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# ECONOMIC AND ENVIRONMENTAL IMPACTS OF PROPOSED CHANGES TO CLEAN WATER ACT THERMAL DISCHARGE REQUIREMENTS

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## Abstract

This paper examines the economic and environmental impact to the power industry of limiting thermal mixing zones to 1000 feet and eliminating the Clean Water Act §316(a) variance. Power companies were asked what they would do if these two conditions were imposed. Most affected plants would retrofit cooling towers and some would retrofit diffusers. Assuming that all affected plants would proportionally follow the same options as the surveyed plants, the estimated capital cost of retrofitting cooling towers or diffusers at all affected plants exceeds $20 billion. Since both cooling towers and diffusers exert an energy penalty on a plant's output, the power companies must generate additional power. The estimated cost of the additional power exceeds $10 billion over 20 years. Generation of the extra power would emit over 8 million tons per year of additional carbon dioxide. Operation of the new cooling towers would cause more than 1.5 million gallons per minute of additional evaporation.

**keywords:** thermal, mixing zone, §316(a) variance, cooling tower, diffuser

## Introduction

At nuclear and fossil-fuel power plants, electricity is generated by heating purified water to create steam. The steam is used to drive turbines, which in turn drive the generators that produce electricity. After leaving the turbines, the steam passes through a condenser, which serves to transfer heat from the hot steam to the cool water. The condenser contains numerous tubes that create a large surface area for heat transfer. A large volume of cooling water circulates through the tubes, absorbing heat from the steam, which independently circulates around the outside of the tubes. While passing through the condenser, the steam cools and condenses, and the temperature of the cooling water rises as the heat is exchanged from the steam to the cooling water. The condensers are designed to produce a vacuum at the outlet end of the turbine, which increases the efficiency of the system — the lower the initial temperature of the cooling water, the larger the vacuum that can be produced and the greater the efficiency.

Most power plants use either once-through cooling or closed-cycle cooling. Once-through cooling systems withdraw large volumes of water from a river, lake, estuary, or ocean, pump the water through the condenser, and return it to the same or a nearby body of water. Closed-cycle cooling systems[1] use a cooling tower and basin or a facility-specific cooling pond or cooling lake. In a closed-cycle cooling system with a cooling tower, water is withdrawn from the basin or other water source, pumped to the condenser, and then returned either to the cooling tower or to the basin

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[1] In this paper, the term "closed-cycle cooling" is meant to indicate use of a cooling tower unless some other type of closed cooling system is specifically mentioned.

or other water source. In a cooling tower, the most common type of closed-cycle cooling system, warm water comes in contact with air, and through a heat-exchange process, heat and moisture are transferred to the air and the water is cooled.

In 1991, the steam electric generating capacity in the United States totaled 568,871 MW. Generating units with 250,466 MW (44%) of this capacity used once-through cooling (Edison Electric Institute, 1993). The temperature of the discharged cooling water from such plants is typically limited by state thermal water quality standards, but two mechanisms allow adjustments to the limits. First, thermal mixing zones may be allowed which provide an opportunity for dilution and in-stream cooling of heated discharges prior to measuring compliance with the thermal standards. Each state has different mixing zone size and shape criteria. Most once-through cooling discharges rely on mixing zones.

Second, §316(a) of the Clean Water Act (CWA) allows the states or EPA to establish alternative thermal limits if the discharger can demonstrate that the otherwise applicable thermal effluent limits are more stringent than necessary to protect the organisms in and on the receiving water body, and that other, less stringent effluent limitations would protect those organisms. The variance does not eliminate the need to meet any applicable water-quality-based limits for constituents of cooling water other than heat or temperature. About 75% of the domestic generating capacity using once-through cooling systems operate under §316(a) variances (Edison Electric Institute, 1993).

In the 102nd Congress (1991-1992), the U.S. Senate considered a CWA reauthorization bill, S. 1081, which proposed limiting mixing zones to 1000 feet from the point of discharge and deleting §316(a) from the CWA (U.S. Senate, 1991). Although S. 1081 was not passed by the Senate, it is uncertain what changes, if any, Congress will make regarding thermal discharges. This paper discusses the economic and environmental impacts that such legislative changes could have on the power industry. The data and information presented in this paper are taken from three recent reports. Veil (1993) and Veil et al. (1993) estimate the impacts of deleting the §316(a) variance from the CWA and Veil (1994) estimates the impacts of limiting thermal mixing zones to 1000 feet.

**Methodology**

Information was collected from a sample of power plants in different parts of the country that use once-through cooling. The power companies were asked what each plant would do if it had to meet thermal limits within a 1000 foot mixing zone or if the §316(a) variance was no longer available. The power companies also were asked to provide cost estimates for constructing new facilities and equipment to meet the changed requirements. While geographical diversity was sought and achieved, this was not a statistically random sample of the steam electric power industry. Therefore, the results of this study are not necessarily representative of the entire industry. On the other hand, there is no reason to believe that the cost estimates developed in this manner are not a reasonably good gauge of the actual costs to the industry. Responses were received from 13 companies representing 79 plants for the mixing zone study and from 14 companies representing 38 plants for the §316(a) variance study.

To estimate national capital costs, cost rates in terms of dollars per kilowatt ($/kW - Veil, 1993; 1994) were multiplied by the number of affected megawatts (MW). This methodology assumes that the limited sample of plants providing data is representative of the nationwide power industry.

**Results**

§316(a) Variance Study - Capital Costs

If 316(a) variances are eliminated, about 189,000 MW of generating capacity (about 33% of the national total) would be unable to meet thermal standards. Of this capacity, 146,000 MW is at fossil-fuel plants and 43,000 MW is at nuclear plants. There are a variety of potential alternatives for each plant, including:

- seeking relaxed thermal discharge requirements from the state regulatory agency;
- retiring a plant;
- operating only seasonally or at a lower output;
- moving the discharge structure to deeper water;
- adding a diffuser; and
- retrofitting cooling structures such as cooling lakes or ponds or cooling towers.

The 14 power companies surveyed reported that they would retrofit cooling towers at nearly all of their 38 plants now operating under §316(a) variances. As a general rule, all fossil-fuel plants would employ mechanical-draft cooling towers and all nuclear plants would employ natural-draft towers. Cost estimates from these power companies to retrofit cooling towers are plotted against power production in Figures 1 and 2. Because costs for construction at a nuclear plant are nearly always higher than those for comparable construction at a fossil-fuel plant, data are presented separately for the two fuel types. The reported cost rates ($/kW scaled to 1992 dollars) for fossil-fuel plants range from $32/kW to $346/kW, with an average of $108/kW for 31 plants. The cost rates for nuclear plants range from $102/kW to $234/kW, with an average of $171/kW for 7 plants (Veil, 1993). Linear regression analysis was performed on the data. The resulting regression equations and correlation coefficients (r) are shown below.

**fossil-fuel plants** $y = 0.105x + 2.2$ $r = 0.77$ (1)

**nuclear plants** $y = 0.151x + 31.4$ $r = 0.53$ (2)

Lines representing these two equations are plotted on Figures 1 and 2, respectively. The regression line for fossil-fuel plants fits nicely and is statistically very significant (probability $< 0.01$). On the other hand, the regression line for nuclear plants does not represent the data set precisely. It is not statistically significant (probability $= 0.125$).[2] This result is a function of the widely spread data

[2] These probabilities represent the probability that the hypothesis (in this case, that the regression equation accurately expresses the distribution of data points) is incorrect. Generally, a probability $\leq 0.05$ is considered significant (the hypothesis is accepted), and a probability $< 0.01$ is very significant.

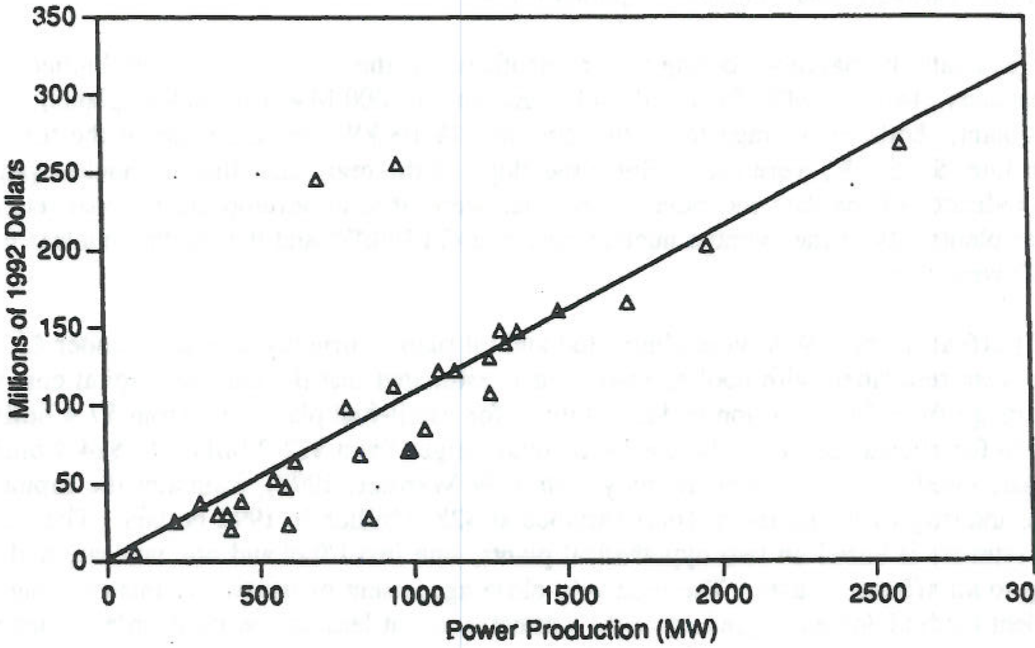


**FIGURE 1 Capital Cost to Retrofit Fossil-Fuel Units with Cooling Towers (from Veil, 1993)**

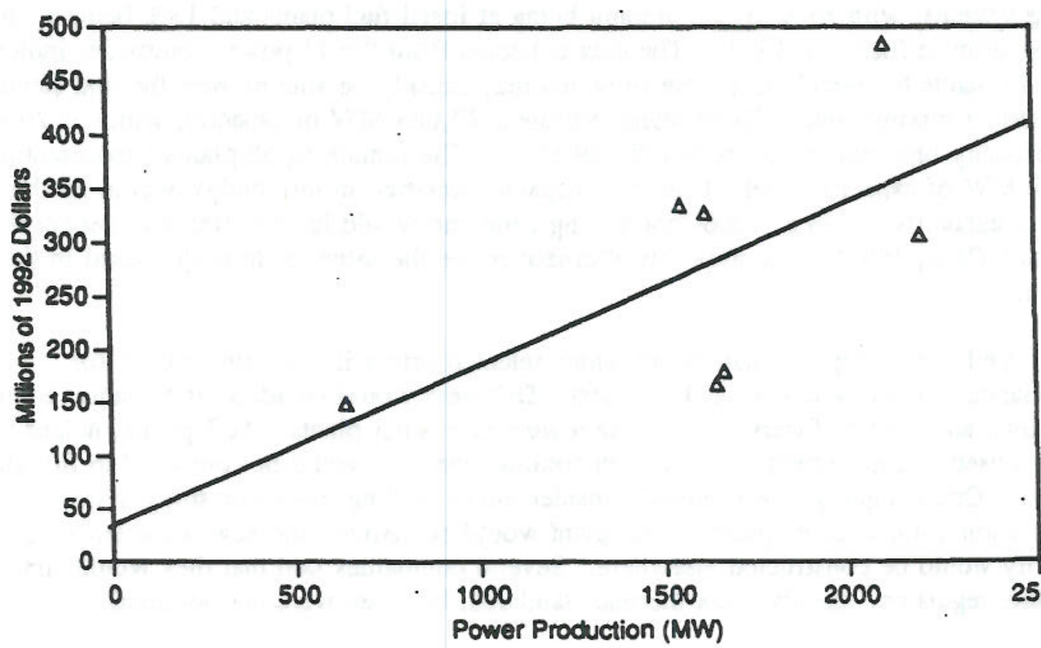


**FIGURE 2 Capital Cost to Retrofit Nuclear Units with Cooling Towers (from Veil, 1993)**

points and the relatively small number of points (N = 7).

To estimate the national cooling tower retrofit costs, the cost rates were multiplied by the affected capacity (146,000 MW for fossil-fuel plants and 43,000 MW for nuclear plants). For fossil-fuel plants, both the average fossil-fuel cost rate ($108/kW) and the slope of the fossil-fuel regression line ($105/kW) were used. Since the slope of the regression line for nuclear plants is not a reliable indicator of the data set, other approaches were used to develop the national retrofit cost for nuclear plants. Both the average nuclear cost rate ($171/kW) and the median nuclear cost rate ($201/kW) were used.

If §316(a) of the CWA were eliminated and all plants currently operating under §316(a) variances were retrofitted with cooling towers, it is estimated that the national capital cost would probably range from $15.3 billion to $15.8 billion for fossil-fuel plants and from $7.4 billion to $8.6 billion for nuclear plants. The combined total ranges from $22.7 billion to $24.4 billion in 1992 dollars (Veil, 1993). A similar study, (Stone & Webster, 1992), estimates the capital cost to the power industry of losing the §316(a) variance at $28.9 billion in 1992 dollars. The Stone & Webster estimate is based on two hypothetical plants, one fossil-fuel and one nuclear, with the costs scaled up to all affected plants. The relatively close agreement of the two estimates using independent methodologies suggests that the estimates are at least in the right order of magnitude.

Mixing Zone Study - Capital Costs

About 44% of the nation's power (250,466 MW) is generated at plants using once-through cooling systems, with 85% of that amount being at fossil-fuel plants and 15% being at nuclear plants (Edison Electric Institute, 1993). The data collected from the 13 power companies indicate that 24 of the 79 plants for which data were provided may already be able to meet thermal standards within a 1,000-foot mixing zone. These plants represent 20,085 MW of capacity, which is 26% of the total capacity reported in the study (78,049 MW). The remaining 58 plants,[3] representing 57,964 MW of capacity (74% of the total capacity reported in this study), would not be able to meet thermal standards within a 1,000-foot mixing zone and would have to find an alternative mode of operation (Veil, 1994). The available alternatives are the same as those discussed in the previous section.

Veil (1994) reports that the 58 plants selected primarily two alternatives for compliance — cooling towers and diffusers. Diffusers would be added at 6 plants, cooling towers at 39 plants, and both diffusers and cooling towers at 8 other plants. At 2 plants, helper towers (towers used to supplement once-through cooling systems) would be converted to full closed-cycle cooling. One company said it would consider either cooling towers or spray systems to enhance evaporation at three of its plants. One plant would be retired, and new replacement generating capacity would be constructed elsewhere. Several companies said that they would first try to have the state regulatory agency relax thermal standards, but they were not optimistic about the success of

[3] The total of 24 plants meeting the mixing zone and 58 plants not meeting the mixing zone adds to 82 rather than 79 plants. Three of the plants have one set of units that can meet the mixing zone and a different set of units that cannot meet the mixing zone. Those plants have been counted in both categories.

such a request. For the sake of calculating a national cost estimate, all alternatives involving use of cooling towers have been combined with the one plant that would be retired[4] into a single category (52 plants). The six plants using just diffusers constitute a second category.

The cooling tower cost rates used to calculate a national cost estimate are the higher end of the ranges from Veil (1993) ($108/kW for fossil-fuel plants and $201/kW for nuclear plants). For diffusers, the only relevant source of data is a report prepared by National Economic Research Associates, Inc. and Stone & Webster (1978). The capital cost rates presented in that report were modified by Veil (1994) to equal $43/kW for fossil fuel plants and $59/kW for nuclear plants.

Table I shows the selected alternatives, the percentage of capacity (based on the sample data for this study) anticipated to use each alternative, the estimated capacity (in MW) nationwide that would use each alternative, the cost rates, and the total capital costs. The total estimated national capital cost for retrofitting plants that cannot meet thermal standards within a 1,000-foot mixing zone is $21.4 billion.

**TABLE I - Calculation of National Capital Cost Estimate (from Veil, 1994)**

| Selected Alternative | Percentage of Capacity Using Alternative[a] | Affected Capacity Using Alternative (MW) | Cost Rate ($/kW) | Total Cost (million $) |
|---|---|---|---|---|
| **Diffuser** | | | | |
| Fossil-fuel plants | 5 | 12,523 | 43 | 538 |
| Nuclear plants | 1 | 2,504 | 59 | 148 |
| **Cooling towers** | | | | |
| Fossil-fuel plants (mechanical-draft towers) | 58 | 145,270 | 108 | 15,690 |
| Nuclear plants (natural-draft towers) | 10 | 25,047 | 201 | 5,034 |
| No changes needed | 26 | 65,121 | N/A | 0 |
| Total | 100 | 250,466 | N/A | 21,410 |

[a] Based on data supplied by power companies for 79 plants.

[4] Because the cost of retiring a plant and building new generating capacity greatly exceeds the cost of adding a cooling tower, retirement is an unlikely alternative for many plants. By combining this one plant with those plants adding cooling towers, the plant is still counted in the data set, and the final cost estimate becomes somewhat conservative as a result.

Costs Associated with the Energy Penalty

Adding cooling towers or diffusers to existing power plants results in an energy penalty, a reduction of plant output. The energy penalty is caused by increases in turbine back pressure that result in less efficient power generation, additional power requirements for pumping recycled water to the top of a natural-draft cooling tower or operating the fans at a mechanical draft cooling tower, and increased pump head requirements due to the restricted flow through a diffuser. Power companies have several options relative to the energy penalty. They can operate the plant at lower net power output, or in some cases, they can run it more frequently or at a higher temperature. The latter option requires that additional fuel be burned to maintain output. In either case, there is an energy cost associated with the retrofitting of cooling towers.

Veil et al. (1993) report that cooling towers result in an energy penalty for fossil-fuel plants ranging from 1.1 to 4.6%, with most of the data falling between 1.5 to 2.5%. The cooling tower energy penalty for nuclear plants ranges from 1.0 to 5.8%, with the most relevant data falling between 2 to 3%. The energy penalty from diffusers is 0.02% for fossil-fuel plants and 0.028% for nuclear plants (National Economic Research Associates, Inc. and Stone & Webster, 1978).

The cost of compensating for the energy penalty has two components — the cost of generating replacement energy and the capital cost of building new generating capacity. The replacement energy cost is a function of the cost per kilowatt-hour, historical capacity factors, and the percent energy penalty. The capital cost is a utility-specific decision based on existing reserve margins, construction schedules for planned facilities, fuel prices, load projections, and the availability of power purchases from interconnected systems. To integrate these capital cost issues, Veil et al. (1993) suggested using a range of replacement capacity costs -- $450/kW for a 50-MW combustion turbine unit to $1080/kW for upgrading a 500-MW coal unit to 600 MW (Electric Power Research Institute, 1988; 1989).

Table II summarizes the energy penalty costs estimated in Veil et al. (1993) and Veil (1994). It

**TABLE II - Nationwide Generation Capacity to Be Replaced Due to Energy Penalty and Associated Energy and Capital Costs (based on Veil et al., 1993 and Veil, 1994)**

| Category | Replacement Capacity Needed (MW) | Annual Energy Cost ($ million) | Levelized Energy Cost for 20 Years ($ billion) | Capital Cost for Replacement Capacity ($ billion) |
|---|---|---|---|---|
| Loss of §316(a) Variance | 3050 - 4940 | 420 - 670 | 11.4 - 18.4 | 1.4 - 5.3 |
| 1000' Mixing Zone | 2700 - 4400 | 370 - 590 | 10 - 16.2 | 1.2 - 4.8 |

shows the estimate of replacement capacity needed for each category (§316(a) variance and 1000 foot mixing zone), the cost of the additional energy needed, and the capital cost of constructing additional generating capacity to meet the energy penalty. The levelized, 20-year costs assume zero real escalation in fuel and variable operating and maintenance costs, a discount rate of 10.5%, and an annual inflation rate of 4%. For both categories, the 20-year energy cost exceeds $10 billion and the capital cost for constructing replacement capacity exceeds $1 billion.

**Discussion**

There are several additional issues relating to thermal discharges and other environmental impacts. These are discussed below.

Heat is a Unique Pollutant

Congress recognized that heat is a unique type of pollutant by including the §316(a) variance in the CWA. Heat is generally not persistent and does not accumulate in the environment. It is not a toxic or hazardous substance, although all organisms can be harmed by excessive heat. The most compelling reason for giving special treatment to heat as a pollutant is that upon entering a body of water, heat rapidly dissipates to the surrounding water and to the atmosphere. The impacts of heat are limited to a relatively localized zone around the source of heat.

Heat is a natural part of the environment, and solar radiation is a primary driving force in ecosystem dynamics. In some cases, thermal discharges can actually create a preferred environment for aquatic organisms. For this reason, fishermen frequent areas around power plant discharges during cool weather. Several power companies in the mid-Atlantic states operate striped bass hatcheries that maintain optimum temperatures year-round by blending the proper mix of ambient water and discharged once-through cooling water.

Discharges of heat are not necessarily harmful to the environment. Regulatory decisions concerning thermal discharges should provide as much flexibility as possible to account for heat dissipation and local aquatic organisms' heat tolerance.

Regulatory Agency Must Be Satisfied that 316(a) Variance is Protective

Although potential impacts are associated with discharges permitted under §316(a) variances, regulatory agencies have the authority and mandate to ensure that the impacts are minimal or nonexistent. A §316(a) variance is not trivially granted. To receive the variance, the discharger must demonstrate to the regulatory agency that a discharge that exceeds the otherwise applicable thermal requirements will still protect a balanced, indigenous population in and on the receiving water. The effort required to make this case varies greatly, depending on state requirements and the site-specific potential for impacts. In nearly all cases, however, the demonstration involves extensive evaluation of potential impacts and characterization of local aquatic populations. A regulatory agency can reject a demonstration or ask the discharger to study certain issues in more detail.

In 1992, the U.S. Environmental Protection Agency (EPA) evaluated the effectiveness of the §316(a) variance program. EPA found that for the majority of facilities, impacts from thermal effluent have not been found to be large or permanent. Several cases in which severe problems were found may have been the result of inadequate permit limits, rather than facility noncompliance with permit limitations (Reiley, 1992).

Considering the oversight authority provided to regulatory agencies, the §316(a) variance program represents a "safe" form of economic incentive for thermal dischargers. The use of §316(a) and other types of CWA variances can greatly reduce the cost to dischargers without increasing the risk to the environment beyond acceptable levels (Veil, 1993a). Congress has been searching for viable economic incentives to include in a reauthorized CWA. Therefore, it seems counterproductive to delete the §316(a) variance.

Environmental Impacts

Retrofitting cooling towers and diffusers would create secondary environmental impacts. For example, generating additional power to meet the energy penalty would increase carbon dioxide emissions by an estimated 8.2 million tons per year for plants not meeting thermal standards within a 1000 foot mixing zone and 9 million tons per year for plants losing the §316(a) variance. Construction of new generating units would cause changes in land use, runoff characteristics, and wildlife habitat. Conversion from once-through cooling systems to cooling towers would result in increased evaporation of about 2.6 million gallons per minute for plants not meeting the mixing zone limits and 1.5-2.8 million gallons per minute for plants losing the variance (Veil et al., 1993 and Veil, 1994). Other potential impacts from cooling towers include cooling tower drift, noise, aesthetics, additional discharge of biocides in cooling tower blowdown, and additional solid waste as cooling tower basin sludge.

Most of the environmental impacts discussed above are not significant at plants where cooling towers have been designed and built as part of the original installation. This conclusion would not hold true if a large number of new cooling towers were installed as retrofits. Many of the plants that currently operate under §316(a) variances are older plants located in or near urban or suburban areas. Environmental impacts like drift or noise, which are mitigated by the large buffer zones around plants in rural locations, could present serious problems for urban locations. Freezing or fogging from cooling tower plumes could present a safety hazard. Zoning concerns in populated areas would likely place greater restrictions on the appearance and noise level of cooling towers.

The water consumption issue may be the most critical concern for a retrofitted cooling tower. If a plant is designed to consume a certain volume of water through evaporation, then that volume is factored in from the time a plant is built. However, if a cooling tower is added later, adequate water resources may not be available to accommodate the increased demand.

Other Affected Industries

Although the steam electric power industry is the primary industrial sector that would be affected by a 1,000-foot mixing zone limit, other industries that use large volumes of water for cooling might also be affected. Included are the steel, aluminum, paper, and cement manufacturing industries and waste-to-energy facilities. No attempt has been made to estimate costs for these other industrial sectors.

The §316(a) variance is used almost exclusively by the power industry and consequently, loss of the variance would have relatively little impact on other industrial sectors.

**Conclusions**

- S. 1081, which would have prohibited §316(a) variances and restricted thermal mixing zones to 1000 feet, was not passed by the 102nd Congress. Although current CWA reauthorization legislation does not propose prohibiting §316(a) variances or restricting thermal mixing zones, it remains unclear how Congress will ultimately deal with thermal discharge issues. Until Congress has passed a CWA reauthorization bill, the potential for changes to the thermal requirements remains. This paper highlights the large costs that are associated with two previously proposed changes to the thermal discharge requirements.

- Based on data collected from a large sample of power companies representing different geographic regions, most plants currently operating under a 316(a) variance could not meet thermal standards without the variance and most plants using once-through cooling systems could not meet thermal standards within a 1000 foot mixing zone. The cost to retrofit cooling towers and diffusers at existing power plants would exceed $20 billion. The retrofitted plants would need to spend more than $10 billion in additional fuel costs and over $1 billion to construct additional generating capacity to overcome the energy penalty.

- The §316(a) variance program has not caused significant environmental degradation and has resulted in considerable cost savings to ratepayers, yet deletion of the variance would have a very large negative economic impact on the power industry. There appears to be no justification for deleting the §316(a) variance.

- Any attempt to place statutory restrictions on thermal mixing zones would result in a very large cost to the power industry and perhaps to other industries as well. Policymakers should give careful consideration to these costs, in addition to the increased air emissions, solid wastes, and water evaporation attributable to cooling towers and diffusers, before adopting any additional national thermal mixing zone restrictions. The potential benefits of a 1,000-foot mixing zone have not been widely discussed. Unless the potential benefits are believed to be commensurate with the large cost, little justification exists for limiting thermal mixing zones to 1,000 feet from the point of discharge.

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