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Passamaquoddy Tribe

Cement Kiln Flue Gas Recovery Scrubber™

Project Performance Summary
Clean Coal Technology Demonstration Program

June 1999

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Industrial Applications

Cement Kiln Flue Gas Recovery Scrubber™

Cement kiln dust, which was posing a major solid waste management problem, was used in a unique Recovery Scrubber™ process to achieve the following objectives:

- **Remove 90+ percent of SO_2 from the flue gas**
- **Convert the kiln dust to feedstock**
- **Produce fertilizer and distilled water**
- **Generate no pollutants**

The successfully demonstrated Recovery Scrubber™ has application not only to coal-fired cement plants, but to pulp and paper and waste-to-energy industries, as well as to power generation where alkali waste is accessible.

Overview

A unique stack gas Recovery Scrubber™ developed by the Passamaquoddy Indian Tribe was demonstrated on the 450,000-ton/yr coal-fired cement kiln at the Dragon Products Company plant in Thomaston, Maine.

The project is part of the U.S. Department of Energy's Clean Coal Technology Demonstration Program (CCTDP) established to address energy and environmental concerns related to coal use. Cost-shared partnerships with industry were sought through five nationally competed solicitations to accelerate commercialization of the most advanced coal-based power generation and pollution control technologies. The CCTDP, valued at nearly $6 billion, has leveraged federal funding twofold through the resultant partnerships encompassing utilities, technology developers, state governments, and research organizations. This project was one of 16 selected in May 1988 from 55 proposals submitted in response to the Program's second solicitation.

Using cement kiln dust waste as the sole reagent, the Recovery Scrubber™ pollutant removal efficiency over the last several months of demonstration averaged 94.6 percent for SO_2 and nearly 25 percent for NO_x emissions. Particulate emissions averaged 0.005–0.007 gr/std ft^3, or less than one-tenth the current limit for cement plants. The cement kiln dust, representing 10 percent of the feedstock otherwise lost as waste, was transformed into kiln feedstock and fertilizer. The only other product resulting from the process was distilled water. No pollutants were generated.

Additional benefits demonstrated were reductions in emissions of volatile organic compounds (VOCs) from 72 to 83 percent and carbon dioxide (CO_2) by 2 percent. Pilot testing indicated that hydrogen chloride (HCl) emissions can be reduced by 98 percent and dioxins and furans can be captured as well.

The estimated capital costs to duplicate the prototype is $10,090,000 in 1990 constant dollars. Annual operating and maintenance costs are estimated at $500,000 (1990 constant dollars). For most cement kiln applications, the Recovery Scrubber™ can be expected to operate at a net annual profit. Costs of capital and interest plus maintenance and operation are generally offset by savings associated with not having to purchase premium fuels, dispose of waste, or procure as much feedstock, and by revenues from fertilizer sales.

Dragon Products continues to operate the Recovery Scrubber™ at the Thomaston plant. The technology has potential in other industrial applications where the solid waste has alkali content, such as the pulp and paper and waste-to-energy industries, and also in the power generation sector where alkali waste is readily accessible.

The Project

The project was initiated as a result of the Dragon Cement Company facing higher fuel costs because of more stringent sulfur emissions regulations and increased kiln dust disposal costs. Existing landfill capacity was nearly exhausted. To meet emission regulations, fuel sulfur would have had to be reduced by half. The premiums associated with the purchase of lower sulfur coal were deemed untenable since fuel costs represented 30 to 40 percent of operating costs. Securing permits for a new landfill also was viewed as too expensive and time consuming because permitting agencies had been focusing a great deal of attention on cement kiln dust issues. To address these concerns, the project sought to accomplish the following objectives:

- Use the cement kiln dust (CKD) as the sole reagent to reduce air emissions
- Achieve 90–95 percent sulfur control while using high-sulfur eastern bituminous coals
- Convert a substantial percentage of the CKD to kiln feedstock
- Produce a potentially significant commercial by-product (potassium-based fertilizer)
- Use waste heat for evaporation and concentration of the potassium-based fertilizer
- Demonstrate the overall technical, economic, and environmental viability of the technology

All objectives were met or exceeded. Further testing was conducted to evaluate scrubber effectiveness in removing NO_x, HCl, VOCs, and particulates. The scrubber was evaluated over 3 basic operating intervals dictated by winter shutdowns for maintenance and inventory and 14 separate operating periods (within these basic intervals) largely determined by unforeseen host plant maintenance and repairs and a depressed cement market. Over the period August 1991 to September 1993, a total of 5,316 hours were logged, 1,400 hours in the first operating interval, 1,300 hours in the second interval, and 2,600 hours in the third interval. Sulfur loadings varied significantly over the operating periods due to variations in feedstock and operating conditions.

Project Sponsor
Passamaquoddy Technology, L.P. (formed upon sale of the Dragon Cement Company by the Passamaquoddy Tribe to CDN (USA), a Spanish-based consortium)

Additional Team Members
Dragon Products Company—project manager and host
E.C. Jordan—system engineer
HPD, Inc.—reactor vessel designer and fabricator
Cianbro Corporation—constructor

Location
Thomaston, Knox County, ME
(Dragon Products Company's coal-fired cement kiln)

Technology
Passamaquoddy Technology, L.P.'s Recovery Scrubber™

Plant Capacity/Production
450,000 tons/yr of cement clinker
100 tons/hr of raw material
52 tons/hr of water (for feedstock slurry)
10 tons/hr of coal (2.5–3.0% sulfur)
250,000 std ft^3/min of kiln gas

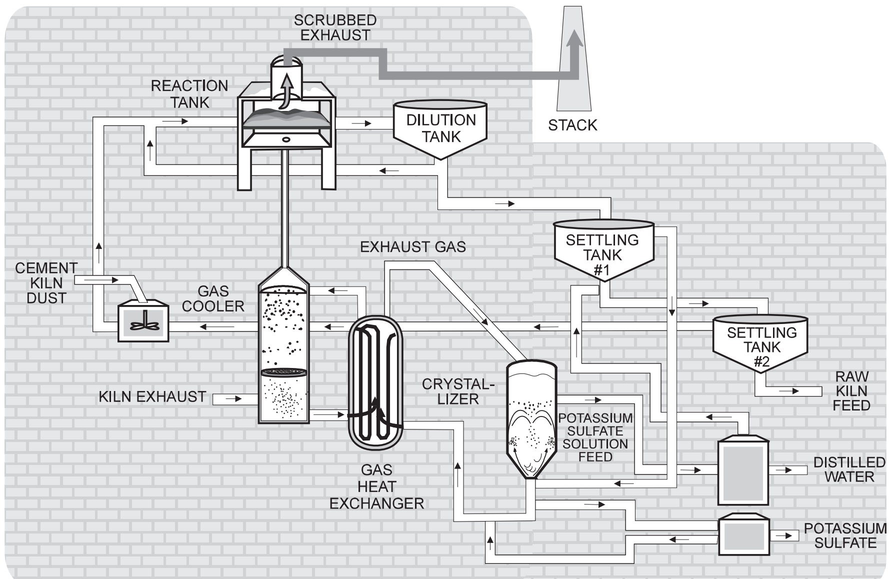
Demonstration Duration
August 1991–September 1993

- 3 basic operating intervals dictated by winter shutdown for maintenance and inventory
- 14 separate operating periods (within the 3 intervals) determined largely by unforeseen host plant maintenance and repairs and a depressed cement market

Project Funding

Total project cost	$17,800,000	100%
DOE	5,982,592	34%
Participant	11,817,408	66%

THE TECHNOLOGY



The technology uses cement kiln dust (CKD), an alkaline-rich (potassium) waste, to react with the acidic flue gas. This CKD, representing about 10 percent of the cement feedstock otherwise lost as waste, is formed into a water-based slurry and mixed with the flue gas as the slurry passes over a perforated tray that enables the flue gas to percolate through the slurry.

The SO_2 in the flue gas reacts with the potassium to form potassium sulfate, which stays in solution and remains in the liquid as the slurry undergoes separation into liquid and solid fractions. The solid fraction, in thickened slurry form and freed of the potassium and other alkali constituents, is returned to the kiln as feedstock (it is the alkali content that makes the CKD unusable as feedstock). No dewatering is necessary for the wet process used at the Dragon Products Plant. The liquid fraction is passed to a crystallizer that uses waste heat in the flue gas to evaporate the water and recover dissolved alkali metal salts. A recouperator lowers the incoming flue gas temperature to prevent slurry evaporation, enables the use of low-cost fiberglass construction material, and provides much of the process water through condensation of exhaust gas moisture.

Waste CKD, exhaust gases (including waste heat), and wastewater are inputs to the process. Renovated CKD, potassium-based fertilizer (either KCl or K_2SO_4), scrubbed exhaust gas, and distilled water are process outputs. There is no waste. Nothing goes to a landfill or sewer.

Demonstration Results

- The SO_2 removal efficiency averaged 94.6 percent during the last several months of operation and 89.2 percent for the entire operating period.
- The NO_x removal efficiency averaged nearly 25 percent during the last several months of operation and 18.8 percent for the entire operating period.
- All of the 250-ton/day CKD waste produced by the plant was renovated and reused as feedstock. This resulted in reducing the raw feedstock requirement by 10 percent and eliminating solid waste disposal costs.
- Particulate emission rates of 0.005–0.007 gr/std ft^3, about 1/10 that allowed for cement kilns, were achieved with dust loadings of approximately 0.04 gr/std ft^3.
- Pilot testing conducted at U.S. Environmental Protection Agency (EPA) laboratories under Passamaquoddy Technology, L.P. sponsorship showed a 98 percent HCl removal.
- On three different runs, VOC (as represented by alpha-pinene) removal efficiencies of 72.3, 83.1, and 74.5 percent were achieved.
- A reduction of approximately 2 percent in CO_2 emissions was realized through recycling of the CKD.
- Capital costs are approximately $10,090,000 for a Recovery Scrubber™ to control emissions from a 450,000-ton/yr wet process plant, with a simple payback estimated in 3.1 years. Operating and maintenance costs, estimated at $500,000/yr, plus capital and interest costs are generally offset by avoided costs associated with fuel, feedstock, and waste disposal and with revenues from the sale of fertilizer. (Costs are in 1990 constant dollars.)

The Passamaquoddy Recovery Scrubber™ made the Dragon Products Company kiln in Maine one of the world's cleanest industrial coal-fired cement-making operations in existence.

Overview of Dragon Products cement plant, showing the rotary kiln in the middle and Recovery Scrubber™ complex to the right

Operational Performance

Several design problems (outlined below) were discovered and corrected during start-up. No further problems were experienced in these areas during actual operation.

- Corrosion on the shell of the evaporator shell-and-tube heat exchanger was corrected by changing from carbon steel to a 1925 HMO alloy.
- Flatness in the reaction tank's perforated tray had to be corrected to plus or minus 1/8 inch over the entire area of 48 x 28 ft. To achieve even gas distribution in the plenum below the perforated tray, which is critical to effective operation, required the addition of baffles.
- Mixing of CKD and water in a tank followed by pumping of the slurry to the reaction tank proved inadequate because gypsum formed in and plugged the feed lines. This system was replaced with a vortex mixer in which dry CKD is introduced as a powder and a high-volume flow of previously reacted slurry is used as a tangentially introduced carrier fluid.
- Particulate buildup at the perforations plugged the reaction tank sieve tray, prompting addition of a high-pressure, moving water spray directed at the base of the tray.

Two problems persisted into the demonstration period:

- The mesh-type mist eliminator, which was installed to prevent slurry entrainment in the flue gas, experienced plugging. Attempts to design a more efficient water spray for cleaning failed. However, replacement with a chevron-type mist eliminator during the third operating interval was effective.
- Potassium sulfate pelletization proved to be a more difficult problem. The cause was eventually isolated and found to be excessive water entrainment due to carry over of gypsum and syngenite. Hydroclones were installed in the crystallizer circuit to separate the very fine gypsum and syngenite crystals from the much coarser potassium sulfate crystals. Although the correction was made, it was not in time to realize pellet production during the demonstration period.

During the last operating interval, Recovery Scrubber™ availability (discounting host site downtime) steadily increased from 65 percent in April to 99.5 percent in July.

Dragon cement plant kiln with cement preparation mixing tanks in Foreground

Recovery Scrubber™ on the left with original stack on the right

Environmental Performance

An average 250 tons/day of CKD waste generated by the Dragon Products plant was used as the sole reagent in the Recovery Scrubber™ to treat approximately 250,000 std ft^3/min of flue gas. All the CKD, or approximately 10 tons/hr, were renovated and returned to the plant as feedstock and mixed with about 90 tons/hr of fresh feed to make up the required 100 tons/hr. The alkali in the CKD was converted to potassium-based fertilizer, eliminating all solid waste.

Figure 1 is a plot of SO_2 levels at the scrubber inlet and outlet in pounds per hour over the 14 operating periods.

Figure 2 is a plot of NO_x levels at the scrubber inlet and outlet in pounds per hour over the 14 operating periods.

Table 1 lists the SO_2 and NO_x inlet and outlet readings in pounds per hour, removal efficiency as a percentage for each operating period, and the number of hours per operating period.

Average removal efficiencies during the demonstration period were 89.2 percent for SO_2 and 18.8 percent for NO_x emissions. No definitive explanation for the NO_x control mechanics was available at the conclusion of the demonstration.

Figure 1. Time Periods 1–14—Inlet SO_2 and Outlet SO_2

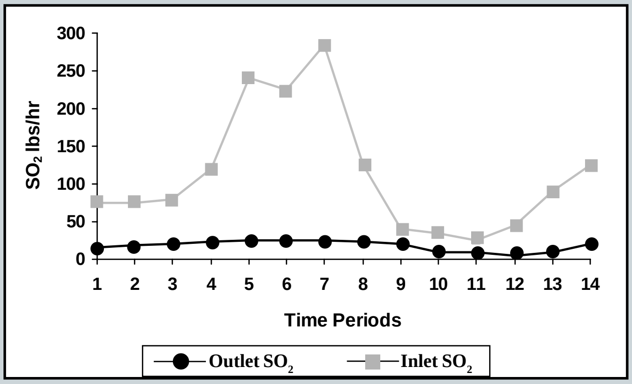


Figure 2. Time Periods 1–14—Inlet NO_x and Outlet NO_x

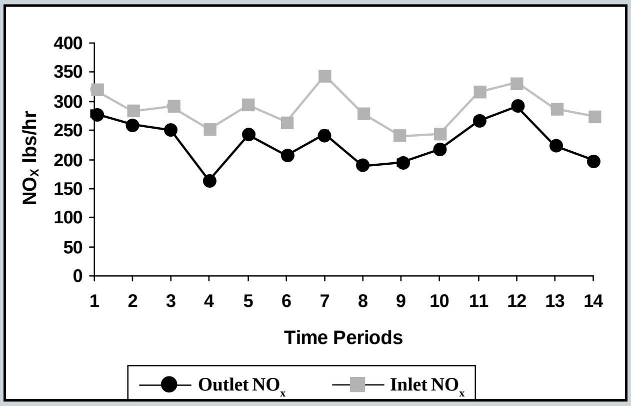


Table 1. Summary Emissions and Removal Efficiencies

Operating Period	Operating Time (hr)	Inlet (lb/hr) SO_2	Inlet (lb/hr) NO_x	Outlet (lb/hr) SO_2	Outlet (lb/hr) NO_x	% Removal Efficiency SO_2	% Removal Efficiency NO_x
1	211	73	320	10	279	87.0	12.8
2	476	71	284	11	260	84.6	08.6
3	464	87	292	13	251	85.4	14.0
4	259	31	252	16	165	87.6	34.5
5	304	245	293	28	243	88.7	17.1
6	379	222	265	28	208	87.4	21.3
7	328	81	345	28	244	90.1	29.3
8	301	124	278	10	188	91.8	32.4
9	314	47	240	7	194	85.7	19.0
10	402	41	244	6	218	86.1	10.5
11	460	36	315	6	267	83.4	15.0
12	549	57	333	2	291	95.9	12.4
13	464	86	288	4	223	95.0	22.6
14	405	124	274	9	199	92.4	27.4
Total	**5,316**						
Weighted Average		**109**	**289**	**12**	**234**	**89.2**	**18.8**

CKD is transformed to feedstock in the Recovery Scrubber™. Typical chemistry for the cement kiln feed, CKD, and treated CKD are provided below.

	Raw Feed	CKD	Range Treated CKD
SiO_2	13.7	13.1	11.6–13.0
Al_2O_3	3.3	2.8	3.2–4.0
Fe_2O_3	1.5	1.3	1.4–1.8
CaO	44.0	46.1	37.8–42.5
MgO	2.9	2.4	2.5–2.9
SO_3	0.3	5.4	2.5–6.0
K_2O	1.1	4.5	1.6–2.6
Na_2O	0.4	0.4	0.3–0.4
LOI	34.5	24.5	30.0–33.0

Aside from the operating period emissions data, an assessment was made of inlet SO_2 load impact on removal efficiency. For SO_2 inlet loads in the range of 100 lb/hr or less, Recovery Scrubber™ removal efficiency averaged 82.0 percent. For SO_2 inlet loads in the range of 100–200 lb/hr, removal efficiency increased to 94.1 percent and up to 98.5 percent for loads greater than 200 lb/hr.

In compliance testing for the State of Maine's Department of Environmental Quality, the Recovery Scrubber™ was subjected to dust loadings of approximately 0.04 gr/std ft^3 and demonstrated particulate emission rates of 0.005–0.007 gr/std ft^3—less than 1/10 the allowable limit. The wet process proved efficient at capturing particles in the respirable dust range of 10 microns or less, which are of particular concern as media for airborne toxins. Removal efficiency could be further enhanced by more rigorous demisting of the scrubbed gas before release, but the increased fan power needed to overcome a higher pressure drop across the demister would increase cost.

A 2-day test was conducted on the scrubber to evaluate its potential for VOC removal. On three different runs, VOC removal efficiencies of 72.3, 83.1, and 74.5 percent were achieved. VOCs were represented by alpha-pinene.

Following pilot testing of the scrubber at U.S. EPA laboratories (under Passamaquoddy sponsorship) where 98 percent HCl removal efficiencies were realized, the U.S. EPA conducted HCl tests at the Dragon Products plant. However, the results of these tests were not available at the close of the DOE demonstration project.

Recycling CKD enabled a 2 percent reduction in CO_2 emissions because the degree of feedstock calcination required was lessened. The percent reduction that can be expected in any given application is in direct proportion to the amount of CKD recycled and the extent of calcination undergone by the CKD.

Economic Performance

The estimated "as built" capital cost to reconstruct the Dragon Products prototype, absent the modifications, is $10,090,000 in 1990 constant dollars. The cost summary by discipline area and system follows:

Discipline Area —		
Civil	20%	$1,997,000
Mechanical	65%	$6,566,00
Electrical & instrumentation	15%	$1,527,000
Total	**100%**	**$10,090,000**
System —		
Exhaust gas related	36%	$3,624,000
CKD related	13%	$1,327,000
By-product related	43%	$4,379,000
Common	8%	$760,000
Total	**100%**	**$10,090,000**

Annual operating and maintenance costs are estimated at $500,000. Long-term annual maintenance costs are estimated at $150,000. Power costs, estimated at $350,000/yr, are the only significant operating costs. There are no costs for reagents or disposal, and no dedicated staffing or maintenance equipment are required.

Considering various revenues and avoided costs that may be realized by installing a Recovery Scrubber™ similar in size to the one used at Dragon Products, simple payback on the investment is projected in as little as 3.1 years. In making this projection, $6,000,000 was added to the "as built" capital costs to allow for contingency, design/permitting, construction interest, and licensing fees. The following revenues and avoided costs were considered:

- Value of raw materials recovered
- Avoided cost of CKD landfilling
- Recovery of existing CKD landfill
- High-sulfur fuel cost savings
- Revenue from sale of potassium-based fertilizer
- Revenue for accepting waste materials and value of waste as a raw material

Included in these considerations are savings on mining and feedstock preparation costs, recovery of usable real estate, elimination of potential future environmental liabilities, and life extension of the raw material quarry.

Reaction tank at base of active stack with adjacent auxiliaries

Commercial Applications

Crystallizer and condenser in foreground and flue gas cooler in background

Of the approximately 2,000 Portland cement kilns in the world, about 250 are in the United States and Canada. These 250 kilns emit an estimated 230,000 tons/yr of SO_2 (only three plants have SO_2 controls, one of which is the Recovery Scrubber™). The applicable market for SO_2 control is estimated at 75 percent of the 250 installations. If full penetration of this estimated market were realized, approximately 150,000 tons/yr of SO_2 reduction could be achieved.

Market drivers also include concerns about costs and the potential environmental consequences from continuing to landfill CKD wastes. Without special precautions, alkalis leach into groundwater, and where hazardous materials are used as fuel, greater precautions and potential consequences are introduced. The Recovery Scrubber™ eliminates the need for landfilling.

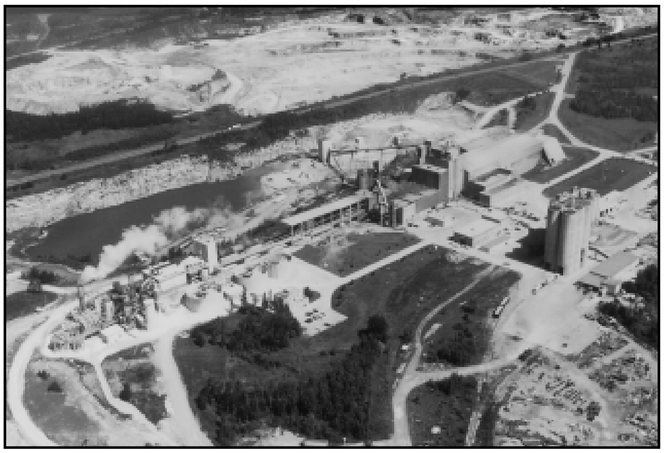
Cement manufacture throughout the world is largely by one of two basic processes, wet or dry. Nearly 40 percent of the operating kilns in the United States use the wet process. Wet-process kilns such as the Dragon products plant are less fuel efficient than dry kilns, increasing the importance of maintaining the options of using indigenous high-sulfur fuels and burning hazardous waste in return for tipping fees. (High specific fuel consumption of the wet processes led to pioneering the use of alternative fuels, including hazardous wastes.) Use of the Recovery Scrubber™ retains both options.

The Recovery Scrubber™ has application to both wet and dry processes. Wet processes produce more waste CKD and should see greater potential savings from reusing the raw material. Wet process plants wasting CKD that apply the Recovery Scrubber™ will generally operate at a substantial profit. The smaller amount of CKD produced from dry processes has higher concentrations of volatile contaminants (potassium, sodium, sulfur, and chlorine) and produces more salt by-product. Because the solid fraction of the Recovery Scrubber™ is a slurry, dry processes must factor in the additional cost of drying the slurry (requisite to use as feedstock).

Pulp and paper mills emit large quantities of acidic exhaust gas. To reduce fuel costs and the volume of solid waste, wood waste, bark, and sludge are used as boiler fuel. This, in turn, produces a high-alkali ash. The alkali in the ash can be used in a Recovery Scrubber™ to scrub acidic exhaust gas. The resulting product can then be used as cement kiln feedstock or disposed of without threat of leachates contaminating groundwater.

Waste-to-energy facilities produce acid gases and solid waste deemed hazardous because of high alkalinity and heavy metals rendered soluble through incineration. The Recovery Scrubber™ has the potential to control acid gases while reducing alkalinity and heavy metal solubility to the point where the product can be safely landfilled or used as cement kiln feed.

The Recovery Scrubber™ also has potential application in the power generation sector where (1) there is opportunity for major fuel cost savings from use of high-sulfur fuels and (2) alkali waste (e.g., biomass ash) is readily accessible.



Overview of Dragon products plant with CKD disposal area in background

Overview of Recovery Scrubber™, showing reaction tank at base of stack, dilution tank immediately adjacent to the right, and settling tank to the far right

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References

- *Passamaquoddy Technology Recovery Scrubber™: Final Report.* Volumes 1 and 2. Passamaquoddy Tribe. February 1994. (Vol. 1 available from NTIS as DE94011175, Vol. 2 as DE94011176.)
- *Passamaquoddy Technology Recovery Scrubber™: Public Design Report.* Report No. DOE/PC/89657-T2. Passamaquoddy Tribe. October 1993. (Available from NTIS as DE94008316.)
- "Success Continues at Cement Kiln Project." *Clean Coal Today.* Report No. DOE/FE-0215P-7. Fall 1992.
- *Passamaquoddy Technology Recovery Scrubber™: Topical Report.* Report No. DOE/PC/89657-T1. Passamaquoddy Tribe. March 1992. (Available from NTIS as DE92019868.)
- "Passamaquoddy Cement Kiln Project Begins Operations." *Clean Coal Today.* Report No. DOE/FE-0215P-1. Spring 1991.
- *Comprehensive Report to Congress on the Clean Coal Technology Program: Cement Kiln Flue Gas Recovery Scrubber™.* (Passamaquoddy Tribe). Report No. DOE/FE-0152. U.S. Department of Energy. November 1989. (Available from NTIS as DE90004462.)

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