sludges & inorganic residuals														●				
12. Pesticides & herbicide wastes										●			●					
13. PCB wastes										●	●		●					
14. Clean up residuals												●	●					

Source: Arthur d. little and Secor

TECHNOLOGY COMPARISON: COST[1]

Along with chemical treatments (except for dehalogenation), biological treatments are fairly cheap, costing - in 1985 dollars - between $15 - $30/tonne.

Scoring for cost objective

	Relative cost	Unit cost ($/tonne)
Possible scores		
Excellent	8	Half
Good	5	Middle
Fair	3	Twice
Technologies		
BIOLOGICAL		
Activated sludge	5	15
Anaerobic digestion	5	15
Fluid bed contactor	5	15
Land treatment	3	30
Activated sludge/ powdered act. carbon	5	20
Rotating biol. contactor	5	15
Trickling filter	5	15
Waste stab. pond.	3	35

(Continued...)

1 *Costs cover all incremental operating costs including labor, materials and power, but do not account for capital recovery charges, return on investment, depreciation or income taxes.*

Scoring for cost objective (Continued...)

	Relative cost	Unit cost ($/tonne)
Technologies		
PHYSICAL		
Air stripping	8	3
Carbon adsorption	3	65
Resin adsorption	3	85
Centrifugation	8	2
Dissolved air flotation	5	20
Electrodialysis	8	2
Emulsion breaking	5	20
Evaporation	5	20
Filtration	8	2
Floc./sedimentation	3	40
Reverse osmosis	8	1
Solidification	3	35
Solvent extraction	3	75
Steam stripping	5	10
Ultrafiltration	8	2
CHEMICAL		
Chemical oxidation	5	35
Chromium reduction	5	35
Dehalogenation	3	1000
Ion exchange	8	5
Precipitation	8	10
Neutralization	8	10
Wet air oxidation	8	15
THERMAL		
Fluidized bed incin.	5	95
Liquid injection	5	90
Pyrolysis	5	95
Rotary kiln incin.	5	105
DISPOSAL		
Geologic isolation	3	175
Deep well injection	8	15
Engineered landfill	5	75
Warehouse storage	3	210

Source: Arthur D. Little of Canada Ltd: Technologies and systems for treatment and disposal of special wastes in Ontario.

- 2 -

STRATEGIC INDUSTRY GROUPS IN CANADA

STRATEGIC GROUPS IN CANADA

NAMES	INTERESTS	AFFILIATION
Traditional suppliers		
Degremont Infilco	Wastewater treatment; biological filters	Degremont S.A. (France)
John Meunier	Wastewater treatment; biological filters	OTV (France)
Pollutors		
Domtar	Pulp & paper waste treatment	———
Falconbridge Ltd	Metallurgy & mining wastewater treatment	———
MacMillan Bloedel Ltd	Pulp & paper anaerobic treatment effluent	Noranda Inc.
Services T.M.G. (Niobec Mines)	Mining wastewater treatment	———
Noranda Inc.	Mineral leaching & effluent treatment; pulp bioleaching; hazardous wastes	———
Waste Management Companies		
Sanexen International	Soil toxic waste biodegradation	Groupe Sanivan
Emerging products		
Bioshell Inc.	Waste upgrading	Shell International
Pegasus Industrial Specialties	Fermentors-bioreactors	———
TCI Superior - Div. Mueller Canada	Fermentors-bioreactors	———

...continued

NAMES	INTERESTS	AFFILIATION
Emerging products...		
Temfibre	Pulp & paper	Tembec
Microbe Inc.	Bacteria: non-engineered	——
Aquaresearch Ltd	Wastewater treatment; bacteria sales	——
Bioprotein Canada Inc.	Bacterial Support	Protein Foods Group Inc.
Bio-Response Systems Ltd	Biosensors/toxicity testing systems	——
Coolwater Farms Ltd	Waste upgrading	——
Thermo Tech Waste Systems	Digestors	——
Paques Lavalin	Wastewater treatment/ anaerobic digestor	Lavalin
Consultants		
ADI Limited	Wastewater treatment	——
Beak Consultants	Varied	Beak Consultants Associates
Bionov	Agriculture & food	Laval University
Biorex Groupe Conseil	Aquaculture; compost	ACSI-Biorex
Canviro Consultants	Aerobic wastewater treatment; anaerobic treatment and biogas use	CH_2M-Hill Inc. Canviro Laboratories
CB Research International Corporation	Monitoring systems (probes)/ mining, pulp & paper industries	——
Gendron Lefebvre	Wastewater; industrial and agricultural waste treatment; biosensors & probes	——

...continued

NAMES	INTERESTS	AFFILIATION
Consultants...		
Gore & Storrie Ltd	Municipal & industrial waste & wastewater treatment	GS Processes
Killborn (Saskatchewan) Ltd	Fermentation; waste upgrading	Killborn Engineering
Groupe SNC	Varied	——
Wardrop Engineering	Bioprocessing waste recovery	——
Research Houses		
ADS Environment	Soil biodegradation	ADS Consultants
B.C. Research	Composting; anaerobic/aerobic digestion	——
Biogénie S.R.D.C. Inc.	Bioreactors for heavily-loaded effluents; soil decontamination	——
Boojum	Mining wastewater	Cangene Ltd; Dearborn
Canber Industries	Toxic waste anaerobic digestion; biogas recovery	Bercan Environmental Resources
Diversified Research Laboratories Ltd	Waste upgrading (also consulting)	George Weston Ltd
Bioquest International	Biomonitoring	American Bioquest (Ill.) Delta Square (Md.)
B.V. Sorbex Inc.	Heavy metal removal from wastewaters (biosorption)	——
Enviromine	Toxic waste biodegradation	——
Gemini Biochemical Research	Mining-methane oxidizing bacteria; bioreactor development	——
Giant Bay Resources	Mineral leaching	International Biotech

...continued

STRATEGIC GROUPS IN CANADA

NAMES	INTERESTS	AFFILIATION
Research Houses...		
Mycotech	Waste biodegradation/mine; pulp & paper; aluminium	———
Nova Husky Research Corp.	Oil recovery; biodegradation; waste upgrading	Nova Corporation of Alberta; Husky Oil Operations Ltd.
Pulp and Paper Research Institute of Canada	Pulp and paper wastes	Canadian Government Canadian Pulp & Paper Ass McGill Univ. & UBC
Centre de recherche en sylvi-chimie de l'Outaouais	Upgrading of lignocellulosic wastes (demonstration	———
Bio-Hol Developments	Upgrading of lignocellulosic wastes; fermentation	Joint venture: Weston Research Center and St. Lawrence Reactors Ltd.
Institute for Chemical Science & Technology	Wastewater treatment; land treatment of industrial wastes	———

- 3 -

COMPANIES COMMERCIALIZING BIOTECHNOLOGY IN THE U.S.

COMPANIES COMMERCIALIZING BIOTECHNOLOGY IN THE U.S.

In the United States, the following companies also commercialize biotechnology applications for the environment. These companies represent only a handful of the total number of companies doing diverse activities in the biotechnology sector.

COMPANIES COMMERCIALIZING BIOTECHNOLOGY IN THE UNITED STATES AND THEIR PRODUCT MARKET

COMPANY	COMMERCIAL APPLICATIONS(1)
Biotechnica International	PA, CCE, SCF, Env., AA, Ph.
Cytox Corp	Env.
Dow Chemical Co.	Ph. PA, CCE, SCF, AA, Env.
Ean-Tech Inc.	El., Env., Ph.
Eastman Kodak Co.	Ph., Env.
Ethyl Corp.	CCE, SCF, Env.
Exxon Research & Engineering Co.	CCE, Env., SCF
General Electric Co.	El., Env., Ph., SCF
Genetics Institute	Ph., PA, SCF, Env.
Genetics International Inc.	AA, Ph., SCF, CCE, Env., El.
Genex Corp.	Ph., AA, SCF, Env.
W.R. Grace & Co.	AA, SCF, Env., PA, Ph.
International Minerals & Chemical Corp.	AA, PA, Env., CCE
Kennecott Copper Corp.	Env.
Microlife Genetics	SCF, Env.
Pfizer Inc.	Ph., PA, CCE, AA, SCF, Env.
Polybac Corp	Ph., SCF, Env.
Standard Oil of California	Env.
Sybron Biochemical	Env.
Synergen	AA, SCF, CCE, Env.
Worne Biotechnology	PA, CCE, Ph., AA, Env., SCF

(1) *Ph : Pharmaceutical; PA : Plant Agriculture; AA : Animal Agriculture; SCF : Specialty Chemicals & Food; CCE : Commodity Chemicals & Energy; Env : Environment; El : Electronics.*
Source: Office of Technology Assessment.

BIOTECHNOLOGY COMPANIES INVOLVED IN WASTE DEGRADATION

COMPANY	MATERIALS TO BE DEGRADED	APPLICATION
Advanced Mineral Technologies Golden, CO	heavy metals	hazardous waste
Air Products & Chemicals Trexlertown, PA	organic compounds	wastewater
Amgen Thousand Oaks, CA	trichloroethylene (TCE)	
Arco Performance Chemicals Philadelphia, PA	paper and pulp	waste treatment
ATW Caldweld Santa Fe Springs, CA		toxic waste
Battelle Memorial Institute Columbus, OH	chlorinated compounds	hazardous waste
Bethlehem Steel Bethlehem, PA	phenols	waste streams
Bioclean Bloomington, MN	pentachlorophenol (PCP)	toxic waste
Bio Huma Netics Chandler, AZ	PCP, polychlorinated biphenyl (PCB), dichloro-diphenyl-trichloroethane (DDT)	
Bioscience Management Bethlehem, PA	organics	soil, surface water, ground water
Biospherics Rockville, MD		wastewater
Biosystems Chester Township, PA	petroleum products, organic pollutants	groundwater, soils
Biotechnica International Cambridge, MA	phenol, coal tars, cyanides, heavy metals	toxic waste
Biotechnology Unlimited Houston, TX	industrial surfactants, petroleum wastes, pesticides, herbicides, organic solvents halogenated, hydrocarbons, PAH	soils, ponds, lagoons, wastewaters
Biotrol Chaska, MN	PCP	groundwater
Cambridge Analytical Cambridge, MA	chlorinated hydrocarbons, cloroethenes	wastewater
Cecos International Buffalo, NY		spills, toxic waste
Chemical Waste Management Model City, NY		toxic waste
Celanese Chemical Co. Corpus Christi, TX		anaerobic, wastewater

BIOTECHNOLOGY COMPANIES INVOLVED IN WASTE DEGRADATION...

COMPANY	MATERIALS TO BE DEGRADED	APPLICATION
Celgene Summiy, NJ	chlorinated compounds, aromatics	
Cyto Culture International San Francisco, CA		wastewater
Detox Industries Houston, TX	PCB, DDT, polycyclic aromatic hydrocarbons (PAH), oil, chlordane	toxic waste
Detox Dayton, OH	organic compounds	wastewater
Ecova Redmond, WA	solvents (butyl acrylate, ketones), chlorinated solvents (TCE, vinyl chloride, ethers), wood preserving products (aromatic hydrocarbons, aliphatic hydrocarbons, polynuclear, aromatic hydrocarbons (PCP), petroleum products (diesel, gas, motor oil), pesticides (phenoxyacetic herbicides, organophosphates)	soils, spills, toxic waste, vapors
Envirogen Princeton, NJ	Substituted aromatics, chlorinated solvents, complex hydrocarbons, heavy metals	soil, groundwater, lagoons, sludges, effluent systems
Flow Laboratories Orange, CA		sewage treatment
General Electric Schenectady, NY	PCB, phenols	toxic waste wastewater
General Environmental Science Beachwood, OH	phenols, hydrocarbons	toxic waste non-toxic waste
Genex Gaitherburg, MD		waste treatment
Groundwater Decontamination Systems Waldrick, NJ	methylene chloride	groundwater
Groundwater Technology Norwood, MA	petroleum products, hydrocarbons, solvents	groundwater
Haztech Decatur, GA	petroleum products	groudwater, hazardous waste, spills
Homestake Mining Co. Reno, NV	copper cyanide, free cyanide, thiocyanate	wastewater
Institute of Gas Technology Chicago, IL		toxic waste
ITT Rayonier Shelton, WA	pulp and paper	
Interbio Naperville, IL	hydrocarbons	soils

BIOTECHNOLOGY COMPANIES INVOLVED IN WASTE DEGRADATION...

COMPANY	MATERIALS TO BE DEGRADED	APPLICATION
International Technologies Torrance, CA	nonhalogenated organics	soils, spills, groundwater
Keystone Environmental Resources Pittsburgh, PA	creosote, coal tars, oils	soil, toxic waste
Metropolitan Environmental Celina, OH		hazardous waste, groundwater, dewatering sludge
Microbe Masters Baton Rouge, LA	phenolics, cyanides, chlorinated hydrocarbons, styrene, tri-methylamine, ethylene dichloride, PCP, creosote	wastewater, municipal waste hazardous waste
Monsanto St.Louis, MO	styrene, fluoride compounds	soils
Motec Mount Juliet, TN	wood preservatives	hazardous waste
Occidental Chemical Grand Island, NY	chlorinated compounds	hazardous waste, soils
Rollins Environmental Wilmington, DE		toxic waste
Solmar Orange, CA	grease	
Sybron Biochemical Birmingham, NJ		wastewater groundwater, spills
Vertech Treatment Denver, CO	pesticides, herbicides, phenols, nitrates, cyanides, benzene, aromatics, nonhalogenated hydrocarbons, coal tars, sulfides, multiple ring compounds	aqueous organics sludges, soils
Westinghouse Bio-Analytical Systems Madison, PA		hazardous waste groundwater
Zimpro Inc. Rothschild, WI	organics, acids, hydrocarbons, leachates, herbicides, pesticides, metals	wastewater groundwater

Source: Genetic Engineering News, Oct. 1988

- 4 -

INTERVIEW CONTACTS

Pierre Béchard
Professor, Dept. of Biology
Université de Sherbrooke
Sherbrooke (Québec)

Dr. Laurent Berthiaume
Professor
Institut Armand Frappier
Laval (Québec)

Claude Bolduc
General Director
Nouveler
Montreal (Québec)

François Cormier
Researcher
Saint-Hyacinthe Food Research Centre
Agriculture Canada
Saint-Hyacinthe (Québec)

Denis Couillard
Professor
INRS-Eau
Institut National de la recherche scientifique
Québec (Québec)

Robert Cyr
V.P. & Technical Director
Degremont Infilco
Montréal (Québec)

René Fontaine
R&D Director
ADS Environnement
Montréal (Québec)

Bryan Forestel
Manager of Environmental Services
Laudlaw Waste Systems Ltd
Burlington (Ontario)

R.T. Fraser
Marketing Director
Pegasus Industrial Specialties
Agincourt (Ontario)

Bryan Imber
President
CB Research International
Sidney (British Columbia)

Mary Insell
Marketing & Sales
Microbe Inc.
London (Ontario)

Bruce Jank
Director
Wastewaster Technology Centre
Burlington (Ontario)

Marc Gagnon
President
Aquaterre inc.
Sainte-Foy (Québec)

Yvon Gauthier
Président
Centre de recherche en sylvichime de
l'Outaouais inc.
Gatineau (Québec)

Dr. Hadi Husain
R&D Director
Wardrop Engineering Inc.
Winnipeg (Manitoba)

Carmel Jolicoeur
Chemistry Dept.
Sherbrooke University
Sherbrooke (Québec)

John Kingscott
SITE Program
EPA
Washington D.C.

Naim Kosaric
Biochemical Engineering Dept.
Western Ontario University
London (Ontario)

Joe Kruger
Solid waste and Emergency Response
EPA
Washington D.C.

Marie-France Lamarche
Strategic Grant Administrator
NSERC
Ottawa (Ontario)

Jacques Lapointe
Assainissement urbain
Assainissement des eaux
Ministère de l'environnement
Sainte-Foy (Québec)

John MacLatchy
Senior Advisor
Office of Enforcement and Compliance
Conservation and Protection
Environnement Canada
Hull (Québec)

Richard Laughton
Vice-president
Pollutech
Oakville (Ontario)

Hugh G. Lawford
President
Fermtech R&D Inc.
Mississauga (Ontario)

Dr. Legg
Chemical Engineering Dept.
University of Waterloo
London (Ontario)

Dr. V.N. Mathur
Researcher
Land Resource Research Centre
Agriculture Canada
Ottawa (Ontario)

Paul Matteau
Biotechnology Coordinator
Biotechnology Program
NRC
Ottawa (Ontario)

Ron McReady
CANMET
Energy, Mines & Resources
Ottawa (Ontario)

Diana Mourato
R&D Director
Sanexen International inc.
Montréal (Québec)

Breda Nadon
Chef interimaire
Assainissement de l'air
Environnement Canada
Montréal (Québec)

Wilfrid Ng
Environmental Contaminant Branch
Ontario Ministry of Environment
Toronto (Ontario)

Chris Noah
Government Marketing & Sales Director
Haztech
Decatur, GA

John Nowland
Director
Land Resource Research Centre
Agriculture Canada
Ottawa (Ontario)

Roger Paquet
President
Bioshell Inc.
Montréal (Québec)

Marc Pedneau
Eaux usées industrielles
Assainissement des eaux
Ministère de l'environnement
Sainte-Foy (Québec)

Yvan Pouliot
President
Bionov CNP
Québec (Québec)

André Proulx
Technical Advisor
Aquarecherches
North Hatley (Québec)

Bob Redhead
Market Development Manager
Tricil
Toronto (Ontario)

Richard H. Royhouse
R&D Director
Rutland Biotech Limited
Vancouver (British Columbia)

Gary Ruthlege
Bureau of Economic Analysis
U.S. Dept. of Commerce

Martin Samoiloff
President
Bioquest International Inc.
Winnipeg (Manitoba)

Réjean Samson
Group Head-Environment Engineering
Biotechnology Research Institute
National Research Council Canada
Montréal (Québec)

Roger Tsé
Centre de recherche industrielle du Québec
Sainte-Foy (Québec)

Yvan Valiquette
Head Technological Development Division
Centre St-Laurent
Environment Canada
Montréal (Québec)

Mark Westray
Program Manager for Bioremediation
Westinghouse
North Carolina

Robert Yarem
President
Bioprotein Canada
Hamilton (Ontario)

Allan Yasser
Vice-President
Cambridge Analytical Associates
Boston (Massachussetts)

Mujeeb H. Zoberi
President
Mycotech
Mississauga (Ontario)

ASSOCIATIONS CONTACTED

Governmental Refuse Collection and Disposal Ass'n
Silver Spring, Md.

Hazardous Waste Treatment Council
Washington, D.C.

Nat'l Solid Wastes Management Ass'n
Washington, D.C.

Ortech International
Mississauga (Ontario)

- 5 -
BIBLIOGRAPHY

Les Affaires, May 13-19, 1989.

Apogee Research Inc., The Nation's Public Works: Report on Hazardous Waste Management, National Council on Public Works Improvement, May 1987.

Arthur D. Little of Canada Ltd: Technologies and Systems for Treatment and Disposal of Special Wastes in Ontario, Final Report to Ontario Waste Management Corporation, Oct. 1986.

Business Communications Company, The Huge Conventional Waste Management Business, May 1989.

Business Development Service Inc., Watermark 85 - January 1985 Survey And Forecast, Feb. 1985.

EPA, Office of Municipal Pollution Control, 1988 Needs Survey Report to Congress. Assessment of Needed Publicy Owned Wastewater Treatment Facilities in the United States, Washington, Feb. 1989.

B.A. Fenton, Science Council of Canada, Water Resources Equipment Industry: Opportunities for Research and Manufacturing, Jan. 1989.

W.M. Glenn, Corpus Information Services, "Jobs and the Environment: Some Preliminary Number Crunching", Alternatives, 14(3) (1987), 25.

"The Air Pollution Control Market in the 1990's", International Journal of Air Pollution Control and Waste Management, March 1988.

Office of Technology Assessment, New Developments in Biotechnology, Report No. 4 - U.S. Investment in Biotechnology, Summary, July 1988.

Office of Technology Assessment, Commercial Biotechnology: An International Analysis, Pergamon Press, Elmsford, N.Y.

SRI International, Hazardous Materials Management Markets, Fall 1987.

Statistics Canada, cat. 64-201, June 1985.

U.S. Bureau of Economic Analysis, Survey of Current Business, May 1987.

U.S. Bureau of Economic Analysis, Survey of Current Business, May 1988.

Waste Age, May 1988.

Weldon Jessie and D.B. Shindler, 1988 Canadian Biotechnology Industry Sourcebook, Industrial Support and Strategic Technologies Programmes Branch, Ministry of State for Science and Technology, July 1988.

White Kristin, "Ecova Uses a Combination of Technologies in its Waste Treatment Systems", Genetic Engineering News, Oct. 1988.

WTI & Co. Management Consultants, 1987 Update - Hazardous Waste Control Industry Outlook, 1987.