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MIT-IPC-Energy Innovation Working Paper 10-002
[also MIT-IPC-10-002]

April 2010

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617-253-7522
web.mit.edu/ipc/www

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Abstract

This paper relies on interviews and documentary evidence to describe federal RD&D policy for SO_2 and NOx emissions controls for coal-fired power plants from 1970 to 2000 and to assess its impact on technology development. The narrative begins by describing the RD&D program of the EPA in the 1970s, which many observers deem to have been successful, but which was largely dismantled after the election of Ronald Reagan to the presidency in 1980. We then turn to the contributions of the U.S. Department of Energy (DOE), which has been the main federal agency operating in this area since 1980, and particularly to DOE's Clean Coal Technology Demonstration Program (CCTDP), which began in 1985. The narrative as a whole suggests a mixed verdict on the effectiveness of past federal emissions control RD&D.

In the paper's conclusion, we mine this narrative history for insights that may be useful to current policy-makers. We argue first that regulatory pull is a necessary component for an effective greenhouse gas reduction policy, while technology push is not. However, a well-designed technology push may enhance the impact of regulation and lower the cost of compliance. Second, we should not expect that these two components will be well-aligned, due to the differences in the institutional frameworks for making the two types of policy. Third, RD&D policy should not be judged a failure if the technological options it supports are not widely commercialized or adopted. Instead, the standard should be whether RD&D led to options that might have been widely adopted if circumstances (regulatory, market, and technical) had been somewhat different. Determining what constitutes a plausible range of circumstances for application of this standard is a job that should be delegated to program managers, who must be able to exercise independent judgment, advised by technical experts who are drawn from diverse backgrounds.

Alignment and Misalignment of Technology Push and Regulatory Pull: Federal RD&D Support for SO_2 and NOx Emissions Control Technology for Coal-Fired Power Plants, 1970-2000[1]

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1. Introduction

Over the past forty years, the U.S. federal government has sought to control airborne emission of pollutants from coal-fired power plants that pose risks to human health and the environment. The scope of federal regulation in this domain has expanded from an early focus on the precursors of local smog to less visible toxic chemicals (like mercury) and regional pollutants (such as those responsible for acid rain). As the country considers whether and how to expand its air pollution control policy once again, in order to reduce carbon dioxide emissions that cause global climate change, its past experience may be plumbed for lessons. We focus in this paper on possible lessons about federal research, development, and demonstration (RD&D) policy that may be learned from past efforts to improve technology for reducing emissions of sulfur dioxide (SO_2) and nitrous oxides (NOx) from coal plants.

SO_2 and NOx contribute to smog at the local level as well as acid rain at the regional level. Not surprisingly, they were among the earliest air pollutants to be regulated by the federal government, with the imposition of standards for new coal plants starting in 1971. The most outstanding fact of the national experience since that date is that concentrations of both gases have declined significantly. The U.S. Environmental Protection Agency (EPA 2009b, 2009a) reports that SO_2 concentrations declined by 71% from 1980 to 2008, while NO_2 concentrations declined by 46% in that period.

A substantial fraction of these reductions is attributable to emissions controls at coal-fired power plants. Although substitution of other fuels for coal has occurred at the margin in recent decades, coal remains the dominant fuel for electric power generation in the U.S., with a market share of about 50%. In absolute terms, electricity production from coal plants grew by 26% between 1980 and 2007 (EIA 2008, Table 1.2), even as SO_2 and NOx pollution declined.

At the plant level, reductions in SO_2 and NOx emissions have been even more impressive. Coal plants constructed today typically emit 98% less SO_2 and 90% less NOx than those built forty years ago (Rubin et al. 2004, NESCAUM 2001). The retrofitting of older plants, although much delayed by legislative deals and legal wrangling, had by 2001 yielded

[1] We would like to thank the Doris Duke Charitable Foundation and the Industrial Performance Center for their support of this research. Margaret Taylor's pioneering work on this subject over the past decade deserves special recognition as well as ample acknowledgement in this paper's citations.

plant level reductions in the neighborhood of 40% on average for the two pollutants (DOE 2001b).

Federal regulation[2] has been the most important immediate cause of these declines. Table 1 summarizes the evolution of SO_2 and NOx emissions standards over time. The 1971 and 1979 New Source Performance Standards (NSPS) implementing the Clean Air Act of 1970 mandated that up to 90% of SO_2 be removed from emissions from new coal-fired power plants on a plant-by-plant basis. The 1990 Clean Air Act Amendments required a group of 265 existing units to reduce their combined SO_2 emissions to the level of 2.5 pounds per million BTU generated under a "cap and trade" policy. Phase II of this legislation extended the cap and trade policy to the entire coal fleet in 2000. (Taylor, Rubin, and Hounshell 2005 provide a detailed history of these standards.)

NOx emissions were reduced at new coal-fired power plants on a plant-by-plant basis by about 65% under the 1971 and 1979 NSPS. These standards were extended to older plants and tightened modestly for new plants under Phase I of the 1990 CAAA under a cap and trade system. In phase II of this act's implementation, EPA imposed a much tougher standard, requiring 80% or more reduction in NOx emissions on a state-by-state or regional basis for all plants in the eastern U.S. under the 1997 "SIP Call,"[3] and for all new units under the 1998 NSPS. (Taylor 2006 provides a more detailed history of these standards.)

Clearly, federal regulation of SO_2 and NOx from coal-fired power plants has "worked" from the perspective of protecting human health and the environment. Whether SO_2 and NOx emissions reductions were achieved in the most economical fashion has been the subject of much debate. The shift in regulatory design for SO_2 control from plant-by-plant mandates (so-called "command and control" regulation) to regional or national aggregate targets mediated by marketable emissions allowances ("cap and trade" regulation) reflects this debate. As the prospect of regulations to limit greenhouse gas emissions draws closer to realization, researchers are making an even more intensive effort to extract lessons about regulatory design from the recent history of U.S. air pollution policy (Burtraw and Palmer 2004; Ellerman, Joskow and Harrison 2003; Jaffe, Newell, and Stavins 2005; Stavins 1998).

Researchers have paid much less attention to the federal government's role in emissions control RD&D. In principle, public support for RD&D can accelerate the pace of emissions reduction by overcoming market failures in the generation of new ideas and inventions and in the translation of these ideas and inventions into commercial practice. Although regulatory policy is the dominant force driving emissions control technology forward, RD&D policy may play a valuable complementary role (Jaffe, Newell, and Popp 2009). Such considerations encouraged federal appropriators to invest hundreds of millions of dollars in RD&D programs related to SO_2 and NOx controls between 1970 and 2000.

[2] States are partners in U.S. air pollution regulation, and some states (notably, California) have imposed emissions standards that are more stringent than the federal government's. But the federal government is the dominant partner, and it seems highly unlikely that stringent state-level standards could be sustained in the absence of the national baseline provided by federal regulation.

[3] Section 110 of the 1990 CAAA authorizes EPA to impose restrictions on sources of NOx emissions, if it deems necessary, to help downwind states comply with nation-wide ozone standards. EPA invoked this authority in 1998 by asking 22 states and the District of Columbia to complement their State Implementation Plans with measures to establish state-level NOx emission caps during the summer. This rule became known as the SIP Call. The federal and state governments have devised regional trading schemes to facilitate compliance (Burtraw and Evans 2004).

Table 1: Federal SO_2 and NOx emissions limits from 1971 to 1998

Source and subjects of application	SO_2	NOx
1971 NSPS Units built after August 17, 1971	1.2 lbs/MMBtu (0%-85% removal rate)	0.7 lbs/MMBtu
1979 NSPS Units built after September 18, 1978	1.2 lbs/MMBtu (90% removal rate) 0.6 lbs/MMBtu (70% removal rate)	0.5-0.6 lbs/MMBtu (65% removal rate)
1990 CAAA, Title IV Phase I: 265 old coal-fired units Effective as of 1996	2.5 lbs/MMBtu	0.45 lbs/MMBtu (T-fired units) 0.50 lbs/MMBtu (dry bottom wall-fired units)
Phase II: 2,500 existing coal-fired units Effective as of 2000	1.2 lbs/MMBtu	0.40 – 0.86 lbs/MMBtu (depending on boiler type)
1997 EPA SIP Call Units in 19 states and the District of Columbia		0.15 lbs/MMBtu (85% removal rate)
1998 NSPS Units built after July 9, 1997		0.15 lbs/MMBtu (modified sources) 1.6 lbs/MWh (new sources)

Sources: Burtraw and Evans (2004), p. 135 and p. 141; DOE (2005), p. 6; 40 Code of Federal Regulations, Title 40, Part 60.

There is no guarantee, however, that public RD&D spending will achieve its goals. It may be wasted on projects that would have been carried out by the private sector in any case, captured and diverted to private ends by narrow interests, or spent carelessly on the pipe dreams of technological enthusiasts (Cohen and Noll 1991, Greenberg 1967). In the case at hand, shifts in regulatory policy design from "command and control" to "cap and trade" also created challenges for RD&D policy-makers. In the next section of the paper, we review key issues in the design and implementation of RD&D policy.

Our historical narrative follows this review. It relies on interviews with participants with decades of experience in SO_2 and NOx emissions control RD&D and related policy-making as well as on documentary evidence. The narrative begins by describing the RD&D program of the EPA in the 1970s, which many observers deem to have been successful, but which was largely dismantled after the election of Ronald Reagan to the presidency in 1980. We then turn to the contributions of the U.S. Department of Energy (DOE), which has been the main federal agency operating in this area since 1980, and particularly to DOE's Clean Coal Technology Demonstration Program (CCTDP), which began in 1985. The narrative as a whole suggests a mixed verdict on the effectiveness of past federal emissions control RD&D.

In the paper's conclusion, we mine this narrative history for insights that may be useful to current policy-makers. Federal RD&D expenditures to support the development of carbon dioxide emissions control technology have begun to be made and will likely grow quite substantially in the near future. Indeed, the high probability that this spending will exceed by an order of magnitude or more that of previous emissions control RD&D programs makes it all the more imperative that we distill whatever guidance may be available from the historical experience.

2. Market and Government Failures and the Design and Implementation of Public RD&D Programs for Emissions Control Technology

The development of emissions control technology is subject to what Margaret Taylor (2008) calls a "dual" market failure. The environmental costs of harmful emissions are not included in the market prices of goods that create emissions. This "environmental" market failure provides the rationale for environmental regulation to reduce emissions. One way to reduce emissions is to develop new technology. But investments in technological innovation, and the scientific research that may underpin such innovation, typically fall victim to "innovation" market failures. Innovation market failures may lead firms to reduce emissions by switching fuels or shutting down plants, rather than by improving their technology.

In the case of coal-fired power plants, we must add a third form of market failure to our analysis. Exceptionally high barriers to entry, such as the capital costs of building transmission and distribution systems, are assumed to preclude competition, creating an "economic" market failure in electric power. Electric utilities in the U.S. have historically been subject to price and entry regulation with the aim of remediating this failure. This rationale has been challenged in recent decades, but neither the rationale nor the regulatory edifice built upon it has been entirely dismantled (Hogan 2009).

The "triple" market failure framework – environmental, innovation, and economic market failure – leads to several insights into the design and implementation of RD&D policy that help us to interpret the history of SO_2 and NOx control technology. The first is that neither environmental nor economic regulation (that is, emissions limits and price controls), even if they effectively address environmental and economic market failures, will necessarily solve innovation market failures. Markets provide weak incentives to invest in any ideas, such as many of those underlying new technologies, that are difficult to protect from imitation (Nelson 1959, Arrow 1962). Regulated firms, like unregulated firms, would usually rather free ride on others' production of these public goods than be the first mover, which may leave no first mover at all unless government steps in.

The second set of insights concerns the role of technological knowledge in the establishment of environmental regulations. Environmental policy-makers, tacitly or explicitly, weigh the expected costs of compliance – including the cost of emissions control technology – against the expected benefits of regulation. Both costs and benefits are subject to uncertainty, which might be reduced through RD&D. However, the utilities that might be subject to environmental regulation are unlikely to invest in uncertainty-reducing RD&D, because it might

market failure alone is insufficient. Post-combustion NOx controls, for instance, were not applied in the U.S. for a couple of decades after their development, because regulation didn't demand them. Post-combustion SO_2 controls were installed and improved because they were required by regulators. In making this argument, we are reiterating a point well-established in the literature (e.g. Jaffe, Newell, and Popp 2009, Taylor 2006)

Our second insight goes one step further. Stringent regulation does not necessarily mean that demand for federally-funded emissions control technologies will materialize. There may be other means to comply with the regulation or other sources for compliance technology. The most obvious evidence for this point in our narrative is the response to 1990 CAAA. The new regulatory scheme allowed plants to comply by switching fuel or purchasing emissions allowances instead of installing emissions controls.

Other episodes reinforce the point. Old technologies may "fight back," improving enough to enable compliance. Wet scrubbing, for instance, was never displaced as the dominant SO_2 control technology, despite federal RD&D investments in alternative technologies and a regulatory regime that tightened considerably. Improvements in operations and maintenance and incremental innovations based on user feedback led to lower costs and higher removal efficiency. Our narrative also reveals that vendors that are not affiliated with public technology programs may respond to the pull of tighter regulation. Foreign vendors that faced stringent regulation earlier in their home countries were especially important in developing NOx emissions controls. Some domestic vendors as well preferred to keep their distance from public RD&D in order to protect proprietary positions (Hilton interview).

Of course, the purpose of regulation should not be to promote technologies simply because they were federally-funded. That would amount to a costly conflict of interest, a concern that may have contributed to the phasing out of EPA's emissions control RD&D program under the Reagan Administration. Our point is rather that the outputs of federal RD&D comprise only a portion of the portfolio of the available responses to regulation and should be both designed and evaluated in light of the rest of the portfolio.

Our third and final insight builds on the fact that the institutions and interests that produce regulatory policy are different from those that produce emissions control RD&D policy. Sustaining alignment between demand for and supply of emissions control technology is therefore intrinsically difficult. The actual impact of regulation, for instance, often depends on the results of litigation and enforcement, whereas RD&D is more directly the province of the federal appropriations process. The incoming Reagan Administration was thus able to express its hostility toward federal activism in air pollution control more quickly and effectively in the RD&D domain than in the regulatory domain. It was also able to reverse ground more quickly in RD&D during Reagan's second term after it reached a diplomatic understanding with Canada on acid rain.

While RD&D policy can generally be altered more quickly and easily than regulatory policy, it takes longer to yield valuable results. Regulation can produce immediate changes in power plant operations or even shut plants down. Effective RD&D requires the building of technical communities and organizational partnerships as well as the simple passage of time to permit experiments to be run, models to be tested, and demonstrations to yield operational data. In some instances, such as the IGCC and FBC power plant designs supported by CCTDP in the late 1980s, the multi-decade time frame for technology development was far longer than the time horizon of legislators, who acted decisively in 1990 and laid out a firm schedule for the following decade.

Turning from the past to the future, we would put forward several guideposts for carbon dioxide emissions control policy. First and foremost, regulatory pull is a necessary component for an effective greenhouse gas reduction policy, while technology push is not. However, a well-designed technology push may enhance the impact of regulation and lower the cost of compliance.

Second, we should not expect that these two components will be well-aligned. Public RD&D funding should be steady, rather than designed to produce specific results to support a specific regulatory process at a specific time. Regulatory change is episodic and unpredictable, because of the complexity of interests and institutions involved. This complexity is heightened in the case of climate change by the global scope of the problem.

Third, RD&D policy should aim to provide new and otherwise unavailable options in the portfolio of compliance alternatives. But the policy should not be judged a failure if the publicly-funded alternatives are not widely commercialized or adopted. Instead, the standard should be whether RD&D led to options that might have been widely adopted if circumstances (regulatory, market, and technical) had been somewhat different. Determining what constitutes a plausible range of circumstances for application of this standard is a job that should be delegated to program managers, who must be able to exercise independent judgment in this regard.

Finally, in exercising this judgment, program managers should be able to draw on a technical community that balances the interests of vendor and utility experts with the views of government scientists, academics, and consultants who have a less direct stake in the outcome. Cooperation and close communication with industry is essential for findings to move from laboratory, pilot, and demonstration to practice. But industry's views may skew toward excessive conservatism or toward excessive optimism. Program managers must tread a fine line to keep projects in the appropriate zone of risk as best they can.

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