316(b) Phase II Closed-Cycle Cooling Retrofit Options: Feasibility and Cost

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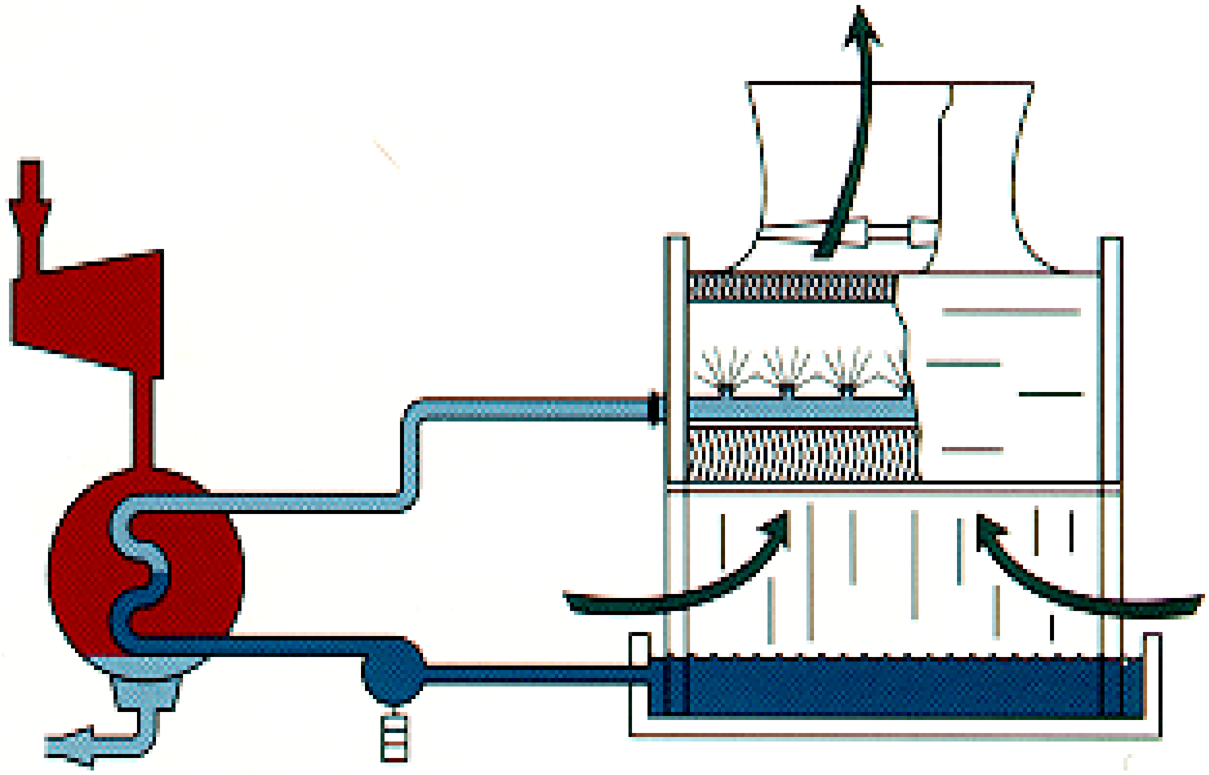
Dry Cooling and Proposed 316(b) Phase II, Federal Register, April 9, 2002, pg. 17168

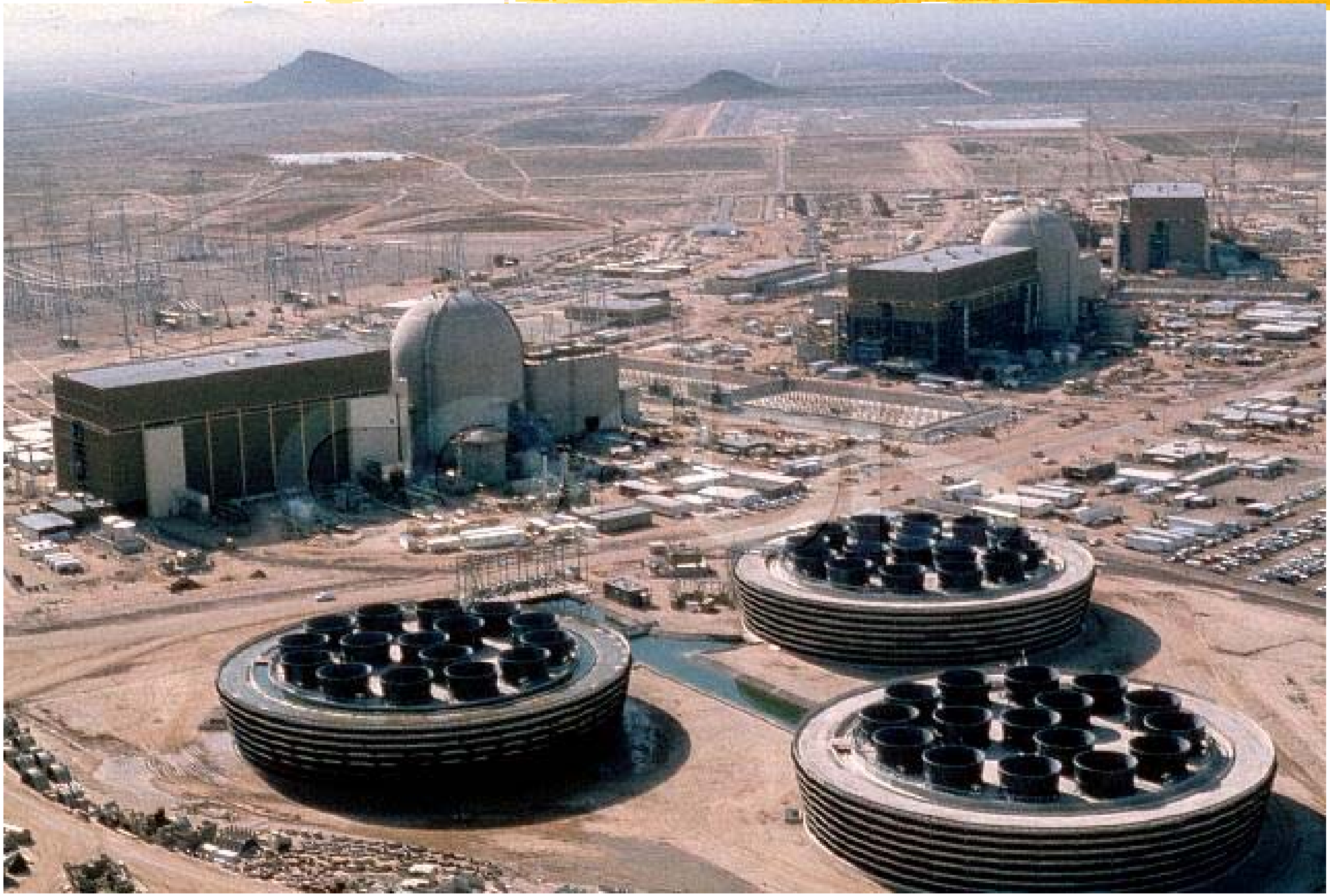
"Although the EPA has rejected dry cooling technology as a national minimum requirement, EPA does not intend to restrict the use of dry cooling or to dispute that dry cooling may be the appropriate cooling technology for some facilities. For example, facilities that are repowering and replacing the entire infrastructure of the facility may find that dry cooling is an acceptable technology in some cases. A State may choose to use its own authorities to require dry cooling in areas <u>where the State finds its (fishery) resources need additional protection above the levels provided by these technology-based minimum standards</u>."

Closed-Cycle Wet Cooling

Courtesy of GEA Power Cooling Systems, Inc.



Palo Verde Nuclear (AZ), 3 x 1,270 MW



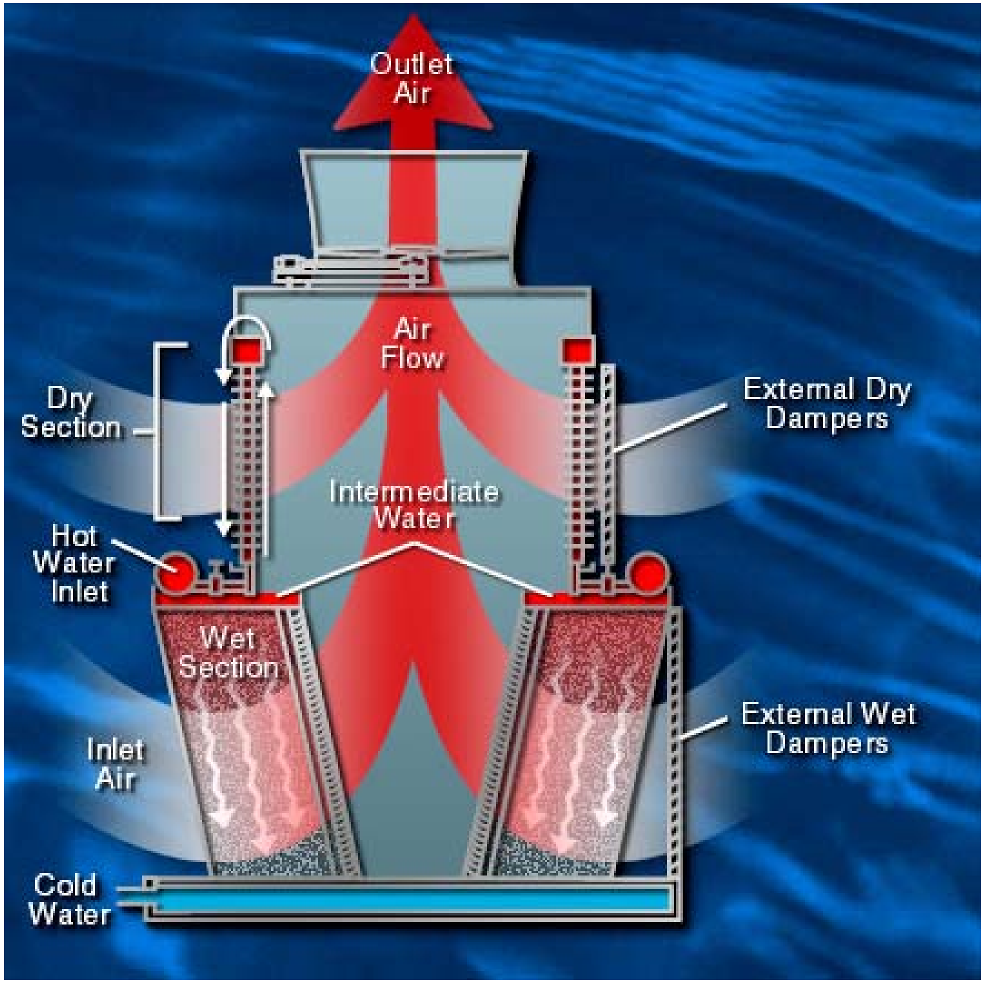
Prairie Island Nuclear (MN), 2 x 530 MW

Vermont Yankee Nuclear, 550 MW, Once-Thru or Closed-Cycle Wet

Vermont Yankee Nuclear, Closed-Cycle Wet Operation

Hybrid (Plume Abatement) Wet Cooling Tower Schematic

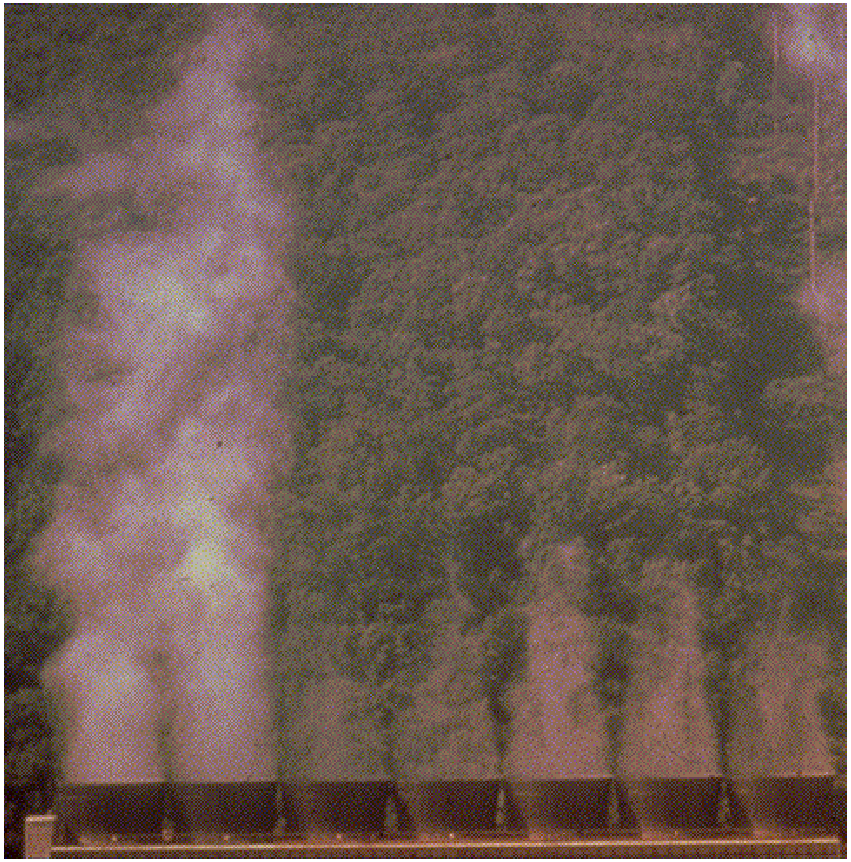
Schematic courtesy of Marley Cooling Technologies, Inc.



Plume Abatement Function

Courtesy of Marley Cooling Technologies, Inc.

- Two cells to right are operating in standard wet tower mode.
- Next two cells have damper 100% open (max. plume abate).
- Next three cells have dampers open 25%.



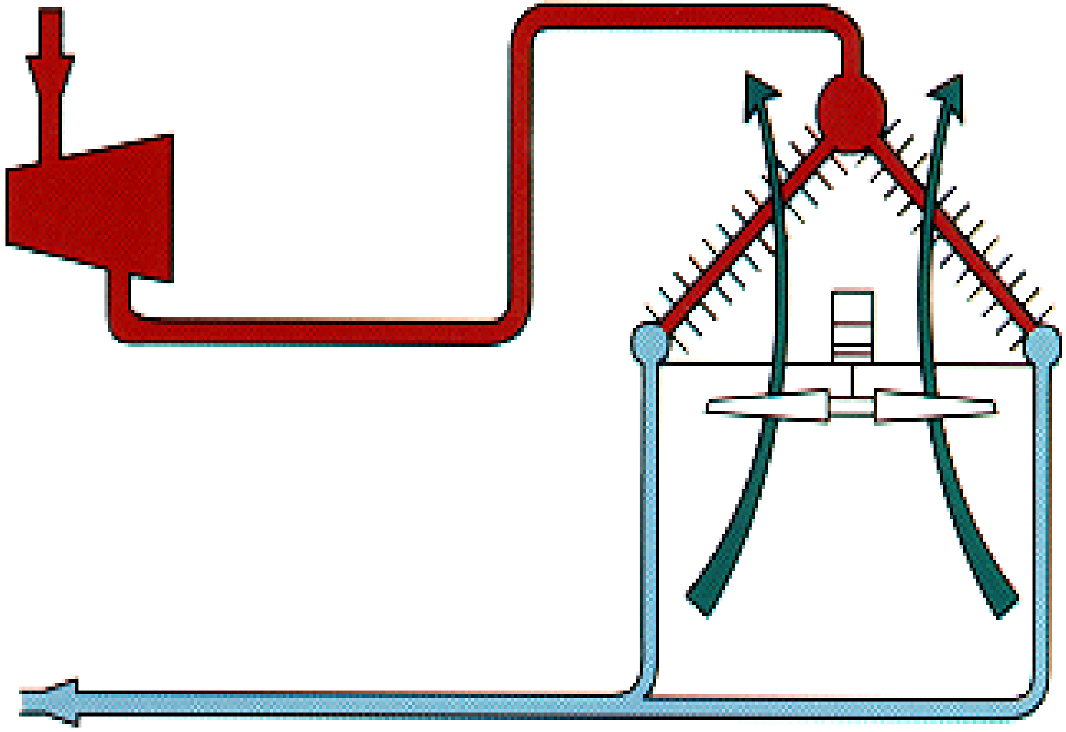
Seawater Cooling Towers

- Technically viable option if freshwater not available, many U.S. and international seawater and brackish water installations.
- Recommended reading: *Feasibility of Seawater Cooling Towers for Large-Scale Petrochemical Development*, CTI Journal, Vol. 24, No. 2 (summer 2003).

CTI: Cooling Technology Institute

Air-Cooled Condenser

Courtesy of GEA Power Cooling Systems, Inc.

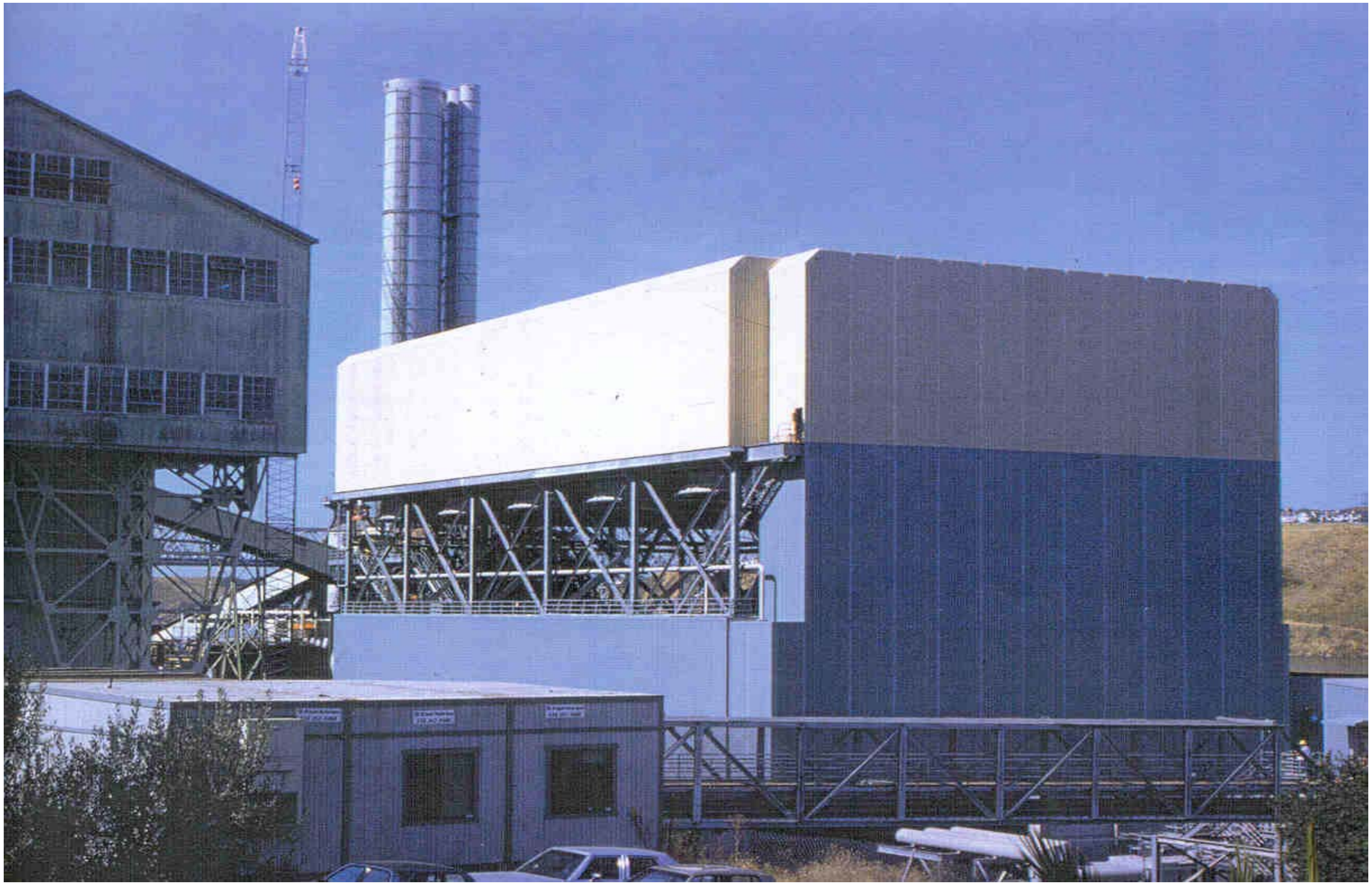


Matimba (S.A.), 6 x 665 MW - 10 years of operation

330 MW Wyodak Station (WY) - 25 years of operation

Roofmounted Dry Cooling - Crockett Cogen Plant

Courtesy of Marley Cooling Technologies, Inc.



Plant Plot Restrictions

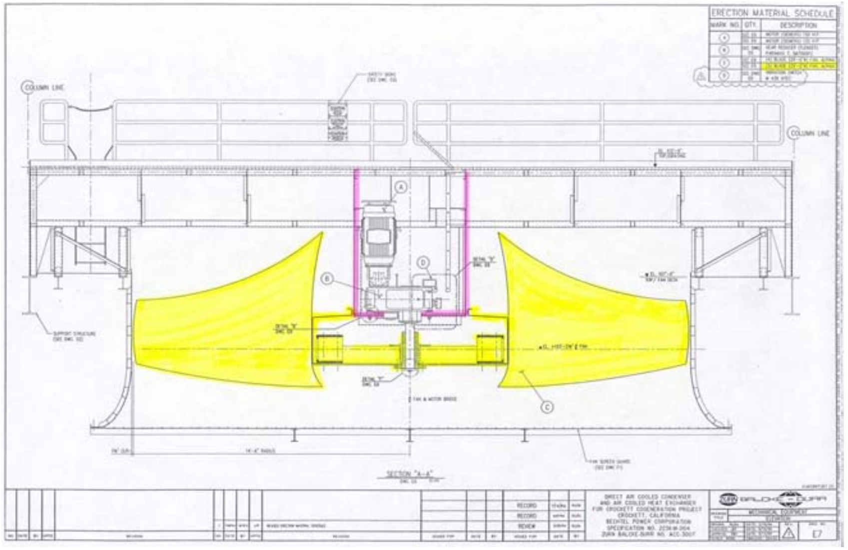
- 2.4 acre site (140′ x 740′)
- Water to the north & east
- Railroad to the south
- Sugar mill to the west
- No room for ACC, except on power plant roof
- Seismic zone 4

Noise Reduction Measures

Courtesy of Marley Cooling Technologies, Inc.

Ultra-low noise fans

Gear motor enclosures



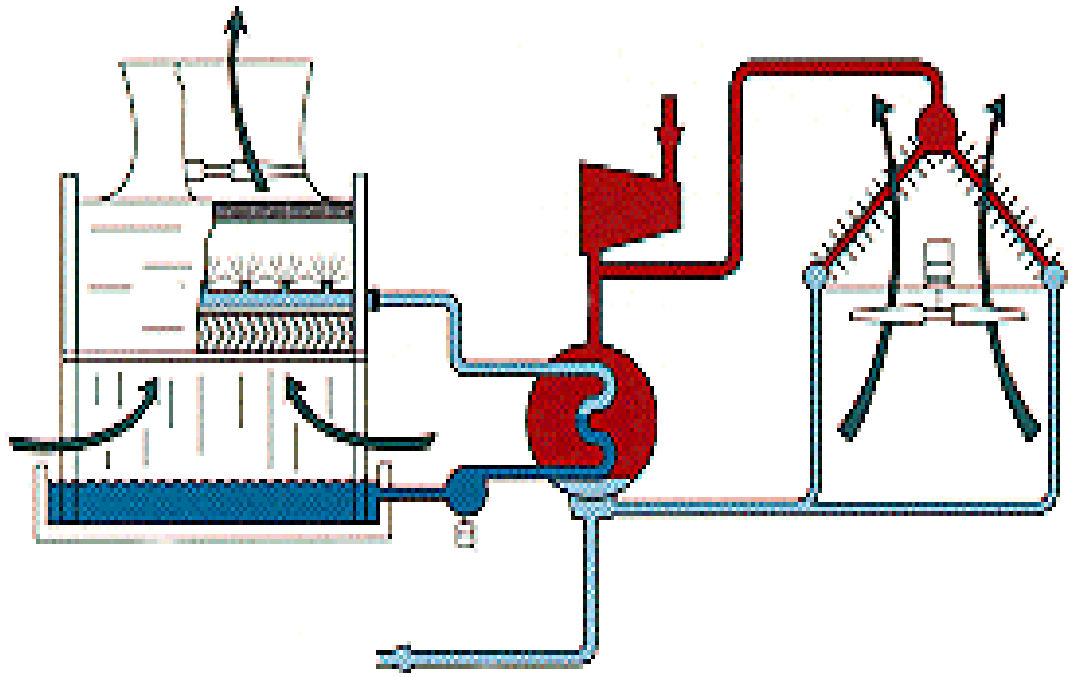
Roofmounted Dry Cooling - Ravenswood Cogen Plant

Courtesy of Marley Cooling Technologies, Inc.

View of the Ravenswood Cogeneration Facility, facing Southwest

Parallel Wet/Dry Cooling

Courtesy of GEA Power Cooling Systems, Inc.



Tucuman 450 MW Combined-Cycle Parallel Wet/Dry Cooling System

Courtesy of GEA Power Cooling Systems, Inc.

Streeter Station Unit 7 (Iowa) - 37 MW Pulverized Coal Plant, Retrofit Wet/Dry System - 1995

Streeter Station Unit 7 - Retrofit Wet/Dry System

- Boiler installed in 1973, retrofit to wet/dry in 1995
- 36.6 MW net GE steam turbine generator
- Pulverized coal
- 1,300 psig/ 950 degrees F B&W boiler
- Designed for 3.5 in Hg backpressure with cooling tower, @ 30,000 GPM cooling water flow
- 10 ^{o}F delta T, two-cell Marley cooling tower

David Rusley, P.E., Manager of Engineering, Cedar Falls Utilities

Streeter Station Unit 7 - Retrofit Wet/Dry Challenges

- Backpressure of steam turbines for wet systems is often lower than a new dry design
- Retrofit of a steam turbine exhaust casing is expensive- consider surface condenser modification
- Locating space to install the massive steam exhaust piping can be a huge challenge.
- Room for turbine overhauls compounds the process.

David Rusley, P.E., Manager of Engineering, Cedar Falls Utilities

Surface Condenser Reinforced for Four ACC Connections

Four Rectangular to 48-inch Round Taps

Staged Construction of 48-inch ACC Takeoff Ducts

Staged Construction of 48-inch ACC Takeoff Ducts

One of Two Turbine Floor Cuts

One of Two Floor Penetrations

Two 48-inch Ducts Transition to One 72-inch Duct

Streeter Unit 7 - Top 102" Header & Five ACC Cells

Case Study: Coal Utility Boiler FGD Retrofits for SO_2 Control

Southern Illinois U., Coal Research Center, Coal Technology Profiles

FGD Type	New ($/kw)	Retrofit ($/kw)	Retrofit Cost Delta (%)	O&M ($/kwh)
Wet	126 to 210	157 to 262	+25	0.0029
Dry	105 to 157	136 to 210	+30 to +34	0.0017

Case Study: Coal Utility Boiler SCR Retrofits for NO_x Control

U.S. EPA, Cost of SCR on Coal-Fired Boilers, EPA/600/SR-01/087, Jan. 2002

- New coal utility generator: $1,200/kw
- Over 200 SCR retrofits assessed by EPA
- Entire range of SCR retrofit costs: $55/kw - $140/kw
- Retrofit SCR on 330 MW units, 90% control: $70/kw - $90/kw
- SCR O&M costs, 300 MW to 500 MW units: $1.6 to $3.2 million/yr

New coal generator cost reference: Western Governor's Asso., Conceptual Plans for Electricity Transmission in the West, August 2001, pg. 40.

Installation and Hookup Times for FGD and SCR Retrofits

U.S. EPA, 2003 Tech. Support Package for Clear Skies, Section G

- Wet limestone FGD installation: 27 months
- Wet limestone FGD hookup: 4-7 weeks
- SCR installation: 21 months
- SCR hookup: 3-5 weeks
- Utility Air Regulatory Group SCR hookup time estimate: minimum of 10 weeks*
- Utility industry practice (fossil fuel units): 2-4 week outage every 1-2 years*

(*) Summary of Indiana Utility Regulatory Commission Workshop on Recent EPA Actions, July 12, 2000, prepared by Hoosier Environmental Council and Natural Resources Defense Council

Case Study: LG&E Corp. SCR Retrofit Program

McGraw Hill Construction, Clearing the Air: Backfitting Powerplants, 3/24/03

- Combustion modifications on 6,000 MW of capacity, SCR retrofits on 4,000 MW
- Total cost more than $600 million
- Sites developed tightly to begin with
- ESP or baghouse may have been added since the plant was built
- Can't spread out, must go up

Case Study: LG&E Corp. SCR Retrofit Program

McGraw Hill Construction, Clearing the Air: Backfitting Powerplants, 3/24/03

- Shoehorning SCR into site is only one challenge.
- At Mill Creek Station, electric transmission lines had to be relocated (added $ millions).
- At Ghent Station, space for SCR but no space for cranes - crane pad built on riverbank, then restored after completion.
- Innovative solutions - runway system to convey ductwork thru sides of building instead of drifting pieces with rigging.

Case Study: Closed-Cycle Wet Cooling Retrofit Costs

U.S. EPA 316(b) Phase II Technical Development Document, Chapter 4

Site	MW	Flowrate (gpm)	Cost of Retrofit ($MM)	Cost of Retrofit ($/kw)
Palisades Nuclear	800	410,000	55.9	70
Pittsburg Unit 7	751	352,000	34.4	46
Canadys Station	490	awaiting data		
Jefferies Station	346	awaiting data		

Hookup Times and Condenser Issues: Once-Thru to Closed-Cycle Retrofits

U.S. EPA 316(b) Phase II Technical Development Document, Chapter 4

Site	Issues
Palisades Nuclear	New intake pumps, new circulating pumps, no modifications to condenser, no problems with plume impacting highway ½ mile away. Hookup time unknown, occurred during multi-faceted 10-month plant outage.
Pittsburg Unit 7	Cooling towers replaced spray canal system. Towers constructed on narrow strip of land between canals, no modifications to condenser. Hookup time not reported.
Canadys Station	Distance from condensers to towers ranges from 650 to 1,700 feet. No modifications to condensers. Hookup completed in 4 weeks.
Jefferies Station	Distance from condensers to wet towers is 1,700 feet. No modifications to condensers. Two small booster pumps added. Hookup completed in 1 week.

Estimate of Plant Efficiency Loss: Once-Thru to Closed-Cycle Retrofits

U.S. EPA 316(b) Phase II Technical Development Document, Chapter 4

- Owner of 346 MW Jefferies Station claimed loss in plant efficiency due to conversion (cause by U.S. Corps of Engineers diversion of Santee Cooper River).
- After extended negotiation, U.S. COE agreed to pay reimbursement for 0.16% efficiency penalty.
- EPA estimates no change in pump power requirements between once-through and wet towers.
- EPA estimates generic wet tower fan parasitic load penalty of 0.73%.
- Overall plant efficiency loss due to conversion: 0.9%

Danskammer, 4 Units, 500 MW: Sites for Wet and Dry Retrofit Options

Danskammer: Cost Estimate for Retrofit Cooling Options

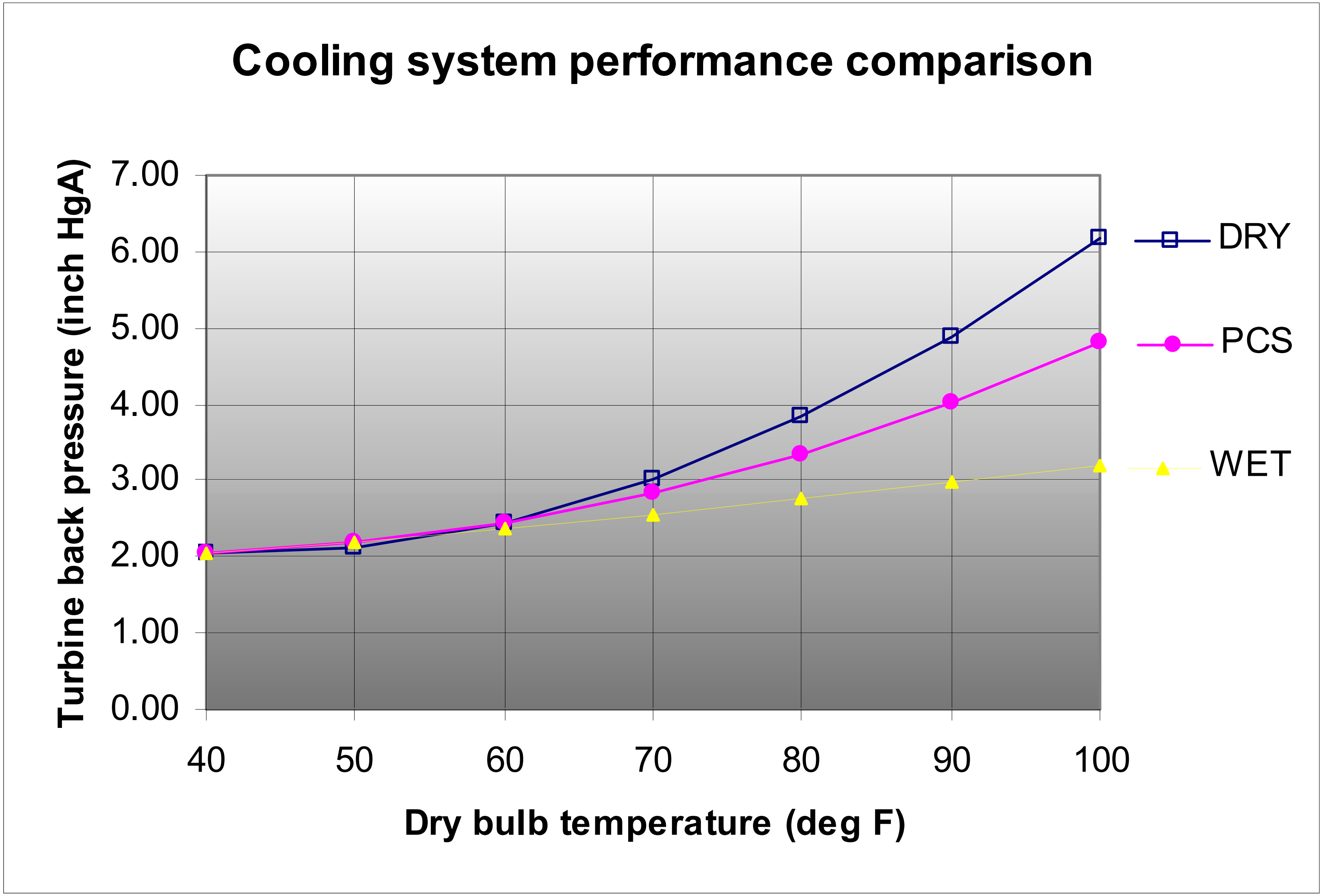
B. Powers preliminary estimate

Retrofit Option	Installed cost ($MM)	Unit cost ($/kw)
1. Hybrid wet towers, Units 1 thru 4, 14 cells, 500 MW	34 - 37	68 - 74
2. Hybrid wet towers, Units 3 and 4, 10 cells, 370 MW	24 - 26	65 - 70
3. Parallel wet/dry, Units 3 and 4, 20 dry/4 wet cells, 5.5" Hg max. @ 90 ^{o}F	30 - 33	81 - 89
4. Dry only, Units 3 and 4, 30 cells, 5.5" Hg max. @ 90 ^{o}F	30 - 33	81 - 89

Cost estimates include (where applicable): wet tower up to 1,700 ft. from boilers, microtunneling under RR tracks, building up to 1/3 of ACC support columns in river.

Danskammer: Cooling System Performance Comparison

Generic performance comparison figure from Hamon Dry Cooling



Indian Point Unit 2 940 MW and Unit 3 970 MW (nuclear reactors): Retrofit to Closed-Cycle Wet Cooling

- Turnkey vendor (Marley) cost estimate for (2) round hybrid towers: $140 million each, $280 million total, or $147/kw
- Owner estimate of installed cost: $740 million
- Owner est. of hookup revenue loss: $600 million
- Owner project cost estimate: $1.34 billion or $702/kw
- Author's estimate of standard hybrid tower (35 cells each) plus 30% for retrofit (FGD experience): $220 million, or $115/kw - space may be issue

Wet vs. Dry Plant Efficiency Penalty - Sites Evaluated

Tellus Institute Comparison of Dry and Wet Cooling Systems (for Riverkeeper), March 2003

Site	Location	Elev (ft)	Avg Temp (°F)	Max Temp (°F)	Avg Humidity (%)
1	Phoenix	1,072	58.4	115	37.5
2	Birmingham	600	62.1	103	70.5
3	Portland	50	51.8	104	73.0
4	Denver	5,260	49.9	101	53.5
5	Anaheim	160	61.0	95	64.0
6	Springfield	600	51.6	97	70.0
7	Boston	20	49.5	92	70.0
8	Anchorage	101	34.6	79	67.5

Annual Wet vs. Dry Plant Efficiency Penalty - Results

Tellus Institute Comparison of Dry and Wet Cooling Systems (for Riverkeeper), March 2003

	Overall Combined-Cycle Plant Efficiency (%)		
Site	**Wet**	**Dry**	**% Loss**
Anaheim	55.9	55.2	0.63
Anchorage	55.7	55.2	0.46
Birmingham	55.7	55.0	0.72
Boston	55.8	55.2	0.56
Denver	55.7	55.1	0.63
Phoenix	55.8	55.1	0.73
Portland	55.9	55.4	0.52
Springfield	55.7	55.1	0.61
Average	**55.8**	**55.2**	**0.61**

Loss in Steam Cycle Efficiency from Switching to Dry Cooling (%)

Tellus Institute Comparison of Dry and Wet Cooling Systems (for Riverkeeper), March 2003

Temperature Range (°F)	Minimum (%)	Maximum (%)	Average (%)
12 to 30	0.5	0.8	**0.7**
30 to 48	0.6	0.9	**0.8**
48 to 66	0.8	1.1	**1.2**
66 to 84	1.0	2.4	**2.1**
84 to 102	1.9	3.5	**3.2**
102 to 120	2.9	4.5	**3.9**

Combined-Cycle Design Options and Impact on Thermal Efficiency

- Incorporation of heavy duct firing increases heat rate ~1%.
- Selection of "least cost" versus "maximum efficiency" design option using GTPro design software increases heat rate by ~2%.
- Use of catalytic NOx and CO controls increases heat rate ~0.5%.

Conclusions

- Closed-cycle wet cooling, parallel wet/dry, and dry cooling are technically viable retrofit options.
- Closed-cycle cooling retrofit cost should be in the same $/kw range, or less expensive, than a SCR or FGD retrofit.
- The O&M cost impact, including heat rate penalty, of a closed-cycle retrofit should range from less than that of an SCR or FGD retrofit (wet towers) to comparable (dry cooling).