

Engineering Clean Air: The EPA Control Systems Laboratory and the Rise of Scrubbers Technology*

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Introduction

Among various pollution issues during the 1970s, the U.S. Environmental Protection Agency (EPA) devoted much time and many resources to sulfur oxides. It was the topic of the first Community Health and Environmental Surveillance System (CHESS) monograph *Health Consequences of Sulfur Oxides*. CHESS researchers at Research Triangle Park (RTP), North Carolina, received pressure from Washington officials who asked for more data about the link between sulfur oxides and respiratory disease. EPA researchers and regulators engaged in an in-house debate on the possible health effects of sulfuric acid from catalytic converters. Eric Stork and his team at the Ann Arbor laboratory argued for the rapid introduction of the device and further research on sulfuric acid. John Moran and his team at RTP laboratory, on the other hand, called for a more precautionary approach. Although the CHESS monograph received nation-wide criticism and catalytic converters were introduced in 1975 model vehicles, concerns about sulfur oxides did not disappear. As the public learned more about the potential health and environmental effects of sulfur oxides from smokestacks and sulfuric acid reaching a long distance from the source, the EPA found a strategic mandate to enforce emission standards and advance pollution control technologies.¹

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* It would have taken much longer if I had not met EPA researchers, archivists, and librarians early in the process. I would like to express my sincere gratitude to the three anonymous reviewers and editorial team who helped me revise this paper. With all this help and support, my research which began as part of my dissertation project finally met a broader audience.

¹ EPA, *Health Consequences of Sulfur Oxides: Summary and Conclusions Based upon CHESS Studies of 1970–1971*. EPA-650/1-74-004 (Research Triangle Park, NC, EPA, Office of Research and Monitoring, National Environmental Research Center, Research Triangle Park, May 1974); John B. Moran, *Assuring Public Health Protection as a Result of the Mobile Source Emissions Control Program*, 1974 Automotive Engineering Congress and Exposition (SAE International, 1974); Eric Stork, “The United States Experience with Imposing Automobile Emission Standards,”

From October 18th to November 2nd of 1973, the EPA held a series of public hearings in Washington, DC. The goal of the hearings was to review the status of power plant compliance with sulfur oxide emission regulations. Testimony was provided by a diverse coalition of stakeholders, including representatives from power plants, trade associations, state regulatory agencies, pollution control technology vendors of scrubbers, and environmental advocacy groups. This scrutiny was critical given that power plants constituted the largest source of sulfur oxide emissions, which were escalating in tandem with the growing national demand for electricity. Under the state implementation plans mandated by the Clean Air Act Amendments (CAAA) of 1970, the power plant industry had only a year and a half left to meet the emission deadline. Flue gas desulfurizers—devices to absorb sulfur dioxide (SO₂) from smokestack gases, or “scrubbers” as many started to call them—were regarded as the most viable technical solution for emissions regulation compliance. However, most power plants claimed that scrubbers were technologically unreliable, expensive, and produced too much waste. They instead preferred more cost-effective options, such as low-sulfur coal, stack height increases, and intermittent control systems.²

Frank Princiotta of the EPA’s Control Systems Laboratory served as the main expert witness regarding scrubber technology. As a chemical engineer in charge of the throw-away scrubbers section at Research Triangle Park (RTP), North Carolina, Princiotta was the primary point of contact for both vendors and operators of scrubbers. He was well aware of the up-to-date materials and process problems in currently operating scrubbers. In addition, he had been involved in operating and testing three prototype 10 megawatt scrubbers at the Shawnee site, alongside of a 0.1 megawatt pilot scrubber in his laboratory for quick test runs. Princiotta showed that major reliability problems—chemical scaling, plugging, erosion/corrosion, and mechanical problems—had already been resolved or can be resolved soon. Princiotta and other EPA witnesses acknowledged that the scrubber-generated sludge raised potential water and land pollution issues. They committed to advancing the development of regenerable scrubbers capable of yielding reusable sulfur compounds. At the same time, Princiotta highlighted that two private companies had already developed sludge fixation and disposal technologies designed to decrease the environmental effects of sludge. Addressing financial concerns, the EPA representatives argued that the power plant industry’s investment in research and development was disproportionately limited in scope, constituting less than 1 percent of their revenues. Princiotta and others contrasted the inaction and indifference of

Paper delivered for the Australian Society of Automotive Engineers, Perth, Australia, September 22, 1976. Copy provided to the author by Stork.

² EPA, *Report of the Panel: National Public Hearings on Power Plant Compliance with Sulfur Oxide Air Pollution Regulations* (Washington, DC: EPA, 1974).

big American power plants with the advanced implementation and successful design of scrubber technologies in Japan.³

This short introduction to the 1973 scrubber public hearings provides an explanation for the widespread use of scrubbers for smokestack SO₂ emission reduction. But it also raises several questions that need more exploration: How is it that engineers like Frank Princiotta came to the EPA's RTP laboratory to deal with coal-fired power plant emissions? What made scrubbers more attractive than other cheaper options? How did Princiotta, the EPA engineers, and their collaborators demonstrate and establish the scrubbers as a successful case of the control technology approach?

The EPA's conceptualization of the environment as a sociotechnical system has largely eluded scholarly discourse, yet it remains foundational to the institution's organizational identity and the trajectory of its regulatory frameworks. The majority of scholarly studies concerning the EPA and its efficacy concentrate heavily on its legal frameworks and political dynamics.⁴ Historians and policy scholars began to focus on environmental scientists and engineers who crafted unique strategies to address pressing environmental challenges. For instance, historian Edmund Russell posits that during its first fifteen years, the agency's focus shifted from nonhuman species to human health, driven by shifting public opinion and the nascent methodology of risk assessment. Furthermore, science and technology policy scholar Sheila Jasanoff argues that the EPA's most controversial regulation cases demonstrate the emergence of a new "regulatory science," which conforms to agency guidelines and while remaining accountable to Congress, courts, and media as well as professional peers.⁵ In a similar vein, I follow a shift in focus from

³ EPA, *Report of the Panel*, 31–32, 36. For more information regarding Japanese scrubbers, See G. A. Hollinden and Frank T. Princiotta, *Sulfur Oxides Control Technology: Visits in Japan-March 1974*, Interagency Report, (October 15, 1974). For more information regarding scrubbers and sulfur dioxide regulation, see Margaret R. Taylor, Edward S. Rubin, and David A. Hounshell, "Regulation as Mother of Innovation: The Case of SO₂ Control," *Law and Policy* 27: 2 (2005), 348–378; Margaret R. Taylor, Edward S. Rubin, and David A. Hounshell, *Effect of Government Actions on Technological Innovation for SO₂ Control*, 37:20 (2003), 4527–4534.

⁴ Robert F. Durant, *When Government Regulates Itself: EPA, TVA, and Pollution Control in the 1970s* (Knoxville: University of Tennessee Press, 1985); Brian J. Cook, *Bureaucratic Politics and Regulatory Reform: The EPA and Emissions Trading* (Westport, CT: Greenwood Press, 1988); Marc Landy, Marc Roberts, and Stephen Thomas, *The Environmental Protection Agency: Asking the Wrong Questions* (New York: Oxford University Press, 1990); David Demortain, *The Science of Bureaucracy: Risk Decision Making and the US Environmental Protection Agency* (Cambridge, MA: The MIT Press, 2020); Charles Andrew Miller, "Fifty Years of EPA Science for Air Quality Management and Control," *Environmental Management* 67:6 (2021), 1017–1028.

⁵ Jeffrey Stine, "Regulating Wetlands in the 1970s: U.S. Army Corps of Engineers and the Environmental Organizations," *Journal of Forest History* 27:2 (1983), 60–75; Joel A. Tarr, *The Search for the Ultimate Sink: Urban Pollution in Historical Perspective* (Akron, OH: University of Akron Press, 1996); Stephen Bocking, *Ecologists and Environmental Politics: A History of Contemporary Ecology* (New Haven, CT: Yale University Press, 1997); Mark R. Powell, *Science*

pollution monitoring to control technology in the EPA. Focusing on Frank Princiotta and fellow EPA engineers underscores the critical juncture where environmental control strategies intersected with the institutionalization of environmental engineering and the birth of the environmental technology industry.⁶ New technologies to control emissions, to reduce discharges, and to process toxic substances were designed, developed, and tested in research laboratories at the EPA.⁷

This paper highlights a critical shift within the environmental protection system: the growing emphasis on the technological solutions for pollutant control. I begin by explaining the historical context of air pollution in the early 1970s. By contrasting the power industry's reluctance to embrace scrubber technology with the EPA's insistence on its adoption, this study underscores the pivotal role of EPA engineers in demonstrating the technology, in collaboration with scrubber vendors. Furthermore I analyze in detail the regulatory implications of pollution control technology demonstrations to emphasize the dual role as both an industry regulator and a technology advocate. Ultimately this paper argues that the EPA underwent a crucial reorientation, prioritizing demonstration of technological feasibility as a cornerstone of environmental protection.

Federal Efforts to Deal with Smokestack Emissions before the 1970s

To understand how Frank Princiotta applied his engineering experience and expertise in the urgent stationary air pollution issues of the time, we need to explore the status of air, its pollution, and people's response before the 1970s.

When fuels containing sulfur are burned, oxides of sulfur are produced. Among them, SO₂ has been found to irritate eyes, aggravate asthma, and damage lung function. People with chronic respiratory disease, the young, and the elderly are most susceptible to SO₂ pollution. When exposed to moisture in the atmosphere, SO₂

at EPA: *Information in the Regulatory Process* (Washington, DC: Resources for the Future, 1999); Samuel Hays, *A History of Environmental Politics Since 1945* (Pittsburgh, PA: University of Pittsburgh Press, 2000); Edmund Russell, "'Lost Among the Parts Per Billion': Ecological Protection at the United States Environmental Protection Agency, 1970–1993," *Environmental History* 2 (1997), 29–51; Sheila Jasanoff, *The Fifth Branch: Science Advisers as Policymakers* (Cambridge, MA: Harvard University Press, 1994), especially 61–83.

⁶ National Industrial Pollution Control Council, *The Engineer's Responsibility in Environmental Pollution Control: Sub-Council Report* (Washington, DC: Government Printing Office, March 1971).

⁷ One reviewer pointed out similar shift in research toward monitoring ambient air quality and suggested to show evidence of subsidies or financial grants to offset high costs claimed by power plants. I have not located yet but curious researchers can start from the work of Margaret Taylor.

oxidizes into sulfuric acid, which comes back to the land or water in the form of acid rain. Acid rain also reduces agricultural and forest production, diminishes visibility, and deteriorates buildings. An increase in SO₂ emissions was closely tied to the rapidly expanding electric power industry. Electricity generation doubled every 10 years after the Second World War and accounted for 60 percent of the SO₂ emissions in the United States by the 1970s.⁸

Scrubbers, or flue gas desulfurization devices, were first developed in the United Kingdom in the early 1930s and had been used in Japan and Sweden. It was not until the late 1960s, however, that some U.S. electric utilities installed limestone scrubbers on coal-fired power plants. Scrubbers were designed to remove SO₂ from gas streams by chemical reaction. It was a more expensive option than other competing SO₂ reduction technologies, like coal cleaning, but achieved higher efficiency.⁹

Scrubbers were the only control technology commercially available in the 1970s to reduce SO₂ emissions and comply with the CAAA. Switching to low-sulfur coal was costly because of limited supply and transportation cost. Coal cleaning had also been adopted by the industry as a standard procedure in conjunction with other technology. However, the power industry preferred tall stacks or intermittent control systems. Power plant owners argued that by increasing the height of the stacks, they could disperse the pollutants, allowing the local air to remain cleaner. The power industry's another preference was the intermittent control system (ICS), which relied on ad-hoc measures. When plants experienced unfavorable meteorological conditions like atmospheric inversions, they had options of using cleaner fuels, shutting down the units temporarily, or reducing outputs at certain plants while increasing production at others. Most sources using ICS curtailed operation only a few days each year.¹⁰

Environmentalists opposed both of these options and called for more constant efforts from industry. EPA regulators were still formulating a clear position on tall stacks and ICS. While they opposed the total reliance on tall stacks or ICS, they also understood these two options as useful tools to meet environmental goals that could be applied on a case-by-case basis. Finally, in September 1973, the EPA established their official position on ICS and stack height regulation. The EPA's Office of Air

⁸ Rena Corman, *Air Pollution Primer*, 3rd ed. (New York: American Lung Association, 1978), 36–37; EPA, *Sulfur Emission: Control Technology & Waste Management* (Washington, DC: EPA, Office of Research and Development, Office of Energy, Minerals, and Industry, May 1979), 4.

⁹ EPA, *Sulfur Emission*; Richard B. Engdahl, "SO₂ Control: Low-Sulfur Coal Still the Best Way," *Power Engineering* 77:11 (1973), 72–76. One reviewer suggested to include explanations about the delayed introduction of scrubbers in the U.S. compared to Japan and Sweden. American regulators and scrubber vendors used successful introduction of scrubbers in Japan and Sweden to persuade the American electric utilities.

¹⁰ R. Shep Melnick, *Regulation and the Courts: The Case of the Clean Air Act* (Washington, DC: Brookings Institution, 1983), 116–118.

Quality Planning and Standards (OAQPS), under the Office of Air, proposed to allow the use of ICS only when “the sole alternatives are either permanent production curtailment or delay of an attainment date for the national standards.”¹¹

Tall stacks raised difficult questions for EPA regulators. The OAQPS approach was that ICS could be allowed if sources installed “reasonably available control technology.” However, the EPA could not decide exactly how much pollution reduction was technologically feasible. Therefore, the EPA could not clearly define how much credit they could give for stack heights as pollution dispersion technology. It was the EPA and its predecessor which first allowed and encouraged tall stacks as “good engineering practice” and now limited the height of stacks by the same term.¹² The shift in the meaning of “good engineering practice” shows how the EPA’s air pollution regulators utilized engineering details to support their regulatory shift. Control of SO₂ was certainly a hot issue among the electric utility industry, vendors of scrubbers and other pollution control technologies, environmental organizations, and the EPA.

Nonetheless, the EPA’s regulators did not provide clear policy until late 1973.¹³ Prior to 1970, the U.S. federal government’s role in air pollution control was limited, with air pollution abatement efforts left to the states and municipalities. The federal government slowly increased funding for pollution research, first supporting the states and later conducting its own research during the 1960s.¹⁴ The Department of Health, Education, and Welfare (HEW) was in charge of research and regulatory activities, and in 1968 the National Air Pollution Control Administration (NAPCA)

¹¹ *ibid.*, 125.

¹² *ibid.*, 126; EPA, *Guidelines for Air Quality Maintenance Planning and Analysis: Volume 3 Control Strategies* (Research Triangle Park, NC: EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards, July 1974), III-51–III-56.

¹³ Melnick, *op. cit.*, 124.

¹⁴ Air Pollution Control Act of 1955, Public Law 84–159, 69 Stat. 322; Clean Air Act Amendments of 1963; Air Quality Act of 1967, Public Law 90–148, 81 Stat. 485. The 1955 act provided funds for federal research and the 1963 act first addressed air pollution control. According to the 1967 act, the federal government began ambient monitoring and source inspection as well as expanded pollution research. To learn more about NAPCA’s research and related issues, see Jongmin Lee, “Designed Tensions and Strategic Coexistence between Health Research and Technology-based Regulation: U.S. Environmental Protection Agency and the National Environmental Research Centers, 1969–1973 환경 연구와 기술 규제, 의도된 긴장과 전략적 공존, 1969–1973: 미국 환경 보호청(U.S. EPA)의 설립과 연방 환경 연구 센터 활동을 중심으로,” *The Korean Journal for the History of Science 한국과학사학회지* 37:3 (2015), 623–652; Yongjoo Han, “Government-scientists’ Air Resource Management and the Legislative Developments of the U. S. National Ambient Air Quality Standards, 1960–1970 미국 대기환경기준의 도입과 관료-과학자 집단의 대기자원화: 미국의 대기환경관리 법제화 분석, 1960–1970” (Master’s Thesis, Seoul National University 서울대학교, 2021); and EPA, *EPA at Research Triangle Park: Twenty Five Years of Environmental Protection* (Research Triangle Park, NC, 1996).

was established as a nascent organization focusing on air pollution under the HEW.¹⁵ Standards were not stringent as they were set by considering the available technology and cost. The control of mobile air pollution sources, or automobiles, was closely related with the development of engine modification technologies and catalytic converters.¹⁶

In the case of stationary sources such as power plants, chemical plants, industrial boilers, and commercial boilers, particulate matter drew the most attention of the federal government. People living near coal-fired power plants expressed concerns about the soot and dust. Power plants, or electric utilities, have been major stationary sources of air pollution and they had already introduced “electrostatic precipitators” in order to reduce particulate matter from the stack gases. The federal government guided and supported the development and application of pollution control technologies on wastes and emissions of power production. But power plants were reluctant to introduce another control technology.¹⁷

Meanwhile, pollution of air by emissions from stationary sources became evident in every part of the United States. State and local governments had limited resources to control all these pollution sources. The federal government tried to intervene to urge their local and state counterparts to monitor pollution makers and force them to follow standards and deadlines. From steel plant emissions in Alabama to Edison plant chimneys in Manhattan, to low-hanging smog in California, and oil refineries in Puerto Rico, scientists and engineers set up stations, collected and analyzed data, and maintained the monitoring network (fig. 1).

The passage of the CAAA of 1970 marked the beginning of the decade of environmental protection. The 1970 Act authorized the federal government to set up National Ambient Air Quality Standards (NAAQS) for carbon monoxide, hydrocarbons, nitrogen oxides, ozone, particulate matter, and sulfur dioxide based only on public health and welfare grounds. The standards were for ambient air quality, not the air quality at the source. Maintaining the level of air quality was the primary focus, with no particular technology suggested to accomplish this. Nor were

¹⁵ National Air Pollution Control Administration, *Control Techniques for Sulfur Oxide Air Pollutants* (Washington, DC: Public Health Service, 1969).

¹⁶ Jongmin Lee, “The Co-production of Environmental Regulation and Pollution Control Technology in 1970s America: The Controversy over Catalytic Converters at the U.S. Environmental Protection Agency 1970년대 미국 환경규제정책과 오염통제기술의 공동형성: 가솔린 자동차 배기가스 저감장치에 대한 미국환경보호청 내부 논쟁을 중심으로,” *The Korean Journal of American History* 미국사연구 55 (2022), 115–164; Lee Vinsel, *Moving Violations: Automobiles, Experts, and Regulations in the United States* (Johns Hopkins University Press, 2019)

¹⁷ NAPCA, *Control Techniques for Sulfur Oxide Air Pollutants*; George D. Clayton, “Air Pollution,” in *Industrial Environmental Health: The Worker and the Community*, edited by Lester V. Cralley, 413–454 (New York, Academic Press, 1972); Richard B. Engdahl, “A Critical Review of Regulations for the Control of Sulfur Oxide Emissions,” *Journal of the Air Pollution Control Association* 23:5 (May 1973), 364–375.

cost factors included in setting up the standards, in contrast to the previous laws. Omission of technology and cost factors in the 1970 Act made it much stronger than its predecessors.¹⁸



Figure 1. Air Pollution in Various Regions of the United States. (Source) Documerica, National Archives (Top left: Steel plants in Alabama; right: Edison plants in Manhattan; bottom left: Smog in California; right: Oil refineries in Puerto Rico), Photo by LeRoy Woodson, Chester Higgins, Gene Daniels, and John Vachon respectively.

<http://research.archives.gov/description/545410>,

<http://research.archives.gov/description/548345>,

<http://research.archives.gov/description/542683>,

and <http://research.archives.gov/description/546384> Accessed June 19, 2026

With stringent laws and standards, the EPA began to deal with air pollution cases that had been traditionally in the realm of state and local governments. The EPA was able to intervene with the states if their plans to improve air quality proved inadequate to meet the federal standards. On April 30, 1971, the EPA published two National Ambient Air Quality Standards: primary standards, to protect public health with an “adequate margin of safety”; and secondary standards, to protect public welfare. Within nine months of promulgation, the states were required to submit an implementation plan. Implementation plans were to include, most of all, emission limitations, as well as monitoring provisions, motor vehicle inspection and testing

¹⁸ Clean Air Act Amendments of 1970, Public Law 91-604, 42 U.S. Code 7609; Rogers, “The Clean Air Act of 1970.” See Jongmin Lee (2022) to learn more about the Clean Air Act Amendments of 1970 from mobile air pollution control perspective.

provisions, and plans for land-use and transportation controls. If plans were not submitted or seemed inadequate to the EPA, the EPA could implement its own plans considering public health, but not economic or technical feasibility. The EPA also could ask federal courts to impose criminal penalties for violators of implementation plan rules. As most states turned in their implementation plans by the end of 1973, the deadline for meeting primary standards was set for July 1975.¹⁹

The growing emphasis on the goal of public health, coupled with the exclusion of cost or technology factors in the standards setting process, shaped the 1970 CAAA as game-changer in air pollution control. This stream of “community health” approach rapidly expanded as the federal government invested a considerable amount of its limited research capacity in exploring the correlation between major pollutants and health indicators. However, the “control technology” approach was also expanding as the EPA elaborated its detailed standards for diverse cases.²⁰

The EPA’s approach to new air pollution sources was more challenging and definitive than its approach to existing sources. Section 111 of the 1970 Act required the EPA to set up a standard that could be satisfied by the “best system of emission reduction,” which had been “adequately demonstrated” as determined by the Administrator of the EPA. I argue that the authors of the Act, in section 111, expected the EPA to establish the standards considering the status of current technology. In other words, lawmakers showed their intended balance between environmental protection and reasonable application of demonstrated technology. Based on an expectation for better performance from the new plants, the EPA set up and promulgated the initial New Source Performance Standards (NSPS) in 1971. The EPA set up 1.2 pounds of SO₂ per MBtu (Mega British thermal unit) as the NSPS, by calculating a 70 percent reduction of SO₂ of the average eastern coal. Bruce Ackerman and William Hassler, legal scholars from Yale, argued that this 70 percent, or 1.2 pounds standard, did not consider the difference in SO₂ per MBtu between eastern coal (3-4 pounds) and western coal (about 0.3 pounds). They also pointed out that the agency’s narrow reading caused its reliance on the use of scrubbers and its initial failure to notice the environmental harms of sludge.²¹ It is noteworthy, for the following story, that U.S. Congress assigned the EPA responsibility to define the adequate demonstration of emission reduction technology. The EPA managers and engineers took this responsibility seriously; they

¹⁹ Clean Air Act Amendments of 1970.

²⁰ See Jongmin Lee, “CHESS Lessons: Controversy and Compromise in the Making of the EPA,” James Roger Fleming and Ann Johnson, eds., *Toxic Airs: Body, Place, Planet in Historical Perspective* (University of Pittsburgh Press, 2014), 127–151 for the detailed explanation of “community health” and “control technology” approaches.

²¹ Clean Air Act Amendments of 1970; Bruce Ackerman and William Hassler, *Clean Coal/ Dirty Air: or How the Clean Air Act Became a Multibillion-Dollar Bail-Out for High-Sulfur Coal Producers* (New Haven, CT: Yale University Press, 1981), 10-11, 19–21; 1,000 British Thermal Unit=1,055 Kjoules.

collected and disseminated information about the current status of technology to reduce emissions from stationary sources, and were finally found deeply involved in the demonstration of the “best system.” To understand how this happened in the relatively short period between December 1970 and November 1973, we need to understand a key figure, Frank Princiotta.

Frank Princiotta’s Timely Arrival to Control Systems Laboratory

Timing is always important, and it was very much so for Princiotta and the EPA. First, managers and engineers who came under the new roof of the EPA continued to work in their own specialty area, be it air, water, pesticides, or wastes. As new legislation reorganized the offices and laboratories and redefined their responsibilities, the demand escalated for a more formally trained workforce possessing diverse educational and professional backgrounds. Among others, the EPA needed more engineers who were competent, versatile, and focused. Princiotta was the one who was ready to move to the newly established research center in North Carolina.²²

His move from Maryland to North Carolina was an outcome of previous connections and coincidence. Frank Princiotta received his chemical engineering degree from City College of New York in 1962 and did graduate work in nuclear engineering at Oak Ridge School of Reactor Technology in 1963. After working at the Atomic Energy Commission (AEC) in New York and at Hittman Associates, a nuclear R&D and consulting firm in Maryland, he moved to RTP in 1971.²³ Sheldon Meyers, his previous supervisor at the AEC, was already at the EPA looking for new hires. Princiotta also thought the move was accidental in the sense that it was not planned ahead.

What was interesting is, at that time I was looking for another job, because the small company [was] having financial problems, the person I worked for at the Atomic Energy Commission had once told me that if I wanted a job with him and he was in a position to do so, he would hire me. Lo and behold, he had my job here in this operation back then, and he asked me if I had interest to come overnight. I

²² To understand how each regulatory and research units and laboratories were initially put under the roof of the EPA and reorganized in the early 1970s, see Lee, “Designed Tensions and Strategic Coexistence between Health Research and Technology-based Regulation.”

²³ Frank Princiotta, Email correspondence with the author, April 23, 2012. One reviewer specifically asked for detailed explanation of Princiotta’s becoming a primary supporter of scrubber and how he managed to organize SOTSEP. Other than what I covered in this paper, I do have more material from two interviews and several EPA reports which I hope I can explain in my future research.

had known very little about environmental protection quite candidly, so he put a chance on me, [the environment] not being much of my area.²⁴

The diversity of the Control Systems Laboratory (CSL)'s workforce actually contributed to the execution of its mission. In the 1970s the engineering community included quite a few nuclear engineers working in diverse areas. The EPA's engineering posts were no exception. All types of engineers were welcomed as long as they could contribute to environmental protection. Princiotta's unit had both new hires like him and older staff moved from the HEW's Cincinnati lab. The 1973 annual report for the National Environmental Research Center-Research Triangle Park highlights how their diverse backgrounds in both government and the private sector helped them carry out the mission successfully: "research, development, and demonstration of equipment and systems to abate, in a timely and cost-effective manner, the emission of atmospheric pollutants from stationary sources to a level that protects public health and welfare, and to do so within the framework of our nation's energy and environmental mandates."²⁵ The contrast between the ends and means of control is critical. Goals of public health and welfare can be achieved by effective research, development, and demonstration. Reference to the nation's energy and environmental mandates clearly signified the challenges of balancing competing interests in energy supply and environmental protection after the oil embargo of October 1973.

As energy supply became national agenda, the CSL became more involved in energy research and development. It's position on the tension between energy needs and environmental concerns is also mentioned at the end of the same annual report, quoted above. "These new energy technologies must be environmentally sound if the future health and welfare of the nation is to be protected. Although environmental considerations may be subjugated to short-term energy needs, there must ultimately be a reconciliation of energy and environmental considerations." The energy needs seemed more important than environmental concerns. However, as the report states: "[a]ctive involvement by [the] EPA will ensure that environmental control systems keep pace with new energy processes."²⁶ The above passage re-emphasized that energy needs to be environmentally sound. Environmental concerns, in their plan, might conform to the energy demands for the short term, but a future reconciliation would be needed. I will revisit this subtle position on environmental protection and energy technology development and its variations in the broader context of the federal interagency program later in the paper.

²⁴ Frank Princiotta, Interview with the author, January 4, 2011.

²⁵ EPA, *NERC, RTP, NC, Annual Report - 1973*, 117.

²⁶ *Ibid.*, 132.

EPA's Defending Scrubbers against the Cost and Reliability Concerns

In this section, I detail how Princiotta demonstrated scrubbers as a successful case of pollution control technology. I utilize the idea of the co-production of engineering and regulation in the EPA, which in turn facilitated the generation of new knowledge, culture, and identity for the new agency.²⁷ The co-production of emissions regulation, environmental institution-building, and control technology took place at the EPA.

When the electric utilities industry preferred other options to reduce or disperse sulfur dioxide emissions from smokestacks, the demonstration of a control technology, the scrubber, addressed cost and reliability issues. However, the increasing waste from scrubbers became another topic of concern. Cooperating with the Tennessee Valley Authority (TVA), one of the main sulfur oxides emitters, and with other manufacturers of scrubbers, CSL engineers shifted the focus from pollution abatement for health benefit to development of pollution control technology for effective regulation. New knowledge about the operation and maintenance of power plants equipped with scrubbers as well as a new identity among engineers from the EPA, TVA, and contractors contributed to the co-production of technology and regulation for environmental protection.

The slow formation of the EPA's policy on tall stacks and ICS earned time for the proponents of scrubbers. Both EPA's top officials and OAQPS's mid-level managers were slow in formulating a clear policy on scrubbers and stationary air pollution. What the EPA produced were a series of ad-hoc responses to individual requests for advice. While scrubbers were manufactured and tested in a few coal-fired power plants, the electric utility industry in general was more inclined to accept tall stacks or ICS. Industry preferred these low cost and flexible options over expensive and unreliable scrubbers. In this gap between regulator's tardy action and industry's economic and technological preferences, engineers at the EPA found scrubbers to be the most advanced technology to meet NAAQS by the 1975 deadline.

Scrubbers dealt with the end-of-pipeline treatment of coal-fired power plants' full cycle: from coal to sludge. After coal was mined and transported to power plants, it was pulverized, or ground to small pieces, and burned in a boiler. While the heat was used to generate electricity, several byproducts were created. Fly ash, with noncombustible minerals like ash, dust, and soot, were captured in an electrostatic precipitator and transported to a pond or a landfill. Scrubbers absorbed sulfur dioxide by reacting lime ($\text{Ca}(\text{OH})_2$, calcium hydroxide or slaked lime) or limestone (CaCO_3 ,

²⁷ Sheila Jasanoff, ed., *States of Knowledge: The Co-Production of Science and Social Order* (New York: Routledge, 2004); Brendon Swedlow, "Cultural Coproduction of Four States of Knowledge," *Science, Technology, & Human Values* 37:3 (2007), 151–179.

calcium carbonate) with SO_2 in water (wet-process) or in the air (dry-process). Sludge ($\text{CaSO}_3 \cdot 2\text{H}_2\text{O}$, hydrated calcium sulfite) or gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, hydrated calcium sulfate) is byproduct of these chemical reactions.²⁸ I will come back to the environmental consequences of and engineering responses to different types of scrubber byproducts in the next section.

The EPA's public hearing on SO_2 control in October and November of 1973 (fig. 2) played an important role in setting up scrubbers as the most practical solution to reducing SO_2 emissions in power plants. This hearing was later called the Quarles hearing, named after its chairperson, John Quarles, EPA's Deputy Administrator. During the hearing, an oil embargo was initiated and extended, and interest in energy independence skyrocketed in the United States.²⁹ For electric utilities, the hearing provided a once-in-a-decade chance to argue for loosening the standards and delaying the deadlines to meet the standards. Twenty electric utilities sent witnesses to the hearing. Testimony came from small utilities like Kansas City Power and Light Company to large ones like the TVA and American Electric Power Service Corporation. The utility witnesses generally agreed that supplies of low-sulfur coal were limited and insufficient to achieve compliance with SO_2 regulations only through switching to this fuel source. Utilities expressed a strong desire to use locally available high-sulfur coal. Although scrubbers could bring utilities into regulatory compliance, not many companies testified that they had plans to install the scrubbers.³⁰

Most utilities argued that scrubbers had problems such as unreliable operation, high cost, and environmental effects. Various parties, from the EPA to vendors and non-governmental organizations, voiced their opinions on these three problems of reliability, cost, and sludge. Frank Princiotta, with other EPA witnesses, expressed a compelling argument against utilities and state regulators dubious about scrubber technology.³¹ I will deal with two of the three issues, reliability and cost, in this section. As the last issue of sludge needs more attention and detail, I will come back to it in the following section.

²⁸ "Fly Ash and Gypsum are Captured," Kentucky Ash Education Site by the University of Kentucky's Center for Applied Energy Research; David M. Hart and Kadri Kallas, "Alignment and Misalignment of Technology Push and Regulatory Pull: Federal RD&D Support for SO_2 and NO_x Emissions Control Technology for Coal-Fired Power Plants, 1970–2000" (Cambridge, MA: MIT Industrial Performance Center, April 2010).

²⁹ Lee, "The Co-production of Environmental Regulation and Pollution Control Technology in 1970s America," 140–142.

³⁰ EPA, *Report of the Panel*.

³¹ *Ibid.*, 32–36; EPA, TVA, and EPRI, *Sulfur Oxides Control in Japan* (Washington, DC, November 1979).

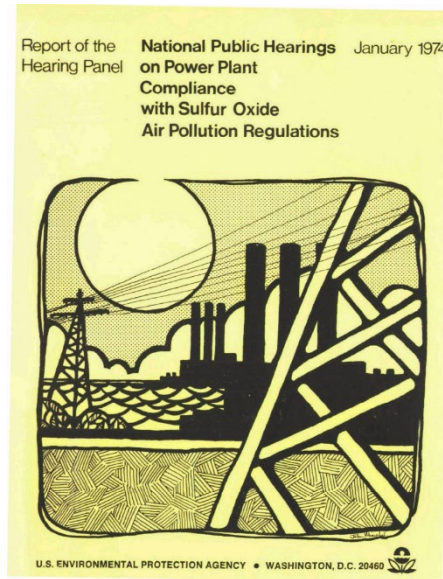


Figure 2. Public Hearing on Regulating Power Plants on Sulfur Oxide. (Source) EPA, *Report of the Panel: National Public Hearings on Power Plant Compliance with Sulfur Oxide Air Pollution Regulations* (Washington, DC: EPA, 1974).

Regarding reliable operations, the EPA's Princiotta and other operators of scrubbers pointed out recent improvements.³² There were concerns of two major phenomena in operating the scrubbers successfully. Scaling, a phenomenon where hard chemicals deposited inside the scrubber, was found in many operations. The other phenomenon of concern was plugging, where soft solids built up. Testimony on Japanese Mitsui and EPA's Shawnee prototype confirmed that plugging had been overcome and scaling control was well underway by changing liquid/gas ratios and maintaining pH within limits (fig. 3). The photo below shows a big decrease in scaling in the Venturi/Spray Tower scrubber. In addition to operational problems, utility industry representatives such as Archie V. Slack of SAS corporations representing West Penn Power Company voiced their concerns about mechanical problems at fans and pumps. Princiotta and other scrubber operators showed evidence of successfully demonstrated scrubbers at a number of units to argue that these problems had been or could soon be solved.³³

³² Richard B. Engdahl, "A Critical Review of Regulations for the Control of Sulfur Oxide Emissions," 364–375.

³³ EPA, *Report of the Panel*, 32–37.

Princiotta claimed that some engineers from the utilities industry who expressed negative opinions during the hearings were actually supportive of his scrubbers at pilot units. For example, Archie V. Slack who reported various problems of scrubbers during the hearings, Princiotta argued, however, expressed his support for lime/limestone scrubbers over other alternatives in other co-authored publication.³⁴

After the reliability issue of the scrubbers had been settled in the hearing, a discussion of the cost of installing and operating scrubbers followed. The authors of the hearing panel did not expect scrubbers to result in a large increase in the cost of generating electricity. General patterns from the data collected from the utilities and operators showed that setting scrubbers in new plants would be less expensive than retrofitting scrubbers in existing plants. In other words, retrofitting old plants might be difficult both for utilities and for vendors of scrubbers when more scrubbers could be applied to new power plants for the same amount of money. Instead, Princiotta and EPA experts argued that ready-to-retire or small industrial plants might find other options. The dry process was later promoted by Princiotta in the late 1970s and early 1980s.³⁵

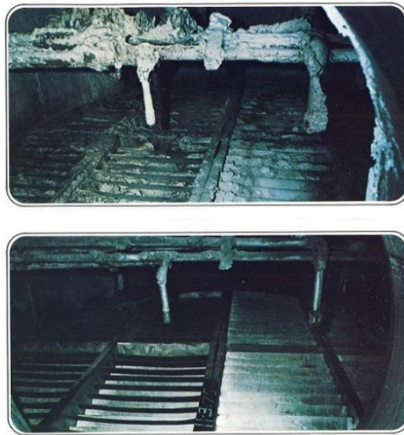


Figure 3. Improvement in Scaling by Alkali Utilization on a Scrubber. (Source) EPA, *Lime/Limestone Wet-scrubbing Test Results at the EPA Alkali Scrubbing Test Facility* (Washington, DC: EPA, Office of Research and Development, Prototype Demonstration Facility, Technology Transfer, 1976) (Top: Scale formed on the top vanes of the mist eliminator; bottom: Scale problem eliminated by alkali utilization and washing with makeup water.)

³⁴ Princiotta, Interview with the author, March 15, 2012; A. V. Slack, "Research and Development Needs for Flue Gas Desulfurization in the 1980's," presented at Battelle's Eighth Annual Meeting of the Stack Gas Emission Control Group, Columbus, OH, Dec. 4, 1980. As cited in Hans T. Karlsson, Jonas Klingspor, Marita Linné, and Ingemar Bjerle, "Activated Wet-Dry Scrubbing of SO₂," *Journal of the Air Pollution Control Association* 33:1 (1983), 23–28.

³⁵ Princiotta, Interview with the author, January 4, 2011.

EPA-TVA-Bechtel Collaboration to Demonstrate Scrubbers

The successful debut of scrubbers in the Quarles hearing represented an important turning point in policy shift. Inside the EPA, the ball was now turned over to the CSL engineers from the OAQPS regulators. As the hearing coincided with the energy crisis of 1973, the federal government moved their focus toward the energy supply, which meant a shift back to coal from oil. The utilities continued to pursue lawsuits, but they slowly and more openly invested additional money and expertise into scrubbing research. All of these changes meant increasing funding and support for Princiotta and his colleagues. In this section, I focus on the details of the EPA's collaboration project with the TVA, a government-corporate power generator, and Bechtel Corporation, a private contractor. Facing inaction and resistance from utilities, the EPA generated new knowledge about scaling and plugging and demonstrated prototype-scale scrubbers at the collaboration project.

In the early 1970s, continuing their work at the new agency, engineers at the CSL invested their energy into two types of scrubbing: a throw-away process and a regenerable (recovery) process. Two branches of the CSL focused on each of the two, and they competed with each other to find better solutions to the SO₂ problem. The throw-away process removed SO₂ from the flue gas and disposed of it. On the other hand, the regenerable process was designed to retrieve sulfur or sulfuric acid out of the flue gas. The throw-away process was generally cheaper than the regenerable process, but sludge disposal posed potential environmental side effects. The regenerable process was first considered to be more environmentally sound, but further research added more complexity. The market for sulfur and its compounds was already competitive. In addition, the electric utilities found not much incentive for using extra energy for the regeneration of sulfur. Sludge disposal was still cheap compared to other coal byproducts disposal and keeping the electricity rate down topped the priority list of the national agenda.³⁶ As a result, the regenerable process gradually lost its impetus and the throw-away process became the main focus of the CSL toward the end of the 1970s.³⁷

Thus, the expansion of the throw-away process throughout the 1970s provided a crucial opportunity for Princiotta. When Sheldon Meyers, the CSL director, hired Princiotta in June 1971, Meyers assigned him to the throw-away process team.³⁸ The CSL had facilities spread out at three locations: the NERC building in RTP, and the

³⁶ EPA, *Sulfur Oxide Throwaway Sludge Evaluation Panel (SOTSEP), Volume II: Final Report-Technical Discussion* (Research Triangle Park, NC: EPA, Office of Research and Development, National Environmental Research Center, Research Triangle Park, April 1975), 35–39; EPA, *Flue Gas Desulfurization: Answers to Basic Questions* (Research Triangle Park, NC, EPA, Office of Air and Waste Management, Office of Air Quality Planning and Standards, October 1973).

³⁷ Princiotta, Interview with the author, January 4, 2011.

³⁸ Princiotta, Email correspondence by the author, April 23, 2012.

Mutual building and its annex in Durham. Princiotta's team was at the annex with Meyers' office. His role in the team was limited at the beginning, compared to his experience in the public and private sectors, and he was expected to show his potential in his new position. The first project Princiotta undertook and executed successfully became a stepping stone for him to increase his role at the CSL.

NAPCA, the predecessor of the EPA in air pollution research, began a stationary air pollution abatement project in June 1968 with two cooperators.³⁹ The TVA provided the site and constructed and operated the units. Bechtel Corporation, an architecture and engineering firm from San Francisco, was the major contractor that directed the test. After the establishment of the EPA in 1970, CSL inherited this project.⁴⁰

The location of the EPA-TVA-Bechtel collaboration project provides an interesting historical background to the EPA's pollution control activities for electric power generation, as well as a good summary of the timeline between World War II and the environmental decade. The project site was at Shawnee on Ohio River, about 10 miles northwest of Paducah, Kentucky, where the TVA built plants powering a uranium enrichment process. Shawnee fossil-fuel power generation plants were built to support the "peace-time" nuclear energy generation program in the Cold War tradition. In addition, the EPA-TVA-Bechtel demonstration project added another layer of emissions control of fossil-fuel power generation in the "environmental decade."⁴¹

In 1968 the project team concurrently began building three 10 megawatt scrubbers: the Marble-Bed Absorber, the Turbulent Contact Absorber (TCA), and the Venturi/Spray Tower. The team chose these three candidates to minimize the total time required to prepare for a demonstration of scrubbing technology and to find the most successful technology out of the pool at the site. Each scrubbing system was designed to treat approximately 10 megawatt equivalents of flue gas from the Shawnee boiler No. 10 (150 megawatt total). The 10 megawatt size was chosen for "minimum cost, consistent with the ability to extrapolate results to commercial scale." Boiler No. 10 burned a high-sulfur bituminous coal leading to SO₂ concentrations of 2,300 to 3,300 parts per million in the flue gas.⁴² (fig. 4)

Pursuing three scrubbing systems at the same time demanded a large budget and strong organizational support. This parallel strategy faced its first challenge as one prototype scrubber failed to be produced on schedule. Combustion Engineering's

³⁹ NAPCA, *Control Techniques for Sulfur Oxide Air Pollutants*.

⁴⁰ EPA, *Limestone Wet-scrubbing Test Results at the EPA Alkali Scrubbing Test Facility: First Progress Report* (Washington, DC: EPA, Office of Research and Development, Prototype Demonstration Facility, 1974), 3.

⁴¹ "Paducah Background" <https://www.energy.gov/pppo/paducah-background> Accessed August 24, 2026

⁴² EPA, *First Progress Report*, 3–4.

Marble-Bed Absorber was discontinued in July 1973.⁴³ Operating problems such as nozzle failure and subsequent plugging of the bed were the main reasons for failure.⁴⁴ So it was important for Princiotta and other engineers that the two remaining scrubbers could generate diverse test data. Systems for the other two scrubbers were designed in such a way that the configuration of the scrubber internals and piping could easily be changed. The TCA, supplied by Universal Oil Products, used a fluidized bed of plastic spheres moving between retaining grids. Operating engineers were able to operate the TCA as a one-, two-, or three-bed unit. They could also dewater the spent solids by a clarifier alone or with a clarifier in combination with a filter or a centrifuge.

The Venturi, manufactured by Chemical Construction, absorbed particulate matter and sulfur components. To supplement Venturi's absorption capacity, engineers attached a spray tower that served to increase contact time.⁴⁵ For both the TCA and Venturi/Spray-tower systems, there was a central panel board that employed cutting-edge sensor and communication technology to monitor and control information. Central board operators used an electronic data acquisition system to record the operating data, and measured and controlled the gas flow rate by venture flow tubes and dampers on the induced-draft fans. They also employed photometric analyzers to measure the concentration of SO₂ in the inlet and outlet gas.

The original test program documented that scaling and plugging were "separate problems, each with separate and distinct solutions."⁴⁶ After identifying scaling and plugging as the two most nagging operational problems of the scrubbing process, team engineers devoted much of their early efforts into characterizing the problems and running experiments. To address the problem of scaling, they designed and executed experiments where they operated the scrubbers with changes in parameters like liquid-to-gas ratio, reaction tank residence time, pH, and percentage of solids in slurry. While changing liquid-to-gas ratio and pH proved to be effective, more effective control methods were washing mist eliminators with fresh make-up water once every 4-8 hours from the top and low pressure drop nozzles. However, finding operating parameters and designing washing techniques demanded more time than the original estimates.

⁴³ John E. Williams, *Summary of Operation and Testing at the Shawnee Prototype Lime/Limestone Test Facility* (Research Triangle Park, NC: EPA, Office of Research and Development, Industrial Environmental Research Laboratory, April 1977), 1.

⁴⁴ EPA, *Lime/ Limestone Wet-scrubbing Test Results, Second Progress Report* (Washington, DC: EPA, Office of Research and Development, Prototype Demonstration Facility, 1975), 4-5. However, this failure did not mean that Combustion Engineering stopped developing its scrubbers. Instead, it developed other commercial options.

⁴⁵ EPA, *Second Progress Report*, 4; EPA, *Lime/ Limestone Wet-scrubbing Test Results, Third Progress Report* (Washington, DC: EPA, Office of Research and Development, Prototype Demonstration Facility, 1976), 4-5.

⁴⁶ Williams, *Summary of Operation and Testing at the Shawnee Facility*, 5.

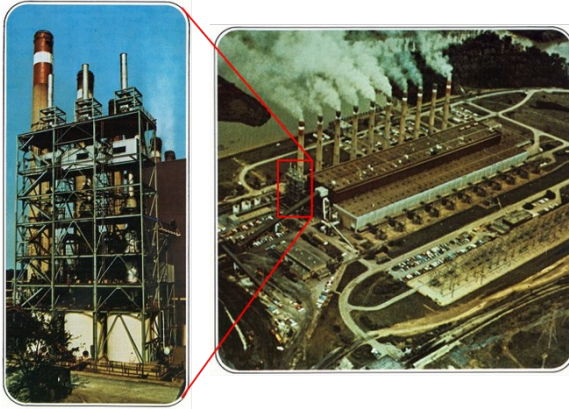


Figure 4. 10 MW scrubbers attached to the Shawnee Boiler No. 10. *Source:* EPA, National Environmental Research Center, Research Triangle Park, North Carolina, Annual Report - 1973 (RTP, NC: EPA, Office of Research and Development, NERC-RTP, NC, 1973) (Left: 10 MW scrubbers; right: TVA coal-fired power plants at Shawnee, KY.)

Solutions to the plugging problem proved more difficult than scaling remedies. The use of a wash tray upstream of the mist eliminator was marginally successful. The wash tray enabled soft solid deposits to be transferred to an area where they could more easily be removed, but the process also reduced gas flow rates. Even though washing techniques were helpful enough to continue operation without shutting down the scrubbers for periodic cleaning, a successful control of soft solids deposit was not achieved in the first phase of the test program.⁴⁷

With internal and external support, Princiotta successfully established an advanced test program by arguing a need for additional development of lime/limestone wet-scrubbing technology. Before the scheduled end date of the program's first phase, the Shawnee test program was expanded and the program's advanced phase began in 1974. While the test program achieved most of its original goals, Princiotta argued that he found additional research and demonstration needs in the areas of "sludge disposal, improved reliability, variable load operation, and improved process economics." In choosing these additional goals, Princiotta relied on comments from utilities and scrubber vendors and encouraging results from the RTP pilot plant.⁴⁸

Princiotta emphasized a multi-step process to reach the final goal and spent enough time in each step to gain enough reliability to proceed to the next process. The program engineers first tested the scrubbing system with air and water to

⁴⁷ Ibid., 5.

⁴⁸ Ibid., 3–4.

determine pressure drop model coefficients and to observe fluid hydrodynamics. Then they tested the system with sodium carbonate (Na_2CO_3) to determine gas-phase mass-transfer coefficients in mathematical models. Finally the team used these coefficients to predict the SO_2 removal rate.⁴⁹

Improved alkali utilization not only decreased plugging, but it reduced both the quantity of lime/limestone input and sludge output and thus enhanced the overall efficiency of the scrubber system. During the tests to improve the alkali utilization method, Princiotta's team found a correlation between alkali utilization and the accumulation of soft solids. Under a system operating above about 85 percent alkali utilization, the solids were easily removed "even with very infrequent (once per 8-hour shift) washing with fresh make-up water." Princiotta first found this at his preliminary test at the RTP pilot plant; he then confirmed this correlation at Shawnee and another TVA pilot plant. This finding was important as it provided solutions to multiple problems at the same time.⁵⁰

Successful demonstration of lime/limestone scrubbers at the Shawnee site answered most questions raised in the Quarles hearing. The scrubbers proved to be more reliable and efficient compared to other engineering alternatives like low-sulfur coal or coal cleaning, as the team engineers separated scaling and plugging and found answers for both by alkali utilization. The utility industry's concern about the high cost of scrubbers, compared to tall stacks or ICS, also decreased as alkali utilization required less lime/limestone and produced less sludge.

Organizing a Multimedia Panel to Address Sludge Issues

One remaining problem was sludge. As more utilities used and were expected to use scrubbers, they would produce more sludge. The potential environmental effects of scrubbers could potentially undermine the EPA's overall efforts in environmental protection. In the worst scenario, scrubbers merely moved sulfur from coal and air into land and water. How did Princiotta and CSL answer this sludge question?

Princiotta identified an opportunity where federal regulation was not yet present. By the time Princiotta found, but not yet confirmed, alkali utilization as a solution to plugging and sludge at Shawnee, sludge-generated waste management had become an important hurdle for proponents of scrubbers in the utilities industry and the government. Princiotta organized and chaired the Sulfur Oxide Throwaway Sludge Evaluation Panel (SOTSEP), EPA's multimedia evaluation panel on sludge. SOTSEP consisted of one staff member from the Office of Research and Development (ORD)'s Air Pollution Control Division, another from the Office of Air and Waste Management, and four CSL members including Princiotta. The

⁴⁹ EPA, *Second Progress Report*, 8; EPA, *Third Progress Report*, 8.

⁵⁰ Williams, *Summary of Operation and Testing at the Shawnee Facility*, 6.

mission of SOTSEP was “the evaluation of the environmental and economic factors associated with disposal or utilization of sludge from nonregenerable” scrubbing processes.⁵¹ In order to execute their mission, SOTSEP members first explored the current status of other alternative control technologies: chemical and physical coal cleaning, coal gasification and liquefaction, and fluidized bed combustion. In its 1975 two-volume report, SOTSEP members argued that these alternatives were still emerging technologies and economically not competitive over the next ten years.⁵² Then they argued that proper disposal of lime/limestone scrubber sludge would be important as they expected a potential high demand for scrubbing.

Increased sludge production from scrubbers became a nagging issue for the EPA, industry, and environmental organizations. Princiotta organized a panel of multimedia specialists, reemphasized the importance of throw-away scrubbers under the ongoing energy crisis, and addressed environmentalists’ and industrialists’ concerns about water and solid waste issues by promising further research as well as suggesting engineering alternatives such as a regenerable process and sludge-gypsum conversion.

The rise of the control technology approach in the EPA also contributed to the expansion of an economic incentives program in the federal government. Developing and using technologies to control emissions from pollution sources became increasingly important for the following reasons. First, the role of pollution control technology in engineering and regulatory practices at the EPA had shifted from support to criteria. Monitoring devices advanced faster than the bureaucratic capacity to administer monitoring activities across the country. The fast development of pollution monitoring technology coupled with increasing needs to control emissions from automobiles and smokestacks culminated in the EPA’s coordination of the Interagency Energy/Environment Research and Development Program. Once catalytic converters and scrubbers became important parts of regulatory engineering at the EPA, subsequent regulatory and research plans presumed the continued use of these control technologies and anticipated further development of advanced ones.

Second, the federal government promoted gradual reform over radical changes. Although the public image of technology in the 1960s and 1970s was more about the production of new commodities, various technologies occupied correspondingly important roles in building the infrastructure for maintaining old rules and standards of the society.⁵³ Technical fixes for social and cultural problems were effective because those social and cultural problems were also problems of technology and engineering. Using control technologies for the betterment of the environment

⁵¹ EPA, *SOTSEP: Technical Discussion*, xiv.

⁵² *Ibid.*, 30–35.

⁵³ David Edgerton, *The Shock of the Old: Technology and Global History Since 1900* (New York: Oxford University Press, 2007).

therefore became a good segue for bureaucrats to promote the environmental technology industry and tone down the uproaring voices of the environmentalists.

Third, the rise of technology as a solution to environmental problems also contributed to the growing dependence on energy policy. Among various types of environmental technologies, from the monitoring and abatement of pollution to the enhancement of the environment, particular technologies became more popular—namely, those that reduced pollution at the end of the pipeline rather than at the beginning. I describe this as the expansion of the “control technology” approach in air pollution management. Air scrubbers reduced smokestack emissions at the end of the coal extraction-processing-combustion cycle.

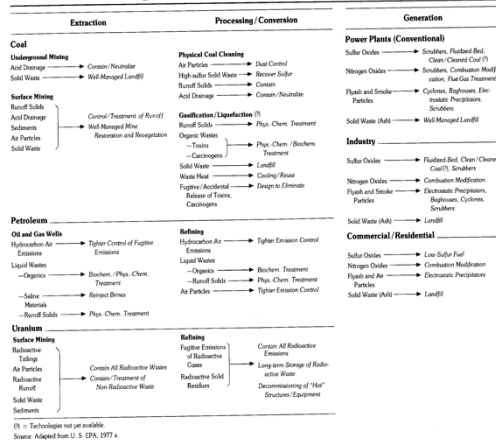
Princiotta utilized both his own CSL pilot scrubber at RTP and TVA prototype scrubbers at Shawnee to test his ideas and to scale up the chemical processes quickly. Apparently the 1973 Quarles hearing put Princiotta as the major figure of this combined efforts to evaluate and promote scrubbers for air pollution regulation. He also ran series of scrubbers symposium between 1973 and 1980 where EPA and other government people, industry engineers, and academics came together to communicate up-to-date information of scrubbers and sulfur dioxide research.⁵⁴

The success of certain technologies also limited the future trajectory of environmental regulation. The successful introduction of scrubbers also delayed the development of technology to reduce sulfur components. Going through two oil crises and economic ups and downs, environmental technologies became mandatory attachments to the energy supply for society’s continuing growth. Figure 5 shows how the EPA conceptualized various emissions and other environmental problems to deal with relevant control technologies at each stage of extraction, processing/conversion, and generation.

The expansion of the “control technology” approach in the EPA also helped Princiotta to move himself upward. After leading the CSL as the director, he moved to Washington, DC to lead the Energy Processes Division in 1975. After about five years’ service in the national capital, he moved back to RTP to lead EPA’s Industrial Energy Research Laboratory.

⁵⁴ For example, EPA, *Flue Gas Desulfurization System Capabilities for Coal-Fired Steam Generators, Volume I. Executive Summary, Interagency Energy-Environment Research and Development*, EPA-600/7-78-032a (Washington, DC: March 1978).

Environmental Problems/ Control Technologies



(?) = Technologies not yet available.
Source: Adapted from U. S. EPA, 1977 a.

35

Figure 5. Control Technologies for Energy Related Environmental Problems. (Source) Department of Energy and EPA, *Energy/ Environment Fact Book* (Washington, DC: EPA, Office of Research and Development, Office of Energy, Minerals and Industry, March 1978), 35.

Conclusion: Expansion of a Control Technology Approach

Princiotta's empirical validation of flue gas desulfurization systems established a shift in stationary source pollution control, precipitating a structural reconfiguration of environmental regulatory frameworks toward technological mandates. Princiotta's and his colleagues' demonstration of scrubbers shows how engineering and regulation became co-produced. In the throw-away scrubbing technology team, Princiotta was able to collect and disseminate information on scrubber manufacturing and operation via government reports, hearings, and other technology transfer activities. In addition, he also generated new knowledge about their reliability and cost.

The driving force behind this transition came both from the engineering achievements and technocratic practices of Princiotta and CSL engineers. While separating scaling and plugging into distinct problems and devising a solution based on alkali utilization is clearly an engineering achievement, Princiotta carefully created the technocratic process by which that achievement was mobilized as a resource for persuasion through congressional testimony, government reports, technology transfer, and the organization of evaluation panels such as SOTSEP. This paper reconstructed the regulatory state at the level of practices in laboratories and

hearing rooms by highlighting the dual role of EPA engineers as regulators and promoters.⁵⁵

While the EPA became the federal government's control tower for regulation and research for environmental protection, there were competing approaches to the management of environmental problems. As technical knowledge and regulatory practices became convoluted, new approaches and identities formed and expanded beyond the EPA. I conceptualize this as the fall of the community health approach and the expansion of the control technology approach.

Princiotta's demonstration of the scrubbers became a powerful tool in elevating the control technology approach in environmental policy. Princiotta's approach to the environmental effects of scrubbers is another point worth mentioning. Instead of minimizing the scale of the problem, the EPA engineers acknowledged the problem and shared the most current information with industry. At the same time, they used it as a way to draw more funding to initiate new projects. So, was Princiotta successfully resolving stationary air pollution by converting it into other types of pollution and continuing to look for engineering solutions? Health researchers at the EPA's ORD, who followed the "community health" approach, became marginalized by the expansion of the control technology approach.

After control technologies were introduced as pollution reduction instruments, control technologies emerged as the primary mechanism through which researchers and regulators addressed environmental problems. Consequently, robust critique regarding the side effects of these new devices diminished, and internal EPA debates concerning the prioritization of health and environmental effects research versus technology development was formally suppressed. Instead, managing the adverse byproducts of pollution control evolved into a distinct, specialized domain of technology assessment, where regulatory engineers assumed the authority to define problems, conduct research, test prototype devices, and formulate policy recommendations. Engineers and scientists who focused on newly created missions like reducing water and soil pollution from scrubber sludge gained institutional prominence. Ultimately, control technology that was embedded in a regulatory interface forestalled certain questions about how much technology would be helpful for dealing with environmental problems and what the EPA should do about the consequences of implementing new control technologies.

⁵⁵ I thank the reviewers and the editorial team to suggest emphasizing the multiple roles of Princiotta group.

Abstract

In this paper, I argue how Frank Princiotta and his colleagues at the Environmental Protection Agency (EPA) successfully demonstrated scrubbers as a viable pollution control technology. The study focuses on the Control Systems Laboratory (CSL) in Research Triangle Park, North Carolina, highlighting it as a crucial site for the co-production of emissions regulations, control technologies, and environmental institution-building. Although the electric utility industry preferred alternative methods, such as tall stacks and intermittent control systems, to disperse sulfur dioxide emissions from smokestacks, Princiotta's demonstration of scrubbers effectively resolved prevailing industry concerns regarding cost and operational reliability. The increasing waste from scrubbers, however, became another concern. Cooperating with the Tennessee Valley Authority (TVA), one of the main sulfur oxides emitters, and with other manufacturers of scrubbers, CSL engineers shifted the focus from pollution abatement for health benefit to development of pollution control technology for effective regulation. New knowledge about the operation and maintenance of power plants equipped with scrubbers, as well as a new identity as a regulatory engineer at the EPA, TVA, and contractors, contributed to expansion of scrubbers as a technology for regulatory engineering. Paradoxically, this regulatory and technological success came with the risk of using more coal-fired power plants facing the energy crisis of the 1970s.

Keywords: scrubber, Environmental Protection Agency (EPA), regulatory engineering, sulfur dioxide, control technology