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Lean and Green:

THE MOVE TO ENVIRONMENTALLY CONSCIOUS MANUFACTURING

Richard Florida

Can corporate efforts to innovate and to adopt advanced technological and organizational approaches to manufacturing be used to achieve simultaneous gains in industrial and environmental performance? The past few years have seen increasing interest in this question from a number of quarters.

This article examines the relationship between advanced production practices and innovative approaches to environmentally conscious manufacturing. It argues that adoption of manufacturing process innovations creates incentives for adoption of environmentally conscious manufacturing strategies. To put it another way, firms that are innovative in terms of their manufacturing process are likely to be more imaginative in addressing environmental costs and risks. Furthermore, close relationships across the production chain and between end-users and suppliers facilitate the adoption of this bundle of environmental and industrial innovations. At bottom, adoption of advanced manufacturing systems creates substantial opportunity for adoption of green design and production strategies since both draw upon the same underlying principles—a dedication to productivity improvement, quality, cost reduction, continuous improvement, and technological innovation.

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To examine these issues, this article reports the results from a national survey of U.S. manufacturing firms. The research effort included a combination of survey research, phone interviews, and field research consisting of factory visits and on-site personal interviews. The study was designed to collect original data on the relationship between advanced manufacturing systems and innovative approaches to environmentally conscious manufacturing (see appendix Research Methodology).

Industrial Innovation, Advanced Manufacturing, and the Environment

It has sometimes been argued that the relationship between industrial and environmental performance takes the form of a trade-off, with environmental quality coming at the expense of industrial competitiveness. Firms have typically invested in end-of-the-pipe treatment and control technology to reduce the toxic content of environmental emissions and wastes. Public policy has sought to use a combination of regulatory standards and penalties to limit the environmental byproducts of industrial production processes, frequently by mandating the use of so-called "best-available" control technology.

A number of studies have recently argued that efforts to lower the costs of waste management and disposal and to reduce waste and emissions need not negatively effect corporate performance, and at times may actually improve it.[1] While the logic underlying this so-called *win-win* argument is somewhat compelling, research to date has mainly consisted of case studies and thus is insufficient to support its claims. Furthermore, the literature has tended to focus on the success stories. As a result, these studies provide little more than existence proofs, but virtually no evidence on the extent of the penetration of advanced practices across the industrial landscape and of the factors that influence their adoption and diffusion. The win-win perspective of Porter and others also tends to overstate its claims by setting up traditional environmental economics as something of a straw-man.[2]

In contrast to the win-win perspective, the rather straightforward hypothesis presented here is that firms that are innovative and adopt advanced manufacturing practices can simultaneously realize improvements in productivity and environmental performance. In other words, environmental improvements to some extent flow from broader corporate efforts to innovate and implement new and more efficient manufacturing systems and practices. A number of studies have provided some evidence that manufacturing establishments are changing their environmental strategies from traditional end-of-the-pipe control to new technologies—such as pollution prevention, production process modernization, materials substitution, and waste minimization—that lead to more general productivity improvement.[3] The data on pollution control and abatement expenditures by U.S. manufacturers compiled by the U.S. government indicate a shift in the share of expenditures from control technology to production process

improvements. Pollution abatement and control expenditures (PACE) for U.S. industrial firms totaled $7.2 billion in 1993; of this, nearly 45 percent ($3.2 billion) was spent on production process enhancements.[4]

A growing number of studies have identified the use of environmentally conscious manufacturing practices by American industry.[5] Research from the literature on organizational and industrial transformation has documented the shift to new and innovative manufacturing systems among U.S. firms.[6] A small but growing number of studies have probed the relationship between industrial and environmental performance more directly. An MIT study suggests a relationship between lean production and innovative environmental manufacturing practices.[7] Researchers at the University of Michigan found that efforts to prevent pollution and reduce emissions had a positive effect on industrial performance.[8]

There is a considerable literature documenting the shift to new and innovative manufacturing systems among firms, referred to variously as *lean production, agile manufacturing,* and *high-performance production.*[9] These advanced manufacturing systems are distinguished by a blend of technological and organizational changes inside the factory (e.g., self-directed work teams, worker rotation, and continuous process improvement) and by close and interdependent relationships across the production chain, particularly between end-users and suppliers.[10] An influential MIT study documented the transition from mass production to lean production in the automotive industry.[11] A survey of U.S. manufacturing establishments by Osterman found evidence of significant adoption of innovative work organization in a large and representative sample of U.S. plants.[12] Survey research by Florida and Jenkins found a significant rate of adoption of innovative manufacturing practices by Japanese transplant manufacturers in the United States.[13] Other studies document performance and productivity gains associated with advanced manufacturing systems. A study by MacDuffie identified performance gains associated with adoption of lean production in a large international sample of automotive assembly plants, while research by Ichniowski and others found significant performance gains associated with the adoption of a bundle of innovative manufacturing and work organization practices in the steel finishing sector.[14]

A number of studies emerging over the past several years have begun to probe the relationship between environmentally conscious manufacturing and efforts to improve manufacturing productivity and performance. Porter and van der Linde provide limited and largely anecdotal evidence to support their interesting contention that firms are responding to a new competitive environment by developing strategies to maximize *resource productivity* by pursuing strategies that enhance industrial and environmental performance. The findings of a group of MIT researchers (who pose the question: "does lean mean green?") suggest that there is some relationship between lean production and innovative environmental practices.[15] In a comparative examination of environmental policy in Europe, the United States, and Japan, Wallace concluded that the pursuit of

both radical technological innovation and continuous incremental improvements in products and processes (e.g., *kaizen*) create substantial opportunities for pollution prevention and waste and emissions reduction.[16] Researchers at the University of Michigan found that efforts to prevent pollution and reduce emissions had a positive effect on industrial performance. This study also found that the biggest benefits accrue to large polluters, noting that the closer a firm gets to zero emissions the more expensive it becomes to further reduce pollution or realize efficiency or performance gains from such reductions.

Furthermore, firms develop their strategies in an evolutionary way to cope with both external constraints and limited information and knowledge. Firms adapt, innovate, and learn. As Schumpeter argued, firms possess the capacity for *creative* as well as *adaptive* responses to situations.[17] That is, firms can create organizational and institutional environments suited to their needs—not just adapt to given conditions.[18] Organizational change is both a product of economic conditions and a determinant of those economic conditions. In this context, firms operating in a highly competitive environment pursue strategies to increase profits by reducing cost, improving productivity, and reducing waste. Among the most effective strategies are ones that conform to Schumpeter's class of *creative responses*—that is, strategies that transform the very nature of competition by overcoming traditional trade-offs. A good example of such a response is the use of total quality management to improve quality and productivity at the same time. There has been an emergence of creative responses with regard to the industry-environment nexus. In particular, the development of innovative manufacturing systems provides firms with a means for improving industrial performance while simultaneously minimizing the costs associated with environmental compliance.

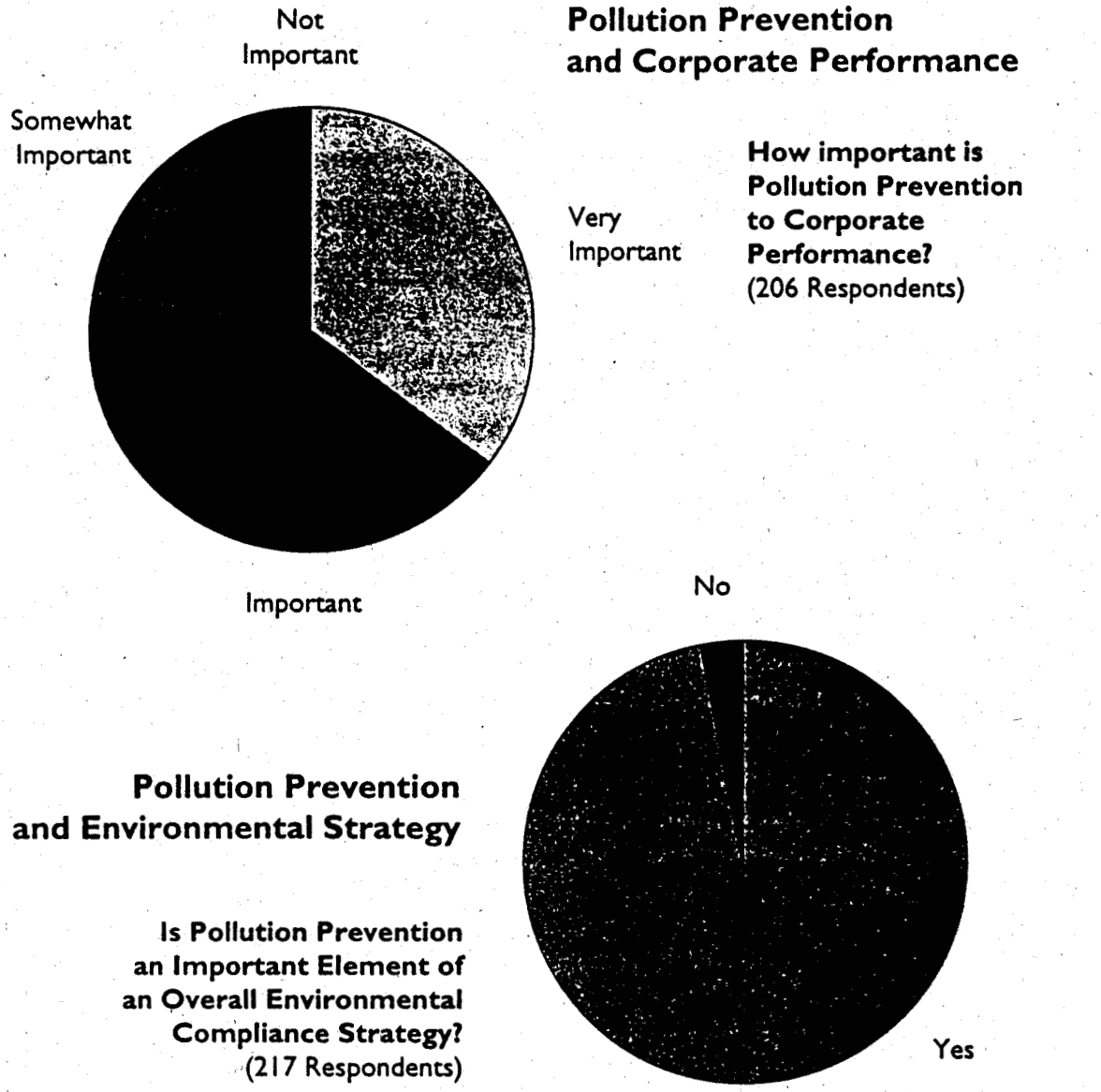
New Manufacturing Technology and Pollution Prevention

The adoption of pollution prevention—and, in particular, the modernization of production processes to prevent pollution—is an important indicator of the shift to advanced manufacturing systems that simultaneously improve industrial and environmental performance. Our survey of corporate environmental practices provides a range of data and information with which to examine the adoption and use of pollution prevention strategies by U.S. manufacturing firms.

Pollution Prevention and Corporate Performance

The survey asked firms to indicate to what degree pollution prevention is important to their overall corporate performance. As Figure 1 shows, more than three-quarters of survey respondents indicated that pollution prevention was important to overall corporate performance with 35.4 percent of respondents indicating that it is very important and an additional 41.5 percent of respondents indicating that it is important. Just one-fifth (20.4 percent) of respondents

FIGURE 1. Pollution Prevention, Environmental Strategy, and Corporate Performance (Percentage of Total Respondents)



Source: Richard Florida, *Survey of Environmental Manufacturing Practices*, 1995.

reported that pollution prevention was only somewhat important to corporate performance, and less than 2 percent (1.9 percent) indicated that pollution prevention was not important to corporate performance. The survey results further indicate that pollution prevention is an important component of firms' environmental strategies. Nearly nine in ten (87.7 percent) respondents reported that

pollution prevention is an important element of their overall environmental compliance strategy.

Zero Emission Manufacturing

Zero emission strategies emphasize the elimination of all environmentally damaging byproducts from the production process. Such strategies are a strong indicator of the move to environmentally conscious manufacturing. The survey asked firms whether they were currently pursuing zero emissions or strategies to reduce emissions. The survey data indicate that a significant fraction of respondents, roughly 16 percent, are actively pursuing zero emission manufacturing. Nearly 85 percent of respondents are pursuing reduced emissions strategies.

It is important, however, to distinguish between zero emission as a goal as opposed to an objectively achievable criteria. The findings from the phone interviews and site visits shed additional light on this issue. The majority of firms reported that zero emission manufacturing is in its early stages of development, and that at this point it functions as a goal or target rather than as an adopted practice or standard. These firms noted that such targets are useful to motivate ongoing improvement efforts even though it may currently be impossible to achieve zero emissions in practice. Here, a number of firms drew a parallel to zero defect approaches to quality, noting that although it is virtually impossible to achieve zero defects in practice, such ambitious goals performed an important function in motivating and focussing quality improvement efforts.

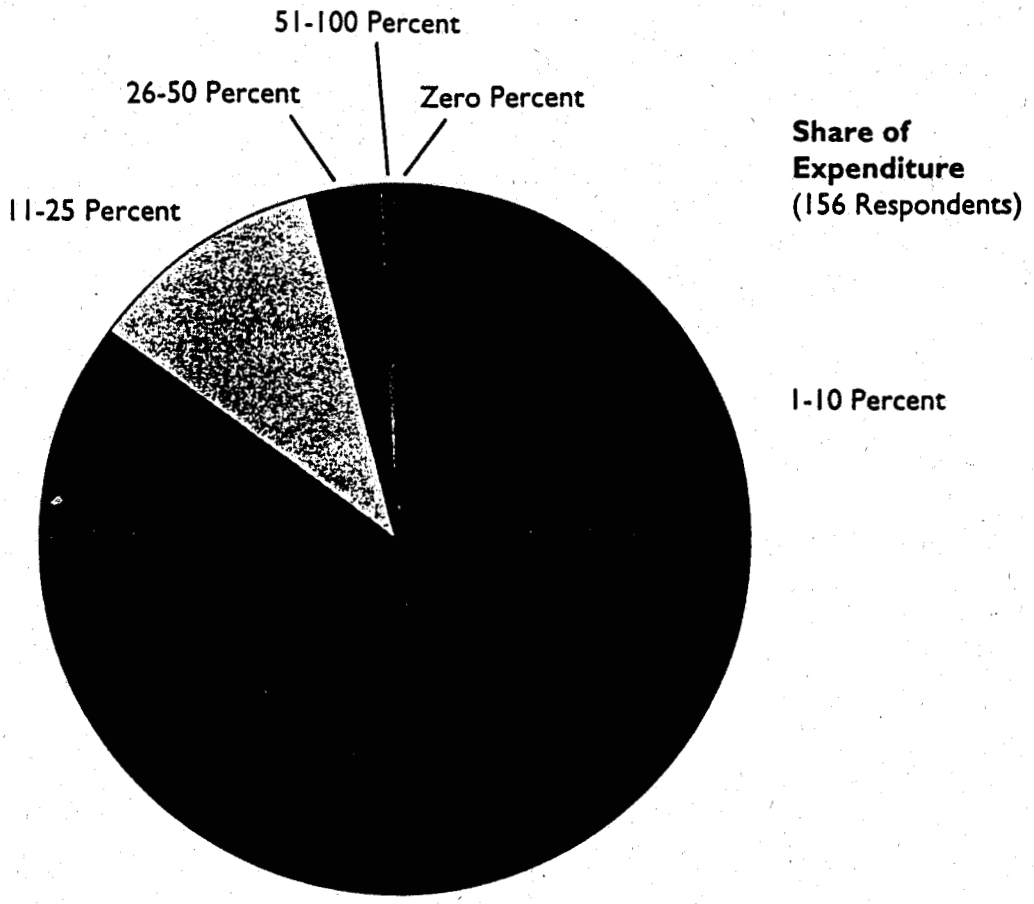
Pollution Prevention Expenditures

While soliciting the subjective preferences of firms on issues such as pollution prevention and emission reduction is useful and illuminating, the survey also obtained a variety of more direct and to some extent objective measures of pollution prevention effort. Of particular relevance, the survey collected data on the share of capital expenditures that firms devote specifically to pollution prevention. Here, the survey results indicate that pollution prevention expenditures are a significant component of overall capital expenditures. As Figure 2 shows, the overwhelming majority of respondents devote between 1 and 10 percent of their total capital expenditures to pollution prevention, with more than eight in ten (84.6 percent) of respondents reporting pollution prevention expenditures in this range. A significant share of respondents do, however, devote a greater share of their capital expenditures to pollution prevention. According to the survey data, one in six respondents devote greater than 10 percent of their total capital expenditure to pollution prevention. Furthermore, only a minuscule fraction of respondents (0.6 percent) reported that they do not devote any capital expenditures to pollution prevention.

Adoption of Technology

The relationship between innovation in environmentally conscious manufacturing and advanced manufacturing in general turns upon the particular

FIGURE 2. Share of Capital Expenditure Devoted to Pollution Prevention (Percentage of Total Respondents)

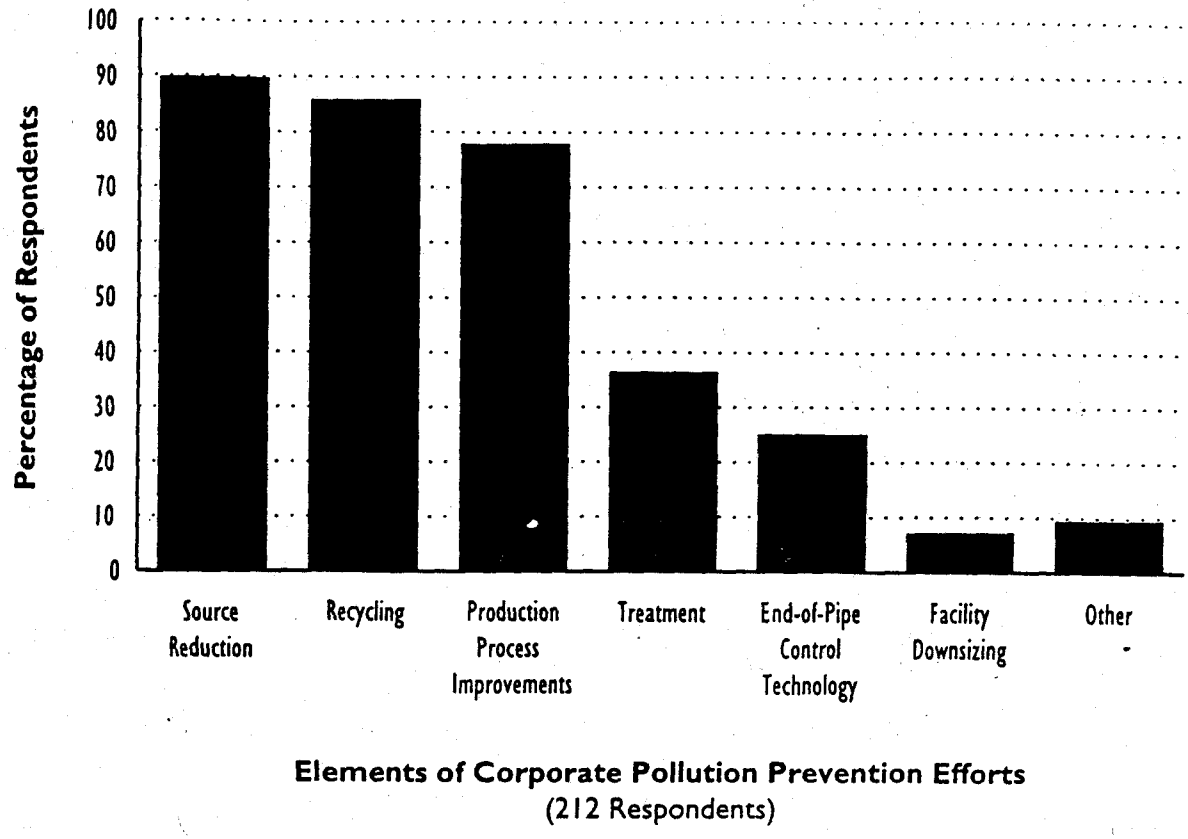


Source: Richard Florida, *Survey of Environmental Manufacturing Practices*, 1995.

strategies firms use to prevent pollution. As noted above, the use of treatment and end-of-the-pipe control technology typically comes at the expense of other manufacturing improvements. The implementation of new technologies and/or production process improvements is an important indicator of efforts to upgrade manufacturing systems in ways that simultaneously achieve improvements in industrial and environmental outcomes. The survey asked respondents to discriminate among different approaches to pollution prevention, such as production process improvements, source reduction, recycling, end-of-the-pipe control, and treatment.

The survey results indicate that manufacturing firms are adopting new technologies and manufacturing systems to achieve joint improvements in environmental and industrial performance. The survey respondents strongly favor source reduction, recycling, and production process improvement over treatment and end-of-the-pipe control technology (see Figure 3). Large fractions

FIGURE 3. Preventing Pollution in Practice

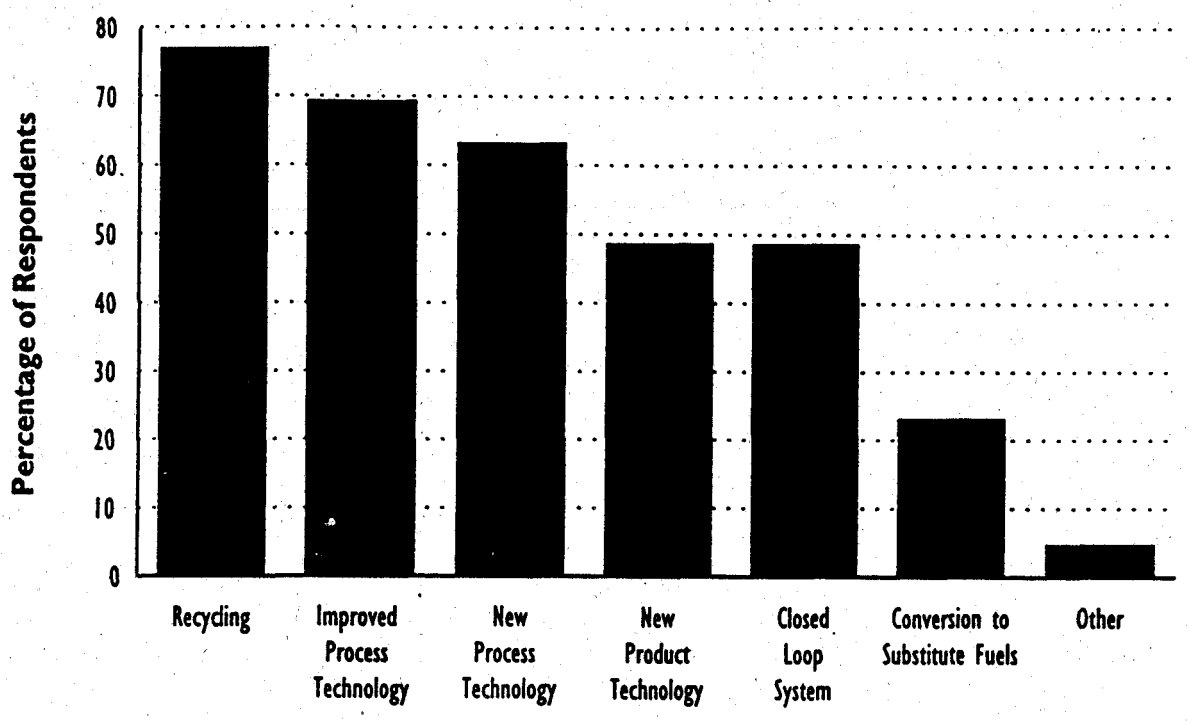


Source: Richard Florida. *Survey of Environmental Manufacturing Practices*, 1995.

of respondents indicate that they utilize source reduction (89.6 percent), recycling (85.8 percent), and production process improvements (77.8 percent) as main elements of their pollution prevention strategies. Significantly smaller percentages report the use of control technology as a main element of their pollution prevention efforts, with 36 percent reporting treatment and 25 percent reporting end-of-the-pipe technology as main elements of their pollution prevention strategy. In addition, the survey asked respondents the degree to which they address environmental outcomes by reducing the size of their manufacturing operations through facility downsizing. Just 7 percent of respondents reported that downsizing was a main element of their pollution prevention efforts. We also looked at the use of various pollution prevention and environmental control practices in combination. More than 30 percent (32.5 percent) of respondents utilized an innovative bundle of production process improvements, source reduction, and recycling in combination.

The implementation of new technologies in the form of production process improvements is a central factor in the development of joint improvements in environmental and manufacturing methods. The survey asked

FIGURE 4. Type of Improvement to Prevent Pollution

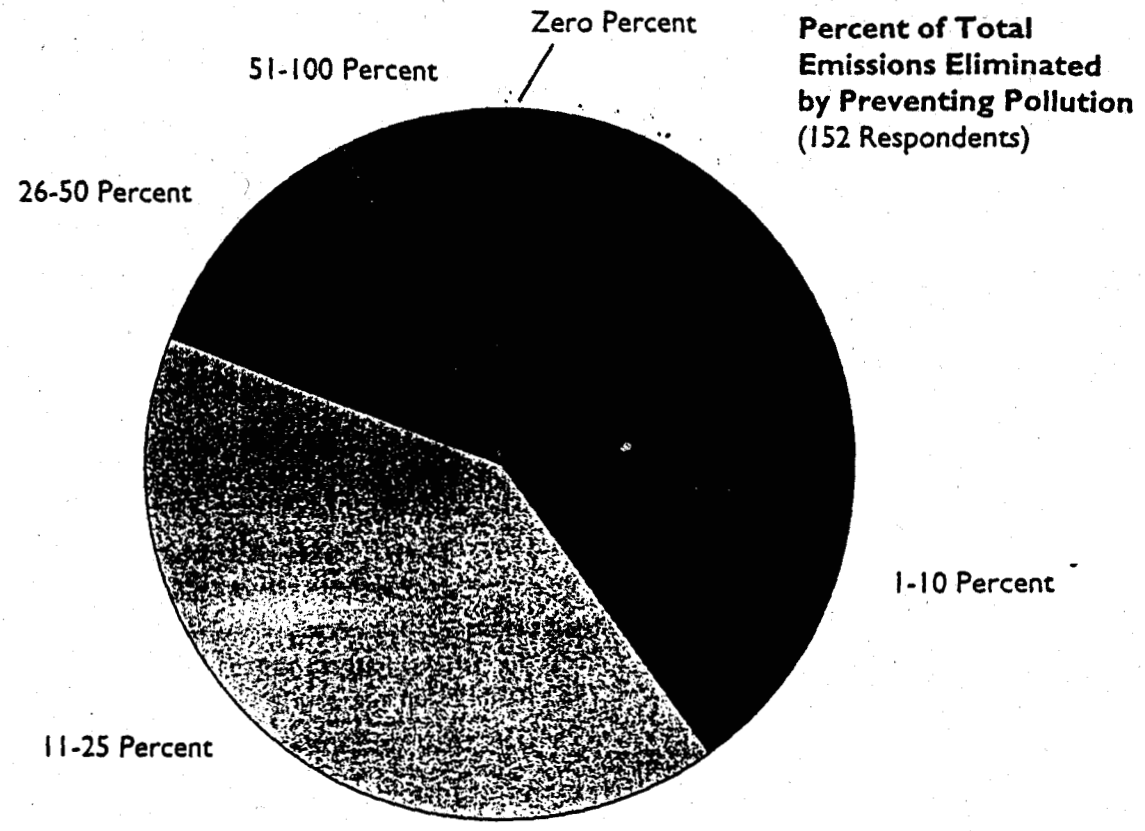


Source: Richard Florida, *Survey of Environmental Manufacturing Practices*, 1995.

respondents to identify the specific types of production process improvements they have undertaken to reduce pollution and improve environmental performance. Here again, the survey results indicate that firms favor recycling and the introduction of new manufacturing process technology. As Figure 4 indicates, more than three-quarters (76.9 percent) of survey respondents used recycling, and roughly two-thirds of respondents upgraded their existing process technologies (69.3 percent) and introduced wholly new process technologies (63.2 percent). In addition, nearly half (48.6 percent) of respondents introduced new product design and product technology, and the same percentage introduced closed loop production systems utilizing waste from one stage of production process as inputs to other stages of production. Overall, the survey responses indicated that instead of simply treating wastes with end-of-the-pipe technology, firms are investing in new manufacturing process technology which simultaneously prevents pollution and increases productivity.

The survey asked respondents to report the level of emission reduction they have achieved by undertaking efforts to reduce waste and prevent pollution. As Figure 5 indicates, these efforts have resulted in considerable emission

FIGURE 5. Level of Emission Reduction with Pollution Prevention (Percentage of Total Respondents)



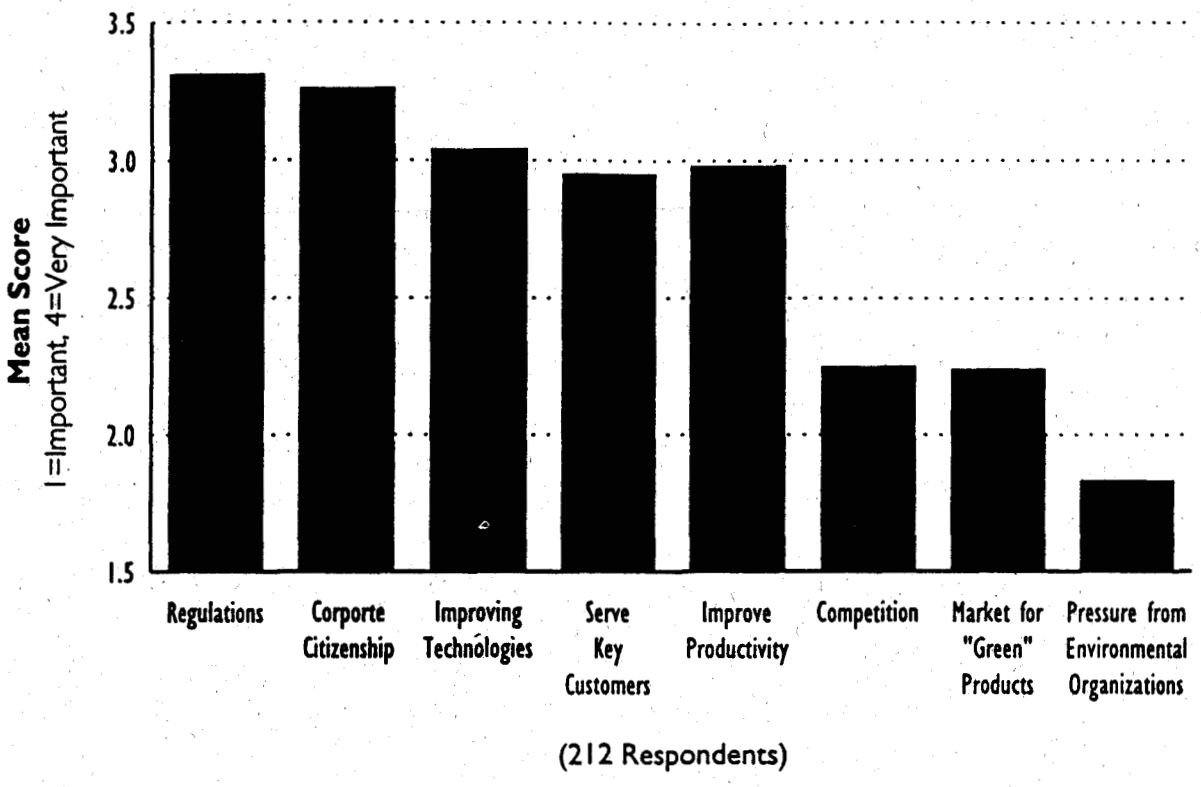
Source: Richard Florida, *Survey of Environmental Manufacturing Practices*, 1995.

reductions at sample firms. Nearly two-thirds of respondents reported emission reductions of greater than 10 percent over the previous year, with 40 percent achieving reductions in the range of 11 to 25 percent, 12 percent reporting 26 to 50 percent reductions, and 7 percent reporting reductions in excess of 51 percent. Just 1 percent of respondents reported that they achieved no emission reductions at all.

Factors Affecting the Relationship between Industrial and Environmental Strategy

The survey asked firms to identify the factors in the broad economic and policy environment that affect their environmental manufacturing strategies. These included: environmental regulations, corporate citizenship, new technologies, productivity improvement, competitors, customers, markets for green products, and environmental groups. The survey asked firms to rank the effect of

FIGURE 6. Key Factors in Corporate Environmental Strategy



Source: Richard Florida, *Survey of Environmental Manufacturing Practices*, 1995.

each of these factors on their corporate environmental strategies and activities on a 1 to 4 scale, where 1 was not important and 4 was very important.

The survey results indicate that environmental regulations and corporate citizenship remain key factors in corporate environmental strategy. The data, however, further indicate that a series of factors associated with industrial performance are important as well. As Figure 6 shows, the survey respondents listed environmental regulations (3.3) and corporate citizenship (3.3) as the two highest-ranked factors. But, the respondents also gave high ratings to a cluster of related factors which bear directly on industrial performance and competitiveness—technology (3.0), serving key customers (3.0), and improving productivity (3.0). These results suggest that improving overall industrial performance and productivity are almost as important as responding to environmental regulations as a driver of environmentally conscious manufacturing efforts. They thus reinforce the conjecture that there is an association between efforts to improve environmental performance and to enhance manufacturing performance more generally.

Organizational Innovations in Environmental Manufacturing

As numerous studies have pointed out, advanced manufacturing systems are distinguished by a series of organizational and managerial practices—such as total quality management, worker involvement in continuous improvement activities, and more effective approaches to supply chain management—that complement and enhance the performance of new manufacturing technologies. This organizational dimension of advanced manufacturing systems is often seen to be as important, if not more important, than the introduction of new manufacturing process technologies.

Total Quality Environmental Management

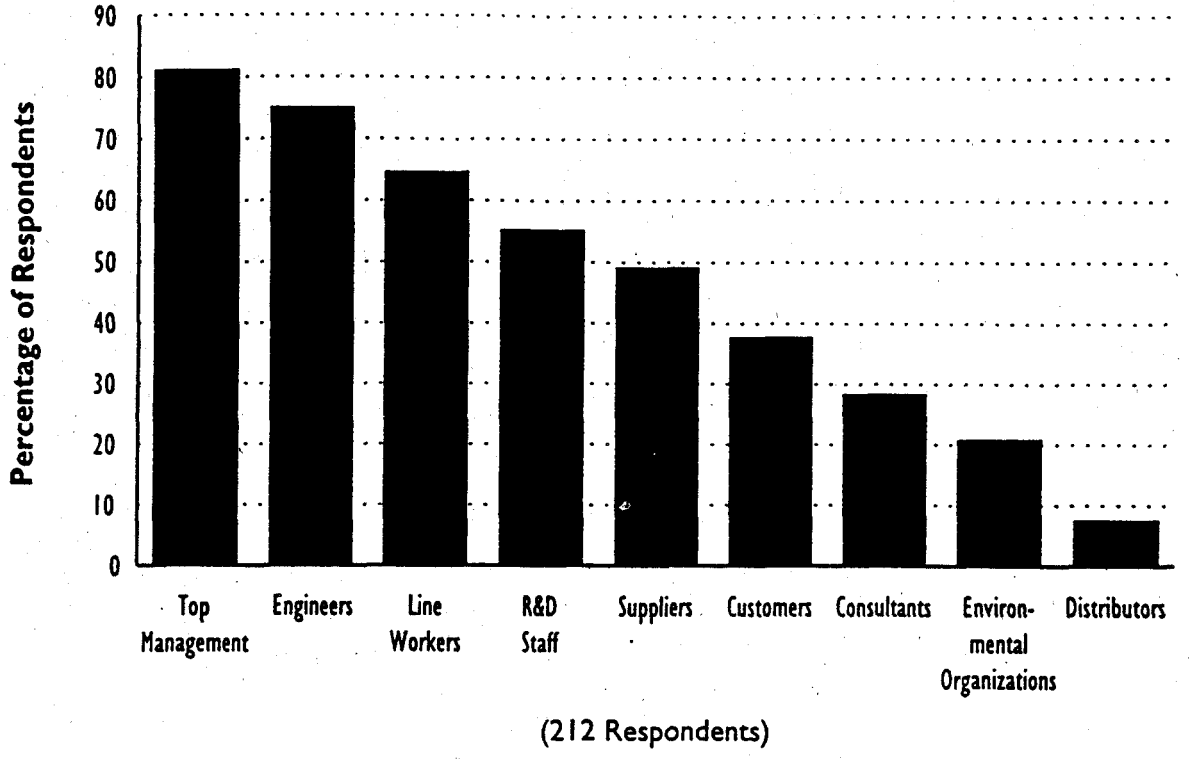
Total quality management is a frequently cited feature of advanced manufacturing systems, particularly among U.S. manufacturers. Total quality management is essentially a method for involving production workers in the improvement of product quality through incremental improvements in both products and processes. Total quality environmental management (TQEM) extends the principles of quality management to include manufacturing practices and processes that affect environmental quality.[19] According to the survey data, 43 percent of respondents employ a TQEM program.

The development of international quality standards—in particular, the ISO series of standards for quality manufacturing—reflects the growing trend toward integrating industrial and environmental outcomes within a quality framework. While the ISO standards are voluntary, many manufacturing firms have used ISO standards to motivate change and to ensure their operations meet recognized quality standards. Environmental quality has been adopted as a central component of the new series of ISO 14000 standards. The phone interviews indicate that a number of manufacturing firms are migrating from the traditional ISO 9000 standards to the new ISO 14000 standards. Ray-o-Vac reported that it was already operating at 95 percent of ISO 14000 standards. Safety Kleen reported that its Elk Grove, Illinois plant was in the process of moving from ISO 9000 to ISO 14000 standards. Sony Corporation also reported that it was shifting from ISO 9000 to ISO 14000 standards for its North American and worldwide manufacturing operations.

Worker Involvement in Pollution Prevention

Employee involvement in continuous manufacturing improvement is a central element of advanced manufacturing systems. Recent research reports that a large and growing percentage of both U.S. manufacturing plants and Japanese-affiliated manufacturing transplants make use of employee involvement in continuous improvement to improve productivity and increase manufacturing performance.[20]

FIGURE 7. Key Actors in Pollution Prevention Efforts



Source: Richard Florida, *Survey of Environmental Manufacturing Practices*, 1995.

As Figure 7 shows, roughly two-thirds of responding firms (64.6 percent) involve production workers in their pollution prevention efforts. Responding firms indicated that only two other groups—top management (81.1 percent) and engineers (75.0 percent)—were more important than production workers to their pollution prevention efforts. Furthermore, the magnitude of the difference between these three groups is sufficiently small, reinforcing the conjecture that production workers are an important component of pollution prevention efforts. The phone interviews and field research lend additional support to this view, indicating that manufacturers increasingly use a team approach where production workers, engineers, and managers combine their efforts to generate productivity-enhancing environmental outcomes. Responding firms reported that production workers were more important to their pollution prevention efforts than research and development staff (55.2 percent), suppliers (49.1 percent), customers (37.7 percent), or consultants (28.3 percent).

The results of the phone interviews reinforce these findings. Quad/Graphics utilized employee teams to significantly reduce hazardous waste.[21] Furthermore, the company reported that employee involvement was a cost-effective way to improve environmental outcomes and reduce costs, involving incremental changes in existing processes and products as opposed to major changes in

technology and large capital expenditures. An IBM disk drive plant involved workers, engineers, and R&D scientists in a plant-wide effort to reduce CFCs. Safety-Kleen used teams of workers and engineers to reduce solvents, minimize waste, and redesign equipment for increased resource efficiency and pollution prevention. Crown Cork and Seal's Minnesota plant involved production workers as the centerpiece of its efforts to eliminate waste and reduce toxins, forming teams of production workers to focus on environmental issues—for example, a *Recycling Team* whose objective focused on an environmental problem, and the *Color Cats Team* whose main effort was quality improvement but whose work had considerable impact on hazardous waste generation. As a result of these efforts, the plant achieved a 60 percent reduction in use of its primary solvents between 1991 and 1993, a 36 percent reduction of air emissions in 1993, and a two-thirds reduction in solid waste disposal from an annual level 300 tons to 100 tons.

In short, firms are adopting a series of internal organizational changes in their manufacturing operations (such as TQEM programs and worker involvement in continuous environmental improvement) as well as new production technologies. These organizational innovations both complement and reinforce investments in new manufacturing technologies.

Supply Chain Management and Environmental Performance

A considerable body of literature has noted the emergence of new and more effective systems of supply chain management as a distinguishing feature of advanced manufacturing systems.[22] Generally speaking, this work suggests that firms are increasing their reliance on outside suppliers and developing new and more interactive approaches to supply chain management. Recent studies further suggest that supply chains constitute potentially powerful mechanisms for the diffusion of advanced manufacturing practices. Research by Florida and Jenkins found that end-user/supplier relations were the key determinant of adoption and diffusion of innovative manufacturing practices among Japanese transplant manufacturers.[23]

Supplier relations and supply chain management can affect industrial and environmental performance in different ways. On the one hand, manufacturers have at times used their suppliers as a vehicle for improving their own environmental records by out-sourcing toxic elements of the production processes, essentially pushing waste and toxins down the supply chain. On the other hand, new models of supplier relationships and supply chain management create opportunities for joint approaches to improve productivity and prevent pollution. For example, the emphasis on just-in-time delivery seeks to reduce both inventory and waste. Pressures for continuous cost reduction and quality improvement create additional incentives for waste reduction and cost savings. Increasing co-involvement in product development between end-users and

suppliers provides opportunities for the design of new products and processes that are both more efficient and environmentally benign. The emergence of mutually dependent relationships between end-users and their suppliers have opened up new pathways for the diffusion of innovative approaches to waste reduction, pollution prevention, and productivity enhancement— particularly as end-user firms actively assist their suppliers in the adoption of new methods.

The results of the survey research, phone interviews, and field research indicate that manufacturing firms are involving suppliers in efforts to improve environmental outcomes and increase productivity. As noted above, the survey of environmental manufacturing practices asked firms to identify the key players in their pollution prevention strategies (see Figure 7). Nearly half (49.1 percent) of the respondents identified suppliers as a key player. In addition, more than one-third of respondents (37.7 percent) identified customers as a key player in pollution prevention efforts.

The phone interviews provide more detailed data on the various ways that supply chain management is utilized to simultaneously achieve improved environmental quality and industrial performance. The results of these interviews suggest that supplier relations create considerable opportunities for joint environmental and productivity improvement. In particular, environmental improvements were seen to result from ongoing efforts to improve productivity and implement advanced manufacturing practices, as well as from more directed efforts to transfer pollution prevention strategies and technologies.

While the majority of respondents indicated that environmental improvements are frequently unintended consequences of broader efforts to improve industrial performance, a number of respondents noted that they pursue more directed efforts with suppliers to reduce waste and prevent pollution. These firms noted that they develop supplier specifications that include environmental objectives, they work with suppliers to develop new products and specifications, and they hold regular meetings with their suppliers to relate their pollution prevention strategies. For example, Motorola noted that it proactively pursues pollution programs with its suppliers. IBM's disk drive factory worked closely with circuit-card suppliers to jointly develop a water-based alternative to a CFC-based chemical. Scott Paper and Safety-Kleen worked closely with suppliers to eliminate toxic chemicals and reduce waste through recycling and process changes. Amko Plastics formed *action teams* with suppliers to develop new materials and processes to convert to water-based inks for printing plastic films.[24] Ray-o-Vac established an environmental audit and ranking system for its suppliers and worked closely with its first tier of suppliers to encourage the diffusion of pollution prevention practices through the supply chain.[25] TRW was in the process of adding an environmental component to its existing supplier assessment program.

Our field research on Sony's Westmoreland, Pennsylvania, television plant and its suppliers reinforces the finding that environmental improvements tend to flow from ongoing joint efforts to improve productivity, eliminate

defects, and reduce costs—that is, rather than from direct efforts to transfer pollution prevention technology or organizational strategies designed expressly to eliminate toxins or prevent pollution. As part of its effort to reduce cost and waste, the Sony plant worked with its suppliers of plastics, metals, solder, and other materials to completely recycle all of the scraps and other products of the production process. Sony worked closely with one of its suppliers, Tuscarora Plastics, to redesign its packaging to be less costly—a design which also used less material and generated less waste. The Sony plant also collaborated with a major paint supplier to reduce the cost of paint by switching to a water-based substitute that was also more environmentally sensitive than chemical-based paints.

In short, the findings support the conjecture that end-user/supplier relationships facilitate the adoption and diffusion of environmentally conscious manufacturing practices. Furthermore, the findings indicate that end-user/supplier relations operate by opening up opportunities for adoption and implementation of innovative approaches to both environmental and productivity improvement.

Adoption of Clusters of Environmental Manufacturing Practices

An increasingly important stream of literature on advanced manufacturing systems suggests that firms tend to adopt related bundles of advanced technologies and organizational practices, and further that such technologies and practices are more effective when they are adopted and utilized as a system.[26] We used cluster analysis to explore the adoption of such bundles of related environmental manufacturing practices by firms in the survey. The cluster analysis included key measures from the survey as well as data on firm size, age, sales, and industry obtained from Dun and Bradstreet. The cluster solution that was most appropriate for these data generated four distinct clusters of advanced-environmental practices. Table 1 summarizes the relevant findings of the cluster analysis.

The firms in Cluster 1 rate pollution performance as very important to corporate performance and exhibit high rates of adoption of both technological and organizational innovations related to environmentally conscious manufacturing. Firms in this cluster can thus be considered to represent a *best-practice* approach to environmental and industrial performance. This cluster contains the largest number of sample firms (n=61)—35 percent of the entire sample. Firms in this cluster are relatively large, with 48 percent having sales of more than $2 billion and just 15 percent in the under $500 million category. As noted above, these firms consider pollution prevention very important to corporate performance and exhibit high rates of adoption of virtually the entire gamut of technological and organizational innovations related to environmentally conscious manufacturing—including source reduction, recycling, production process technology, TQEM, and worker involvement in continuous environmental

TABLE 1. Cluster Analysis of Environmental Manufacturing Practices

	Cluster 1 Best-Practice N=61	Cluster 2 N=43	Cluster 3 N= 40	Cluster 4 Traditional N= 29
Pollution Prevention as Source of Corporate Performance	●	●	❁	❁
"Green" Process Technology	●	❁	●	○
Source Reduction	●	●	●	❁
Recycling	●	❁	●	○
TQEM	●	○	❁	○
Worker Involvement	●	❁	❁	○
Supply Chain Integration	●	○	❁	○
Productivity and Technology Role in Environmental Strategy	●	●	○	○
Pollution Prevention Expenditure	●	●	❁	❁
Emission Reduction	●	●	○	○
Size	Large	Medium	Small	Small

Note: ● = High, ❁ = Moderate, ○ = Low

Source: Richard Florida, *Survey of Environmental Manufacturing Practices*, 1995.

improvement. Firms in this cluster tend to integrate their pollution prevention efforts across the entire industrial chain and to rate productivity and technology as key drivers of their environmental manufacturing strategy. These firms devote a relatively high level of capital expenditures to pollution prevention and achieve high levels of emission reduction.

Firms in Cluster 2 rate pollution prevention as relatively important to overall corporate performance. However, the percentage of firms responding very important to this question is significantly less than for Cluster 1—35 percent versus 49 percent. Firms in Cluster 2 devote a relatively high level of capital expenditures to pollution prevention and report a relatively high level of emission reduction. However, these firms report very low levels technology adoption related to pollution prevention, and are also less likely than firms in Cluster 1 to adopt organizational innovations such as TQEM or the involvement of workers in continuous environmental improvement. These firms also exhibit a low level of integration of pollution prevention efforts across the supply chain. One potential explanation for this pattern is that Cluster 2 firms may generate types of pollution (e.g., solid rather than hazardous waste) that can be prevented by relatively straightforward methods, such as recycling and source reduction, rather than requiring high levels of technological and organizational innovation. It is also worth noting that this cluster is distinguished by a heavy concentration of consumer and personal care products firms for which brand name recognition

and corporate reputation are important, and thus may pursue pollution prevention to enhance their overall corporate image.

Firms in Cluster 3 rate pollution prevention as of moderate importance to corporate performance. These firms exhibit relatively high rates of adoption of new production process technology, recycling, and source reduction. These firms, however, exhibit only moderate levels of adoption of organizational innovations such as TQEM and worker involvement. They also show only a moderate level of integration of pollution prevention efforts across the supply chain. Moreover, Cluster 3 firms do not rate either productivity improvement or new technology as significant drivers of their environmental strategies. These firms devote a moderate level of capital expenditure to pollution prevention and realize a low level of emission reduction from their efforts. This leads us to surmise that the pollution prevention efforts of these firms may be a consequence of unrelated corporate efforts to improve quality, reduce cost, and/or increase performance rather than from a directed and strategic effort to achieve joint gains in industrial and environmental performance.

Firms in Cluster 4 rate pollution prevention as relatively unimportant to corporate performance and engage in low levels of technological and organizational innovations related to environmental manufacturing. This cluster has a disproportionate concentration of smaller firms, with more than 40 percent having under $500 million in sales. These firms devote a moderate level of capital expenditures to pollution prevention and achieve a low level of emission reduction. Firms in this cluster show little evidence of adoption of organizational or technological innovations related to environmentally conscious manufacturing.

The results of the cluster analysis indicate that firms differ considerably in terms of the level of effort and strategies used to achieve industrial and environmental performance. Perhaps most importantly, the cluster analysis findings indicate that a significant fraction of sample firms—more than one-third of all respondents—are actively pursuing a related bundle of advanced technological and organizational innovations associated with advanced and environmentally conscious manufacturing systems. These firms can be considered leaders in the adoption of advanced manufacturing technologies that generate simultaneous improvements in industrial and environmental performance. It should also be remembered, however, that a smaller but still considerable fraction of firms show much lower rates of adoption of such practices and that there is little evidence of their moving to adopt technological and organizational innovations that offer joint industrial and environmental gains. At bottom, the findings of the cluster analysis indicate that there is a class of firms that are able to implement a related bundle of technological and organizational innovations associated with advanced, environmentally conscious manufacturing and that are able to realize considerable emission reduction while enhancing productivity as a result.

TABLE 2. Advanced Manufacturing and Green Design

Factors Associated with Adoption of Green Design	Green-design Plants	Non-Green-design Plants	Significance Level
Employment	472	243	**
Sales	$145.3 million	$62.2 million	**
R&D Spending	$4.2 million	$0.4 million	*
Capital Investment	$56.0 million	$46.8 million	*
New Product Introductions	9.4	4.0	**
Product Design Changes	14.9	8.4	**
Suggestions by Production Workers	185	87	**
Total Quality Management (percent of plants)	71 percent	56 percent	*
Statistical Process Control (percent of workforce)	40 percent	27 percent	**
Inventory (current level)	9 days	12.7 days	*
Return on Assets	13.6 percent	8.5 percent	**

Note: * is significant at the .05 level. ** is significant at the .01 level.
Source: Data are from Richard Florida and Davis Jenkins, *Survey of Japanese Affiliated Manufacturers and Their U.S. Suppliers* (Pittsburgh, PA: Center for Economic Development, Carnegie Mellon University, 1995). Mark Atlas conducted the statistical analysis reported here.

Advanced Manufacturing Systems, R&D, and Green Design

To shed additional light on the relationship between innovations in environmental manufacturing and the adoption of advanced manufacturing systems in general, we utilized the detailed establishment-level data collected in the survey of Japanese manufacturing transplants. As noted previously, these data enabled us to examine the relationship between the adoption of green design and other aspects of advanced manufacturing and innovative work organization. This was done in two ways.

First, the survey data were utilized to identify those plant characteristics that are associated with the adoption of green design. The results of this analysis are summarized in Table 2. In short, the findings reinforce the hypothesis that plants that practice green design are also those that are involved in advanced manufacturing more generally. The green-design plants tended to be larger, to be more R&D-intensive, to introduce greater numbers of products and product designs, and to involve workers in continuous improvement. The green-design plants were twice as large, on average, in terms of employees and sales than those which did not engage in environmentally sensitive product design. Moreover, there was a strong relationship between R&D intensity and green design,

TABLE 3. Adoption of Green Design and Other Advanced Manufacturing Practices by Type of Manufacturing System

Manufacturing Practice	Type of Manufacturing System		
	Taylorist	Transitional	Advanced
"Green" Product Design	No	—	Yes
Total Quality Management	No	Yes	Yes
Quality-Oriented Design	Limited	—	Extensive
Quality-Oriented Process Improvements	Infrequent/ Limited	Frequent/ Extensive	Frequent/ Very Extensive
Inventory	High*	Moderate*	Low*
Concurrent Engineering	Limited	—	Extensive
Ratio of Managers to Workers	High	—	Low
Employment Security	No	—	Yes (No Layoff Pledge)
Supplier Relations	Arm's Length	—	Cooperative
Electronic Design Interchange	No*	—	Yes*

Note: * Indicates that finding is mainly attributable to the automotive sector.
— Indicates that there is no statistically significant relation between the given characteristic and the type of manufacturing regime at the $p < .01$ level.

Source: Davis Jenkins, *Japanese Transplants and the Work System Revolution in U.S. Manufacturing* (Pittsburgh, PA, Heinz School, Carnegie Mellon University, unpublished doctoral dissertation, July 1995).

suggesting that environmental innovation is associated with innovative effort and activity more generally. Plants which practice green design spent on average ten times as much on R&D as those that did not. The green-design plants also introduced roughly twice the number of new products and new product designs than those that did not engage in green design. Furthermore, the green-design plants were more likely to be involved in total quality management, to utilize statistical process control, and to have lower levels of inventory. Consequently, we are led to conclude that firms that are innovative and engaged in continuous improvement of and frequent changes to their products and product designs have a greater opportunity and incentive to take environmental considerations into account, because they are already engaged in product design changes and thus are better able to absorb the fixed costs associated with such changes.

Second, in related research, Jenkins used factor and cluster analysis to identify three groups or clusters of manufacturing establishments: taylorist, traditional, and advanced.[27] As Table 3 shows, plants in the advanced regime were found to adopt a related bundle of advanced manufacturing practices including total quality management, quality-oriented product design, just-in-time inventory control, a flat organizational hierarchy (e.g., a low ratio of managers to production workers), high levels of employment security, cooperative supplier relations, and electronic data interchange as well as green design.[28] The results

of this analysis indicate that green design is one of a bundle of practices associated with advanced manufacturing systems. This lends considerable support to the hypothesis that adoption of innovative environmental practices is an element of a more general strategy of productivity-enhancing manufacturing process improvement on the part of firms.

Summary and Conclusions

We started from the hypothesis that the adoption of environmentally conscious manufacturing is related to the adoption of advanced manufacturing systems more generally. The combined results of the survey research, phone interviews, and field research provide considerable support for this view. These results can be summarized in terms of four key points.

First, firms are leveraging their industrial modernization strategies for environmental ends. Firms strongly favor source reduction, recycling, and production process improvement over treatment and end-of-the-pipe control technology. The large majority see pollution prevention as important to overall corporate performance and indicate that it is the central element of their overall environmental compliance strategy. Moreover, firms that adopt related bundles of technological and organizational innovations related to advanced, environmentally conscious manufacturing are able to considerably reduce emissions in ways that simultaneously enhance their productivity.

Second, there is a close relationship between green design and R&D spending, product innovation, and a range of advanced manufacturing practices—including employee involvement in continuous manufacturing process improvement and close supplier relations. These findings suggest that green design is one of a bundle of practices associated with innovative manufacturing systems.

Third, while environmental regulations and corporate citizenship remain key elements of corporate environmental strategy, a series of factors associated with industrial performance are also important. The survey respondents rated technological improvements, customer demands, and productivity improvement as important drivers of environmental manufacturing strategies, providing a clear indication of the connection between environmental and industrial strategy and performance.

Fourth, close relationships across the production chain—and between end-users and suppliers in particular—facilitate the adoption of advanced manufacturing practices, creating new opportunities for joint improvements in productivity and environmental outcomes. Generally speaking, environmental improvements flow from ongoing joint efforts to improve productivity, eliminate defects, and reduce costs, rather than from direct efforts to transfer pollution prevention technology or organizational strategies designed expressly to eliminate toxins or prevent pollution.

Taken together, these findings suggest that the efforts of firms to improve manufacturing processes and increase productivity create substantial opportunities for environmental improvement. The adoption of manufacturing process innovations provides incentives for the adoption of environmentally conscious manufacturing strategies. We are led to conclude that firms and plants that are R&D-intensive and manufacturing innovators possess the capacity to both improve productivity and reduce environmental costs and risks. Furthermore, the emergence of productivity-enhancing environmental strategies is a product of evolving *creative response* on the part of firms to transform the traditional industry-environment trade-off and to optimize their manufacturing processes in ways that simultaneously improve environmental and industrial performance. In other words, the pursuit of zero defect and zero inventory manufacturing strategies produces spill-over benefits to the environment and creates the context for innovative approaches to emission reduction and pollution prevention, leading in turn toward zero emission manufacturing strategies. It is in this sense that we can speak of the convergence of zero defect, inventory, and emission approaches to manufacturing as well as the emergence of new and more efficient approaches to manufacturing that integrate environmental improvement as part of ongoing, broader efforts to enhance productivity, performance, and profit.

APPENDIX
Research Methodology

This survey was administered to a stratified random sample of 450 manufacturing firms. The sample was drawn from the Standard and Poor (S&P) directory of manufacturing firms and included 250 larger firms from the S&P 500 Index, 100 mid-size firms from the S&P Midcap 400 Index, and 100 small firms from the S&P Smallcap 600 Index. The survey instrument contained questions on: the level of pollution prevention expenditures, the main components of pollution prevention efforts, manufacturing process improvements for pollution prevention, the role of pollution prevention in corporate performance, zero emission manufacturing, total quality environmental management, emission reductions, role of managers, engineers, workers, and suppliers in pollution prevention efforts, and the economic, political and other factors affecting the adoption of environmentally conscious manufacturing strategies. To maximize response rate, the survey was designed as a short user-friendly instrument and administered via facsimile, resulting in successful contacts to 423 of the 450 firms in the original sample. Of this number, accurate and completed surveys were returned by 256 firms, for an adjusted response rate of 60.5 percent.

In addition, this article draws from a survey of 1,500 Japanese-affiliated manufacturing establishments, or so-called transplants.[29] The survey examined the adoption of innovative manufacturing and work organization practices by Japanese transplants across industrial sectors (n=1,195) and a control group of

U.S. suppliers to the automotive transplants (n=338). The survey collected detailed information on plant-level characteristics and products, work organization, manufacturing process innovation, and end-user/supplier relations. It was administered through a combination of mail and telephone contacts and resulted in an unadjusted response rate of 40 percent.[30] While the main purpose of the survey was to examine the factors affecting the adoption of innovative manufacturing and work organization in the manufacturing plants, the survey included a question on the integration of environmental considerations in the design of products, which all mail survey respondents (n=316) answered.[31] These survey data were used to examine the relationship between green design and other aspects of advanced manufacturing.

Phone interviews and field research at factory sites were used to collect more detailed and comprehensive information on the relationship between environmentally conscious manufacturing practices and manufacturing innovations more generally. We used a modified *delphi* methodology to identify candidate firms, contacting trade associations, environmental agencies, and pollution prevention agencies to identify potential candidates. More than 50 organizations and experts were contacted, and they provided a list of 39 candidate firms including large firms such as 3M, General Electric, Motorola, TRW, Steelcase, Sony, and Honda, and a wide range of small and medium-size companies. These firms were contacted by facsimile and 18 provided information on their environmental manufacturing efforts and indicated that they were willing to participate in phone interviews or site visits. As a cross-check, we examined the toxic chemical reduction records available from the U.S. Environmental Protection Agency (EPA) for a group of roughly 50 manufacturing companies that are recognized as manufacturing innovators. While coverage of these companies in the EPA data was spotty, toxic chemical reduction data was available for a number of firms, and we were able to identify a number of large reducers in the sample.[32]

Phone interviews were conducted with 12 manufacturing firms in a variety of industrial sectors including: advanced electronics (Motorola), computer disk drives (IBM), televisions (Sony), automotive components (TRW, Toyota, Johnson Controls), batteries (Ray-o-Vac), chemicals (Safety Kleen), plastics (Amko Plastics, Tuscarora Plastics), aerosol cans (Crown, Cork and Seal), paper (Scott Paper), and printing (Quad/Graphics). These interviews focussed on corporate and plant-level environmental manufacturing initiatives, the relationship between environmental strategies and manufacturing innovation, and the role of supply chain in the adoption and diffusion of advanced manufacturing practices. A site visit to Sony's Westmoreland Pennsylvania plant and a number of its suppliers was conducted to obtain more detailed information on the these issues, particularly the degree and level of interaction between end-users and suppliers.

Notes

1. Stephan Schmidheiny, *Changing Course: A Global Business Perspective on Development and the Environment* (Cambridge, MA: The MIT Press, 1992); Bruce Smart, ed., *Beyond Compliance: A New Industry View of the Environment* (Washington, D.C.: World

Resources Institute, 1992); Bruce Smart, "Industry as Metabolic Activity," *Proceedings of the National Academy of Science*, 89, (February 1992): 804-806; Michael Porter and Class van der Linde, "Green and Competitive: Ending the Stalemate," *Harvard Business Review* (September-October 1995): 120-134; Michael Porter and Class van der Linde, "Toward a New Conception of the Environment-Competitiveness Relationship," unpublished paper, March 22, 1994; Richard A. Clarke et al., "The Challenge of Going Green," *Harvard Business Review* (July/August 1994); Noah Walley and Bradley Whitehead, "It's Not Easy Being Green," *Harvard Business Review* (May/June 1994).

2. This literature has tended to set up neo-classical environmental economics a something of a straw-man. While the neo-classical perspective suggests that there is a trade-off between environmental improvement and productivity improvement at any *given* point in time, firms can and typically do improve both their environmental and industrial performance over time. For neo-classical economics, improvements in productivity and environmental performance are both driven by the same competitive pressure on firms to economize on inputs through technological change. I am indebted to one of the referees of helping to clarify this important point.
3. See U.S. Office of Technology Assessment, 1994.
4. Data are from U.S. Bureau of Census, *Current Industrial Reports: Pollution Abatement Costs and Expenditures, 1993*. MA200(93)-1 (Washington, D.C.: U.S. Government Printing Office, 1994).
5. There is a growing literature on corporate environmental practices. See, Office of Technology Assessment, *Industry, Technology, and the Environment: Competitive Challenges and Business Opportunities* (Washington, D.C.: U.S. Government Printing Office, 1994); Deanna Richards and Robert Frosch, *Corporate Environmental Practices: Climbing the Learning Curve* (Washington, D.C.: National Academy Press, 1994); David Wallace, *Environmental Policy and Industrial Innovation: Strategies in Europe, the U.S., and Japan*. (London: Royal Institute of International Affairs, Earthscan Publications Ltd., 1995); Kurt Fischer and Johan Schot, eds., *Environmental Strategies for Industry: International Perspectives on Research Needs and Policy Implications* (Washington, D.C.: Island Press, 1993). Also see the related literature on industrial ecosystems: Robert Frosch, "Industrial Ecology: A Philosophical Introduction," *Proceedings of the National Academy of Science*, 89 (February 1992): 800-803; Robert Frosch, "Industrial Ecology: Minimizing the Impact of Industrial Waste," *Physics Today* (November 1994), pp. 63-68; Robert Frosch and N.E. Gallopoulos, "Towards an Industrial Ecology," in A.D. Bradshaw, Richard Southwood, and Frederick Warner, eds., *The Treatment and Handling of Wastes* (London: Chapman and Hall, 1992); Braden Allenby and Deanna Richards, eds., *The Greening of Industrial Ecosystems* (Washington, D.C.: National Academy Press, 1994); Jessie Ausubel and Hedy Sladovich, eds., *Technology and the Environment* (Washington, D.C.: National Academy Press, 1989); Robert Ayres, "Industrial Metabolism," in Jessie Ausubel and Hedy Sladovich, eds., *Technology and the Environment* (Washington, D.C.: National Academy Press, 1989).
6. See, for example, James Womack, Daniel Jones, and Daniel Roos, *The Machine that Changed the World* (New York, NY: Rawson and Associates, 1990); Paul Osterman, "How Common Is Workplace Transformation and Who Adopts It?" *Industrial and Labor Relations Review*, 47/2 (January 1994); Martin Kenney and Richard Florida, *Beyond Mass Production: The Japanese System and Its Transfer to the United States*. (New York, NY: Oxford University Press, 1993).
7. James Maxwell, Sandra Rothenberg, and Brian Schenck, "Does Lean Mean Green: The Implications of Lean Production for Environmental Management," MIT, International Motor Vehicle Program, July 1993.

8. Stuart Hart and Gautum Ahuja, "Does it Pay to Be Green? An Empirical Examination of the Relationship between Pollution Prevention and Firm Performance," unpublished paper, University of Michigan, School of Business Administration, Corporate Environmental Management Program, 1994.
9. See, Womack, Roos, and Jones, op. cit.; Osterman, op. cit.
10. While there are reasons to expect that innovative approaches to manufacturing may spill-over into firms' environmental strategies, there may be factors which may make it difficult for manufacturing plants to link their environmental and overall production strategies. In most manufacturing plants, the responsibility for environmental compliance is a specialized function outside the purview of production and operations management. Furthermore, there tends to be a natural division between environmental management and production and operations management. For example, production and operations management is typically responsible for optimizing the production process, while environmental management focuses on ensuring that the environmental byproducts of this process comply with government standards. Simply put, the responsibilities of environmental management tend to pick up where those of production management end.
11. Womack, Jones, and Roos, op. cit.
12. Osterman, op. cit.
13. Richard Florida, *The Japanese Transplants Project: Final Report to the Sloan Foundation* (Pittsburgh, PA: Carnegie Mellon University, Center for Economic Development, 1995); Paul Davis Jenkins, *The Japanese Transplants and the Work System Revolution in U.S. Manufacturing*, Carnegie Mellon University, Ph.D Dissertation, 1995; Paul Davis Jenkins and Richard Florida, "Modelling Structures for Learning Within and Between Corporations," Heinz School Working Paper, Carnegie Mellon University, Pittsburgh, PA, October 1995; Florida and Jenkins, "Adoption of Organizational Innovations by Japanese Transplants," Heinz School Working Paper, Carnegie Mellon University, Pittsburgh, PA, August 1996.
14. John Paul MacDuffie, "Human Resource Bundles and Manufacturing Performance: Flexible Production Systems in the World Auto Industry," Wharton School, University of Pennsylvania, Revised March 1994; Casey Ichniowski, Kathryn Shaw, and Giovanna Prennushi, *The Effects of Human Resource Management Practices on Productivity*, Columbia University, Carnegie Mellon University, and the World Bank, Draft Manuscript, July 1993.
15. Maxwell, Rothenberg and Schenck, op. cit.
16. Wallace, op. cit.
17. Joseph Schumpeter, "The Creative Response in Economic History," *Journal of Economic History*, 7 (1947): 149-159.
18. Richard Florida and Martin Kenney, "Transplanted Organizations: The Transfer of Japanese Industrial Organization to the United States," *American Sociological Review*, 56/3 (June 1991): 381-398.
19. President's Commission on Environmental Quality, *Total Quality Management: A Framework for Pollution Prevention* (Washington, D.C.: President's Commission on Environmental Quality, Quality Environmental Management Subcommittee, January 1993).
20. See, Osterman, op. cit.; Florida and Jenkins, op. cit.
21. The firm reported that as a result of these measures it reduced hazardous waste by 27 percent and non-hazardous liquid waste by 47 percent over two years in its Wisconsin plants, with estimated cost savings in excess of $600,000.
22. Paul Roberston and Richard Langlois, "Innovation Networks and Vertical Integration," *Research Policy*, 24 (1995): 543-562.
23. See, Florida and Jenkins, op. cit.

24. The company noted that: "In addition to those programs which we have initiated, we have been invited by suppliers of our plastic raw materials, color concentrates, printing inks, extrusion equipment, printing plate processing equipment, printing presses, and specialty film additives to work jointly with them in the development of new technologies and products which enhance product quality and generate environmental benefits at the same time."
25. Ray-o-Vac indicated that "poor environmental performance can disqualify a supplier, while strong environmental performance can qualify a vendor for bonus contracts."
26. See, Ichniowski et al., op. cit.; MacDuffie, op. cit.; Jenkins and Florida , op. cit..
27. See, Jenkins, op. cit.; Jenkins and Florida, op. cit.
28. According to this analysis, transitional plants were found to be large, unionized plants which used heavy investments in training as a means of *transitioning* workers toward more advanced production systems. Taylorist plants were found to have a very traditional approach to work organization both inside and outside the plant. They did not use work teams, have large numbers of job classifications, and so forth.
29. See, Florida, op. cit.; Jenkins, op. cit.; Jenkins and Florida, op. cit.; Florida and Jenkins, op. cit..
30. The results of the Japanese transplants survey were compared on an industry basis to those of a survey of U.S. manufacturing plants conducted by Paul Osterman, who made his database available to us.
31. The survey question specifically asked: "Have environmental considerations had a significant impact on the design of the products produced by the plant?"
32. Since the purpose of the phone interviews and field research was to explore the relationships between zero defects, zero inventory, and zero emission strategies, this aspect of the research effort focussed on manufacturing plants that were either recognized as manufacturing or environmental leaders. While this strategy was efficient in developing useful and important information, it is the source of some selection bias which needs to be taken into account when interpreting the findings outlined below.