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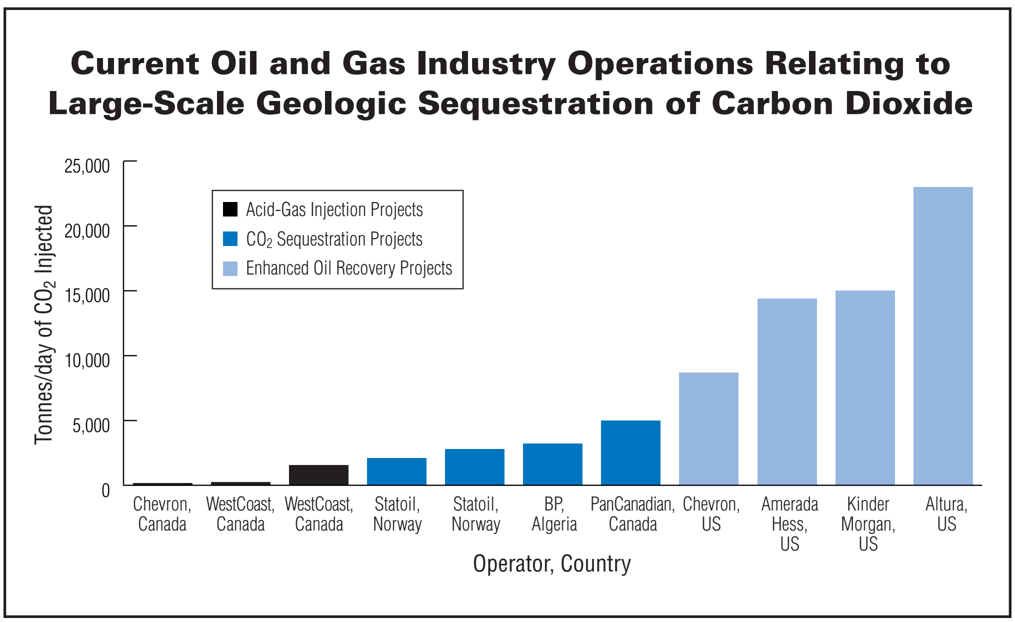
RESEARCH REPORTS

MIT LABORATORY FOR ENERGY AND THE ENVIRONMENT JULY–SEPTEMBER 2002

Carbon Sequestration: Public and Regulatory Responses

One way to reduce greenhouse gas emissions is to capture the carbon dioxide (CO_2) in emissions and store it in geologic formations or the deep ocean for the long term. MIT researchers have been investigating the economic and technical promise of that approach for more than ten years. But last year they were taken by surprise when local opposition forced a halt to a field experiment in which they planned to inject a small amount of CO_2 into the ocean near Hawaii. The experience showed them the importance of early public outreach and demonstrated a serious problem with most climate change efforts: while benefits are reaped globally and well into the future, costs are borne locally and immediately. The researchers have since begun to look at related activities for insights into potential public and regulatory responses to carbon sequestration. In the oil and gas industry, transporting, injecting, and storing CO_2 is commonplace as companies try to enhance production and get rid of wastes. Carbon sequestration would involve dramatically larger quantities of gas stored over longer periods of time, but today's industrial operating practices and management strategies would be directly relevant. Studies of siting and regulation of other storage activities, from landfill to nuclear wastes, suggest that carbon sequestration facilities will be difficult but not impossible to site. Regulations imposing subsidies or taxes on carbon sequestration could make or break the economic viability of the process. Also important to its success is convincing skeptics in the environmental community that developing carbon sequestration is not simply a diversion of resources away from pursuing non-carbon energy options. Indeed, carbon sequestration could play a critical role if the need to address climate change becomes urgent.

INSIDE:



The oil and gas industry has for decades carried out operations that involve injecting CO_2 into the ground. These bars show current projects representing three types of activities: acid-gas injection, CO_2 sequestration, and enhanced oil recovery. (For descriptions, see text on page 3.) If carbon sequestration were mobilized as a climate-change-mitigation technology, typical projects would involve injecting 10,000 to 50,000 tonnes of CO_2 per day. Current industrial projects, while smaller in scale, can provide important insights into effective operating procedures and management strategies for the larger-scale operations. (Figure: Jason J. Heinrich)

Why Carbon Sequestration?

In the struggle to reduce greenhouse gas concentrations in the atmosphere, one valuable tool to have in our arsenal would be carbon capture and sequestration. This strategy involves capturing CO_2 emissions from power plants, industrial facilities, and other sources and injecting it into geologic formations or the deep ocean for long-term storage. With this approach, the fossil-fuel-dependent world could dramatically reduce CO_2 emissions while continuing to develop and implement efficient and carbon-free energy sources. Carbon capture and sequestration is now receiving international attention and considerable support—both financial and strategic—within the United States, Norway, Canada, Japan, and many other nations.

While widespread interest in carbon sequestration is relatively recent, Howard J. Herzog and his colleagues at the Laboratory for Energy and the Environment have been working on various aspects of the process for more than a decade. They have tackled the technical challenges involved in capturing, transporting, and disposing of CO_2; they have studied potential costs of the process and ways to reduce them; and they have performed integrated assessments of the viability of sequestration under various assumptions about future technological development and economic growth (see *e-lab*, October–December 1992, January–March 1996, and July–September 1999). Their results have consistently demonstrated the promise of the approach.

But while the technical and economic outlook seems promising, other potential obstacles must be considered. To date, relatively little attention has been paid to social, political, and regulatory obstacles that might keep the capture and sequestration technology from entering the marketplace. Key questions need to be answered. Will the public accept carbon sequestration activities? What are the likely risks involved? What regulations are likely, and how will they affect the viability of sequestration? Since CO_2 sequestration is not yet a commercial industry, Mr. Herzog, David M. Reiner (a post-doctoral fellow trained in political science), and their colleagues have been studying related activities that provide some initial insights into the answers to such questions.

Ocean Sequestration: The Hawaii Field Experiment

One study focuses on a field experiment that never happened. In summer of 2001, Mr. Herzog, Dr. E. Eric Adams, and an international team from the United States, Japan, Norway, Canada, and Australia planned to inject a small amount of liquid CO_2 into the waters off the Kona coast of the island of Hawaii. Their goal was to gather field data on how the chemical environment of the deep ocean might be affected by the direct injection of CO_2. The project team chose the site because the waters are very still and deep and the area is a federally designated "research corridor" so permitting was thought to be straightforward. However, local opposition to the experiment developed; and there were many delays in obtaining permits to do the experiment. The researchers began looking for another test site.

Although the researchers never actually injected any CO_2 into the ocean off Hawaii, they sought to learn from the experience. Graduate student Mark A. de Figueiredo prepared an in-depth analysis of the events and their implications. One lesson came from looking at the groups that made up the opposition. Fishermen and some local residents simply wanted the experiments to occur elsewhere—the standard "not in my backyard," or "NIMBY," objection. Environmentalists and native Hawaiians wanted to protect the ocean from any human interference. And some people objected to carbon sequestration itself, proclaiming it a diversion of attention and resources away from the pursuit of energy efficiency and renewable energy. A few local leaders quickly mobilized those disparate groups into a powerful opposition force.

The researchers' plans had included a program of public outreach, but it was not yet funded when the project was reported in the local press. The international agreement to undertake the experiment had been signed with much fanfare in Kyoto, Japan, at the Third Conference of the Parties in 1997. Between the time the story broke and the project team held its first public meeting, opposition leaders had already "educated" the local community about carbon sequestration and the "outsiders" who would be coming in to perform the experiment.

Clearly, significant resources must be devoted to public outreach, even if funds must be diverted from the research itself. And efforts must start early. Indeed, people are beginning to demand that scientists make their plans public before their experiments begin—the opposite of the traditional scientific paradigm of conducting an experiment and then going public with results.

The researchers' experience also demonstrates a dilemma typical of climate change research: the costs tend to be borne locally and immediately, while the benefits are reaped globally and over a long period of time. In Hawaii, the opposition leaders even admitted that the risks posed by the field experiment were minimal. Nevertheless, the opposition prevailed in part because there were no perceived near-term benefits for the local community.

Geologic Sequestration: Good Practices, Potential Risks

Sequestering CO_2 deep in the ocean is just one storage concept. Another approach is to sequester it in geologic formations or reservoirs such as depleted oil and gas fields, aquifers, and "unmineable" coal beds. For insights into the geologic storage option, Jason J. Heinrich turned to the oil and gas industry. Through an extensive literature search and a series of personal interviews, he built up a picture of industrial practices that involve injecting and storing gases in geologic formations.

Such practices have been going on for decades. Since 1915, companies have been storing natural gas in partially depleted gas fields, where they can withdraw it as needed to meet short-term peaks in demand. Since the 1970s, companies have been injecting CO_2 into oil-producing formations to increase oil production (enhanced oil recovery). And in the late 1980s, in response to Canadian regulations, companies began disposing of captured CO_2, hydrogen sulfide, and other impurities by injecting them into non-producing formations (acid-gas injection).

These activities involve operating procedures and management strategies directly relevant to geologic CO_2 sequestration. However, sequestration would involve significant increases in both the volume of CO_2 being stored and the length of time it would be stored. The scale-up could, however, be gradual, following the models of enhanced oil recovery and acid-gas injection, both of which evolved from small-scale operations into larger commercial activities. A gradual scale-up would give operators and researchers time to deal with any special challenges posed by large-scale CO_2 sequestration.

One goal of Mr. Heinrich's study was to get insights into risks that might be associated with geologic CO_2 sequestration. Compared to many risks to public and occupational health, those associated with storage activities in the oil and gas industry are quite small. Based on his studies, he identified the following risks as potentially relevant to CO_2 sequestration operations.

Leakage within the geologic formation: CO_2 could migrate to other areas of the subsurface, with unknown consequences. It could spread for many miles and then re-accumulate in an unexpected, less-contained area.

Leakage from the formation to the surface: CO_2 could vent to the surface through various man-made pathways including the well bore itself. CO_2 is not combustible, but it is denser than air and can cause asphyxiation if allowed to accumulate and displace oxygen in confined living spaces. Slow leaks of CO_2 can also harm the roots of plants and trees.

Seismic events: Large volumes of injected fluid can increase reservoir pressure, displace other fluids, and induce seismic events. Conversely, seismic activity could damage CO_2 transportation and storage facilities.

Operational risks: CO_2 sequestration activities would be susceptible to the same types of operator error present in current operations in the oil and gas industry.

The potential for some type of catastrophic event appears very small, and many of the other risks can be reduced considerably by a moderately stringent regulatory system. Operational risks are generally well understood and can be controlled by methods now used in the oil and gas industry. The greatest uncertainty centers on the ability of geologic formations to adequately contain large volumes of CO_2 over extended time periods. The resulting risks can be managed to a certain extent by careful reservoir screening and isolation techniques such as those used in acid-gas injection operations. However, more research and experience are needed to understand the behavior of CO_2 within geologic formations.

How much risk will the public accept? It appears quite a lot, if the associated benefits are sufficient. In Seminole, Texas, for example, Amerada Hess Corporation maintains more than 70 oil wells within the city limits, many situated in people's front yards. One key to success is community involvement. A large fraction of the resident population works in the oil industry, and oil operations account for fully 85% of the local tax base. Another key is company communications and responsiveness. Amerada Hess provides detailed information to all residents, checks each oil well twice every day, responds immediately to incidents and concerns, and has a well-developed emergency response plan. This program can serve as a model for CO_2 sequestration, if and when commercial operations begin.

Potential Regulatory Regimes

Another factor that will influence the viability of geologic carbon sequestration is the set of regulatory and permitting requirements imposed. For insights, Dr. Reiner has been looking at what he calls "regulatory analogs"—storage activities that may differ technically or functionally from carbon sequestration but still offer lessons for the likely evolution of regulation. His analogs include waste disposal (solid waste, hazardous waste, acid-gas injection, high- and low-level nuclear waste), energy storage (storage of natural gas and liquefied natural gas, petroleum reserves), and energy production (enhanced oil recovery, enhanced production of methane from coal seams). Findings from Mr. Heinrich's study of the oil and gas industry are a major input.

If CO_2 sequestration is commercialized and practiced widely, a regulatory system will be needed to site and manage the reservoirs. Devising a regulatory system suited to long-term storage of even relatively benign materials is a challenge. Political deliberations are poorly suited to problems that persist for multiple decades because of the tendency to neglect the needs of future generations. The possibility of slow leaks, the difficulty of monitoring over long time periods, and the need to defend near-term costs of action against long-distant benefits are all familiar characteristics of long-term policy problems.

Regulation of carbon sequestration is currently a blank slate, but some observations can be made. For instance, siting CO_2 sequestration facilities will almost surely require a myriad of permits from various organizations. Mr. Heinrich observes that siting CO_2 sequestration projects will be difficult but not impossible, as is the case for solid-waste, hazardous waste, and low-level nuclear waste. Carbon sequestration has the advantage of the less-dangerous image of CO_2, but it has the disadvantage of some groups' opposition to sequestration as a technology for mitigating climate change.

Another observation from the analogs is that regulations for CO_2 sequestration will probably change over time. One driver for change is evolving attitudes toward regulation. For example, the past half-century has seen the rise and then virtual disappearance of price controls in the energy sector. New scientific evidence will also influence regulatory requirements. In the 1980s, experimental studies showed that hazardous wastes could escape from the state-of-the-art double plastic liners. New regulatory requirements for hazardous waste containers were quickly adopted.

Accidents or other unexpected events also provide a powerful impetus for regulatory change. In a recent event in Kansas, stored natural gas migrated underground and re-accumulated, ultimately erupting through old abandoned wells and exploding, killing two people and destroying buildings. When the problem turned out to be poor maintenance and weak regulation, Kansas rapidly adopted the stricter regulations in effect in Texas. Interestingly, calls came in from as far as Europe to find out the cause of the accident to determine if any changes were needed in existing regulation. One warning for carbon sequestration activities is that early failures are not easily overcome. In all the cases reviewed, significant problems in the early years of a technology's development affected public perceptions and produced regulatory regimes and political battles that took decades to reform or resolve.

A final observation is that the regulations adopted could significantly influence the economic viability of the carbon sequestration option. And the impact may not always be negative. For example, a new tax credit led to a dramatic increase in the production of coal-bed methane. Regulations will also help determine the relative attractiveness of alternatives to carbon sequestration, including those considered more environmentally benign such as renewable-resource-based technologies, fuel switching, and conservation. Any regulatory regime will have to decide whether to tax or subsidize both carbon storage and the alternatives, and the outcomes of those decisions could move carbon sequestration from a marginal competitor to a favored option. Of course, meeting a truly aggressive CO_2-reduction target will require bringing all of the strategies into play.

Further Insights from Regulatory Analogs

Research is now beginning to focus on other characteristics of regulatory analogs, on both the national and international levels. Gemma A. Heddle is examining the potential impacts on carbon sequestration of environmental justice claims by looking at experiences with waste disposal and energy storage facilities. Such claims are a response to a 1994 Presidential executive order that instructed federally funded organizations to consider whether specific facilities unfairly burden minority or low-income groups. Environmental justice claims could be an issue in the siting of carbon sequestration projects simply because those projects will likely be located near power plants or other CO_2 sources, which themselves tend to be near such community groups. Ms. Heddle has already found several cases in which environmental justice claims delayed the siting of landfills and industrial facilities for so long that the developers went elsewhere. She has also observed conflicts within the community between people who see a new facility as a source of risk and others who see it as a source of economic growth and jobs.

Mr. de Figueiredo is considering the legal framework for sequestration, with a particular focus on liability issues. As analogs, he is studying the legal treatment of natural gas, radon, low-level nuclear waste, and Superfund sites. Key questions include whether there will be a cap on liability, whether everyone in the chain of events will be liable, as they are at Superfund sites, and what legal arrangements other countries will adopt.

Finally, Dr. Reiner and his colleagues are seeking to tie these disparate elements into a single framework that will help them evaluate the usefulness of regulatory analogs for guiding the evolution of a regime for carbon sequestration.

Clearly, addressing all the technical challenges and the regulatory, legal, and public concerns about sequestration will require a considerable commitment of time and money. But if the need to reduce CO_2 emissions becomes urgent, carbon capture and sequestration will be a valuable tool to have available.

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Special Report: Public Environmental Regulation and Private Business Risk

Introduction

The Laboratory for Energy and the Environment (LFEE) and the Center for International Studies (CIS) have launched a joint project on public environmental regulation and private business risk. Designing economically and environmentally effective regulations requires consideration of how regulations affect the competitive position of firms as well as environmental and health outcomes. Identifying the long-term effects of regulation on the competitive position of firms may provide a foundation for upgrading national regulations and international environmental standards. The MIT research team is working with business, regulators, and non-governmental organizations (NGOs) to identify:

- **business strategies** that directly or indirectly use environmental and health regulations to contain private business risks and to shift terms of competition across firms and across sectors;
- **national environmental policies** that use knowledge of effects of regulation on the competitive position of firms to sharpen performance incentives, to improve environmental and health outcomes, and to broaden domestic environmental coalitions; and
- **regional and international standards** that use knowledge of the effects of regulation on the competitive position of multinational and national firms to sharpen corporate environmental performance incentives, to improve environmental and health outcomes, and to broaden transnational environmental coalitions.

This approach to evaluating firm strategies and regulatory policies departs from two classic schools of thought on the relationship between private interests and public regulation. One traditional perspective assumes that business and government are locked in conflict, as public environmental policy imposes substantial costs on private business. Within this school, those on the right seek to limit regulatory power to diminish costs imposed on business, while those on the left seek to limit business power and strengthen environmental regulation. Both of these views are premised on the assumption that public and private interests in regulation are inherently opposed, an assumption challenged directly in the LFEE-CIS study. A second school of thought sees private and public interests in regulation as fundamentally win-win, as improved environmental performance and business success go hand in hand. This school sees government and businesses as sharing interests that are fundamentally complementary. By contrast, the LFEE-CIS project examines the redistributive effects of regulation, identifying private sector losers as well as winners.

Private Interests: Regulation, Risk, and Competitive Advantage

From the perspective of private firms, the promotion of stringent environmental regulation, taken in conjunction with technology development programs, can be an effective instrument of competitive corporate strategy. During periods of fundamental change like the present, conceptions of business interests are subject to reappraisal. The conjunction of an information revolution, large-scale internationalization of production and distribution, and rapid technological change may encourage reassessment of business interest in regulations—in particular, regulations that may restrain a firm's behavior but at the same time restrain competitor behavior in a way that makes the market competition more predictable. Changes in industry structure reflect concentration, growth in the number of multinational firms, market segmentation and product specialization of industry segments, and the "speciation" of varieties of forms of global supply-chain networks. Thus, specialization within product-markets is a dominant theme, with increasing market segmentation and fragmentation of product sectors into many niche markets. The promotion of regulation—especially harmonized regulation—may become a more prominent aspect of corporate competitive strategies.

Contrary to nostrums of the business magazines, this project suggests that the importance of regulation to business is rising rather dramatically. The gist of the argument, stripped of caveats and qualifications, rests on erosion

This article was prepared by James L. Foster and Kenneth A. Oye. Dr. Foster is a research associate of the Center for International Studies. Professor Oye is an associate professor of political science and director of the Political Economy and Technology Program of the Center for International Studies.

of traditional sources of competitive advantage. Information technologies are driving down information costs and improving the ability of consumers to compare prices; globalization is expanding the geographic scope of competition; and technological change is blurring the definition of industry boundaries. There is now less profit to be derived from market segmentation through ignorance and local biases, even as new forms of competition cut across traditional sectoral divides.

Under these conditions, imperfect competition is an increasingly significant source of enduring competitive advantage and profitability. Imperfect competition follows from network externalities, economies of scale, learning effects, and other more or less natural scale effects that provide a basis for market power. Imperfect competition can also be a product of regulation. Regulation may be of rising significance in creating markets for products, in differentiating or segmenting markets for products, and in limiting competition.

The LFEE-CIS project is now focusing on the relationship between these two elements of imperfect competition. The research group emphasizes how regulatory effects may reinforce or weaken other forces affecting market structures. The group is now examining ways that regulation may shift or contain business risk, with attention to ways that the regulation of health, safety, and environmental risks affects price, competition, and conditions of entry. The group is also examining how innovative firms may devise strategies to develop and exploit regulatory advantage. These issues are likely to be of increasing centrality to business as other sources of competitive advantage and profit erode.

Public Interests: Mobilizing Support for More Effective Environmental Regulation

From the perspective of regulators, private firms are most likely to join coalitions promoting more effective public environmental policies when there are long-term benefits for industry. Turning business interests to advantage in the pursuit of more effective environmental protection requires better understanding of the nature and determinants of competing business interests and how they can be altered by persuasion, by financial and other incentives, and by regulation. The information revolution, globalization, and rapid technological advance and resulting fragmentation of industry interests have important implications for regulators. The interests of firms within sectors appear to be diverging, with sectoral associations finding it increasingly difficult to identify common industry positions. And across sectors, identifiable common interests of business may become even more limited. Current regulatory theory emphasizes relatively simple "rent-seeking" behavior, with emphasis on rents secured through "capture" of regulatory agencies. By contrast, the LFEE-CIS project suggests that capture of regulatory agents by an industry has little meaning. Instead, what is emerging is a political marketplace marked by intense "regulatory competition." Here, firms seek competitive advantage—as opposed to guaranteed rents—through strategies directed at the regulatory process and at unilateral efforts to improve environmental, health, and safety performance to meet changes in standards more efficiently than do competitors.

The LFEE-CIS effort to develop new regulatory approaches assesses likely corporate responses to particular policy instruments or incentives, the relative effectiveness of alternative instruments, and industry structure features or corporate attributes affecting the willingness and capacity to promote improved environmental performance. Crucial gaps in knowledge include the lack of systematic analysis of how business interests vary across firms within sectors and across sectors and of how business perceptions of their interests affect their responses to incentives for improved environmental performance. If industry will promote improved environmental performance only where there are benefits for industry, then the following questions loom large: What are the long-term benefits for firms from more stringent and harmonized environmental regulation? Does industry recognize these long-term benefits? What is necessary for particular firms to capture these benefits?

Examples of Strategies of Regulatory Competition

In preliminary work, the LFEE-CIS team has identified three pathways through which environmental, health, and safety regulations have conferred competitive benefits on businesses. The table to the right summarizes these pathways and several simple examples of each. With limited exceptions, these regulations that shifted risks and conferred competitive advantage on individual firms also produced substantial environmental and health benefits.

Regulations can create demand for product and/or increase the value of proprietary technologies: Consider the example of the Montreal Protocol on protection of stratospheric ozone, a case where corporate environmental stewardship and good business practice went hand in hand. The Protocol phased out chlorofluorocarbons (CFCs) and thereby increased demand for substitutes. DuPont and ICI were major producers of CFCs as well as holders of patents on substitutes for CFCs. The market for CFCs was increasingly commodity-like, with increasing numbers of entrants and the prospect of falling prices and declining margins. The Protocol protected stratospheric ozone by barring CFCs, which created a market for CFC substitutes and increased the value of patents on substitutes. To limit rents to the patent holders, the Protocol required some sharing of intellectual property rights on substitutes.

Regulations can create or exploit production cost differentials: Consider the example of regulations that now mandate use of Hazardous Analysis and Critical Control Points (HACCP) approaches to food safety. Mandatory use of HACCP was initially opposed by industry associations of food processors. Over time, differences in the interests of food-processing firms emerged. The cost burden of implementing HACCP is more easily borne by large, technologically advanced food producers than by smaller, less-sophisticated competitors. Furthermore, the value of an image of food safety is greater for large firms with substantial sales than for small firms with smaller sales bases.

Regulations can control sources of inputs: Consider two examples of regulations that control critical inputs. The United Nations "Conflict Diamonds" initiative requires documentation of the sources of diamonds. The goal is to bar the sale of diamonds from conflict-ridden areas to cut off one important source of funding for insurgences in developing countries. As a side effect, the ban also eliminates one major source of black-market diamonds that threatens the position of established diamond marketers such as Russia and deBeers LV. The second example involves Rock-Tenn Company, which makes

EFFECTS OF ENVIRONMENTAL, HEALTH, AND SAFETY REGULATIONS ON THE COMPETITIVE POSITIONS OF BUSINESSES

Pathways for Effects	**Regulations:** Parties Affected by Regulations (winners > losers)
Creating demand for product and/or increasing value of proprietary technologies	**Oxygenate standard:** MTBE and ethanol producers **State Implementation Plans under Clean Air Act:** producers of boutique fuels and producers of low-emission and zero-emission vehicles **Phossy Jaw regulations:** Diamond Match > small match makers **Montreal Protocol:** DuPont and ICI > generic entrants **EU light-duty-vehicle diesel subsidies and nitrogen oxides and particulate emissions regulations:** EU car makers > US and Japanese car makers **Reformulated gasoline flexible standards:** UNOCAL > other refiners
Creating production cost differentials	**Organic certification standards:** small farmers > large farmers **Hazardous Analysis and Critical Control Points plans:** large, advanced > small, primitive food producers **Lax fuel standards and tight auto emissions standards:** small, dirty refiners > auto makers and large, clean refiners
Controlling sources of inputs	**Conflict Diamonds ban:** deBeers and Russia > new entrants **Recycling regulations and refuse-handling and cogeneration contracts:** Rock-Tenn > potential recycled paper entrants

packaging products from recycled materials. The company has been working with various US municipalities to support passage of strict recycling and refuse-handling regulations. The company thereby ensures the availability of the raw materials it needs. When possible, it also writes long-term contracts with the municipalities to take care of all of their wastes. Rock-Tenn uses part of the waste stream as raw material for its packaging process; it burns part in clean, efficient cogeneration facilities to produce heat and electricity; and it responsibly disposes of the part that remains. Municipalities thus see Rock-Tenn as a low-cost, reliable solution to their waste as well as their power-generation problems. Competitors need not apply.

More complex approaches may link regulatory, research and development (R&D), and acquisitions strategies. Some companies have sought to shape regulations to improve environmental, health, or safety outcomes, to conduct research to satisfy stringent regulations sooner or cheaper than competitors, and to use acquisitions policies in support of these goals. For example, BP developed a complex multiphase strategy spanning technology development, acquisitions, and regulation. BP conducted R&D on the production and distribution of clean fuels and publicly announced its intention to produce and market clean fuels in advance of regulatory requirements. It also bought up smaller, dirtier European oil companies, less to acquire refining capacity and crude oil contracts than to limit one source of possible opposition to regulations mandating clean fuels. BP then created a capacity for advanced refining and a separate distribution system for clean fuels, securing a reputation for environmental stewardship and demonstrating the feasibility of meeting stringent fuel standards. Now BP is pushing for standards that require even cleaner fuels—changes in standards that would increase the value of their investments in R&D, in advanced refining, and in the clean-fuel distribution system.

The LFEE-CIS research team notes that regulators, businesses, and other organizations concerned about the environment may form effective mixed coalitions. Policy makers and NGOs often consider how proposed policies will affect business interests and then collaborate with companies that may benefit. Working together, such groups can share information on goals, risks, and technological capabilities and possibilities. They can then design regulations that best serve these goals and join in advocating these regulations. A successful coalition may have a diverse list of members. For example, regulations prohibiting the production of matches with phosphorus to eliminate the occupational disease called Phossy Jaw were supported by unions, academics, health officials, and the Diamond Match Company. The Montreal Protocol to protect stratospheric ozone was supported by environmental NGOs, atmospheric scientists, DuPont, and ICI.

Opportunities for action by such coalitions exist now. For example, lax fuel standards are currently defended by Senators from the Rocky Mountain states where small, relatively dirty refiners are located. Accelerated phase-in of clean fuel requirements would produce environmental benefits by reducing emissions of nitrogen oxides, sulfur dioxide, and particulates; would benefit large refiners that are better positioned economically and technologically to produce cleaner fuels; and would allow engine and after-treatment systems to function more effectively, albeit at the expense of small refiners.

Future Research

Discussion of ways to improve regulatory strategies must rest on the systematic analysis of incentives that drive corporate environmental behavior across different sectors and in different types of firms within sectors. To establish such an empirical foundation, the LFEE-CIS team will kick off the project with a workshop at the Alliance for Global Sustainability (AGS) meetings in November 2002. The workshop will begin with a preliminary assessment of environmental performance by firms within highly regulated industries and follow with examination of the degree to which firms within those sectors respond to alternative performance-incentive schemes. Presentations on contemporary examples from selected sectors compiled from past AGS work and from a study in progress with the Finnish Environment Ministry will be combined with historical cases of regulatory effects on competition.

Subsequently, these issues will be addressed by research that is global in scale and based on cross-national and cross-industry analysis of firms in six sectors: motor vehicles, petroleum refining, chemicals, food processing and distribution, paper products, and biotechnology. The research project will focus on these six sectors plus insurance, with attention to how regulation of environmental, health, and safety risks affects firms within these sectors as well as insurers and reinsurers. The sectors differ along a number of dimensions that affect their sensitivity to regulatory incentives and environmental performance. These dimensions include degree of industry concentration, dependence on international trade, degree of market segmentation for specialty products, rates of technological advance, and operational regulatory standards.

The November workshop and subsequent research will focus on the following questions.

• Are there systematic differences in environmental performance across industries or across different types of firms within an industry? Why do some firms significantly outperform others, or at least appear to do so? What changes in regulation and enforcement methods would be desirable both for business interests and for regulators?

• Are firms that employ best performance practices systematically responding to similar incentives—incentives that can be reproduced in other corporate settings? For different types of firms, what are the motivations for employing best practices; and how might regulatory instruments be designed to promote best practice performance?

• How does regulation affect the competitive positions of particular firms? What types of firms in what types of product markets (e.g., commodity markets versus niche markets) benefit either from regulatory restrictions on or approval of new technologies? To what extent do some firms use environmental performance as a marketing tool?

• Do firms promote more stringent regulatory regimes that disadvantage competitors who lack the technology or financial capacity to compete effectively against higher performance standards? To what extent are these tendencies evident among national firms interacting with domestic regulators? Among multinational enterprises interacting with regional and international regulatory authority?

• To what extent have these tendencies affected the composition of national and transnational coalitions that support or oppose rigorous and comprehensive regulatory standards? To what extent have regulators shaped regulations to accentuate incentives for competitive environmental performance? How might regulations be reshaped to sharpen incentives and improve environmental performance?

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News Item

MIT Department of Facilities and Laboratory for Energy and the Environment Launch Photovoltaic Project

• *By Dr. Teresa Hill, LFEE*

On October 10, the MIT Department of Facilities (DOF) Utilities Group and the Laboratory for Energy and the Environment (LFEE) were awarded a grant for the MIT Community Solar Power Initiative from the Massachusetts Renewable Energy Trust. The initiative will involve MIT faculty, staff, and students as well as Cambridge and other Boston-area communities. It reflects Institute support for renewable energy research and uses MIT's own buildings and personnel to test the feasibility, effectiveness, and consumer acceptance of photovoltaic (PV) power generation. Each square meter of solar cells in the Boston area will produce 100–150 kilowatt-hours of electricity per year, equal to about a week's demand for a typical home.

The project will install PV panels on participating MIT laboratories, dormitories, and offices and on the homes of participating MIT faculty and staff. The project also proposes to place PV systems at public schools in Cambridge. Edward Kern, a research engineer in the LFEE, and Laxmi Rao, a senior project manager in MIT Utilities, will direct the project. Peter Cooper, director of Utilities, will provide the MIT expertise, personnel, and access to Institute facilities. Private sector partners in the initiative include Evergreen Solar, Massachusetts' fastest growing PV manufacturer, and Conservation Services Group (CSG), a national leader in developing markets for environmentally conscious electric power.

The grant awarded to MIT requires the solar-cell installations to be clustered in a geographic area that does not overlap that of other grant awardees. The Route 2 corridor from Cambridge to Lexington is the assigned area for MIT's grant, as a concentration of MIT's faculty and staff members live along this corridor. Members of the communities in this area share a generally high level of education, environmental stewardship, technological leadership, and receptivity to innovation. Project managers believe that enough MIT faculty and staff living in this area will be willing to pay extra for clean electricity and participate in a program testing a technology with significant promise for addressing the environmental challenges of the 21st century.

Through their participation, members of the MIT community will help to promote innovations in the technology, increase application of solar power, and support awareness of the benefits of solar power technology in their towns. In the future, their leadership will encourage neighboring towns to incorporate PV power into their energy strategies.

This initiative has several important educational objectives. First, through participation and exposure, MIT students will become aware of the potential of solar power. Second, towns will integrate this power source into their conventional systems and gain experience in the performance of the technology. Third, Cambridge high-school and middle-school teachers may design related projects for their students. PV panels placed on public school buildings will bring MIT's home community into the project.

Orientation and potential shading of the panels, the cost of support structures to hold them in place, the cost of wiring, and aesthetics are all factors in selecting locations for them. A team of two students in the MIT Undergraduate Research Opportunities Program (UROP) is developing a PV "Rover" unit to be used in the initial phase of the project to find the best places on campus to install PV panels. The Rover units will be equipped with sensors that will record conditions at trial locations and transmit the data over the MIT wireless network for display on the Web. The UROP project is a partnership among the LFEE, DOF, and the Edgerton Center.

MIT will finance part of the cost of installations on campus buildings. Installations on homes of MIT faculty and staff will be subsidized by this grant in the same proportion as the campus installations are. Evergreen Solar will provide complete system packages to MIT for all the program installations; the Institute will make them available to individual participants at significantly reduced cost. CSG will handle transactions for MIT among other project participants, including MIT faculty and staff. Participants wishing to sell the renewable energy credits generated by their systems, called "Green Tags," will also work through CSG.

The ultimate goal of the project is to reduce installed costs of PV systems by increasing the efficiency of the distribution infrastructure and by providing valuable feedback to designers and manufacturers. The electricity that MIT program participants will derive from their PV systems will be, per kilowatt-hour, more expensive than electricity derived from today's fossil-fueled power plants. However, this grant will allow homeowners to purchase PVs at much-reduced costs.

LFEE and the DOF are scheduling a seminar series during MIT's Independent Activities Period in January 2003 to promote and explain the program to potential participants. Installation of the PV systems will begin in spring of 2003. The MIT Community Solar Power Initiative links MIT research with the MIT community, Cambridge and surrounding cities and towns, the Massachusetts Renewable Energy Trust, and private-sector partners Evergreen Solar and CSG to improve environmental conditions and reduce dependency on fossil fuels through advanced technology.

For further information, please e-mail Dr. Kern at ekern@mit.edu or Ms. Rao at lrao@mit.edu.

Publications and References

The following publications covering Laboratory for Energy and the Environment (LFEE) and related research became available during the past period or are cited as references in this issue. Center for Advanced Nuclear Energy Systems (CANES) reports are available from Michael Messina, MIT Department of Nuclear Engineering, Room 24-212, Cambridge, MA 02139-4307 (tel.: 617-253-3808). MIT theses may be ordered from Libraries Document Services, MIT, Room 14-0551, Cambridge, MA 02139-4307. Other publications may be ordered from LFEE Publications, MIT, Room E40-473, Cambridge, MA 02139-4307, only if a price is assigned and only if prepaid by check payable to "MIT Laboratory for Energy and the Environment." Prices are postpaid surface mail. For air delivery, add 15% to US, Canada, and Mexico, and 30% elsewhere. A list of publications is available on request.

Publications marked by an asterisk (*) can be found or are forthcoming on-line via the following addresses:

Laboratory for Energy and the Environment:
http://lfee.mit.edu

Center for Energy and Environmental Policy Research:
http://web.mit.edu/ceepr/www/

Joint Program on the Science and Policy of Global Change:
http://web.mit.edu/globalchange/www/

Instructions for ordering paper copies of the reports and working papers are also available at the sites listed above or by telephoning 617-258-0307 for LFEE publications, 617-253-3551 for Center publications, and 617-253-7492 for Joint Program publications.

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NEW AND RENEWED PROJECTS, JULY–SEPTEMBER 2002

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GIFTS AND CONTRIBUTIONS		
Center for Energy and Environmental Policy Research membership	Shell Oil Co. Foundation	
Joint Program on the Science and Policy of Global Change membership	ExxonMobil Corp.; General Motors; Murphy Oil Corp.; RWE/Rheinbraun	
NEW PROJECTS		
Sustainable Chemical Processes in Environmentally Friendly Media	Cambridge-MIT Institute	J. Tester *(Laboratory for Energy and the Environment)*
Framing the Issues of Liability and Social Justice in the Context of Carbon Sequestration	Electric Power Research Institute	H. Herzog *(Laboratory for Energy and the Environment)*
Factors Affecting the Rate of Penetration of Large Scale Electricity Technologies: The Case of Carbon Sequestration	US Department of Energy	H. Herzog *(Laboratory for Energy and the Environment)*
Wind Force Measurements on Solar Panels	Schott Applied Power Corp.	D. Marks E. Kern *(Laboratory for Energy and the Environment)*
RENEWED PROJECTS		
Computational Investigation Into the Mechanisms that Control Oxygen Diffusion in Oxides	Ford Motor Co.	G. Ceder *(Materials Science and Engineering)*
Traffic Flows	Ford Motor Co.	I. Chabini *(Civil and Environmental Engineering)*
Promoting Innovation and Productivity in Electricity Markets	Cambridge-MIT Institute	A. Ellerman *(Sloan School of Management)* P. Joskow *(Economics)*

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