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RESEARCH REPORT

Research and Development Practices in the Environmental Technology Industry

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RESEARCH AND DEVELOPMENT PRACTICES IN THE ENVIRONMENTAL TECHNOLOGY INDUSTRY

Environmental Law Institute

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Disclaimer

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Preface

The findings of this report provide grounds for significant concern about the research and development (R&D) practices of environmental technology firms. The report reveals very little investment in R&D by these firms, and virtually no investment in more basic R&D to invent new solutions to environmental problems. This lack of R&D in environmental technologies places an even greater reliance on government research funding, yet it too has declined in recent years. The resulting lack of technological innovation may seriously hamper the attainment of public health and environmental quality goals in the United States.

The fundamental findings of this report are:

- Environmental technology firms spend only 3% of their revenues on R&D in the principal market sectors for products to control air and water pollution;
- Two-thirds of the firms report that 90-100% of their R&D is applied, with payback expected in less than two years; and
- The primary source of financing for R&D in environmental technologies is the firms' investments of their own capital.

Given the significant public health benefits accrued from achieving environmental quality, this lack of investment in R&D on new technologies by the environmental industry -- and the near-total lack of basic research -- is a very serious public policy concern. This report indicates the need for strengthened government programs to encourage development of environmental technologies and especially basic, long-term research. Bill Gates of Microsoft and economist Paul Samuelson have recently stressed the need for government support of basic research as one of its most essential functions. Their views are echoed by many of the technology firm managers interviewed for this report, who noted that their privately-funded research is, of necessity, short-term and product-oriented. These managers strongly support greater government funding of basic research which will provide the "building blocks" for developing future environmental technologies.

While this report does not explore the underlying reasons for the lack of investment in R&D for environmental technologies, one cause may be the nature of the demand for these products. Because the industry is largely driven by the standards required in government regulations, it has oriented itself to solving specific problems rather than producing better solutions. The constantly changing and unpredictable course of environmental regulations has driven technology developers and their potential customers to seek short-term adaptations of existing products, rather than invest in basic R&D for new technologies. Yet, certainty about government standards is precisely the most crucial

element needed by the environmental technology industry to be able to justify to their investors the long-term commitment of funds needed for R&D on new technologies. Without market drivers or public policies which promote a paradigm of continuous improvement, the environmental industry will continue to lack the necessary motivation for investing in R&D on technologies designed to protect public health and enhance environmental quality.

Executive Summary

This report presents the results of research conducted by the Environmental Law Institute (ELI), in collaboration with Environmental Business International (EBI). Together, ELI and EBI have studied the research and development (R&D) practices of environmental technology developers, as well as how government actions could best support these technology development efforts.

ELI conducted the research by interviewing key managers at 45 firms that represent small to medium-sized firms exclusively dedicated to developing environmental technologies. Firms were selected equally from the four principal categories of environmental technology firms identified by EBI: Air pollution control equipment; water pollution control equipment; monitoring instruments; and process and pollution prevention technologies. The air and water equipment manufacturers represent the bulk (90%) of the industry, with pollution prevention technologies a relatively small (2%) share.

Sector	Sector size ('96)	Average firm size
Water	$17.5 billion	$ 210 million
Air	15.7 billion	$ 45 million
Instruments	3.1 billion	$ 23 million
Poll. Prev.	0.8 billion	$ 23 million

This research found that relatively little is being spent on R&D, as only 3% of revenues in the principal market sectors of air and water technologies is designated for R&D. In addition, two-thirds of all firms report that 90-100% of their R&D is applied, with payback expected in less than two years. Involvement of these firms with government research programs ranged from minor in the larger air and water sectors to significant in the newer process and prevention technologies.

1. Origins of the environmental technology

- In almost half (47%) of the firms, the original research for their technology came from sources outside the firm and, in an additional 28% of firms (75% in all), outside sources were a major factor in the origin of the technologies. The principal outside sources of these ideas were other companies (31%), federal government (27%), and individual inventors (20%), with a lesser role played by universities (7%).

- For half of the environmental technologies, the original research was not oriented specifically to solving an environmental problem.

- An average of 3.5 years was required before these technologies were brought to marketability, significantly longer than the time periods in which these same firms expect to commercialize their current research and development efforts.

2. Current research efforts

- Ninety six percent of firms reported that their own staff undertake a major portion of their research efforts and, in half of these, their staff is the only major source of research. Three other groups were also mentioned as major participants in current R&D efforts: 40% of firms listed another company, especially customers; 20% mentioned universities; and 18% mentioned government sources.

- Cost reduction and improved performance of existing products are the highest R&D priorities in the majority of companies.

a. Extent of R&D

- Average investments in R&D for water and air technology firms were 2.5% and 3% respectively. Instrument manufacturers invest an average of 8% of total revenue in R&D, while process and prevention technology firms invest an average of 25% of total funds in R&D.

- Fifty percent of these technology firms spend less than $1 million a year on research and development, indicating the relatively small average size of the environmental technology companies interviewed (median size was $25 million).

b. Long-term research

- Two-thirds of the companies indicated that at least 90% of their research has a short-term focus of one to two years. In contrast, only 8% of companies, typically those still researching their technologies, said that 50% or more of their research had a longer-term focus.

- The principal reason given for the lack of investment in long-term research in the environmental technology community is economic pressure. Companies typically described their research as market-driven and oriented to developing specific products, with a correspondingly short time frame.

- Other reasons given for lack of investment in long-term R&D were: the relative maturity of some sectors; the lack of certainty in environmental markets; the lack of uniformity or standardization to environmental solutions and products which limits market size; and the focus on meeting regulatory requirements.

- A few companies stated that changes in the economic climate in the past 5 to 10 years have led them to reduce the amount they invest in long-term research.

c. Collaboration

- Collaboration between firms on R&D issues was reported by 40% of firms but is generally ad-hoc in nature and designed to overcome specific marketing or technological problems. It is rarely used to develop long-term relationships based on the mutual benefits of joint R&D.

d. Financing

- The primary source of financing for R&D is the firms' own capital. Almost 80% of the air and water companies and 60% of the instrument companies cite their own company's capital as their only source of financial support. Government funding was significant only for the smaller process and pollution prevention segment.

- To the extent they are available, government funds are used primarily in the idea development phase, whereas venture capital and public offerings are used primarily in bringing technologies to market.

- Of those companies which identified R&D issues not adequately addressed by firms like theirs, 50% cite a lack of long-term basic research.

- Almost a third (31%) of the companies report that a part of their R&D is conducted outside the United States.

3. Government Roles in Technology R&D

- Only 6% of air, water and instrument companies identify the federal government as a major participant in their current R&D efforts.

- When asked to identify the most important roles the federal government can play to assist firms in developing environmental technologies, companies identified key roles for government in: support of basic research; support of the demonstration and commercialization process; providing information about new technologies; and providing regulatory flexibility. A lesser but still significant number support a government role in testing or verifying the performance of new technologies.

- Few firms support direct federal assistance in marketing new technologies, except to overseas customers.

- Although relatively few firms have received assistance from state government technology programs, 58% of the firms interviewed say that state or local governments could provide assistance to technology firms, especially in their regulatory role.

4. Protection from Appropriation

- Patents and trade secrets are the primary strategies that the firms use to protect new technology ideas from appropriation by others.

- Patents are regarded as especially useful when going public or selling a firm. Firms noted some disadvantages of the patent system, however, because it is expensive and is a "two-edged sword" requiring considerable disclosures about the technology.

5. Marketing

- Almost all firms (85%) rely on their own marketing efforts domestically, and 58% use commissioned sales representatives. Twenty nine percent of firms develop relationships with consulting engineers and 22% license their products to other producers.

- When marketing overseas, 55% of firms directly market to foreign firms, 45% use foreign sales agents, 30% use foreign licensees, and 25% work through a parent or affiliated company overseas.

Research and Development Practices in the Environmental Technology Industry

This report presents the results of research conducted by the Environmental Law Institute (ELI), in collaboration with Environmental Business International (EBI). Together ELI and EBI have studied the research and development (R&D) practices of environmental technology firms, as well as how government actions could best support these technology development efforts.

I. METHODOLOGY

ELI conducted the research by interviewing key managers at 45 firms identified in collaboration with EBI. Those firms represent small to medium-size companies exclusively dedicated to developing environmental technologies in four sectors: Air, water, instrumentation and process and pollution prevention. Each manager was interviewed at length by telephone, based on a 24 question format (Appendix A).

The guidelines used in selecting the firms to be interviewed influenced the nature of the results. First, the research focused exclusively on small and medium-size firms dedicated to the development and commercialization of environmental technologies. This criterion excluded a few of the largest firms in the industry, such as Westinghouse and General Electric. It also excluded the technology adaption and development efforts of manufacturing industries which are the primary users of environmental technologies. This study focuses on the research practices of the vendor side of the environmental technology industry.

Firms were selected equally from the four principal categories of environmental technology vendors: Air pollution control equipment, water pollution control equipment, monitoring instruments, and process and pollution prevention technologies. The air and water segments are $15 billion and $17 billion in size, respectively, many times larger than the $3 billion instruments sector or $1 million pollution prevention sector. This difference somewhat biases the results of our research towards the responses from the latter two groups. When responses differed between groups, this was identified, and responses from the larger segments should be considered as more characteristic of the industry.

Second, the selection criteria produced a larger representation of small firms which have often been the leading edge of innovative technology development. An equivalent number of medium-size and small firms were initially selected, although this over-represented small firms on a revenue basis. This approach was chosen to recognize the fact that significant innovation occurs at the small firm level, and their research practices may be of equal importance to that of medium-size firms.

The methodology for selecting the firms to be interviewed relied heavily on databases of environmental technology firms maintained by Environmental Business International (EBI). Firms with revenues or expenses in excess of $20 million were considered medium-sized firms and were randomly selected from the list of leading firms in each category published biennially by EBI, with an attempt made to select both private and publicly held companies. Small firms, which were not represented in these lists, were randomly selected from the comprehensive database of technology development firms maintained by EBI.

An exception to these methods was used to select firms in the process and prevention (PP) category. Although PP a relatively small industry segment, representing only 2% of the industry as defined above, many leading prospects for future environmental technologies are being developed by this sector. Publicly held PP firms were chosen both from the EBI list of leading firms and by selecting a few leading environmental energy firms. Private PP firms were selected individually due to their prominence, receipt of awards, or success in raising capital. This sector thus over-represents developing technologies of an innovative nature, and findings for this group should not be interpreted to apply generally to the environmental technology industry.

Forty-five firms were interviewed, out of a total sample of 55, in the following categories:

	Air	Water	Monitoring Instruments	Process & Prevention
Medium sized firms	8	9	5	6
Small sized firms	4	2	5	6
Total firms	12	11	10	12

The average revenues of the medium size firms from their environmental technologies was $50 million, excluding four large water and air firms with over $100 million in sales. The average size of the small firms (defined as firms with revenues less than $20 million) was $10 million. The median size of environmental technology revenues for all firms was $25 million.

The report is organized according to the questions asked during the telephone interviews (see Appendix A); a summary of the results follows each question.

II. ORIGINS OF THE ENVIRONMENTAL TECHNOLOGY

A. Who are your customers and how do they use your products?

Air: Customers of the 12 air technology firms are concentrated in a wide variety of private industries, but also include state and municipal agencies and residential and commercial buildings. Almost all of these purchasers are motivated by compliance with air

pollution control and permitting requirements. A few interviewees also mentioned energy savings, resource recovery, and recycling as their customers' motivations.

Water: Customers for the 11 water technology firms are largely either municipal governments, publicly owned wastewater treatment plants or manufacturers. Their motivations for buying water technologies include water purification, filtration, aeration, waste treatment and de-watering, pollutant removal. More generally, these customers are motivated by seeking to (1) reduce their costs or achieve greater cost-effectiveness, (2) improve their manufacturing processes, or (3) minimize their wastes. One water interviewee specifically mentioned that concerns about water pollution are not a primary driver for purchasers of their technologies.

Instruments: Customers of the 10 instrument firms include government agencies at all levels, publicly owned wastewater treatment plants, and a wide variety of private industries. The motivations of instrumentation customers are compliance with regulatory requirements for reducing pollution (air, water and soil), fuel and energy savings, cost savings, improved process efficiencies, and faster analytical results.

Process & Prevention: Customers of the 12 process and pollution prevention (PP) firms range from large manufacturers to retail buyers, owners and remediators of contaminated sites, and both industrial and government generators of hazardous wastes. The motivations of customers are varied. Some are driven by regulatory requirements and a desire to reduce levels of hazardous emissions; others, by energy conservation, cost effectiveness, process efficiency, or pollution prevention.

B. What led your firm to develop your technology?

Air: All but one of the air firms said the primary factor leading to development of their technologies was EPA's air emission requirements starting with the original 1970 Clean Air Act. Other firms developed their air technologies to meet more specialized needs of their customers, to achieve vertical integration with a new product that would enhance the performance of another non-environmental product, to achieve energy savings or because they saw a good financial opportunity.

Water: In contrast to the relative newness of most air technologies, many of the water technologies originated more than 60 years ago. Factors leading to their development include the need for water treatment, for cleaner or desalinated water in some industrial applications, and customer demands for pollutant removal or de-watering solids. For others, passage of the Clean Water Act in 1973 gave the impetus for development of their technologies.

Instruments: Half of these technologies were originally developed as sensors or detectors for other purposes, and their application for environmental uses was identified later. Three originated in military applications. Another product was developed by adapting

existing medical testing technologies, and another technology for detecting and extracting metals at mines was adapted to measuring organics and PCB contamination in soils. The other firms developed their sensors, monitors and ultrasonic flow meters for pollutants in response to regulations establishing threshold limits for toxic emissions and other criteria air and water pollutants.

Process & Prevention: Three of these technologies began with government programs (Livermore Lab, Los Alamos Lab, and the Canadian government); and one was originally developed with joint funding from New York State and private industry. Two PP technologies were developed by collaborations between individual entrepreneurs and universities (MIT and Stanford) to commercialize patents developed by the universities, and the other PP technologies were developed by individuals or companies doing their own research because they saw a potential market.

C. What were the major and minor sources of the original research for your environmental technology?

	Major	Minor
- your company's own staff?	53%	--
- other companies?	27%	4%
- individual inventors?	20%	2%
- government research?	18%	2%
- federal government labs?	9%	4%
- universities?	7%	9%
- a parent company?	4%	2%
- other [old/standard tech.]	15%	--

The most notable aspect of the responses to this question was the extent to which the original research was done not by the firm itself, but by outside sources. In almost half (47%) of the firms, the research was conducted exclusively by sources outside the firm. In an additional 28% (75% in all), these outside sources were a major factor in the origin. The three principal outside sources were other companies (31%), federal government (27%) and individual inventors (20%), with universities playing a more minor role (7%).

This migration of ideas took a number of forms, although the role of the individual was prominent in many. Examples include individuals leaving a firm with a good idea to form a company on their own; companies creating a specialized firm in order to develop a promising technology; migration of ideas from universities or federal labs through the pioneering work of an individual or through purchase of rights by a company; and individuals or firms taking over an insolvent company to lead it in a new direction. Five

firms, or 10% of the sample, had ideas that originated from military applications; and an additional 4% of the technologies came from the space program.

There were notable differences in the origin of the technologies among the different sectors. Almost half of water technology firms reported that their companies adopted standard technologies, which had a new application when the Clean Water Act was adopted in 1973. This result may reflect the older age of this sector and the companies and technologies in it. The newer pollution prevention firms show a much higher rate of government participation. Five of the 12 PP firms (37%) reported the federal government as a major source of their original research, more than twice the rate (16%) in the other three sectors.

D. Was this original research focused on solving an environmental problem, or was it developed in a related field and then adapted to address an environmental problem?

Environmental 52% Other/related field 48%

Nearly half of environmental technology firms (48%) developed their products from basic research which was not oriented specifically to solving an environmental problem. This tendency was greatest with the PP firms, where a majority reported their technologies derived from research outside the environmental field. In the air, water and instruments sectors, slightly more than half of the firms reported their original research was related to an environmental problem, although some of these products are relatively old technologies which found a new use when most environmental laws were adopted in the 1970's. Some of the research originated in related fields like energy applications, but for the most part their technologies were developed for unrelated purposes and were applied to environmental problems. Reasons for this may be related to the under-investment in technology research and development in the environmental industry, as revealed in part III below.

E. How long did it take to bring your technology from the initial research stage to marketability?

The average time for bringing an environmental technology to marketability is 3.5 years, although this period varied depending on the sector:

Air pollution control:	3.7 years
Water equipment:	3 years
Monitoring instruments:	2.1 years
Pollution prevention:	5.2 years

The longer time for PP technologies is partly due to the very innovative character of many of these technologies, some of which are still in development.

It is interesting that the average time-frame of the responses to this question, based on commercialization achievements in past decades, is significantly longer than the time period of one to two years during which these same firms expect to commercialize their research and development efforts today. A few firms commented on this, stating that today competitive pressures are greater and are forcing them to bring their products to market in a shorter time.

III. CURRENT RESEARCH EFFORTS

A. Which of the following sources of technology ideas have played a major or minor role in your research and development efforts?

	Major	Minor
- Your company's own research	96%	4%
- Universities	20%	31%
- Other companies	20%	29%
- Customers	18%	29%
- Industry associations	11%	22%
- Other gov't research funding	11%	29%
- Federal government labs	7%	24%
- A parent company	7%	4%
- Subcontractors	4%	18%
- Individual inventors	4%	11%
- Other: _____	4%	4%

The firms placed great reliance on their own research capability, as ninety six percent reported that their own staffs was a major source of their research efforts. In almost half of these (42%), it was the only major source, and for 11% was the only source. The two firms not relying on their own research as a major source instead relied on universities and other companies to perform their research.

Firms mention several other sources as also playing a major role in their research and development efforts. These sources were other companies, universities and the federal government. If one groups all four categories of company sources, including parent companies and customers, 40% of firms listed one of these company sources as a major source, and 82% as either a major or minor source. The next most important source is universities, which 20% percent of companies regard as a major source, and 51% as a major or

minor source. In a parallel manner, 18% of firms listed one of the two government sources as a major source, and 54% as either major or minor.

The role of the individual, so prominent in the origins of environmental technologies, now has sunk to minimal levels as companies instead rely on their own staffs and alliances with other corporations, universities or the government to continue their R&D efforts today. Subcontractors are also used very little in comparison to these other sources.

There are significant differences among the sectors in how they have used the federal government as a research source. Fifty percent of pollution prevention companies list government as a major source, and 100% as either a major or minor source. On the other hand, very few (6%) of water, air and instrument companies list government as a major source although another 30% regard it as a minor source.

Overall, there are no significant differences in sources of R&D efforts today between small and medium-size companies, except possibly a slightly greater tendency for medium-size companies to work with other companies in their research efforts.

It is important to note the variety of sources for technology ideas today, other than the firms' own staffs. At least one third of the firms also relied on a combination of other sources such as universities, customers, other companies, government agencies and industry associations. Apparently these environmental technology firms are currently trying to augment their own staffs' creativity and problem-solving capacity by finding other sources of new ideas, and there is no central or R&D source for specific industrial users. As one firm's manager said: "In developing our technology, we encountered all kinds of technical needs. We needed help on chemistry, on combustibility, on corrosivity. We don't have staff to handle all these, so we entered into a technical agreement with [a university], who has all this kind of varied expertise. We're always cash short."

Similar comments were made by other firms:

- "We used to do our research by identifying a technology after EPA defined criteria pollutants. Then it was clear what to aim at, and we identified techniques which became the industry standard. Now we have started to license technologies from small R&D companies and university groups. People come to me with proposals for new technologies. My job now is to evaluate these - to look out for best ideas. Then we develop a relationship with a company and do the product development."

- "Our primary source, other than strictly in-house research, is to make acquisitions of technologies which are incorporated into our own firm's products. We have done this especially for some additional treatment technologies."

- "Our company has ongoing 'alliances,' or case by case subcontractors, based on field assessments of remediation needs. After this, we assess what we have in-house, and what we need to get from others."

- "It is very hard to sell anything on an environmental basis, as companies are not interested in doing good for the environment. We must sell our technologies on an economic basis. Our sales [of one product] only started to catch on when we stopped selling on its environmental performance and started tying its use into economic advantages to clients."

- "Our clients all want guarantees and other concessions because they are scared to death of innovative technologies. They are sophisticated, know how hard it is to market an innovative technology, and know they can get these guarantees and concessions if you are marketing one, which they could never get with traditional technologies. The marketplace is savvy about how to exploit innovative technologies."

B. What is the focus of your firm's R&D?

	Major	Minor	N/A
- Improving performance of existing products;	68%	16%	5%
- Reducing cost of products;	56%	20%	5%
- Tailoring products to customer need	51%	22%	7%
- Developing new lines of business;	44%	24%	11%
- Finding other uses for products;	27%	44%	5%

Cost reduction and improved performance of existing products were the highest priorities in the majority of companies interviewed. Tailoring products to customer need and developing new lines of business were almost as important. Finding other uses for products was only mentioned as a major objective by a quarter of the firms. The results of this question indicate applied research tasks, such as cost reduction and product improvement, top the research agenda of most environmental technology companies, reinforcing the results of the next question.

C. How much of your current research is applied research with a short-term time horizon of 1-2 years before a commercial payoff, and how much is more fundamental research with a longer time frame? [how long?]

Short-term:	100-90%	89-80%	79-70%	69-60%	59% or less
	66%	8%	11%	6%	8%

Two-thirds of the companies who responded to this question (24 out of 36) indicated that at least 90% of their research had a short-term focus of one to two years. In contrast,

only 8% of companies, typically those with technologies still in development, identified that 50% or more of their research had a long-term focus. Most companies defined applied research as having results in 18 months to two years. The companies who cited a greater focus (more than 10% of total research) on long-term research almost unanimously identified "long-term" as meaning from three to five years. Only two companies mentioned any research exceeding five years.

When asked why they did not invest more in long-term research, companies typically answered that their research was oriented to developing products and had a correspondingly short time frame. They emphasized that they and other corporate entities could not pursue "curiosity-driven" or "academic" research. As one manager said, "Our research is market-driven, not idea-driven." Another mentioned that long-term research takes too long, creates competitors, can miss the market, and costs a lot. It appears firms competing in today's economy place virtually no funds in basic or longer-term research.

A few companies stated that changes in the economic climate in the past five to ten years have led companies to reduce the amount of money invested in long-term research. Indeed, one of the technologies originated because a large firm formerly allowed its research staff to devote 10% of their time to projects of their own selection. However, such corporate commitment to curiosity-driven research appears to be a thing of the past, at least among small and medium-size environmental technology firms.

The principal reason given for the lack of investment in long-term research by the environmental technology community was economic pressure. Thirteen out of 36 companies specifically mentioned financial constraints as reasons that they focused on short-term, as opposed to long-term research. Investors create pressure for results and, as one company stated, returns from long-term, research "are too long-term for venture capital." Larger companies, which are typically public, also mentioned quarterly earnings pressure. Economic considerations appear particularly relevant to smaller companies, and several companies specifically stated that long-term research was not economically feasible at their small size, in one case adding that "not even a tax write-off" would make such research feasible. Long-term research appears to be beyond the means of smaller technology companies who are struggling to market their current products in order to survive.

Other reasons a for short-term focus derive from the uncertainty or lack of a market for these products, which is ultimately a result of regulatory demands for environmental quality. Remediation companies noted the wholesale change in their customer base from private firms to government agencies in the past few years, and uncertainty over the regulatory drivers in the future. Uncertainty in air regulation was also noted, leading one air technology company to say, "Current technology is sufficient for the long-term." Another said that it "didn't really need to improve existing technology because it wasn't really embarking on new ventures."

D. [How] do you conduct your R&D in cooperation with other firms?

As noted above, 40% of companies cite another company as playing a major role in their R&D effort, and 82% say that another company played at least a minor role. These relationships are varied and sometimes ad-hoc in nature, designed to overcome specific marketing or technological problems. In general, environmental firms have teamed with each other in order to satisfy a client or solve a problem, but rarely to develop long-term interests based on the mutual benefits of joint R&D.

A substantial number of these cooperative efforts are with customers, and have resulted from applying environmental technologies to meet specific customer needs. Because environmental problems are varied and tend to resist uniform or standardized solutions, they require engineered solutions and applications, with customer involvement. One leading firm estimates that, for every dollar it spends on R&D, $4 are spent by its partners who tend to be potential customers looking for new applications to solve an existing problem.

Firms also report collaborating with sister companies so their technologies could work together to solve a problem. The same fragmentation of solutions in the environmental field may lead to this need for alliances with other technology manufacturers. Firms report different strategies to achieve this integration. Several have created alliances with other technology providers, based on a win-win situation. A few firms also report a strategy of integrating component manufacturers or related technology providers through acquisitions. The small to medium-size character of firms in this industry appears to require considerable joining of forces.

A third area of cooperation mentioned less frequently is with component providers. One company assists smaller ones in preparing Small Business Innovative Research (SBIR) proposals, in the hope that the smaller firms' technologies might develop in two to three years and then be incorporated into the larger firm's technology. More typically, firms created subcontracts or other commercial relations with their component providers. There was also evidence that firms have vertically integrated or acquired component manufacturers to form a unified company.

E. What are the primary sources of financial support for your firm's R&D [for its principal technology] and have they changed over time?

	Total	Air	Water	Inst	PP
-Your own capital	93%	100%	100%	90%	83%
-Government funding	24%	17%	--	--	75%
-Other private financing	20%	17%	--	10%	50%
-Public stock offerings	20%	--	9%	30%	42%
-Other 4%	--	--	10%	9%	

[Columns add to over 100% because more than one category could be chosen.]

The primary source of R&D financing is clearly the firms' own capital. Indeed, almost 80% of the air and water companies and 60% of the instrument companies cited their own company's capital as their *only* source of financial support for R&D. Government funding was significant only for the process and prevention companies although two air companies benefited from the SBIR program. No water or monitoring companies received significant government support. Public offerings and other private financing are less frequently cited as sources of financial support, and again mostly by the process and prevention companies. In the "other"category, one remediation instruments company relied exclusively on contracts to fund their research, and another firm relied on an outside company for R&D funding.

These R&D funding restrictions are clearly a major limiting factor. One manager pointed out, "the problem with these things is money," and another, "funding is the major problem. We could have five products being sold today, if they had money to develop the technology for the different applications. These would all be profitable investments, but returns are too long-term for venture capital, which can earn more money [elsewhere]." This person went on to emphasize the need for a financing source such as government which recognizes the social as well as financial benefits from innovation in environmental technologies. Another said, "Several projects of ours have taken $20 million just to get out of research, $12 million of our own, $8 million from the government."

F. Could you allocate financing sources used during each of the following stages for developing the firm's principal technology: I - idea development; II - demonstration; III - scale-up; V - commercialization?

					[detailed answers]			
	I	II	III	IV	I	II	III	IV
Your own capital:	20	20	19	18	5	5	4	3
Government funds:	6	4	3	--	6	4	3	--
Other private financing:	--	2	1	--	--	2	1	--
Public Stock offer	--	--	2	--	--	--	2	--
Other:	1	--	--	1	1	--	--	S1

[Figures show actual number of company responses.]

The number of companies responding is shown above. It is difficult to interpret results for this question, as only eight companies were able to respond in detail (presented at right hand of above table). Another 15 companies used their own capital for the entire

development process, but it was difficult to assess the response for companies with relatively old technologies or where a company did not conduct the initial research. The apparent decline in number of companies responding in parts III and IV is due to several firms which have not yet reached the stage of commercial sales.

Even with these limitations, the predominant use of a company's own capital is evident. As for other sources, government funds were used primarily in the idea development phase, and declined thereafter, whereas other private capital and public offerings were used primarily in subsequent stages for bringing technologies to market.

G. How much do you spend annually for R&D and has this changed over time (such as higher initial R&D costs)?

8%	$0-100,000
30%	$100,000 - 500,000
12%	$500,000 - 1 million
30%	$1-5 million
20%	More than $5 million

Fifty percent of companies spend less than $1 million a year on research and development, indicating the relatively small size of most environmental technology companies.

H. What percentage of your firm's current annual revenue for environmental technologies is spent on R & D?

Air	3%
Water	2%
Instruments	8%
Pollution Prevention	
- with sales	25%
- in development	25%
- in research	100%

Average investment in R&D for water and air companies is 2.5% and 3% respectively, with medium-size firms averaging slightly lower levels of investment. The investments by air and water companies range from less than one percent to six percent. Instrument manufacturers invest an average of 8% of total revenue into R&D, with individual firms ranging from 5% to 10%. Only a few process and prevention technology firms are at the

stage of commercial sales, but these companies average 25%, demonstrating the highest percentage investment in R&D. Six PP companies interviewed did not yet have commercial sales. Two of these firms are still developing their research and spend almost all their funds on R&D; and four are in the demonstration phase, spending 25% of their funds for R&D.

Various reasons were given by these firms for the lack of investment in R&D. Some reasons, such as the pressure on profits and lack of financing for R&D, are not unique to the environmental industry, especially for small businesses. Other reasons more specific to the industry include the relative maturity of the air and water sectors, the lack of certainty in environmental markets, the lack of uniformity or standardization for environmental solutions and products which limits market size, and the focus on meeting regulatory standards instead of a culture of continuous improvement. The presence of each of these factors may discourage investment in research and development which requires a long-term focus and commitment.

I. Was any of your firm's R & D conducted outside of the U.S., and/or did any foreign ideas play an important role in the technology developed by your firm?

YES 31% NO 69%

Almost a third (31%) of the companies reported that at least a part of their R & D is conducted outside of the United States. Of these, several companies said they have research taking place at their subsidiaries outside of the United States and two companies reported that most of their R & D is done by their overseas parent companies. Other business practices outside the U.S. include licensing technology from an overseas company and joint ventures abroad.

A majority (69%) of companies reported that none of their R & D is conducted outside of the United States at the present time. However, not all these responses were unequivocal. Two companies expressed future interest in research conducted outside of the United States, and a third company reported they had recently investigated a research partnership with a Swiss company but the technology "did not work out." A fourth company reported that, in the past, most of their research was conducted in Great Britain but was moved to the U.S. when the subsidiary in the U.S. bought out the parent company in the U.K. In addition, two companies reported they participate in collaborative efforts with foreign companies in "design" aspects of product marketing and in pursuing "other technology ideas". If one were to consider these six companies as having interests abroad, the percent of firms with strictly domestic R&D would become 55%.

J. What R & D issues do you think are not being addressed adequately by firms like yours?

Only twenty companies responded to this question, and ten of these (50%) cited a lack of long-term basic research as the major problem in R & D. This sentiment was expressed in a variety of ways: "Not enough future-looking research," "more pure research needed," "next-generation research needed," "lack of high-risk long-term return research." The most common reason given for lack of long-term research was that the firm's profit margin is not high enough to support it or, similarly, that a focus on increased revenues precludes more money being spent on fundamental research.

A variety of other R&D problems were mentioned by a few companies. Some companies cite a lack of sufficient effort in defining future demand or contacting potential clients. One of these firms specified that they were too specialized within a niche market and needed help both in understanding where market demand was heading and in contacting a more mainstream market. Another company cited the need for keeping up in software developments, which is critical for marketing success, but very burdensome for small companies. Two companies stated that they needed to do more research to improve product functioning, and another suggested that they could focus R & D on older products in order to "revitalize them."

K. Comments regarding basic research

As noted from the above responses, commercial firms are doing very little basic R&D. However, several firms offered lengthy comments on how to promote basic research:

- "The R & D guys who create new environmental technologies do not know what is needed in the real world - they are building mousetraps, but now the world needs rat traps or something else. The government laboratories are very ill-equipped to commercialize the technologies that are developed there. [This firm] ran a lab for 12 years, never commercialized a single technology. Consulting engineers know what the customers need but are not in a position to develop technologies. Our firm is trying to fill this gap by finding good ideas, based on our technical knowledge of the marketplace, and then invest private capital from our parent company in developing those ideas into new technology products."

- "There's a difference between a progressive product and a breakthrough product. The market has harder time accepting the latter. Federal funding and evaluation of breakthrough technologies is needed. Example: DOE advance turbine technology."

- "Federal government R&D - there are fights within government to spend R&D funds internally, especially the labs. Private capital for technology developers is low, and private venture funds are near absolute zero. It is not right for federal R&D to turn internal. The federal strategy falls apart at the commercialization stage; government entities have the least experience with the market. A good model is the drug industry. There is a very healthy external drug industry and a good federal policy for orphan drugs, or those where the market is inadequate for private firms to be interested in. Here the federal government creates incentives to develop orphan drugs. Environmental technology also needs breaks if inadequate private capital flowing into it now. The problem is not in research, but in commercialization and application. We need assistance putting technologies through initial applications or new applications of existing technology from other fields."

- "We have set up a major technology innovation program with Canada's equivalent of the National Science Foundation in cooperation with Canadian universities. In our case, the government supports research by five professors in two nearby universities, who were self-selected. Industry and universities collaborated to set overall targets for a five-year research program and to gain insights about industry's needs. The Canadian government pays for the universities' staff and resources while industry contributes insights and approves research objectives. Industry acts as an advisor to that program. We can bring our resources into that program as needed and provide the universities with insight, but not our views of what to do. This is good concept for how industry, government and universities can work together. Even though we are working well together, we have had to reach some compromises because we in industry are very concerned about protecting intellectual property whereas the university people are more interested in publishing the results of their research. This program might serve as a useful model for the federal government to work with universities in the US."

- "It is absolutely necessary for commercial growth for there to be a level of curiosity-driven R&D that will provide the basis in 50 years for the breakthroughs we need. It's wrong to say all university or government research has to be goal-oriented. This view will cause a deficit of building-blocks for future technology advances."

- "In my experience, real breakthroughs typically do not come from organizations working on a problem for four or five years. If they work on technology daily, they buy into existing methods and what "can't work" within an organization. The best breakthroughs have come from people who knew little about [their technology] and tried stuff. So to have innovation, you either need a trigger -- a problem no-one knows how to solve -- or individuals outside the existing paradigm and in sufficient numbers to be significant. If not, you can't overcome the inertia. You need one such person in a four person shop, not one in a 100 person shop. We try to do this with universities, by bringing in bright people who don't necessarily know about [the technology]."

- "Our research is 80% applied, 20% longer [term]. It is hard to find matching funds, even if we use federal money, for anything over 2 years. The market has changed. It used to be, even 5-10 years ago, there was more money for long-term research.

- If the federal government doesn't support long-term research, it won't happen. Our [need for] funding is too long-term for venture capital, so we need someone with a long-term view based as much on social welfare as on immediate economic return. In my view, it must be the government."

- "Long-term research is an appropriate place for government funding. Government should be funding long-term activities in the public interest which won't happen through the operation of a free market (which has a short-term focus, measured on quarterly returns). One of the responsibilities of government is to take a long-term view. In terms of investing, government needs to create infrastructure and invest in the future of technology."

- "Should basic research be done by government labs or others? I'd this in most efficient way. [I am] open to question whether universities or labs better. Government labs make sense in identifiable public need which requires a concentration of resources, i.e. build a bomb or a huge accelerator. Or if it is a massive single investment, it must be focused in one place. These two are appropriate for government labs. If we are trying to create a body of people, students, which is distributed, we need to establish this capacity around industries to support them and do it through universities."

IV. PROTECTION FROM APPROPRIATION

A. What strategies have been important for your firm to protect your new technology ideas from appropriation by others?

	Major	Minor
- patents	76%	13%
- trade secrets	60%	27%
- consolidating your leader-ship position by new product development	47%	22%
- first mover advantage	40%	24%

Patents and trade secrets head the list of strategies that firms use to protect their new technology ideas from appropriation by others, although all the methods listed receive considerable support.

Although 76% of firms regard patents as a major strategy to protect their technology ideas, many firms expressed concerns about the operation of the patent system. Even those using the patent system aggressively complain about the expense of the system, and that it is a "two-edged sword" which requires considerable disclosure of the technology. One firm is using the patent system more, in part because of changes in the Patent Office in past 7-10 years: "The process of getting patent improved (re resolving conflicts) and the appeal process is better regarding time limits, and court enforcement is more active." Other positive aspects mentioned by several firms are that patents are especially useful when going public or selling a firm ("Wall Street likes patents!"), and that patents are a useful bargaining chip in forming strategic relationships with other firms.

A few firms indicate the latter values may be the main benefit of patents because patents are hard to use to protect your technology: "The only thing patents do is help you go public due to PR value." These firms tend to emphasize negative aspects of patents such as the need to reveal the workings of the technology, which they believe would allow competitors to invent around the product and give competitors a “free ride” when the patent expires. Many firms commented that patents are even expensive to maintain. Several mentioned the expense of litigation, especially for small firms. One had formed strategic relationships with larger companies to get them interested in their success but also to "keep the bullies at bay" by having the resources to defend patents if necessary.

Another problem cited by a few firms is that there is no patent protection in some countries, a major issue to some firms marketing outside the U.S. This gap doesn't prevent them from going abroad, but they operate in a less desirable way. One firm is exploring trademark protection in India.

As a consequence of these problems, many companies report doing internal evaluations about which elements are best to patent and which are best left as trade secrets, the next most popular protection strategy used by 60% of firms. Several report that they are opting increasingly for trade secrets, while others mention the reverse. One firm noted that even trade secrets are becoming less viable to protect technologies due to today's rapid communications.

Several companies noted that their primary strategy is to engineer a better version of their product. One manager commented: "You can't really protect technology in this business - you must stay one step ahead. Patents only important if selling firm; it's very difficult to protect with patents." Another noted that a fundamental reason for having an R&D department was to stay ahead of the competition.

Other devices for technology protection include ISO 9000 certification as a good tool to maintain market-share and non-disclosure and confidentiality agreements for partner in short-term research.

V. MARKETING OF ENVIRONMENTAL TECHNOLOGIES

A. How do you market your new environmental technology?

85% Your firm's own efforts
22% Licensing to other producers
11% Selling your technology to another firm
58% Using commissioned sales representatives
29% Developing relationships with consulting engineers
7% Merging with another firm
18% Being the first to obtain permits or other regulatory approvals

Almost all (85%) of firms rely on their own marketing efforts, and just over half (58%) use commissioned sales representatives. About a quarter of firms develop relations with consulting engineers or license their products to other producers. Other methods are used less frequently.

B. What are the principal strategies that have helped you to win any export orders for your product?

55% Direct marketing to foreign firms
15% Following your customers abroad
5% Trade missions abroad
45% Foreign sales agents
28% Meetings with potential customers overseas
30% Through foreign licensees
25% Through a parent or affiliated company overseas
20% Other:_____

Of the forty firms replying to this question, a bare majority (55%) directly market to foreign firms, considerably less than the 85% which rely on their own marketing efforts in the domestic market. Many firms use other marketing methods, principally foreign sales agents (45%), foreign licensees (30%), or a parent or affiliated company overseas (25%).

VI. GOVERNMENT ROLES IN R&D

A. What are the (one or two) most important roles that the federal government can play to assist firms like yours in developing environmental technologies?

	Major	Minor	N/A
- Providing information about new technologies	64%	23%	--
- Providing regulatory flexibility	61%	20%	--
- Providing funding for research	59%	25%	7%
- Testing or verifying performance of new technologies	45%	25%	14%
- Providing technical assistance to develop new products	30%	32%	16%
- Purchasing new technologies	27%	27%	16%
- Providing a source of new ideas	23%	50%	9%
- Helping to market new technols.	20%	27%	36%

In general, these comments received reveal several key roles for the federal government. A majority of firms supported federal government roles in providing information about new technologies, providing regulatory flexibility and support of basic research. Responses here and comments in many other questions reveal support for the demonstration and commercialization process, and testing or verifying the performance of new technologies also received some support. The remaining roles listed were thought to be less important by most of the firms interviewed. There was least support for direct government assistance in marketing new technologies, except to overseas customers.

B. Comments received on specific government roles (in order of support received).

1) Federal government providing information: The highest number of companies (64%) supported the federal government's role in providing information. Some stated that, while government cannot help market technologies directly, its research and information-sharing activities are appropriate and very important to marketing. Particular support was given to the government both supporting universities' role in reviewing and reporting on technologies and providing informational support to small businesses.

Comments on Providing Information:

- "Government should support and help universities review and report out on technologies, to provide information about technologies. Government cannot help market technologies directly, but can do this through research, information etc. This is the government's appropriate role and very important. It can create awareness about technologies. More funds and research funds are needed here."

- "Small technology firms need help to keep aware of how regulatory requirements are constantly evolving and figure out how to interpret them in order to understand better the impacts on themselves and their customers. Technology firms could use help through seminars, newsletters, and internet sites because, unlike larger companies with government affairs staffs, smaller technology firms do not know how to obtain information effectively."

- "The most important role for the government is to provide industry with a clear understanding of what regulations will require in the future and to help technology firms with long range planning on how to service their customers."

- "We are at an "in-between" size, not a large company that can do planning. We are short-sighted and focus on what we feel the market needs. I am the one to do it, and I haven't had time to think. [Government or other] help would be great in longer-range planning."

2) Federal government providing regulatory flexibility: There was considerable support for regulatory flexibility, a somewhat surprising result because technology vendors might be expected to benefit from stringent regulation. Firms said current federal regulations overly constrain industry and preclude the use of alternative technologies. They expressed concerned about the costs and the length of time involved in obtaining permits for new technologies, the variation in permit requirements between states, and the lack of clarity in regulations which promotes too much uncertainty and delays. They are also concerned that agency staffs are not in touch with the real problems and often require industry to do things in the most difficult and expensive way possible.

Comments on Regulatory Flexibility:

- "We can be precluded from bidding, as our technology gets down to very low levels, and gets to and beyond drinking water quality, but can't get to 'detection' levels. Remediation can require this and results in 4-5 time too much capital being spent to

get to these minute levels. How clean is clean? We could bid on an order of magnitude more projects if this issue could be resolved."

- "The federal government should pay more attention to the cost of attaining low emission levels. In the past, maximum allowable emissions have been based on the ability to detect a substance regardless of cost. The problem in marketing environmental control and monitoring technologies is that the cost of complying with these low emission levels is too high for most potential customers to be able to afford these products."

- "Regulators are reluctant to approve the use of new technologies and customers are thus reluctant to buy them. The federal government should provide tax credits to buy new technologies and offer flexibility in meeting regulatory requirements with those new technologies."

- "Government should give some ultra-clean technologies a nationwide permit for anywhere in USA. Otherwise, it takes six months to a year to get permitted even if achieving zero emissions."

3) Federal government providing funds for research: Federal funding for basic research was advocated by many firms, emphasizing that the corporate sector could not conduct new, idea-driven research, and that this is an essential role for government funding and universities. Firms emphasized the need for public funding in this field because the private market does not place value on the social benefits provided by new environmental technologies. Some thought it was more important for the government to fund longer-term and high risk research rather than development and demonstration of specific technologies. There was specific support for the SBIR program, which is seen as practical and oriented to the right constituency. One firm mentioned that the SBIR program needs to be speeded up because the 9-month waiting period is too long and the $5,000 support for product testing is too low.

Some oppose government funding for basic research because they do not want to have any "strings attached" to their products, or they are wary of government intrusion and control of private companies. Another opponent of government funding called it a "two-edged sword" because "government always wants a lion's share of the product." Instead, this firm wanted "private industry to stay private" and to rely on the patent system as the "backbone of the free enterprise system" even though it is expensive.

Comments on Government Funding of Research:

- "Government funding sources for research and development are vital to small companies. Companies are reluctant to invest in R&D and their managers are very risk-averse. The government needs to help them move their technologies to the commercialization phase."

- The "SBIR approach is vital. It allows companies to guide smaller organizations, which are likely to come up with new ideas. The SBIR program provides the right level of initial funding. Second tier level funding is OK too. SBIR supports things which have a chance of being successful. It should be expanded."

- Larger firms have an advantage because they can support a central R & D department to explore completely new approaches. Instead, smaller firms have to rely on ideas generated from government laboratories and other NASA or defense-related information about new technologies."

- "Research funding from the federal government would be especially helpful for very high risk projects that a firm cannot fund on its own, such as that needed to produce a very innovative product."

- "Small start-up technology companies often approach our [larger] firms for funding to support their R & D, and the federal government could help by sorting out the most promising new technologies and thereby helping them select and fund them."

4) Federal government role in verification: Forty-five percent of firms selected testing or verifying product performance as one of the most important roles because they have found barriers to marketing new technologies without prior acceptance by the government. They emphasized that such evaluations have to be done quickly and at an early stage, however, in order to help in creating markets for new technologies. A few firms mentioned concerns with the federal government doing technology verification, including speed and confidentiality. Another urged nationwide permitting once verification of a new technology is completed.

5) Federal government support for demonstration and commercialization activities: Many firms emphasized the gap in the technology development process from a pilot or lab-based demonstration to creating a broader commercial market for a new product. They urged that government funds be focused on the demonstration, scale-up and commercialization phases because private funds and venture capital are often available for the idea development phases. One firm said federal funding for technology demonstrations was the "single most

valuable investment" by the government because it enabled the firm to develop data on the performance of their product, which convinced their private customers to buy it. Another said the "most important government role is providing finance for development. Something like NSF or funding for the linear accelerator. [The government] would need competent technical staff to conduct evaluations."

6) Federal government purchasing: Several firms commented that the government's early adoption and purchasing of products can help to validate their performance and expand their markets for new technologies. Again, they said that, while government shouldn't help market new technologies directly, it can be of major assistance to marketing in acting as an early adopter or validator.

Comments on Government Purchasing:

- "Government purchase and verification are related and can be a big assist to marketing. Government shouldn't help to directly market new technologies, but government can be a major contributor to marketing in acting as early adopter or through validation. These in reality are major assists to marketing. Government as an initial acceptor is especially prevalent in military."

- "Some federal support or purchasing preferences for new technologies is needed even when a product is fully developed."

7) Federal government as source of new ideas: Although most firms supported a government role in basic research, many more chose government support of private research than the government attempting itself to generate new ideas. A number of reasons were given: The government is not close enough to the customers, government employees are too conservative and have few new ideas, the government bureaucracy is too slow while the market moves quickly, and there are too many proprietary issues if the government becomes involved.

8) Federal government help in marketing: Most firms said that this role is not appropriate for government, except overseas. One firm commented: "Government doesn't understand products. Customers are not buying to meet regulatory needs and not buying a technology. They are buying a product to solve a problem and save money. The problem is people are selling a technology; the product elements include control systems, automation,

corrosion resistance, low operating cost, etc. - factors that have nothing to do with the technology."

9) Other: Two other issues related to government's regulatory role were mentioned by firms. The first was the lack of stability in environmental regulations, which hurts market demand. One manager observed: "The federal regulatory programs, particularly the air program, have been through so much radical change that it has created chaos in markets for new environmental technologies. The delay in EPA's adoption of final Title V air permitting rules has depressed the market for air control technologies to one-third of its former size." Others complained of the lack of enforcement, believing that greater enforcement would lead to improved business opportunities for marketing environmental technologies, both in the U.S. and abroad.

Comments on Other Regulatory Issues:

- "The lack of enforcement and certainty about air permitting requirements has led companies to try to delay their capital investments in air pollution control equipment, including new technologies."

- "EPA also needs a better understanding of the industrial processes that they regulate and how pollution control equipment works so that EPA's rules can be more practical, more easily implemented, and better enforced."

- "It is difficult for technology firms to serve industry and meet regulatory requirements because emission limits often do not have a valid technological basis. For example, boiler emission limits are now based on concentration because that is easier to measure, but they should be based on total emissions instead."

- "The government could be helpful if only it did not take so long to get things done."

- "A critical issue is the need to follow new regulatory requirements with enforcement. Unless the government enforces its rules, firms cannot sell environmentally superior technologies which cost more than traditional ones. Enforcement is an even bigger problem overseas."

C. Has your firm benefitted from any federal programs relating to technology and, if so, what types of programs?

Almost half (44%) of the firms interviewed have benefitted in some way from federal technology programs, with the highest percentages in PP firms (75%), and instruments (60%),

then air (25%) and water (9%). There are significant differences among the sectors, however, with only a fifth of the air and water technology firms which represent (90% of the industry) reporting federal involvement, and that being relatively minor in nature. Two had received SBIR grants, and others had collaborated with EPA on particular aspects of their technologies.

On the other hand, most instrument and PP firms have benefitted from federal programs, some substantially. Several firms have received funding from two or more federal agencies, and others are involved in a wide variety of federal assistance programs. Nine firms had received funds from various Department of Energy programs such as RCI, CRADA and START; six had been helped by the Department of Defense or one of the military services; four firms had been assisted by EPA programs; and two had received SBIR grants. NSF and GSA programs each have assisted one firm. Another firm noted that, although they received no direct assistance, several of their smaller collaborators have obtained government funding.

D. Could state or local governments provide any similar assistance or help technology firms in other ways?

Although relatively few firms receive assistance from state government technology programs, slightly more than half of the firms interviewed (58%) said state or local governments could help technology firms. Most comments were about states providing assistance via their regulatory roles. A number of interviewees suggested: (1) Providing more state regulatory guidance about required performance levels, (2) promoting emissions trading, (3) providing state regulatory relief or other incentives for installing new technologies, (4) eliminating confusing variations in state permitting requirements, (5) directing state university research toward development of environmental technologies, and (6) offering discounts on state contracts. Some of these firms are also working with state programs for funding research and development, providing funds to match federal or private investments, guaranteeing loans, or verifying the performance of innovative technologies. They specifically mentioned California, Massachusetts, Maryland, New York, New Jersey, Pennsylvania and Texas.

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