Improvement to Air2Air^{TM} Technology to Reduce Fresh-Water Evaporative Cooling Loss at Coal-Based Thermoelectric Power Plants [Award, NT05647]

Final Report

Reporting Period: 10/1/08-12/31/11

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Advanced Technologies and Concepts to Minimize Freshwater Use in Coal-Based Thermoelectric Power Plants

CFDA Number: 81.089 Fossil Energy Research & Development

DISCLAIMER

ABSTRACT

This program was undertaken to enhance the manufacturability, constructability, and cost of the Air2Air^{TM} Water Conservation and Plume Abatement Cooling Tower, giving a validated cost basis and capability. Air2Air^{TM} water conservation technology recovers a portion of the traditional cooling tower evaporate. The Condensing Module provides an air-to-air heat exchanger above the wet fill media, extracting the heat from the hot saturated moist air leaving in the cooling tower and condensing water. The rate of evaporate water recovery is typically 10% - 25% annually, depending on the cooling tower location (climate).

This program improved the efficiency and cost of the Air2Air^{TM} Water Conservation Cooling Tower capability, and led to the first commercial sale of the product, as described.

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Executive Summary

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SPX Cooling Technologies had previously completed initial investigation of a new water conservation and recovery technology Air2Air® for evaporative cooling towers under DOE Grant No. DEFC2606NT42725. The findings from this research were very encouraging, demonstrating that the basic principles behind the technology are sound, and the water savings and the plume abatement effects on the evaporative cooling tower are substantial. In the course of evaluating the water conservation and plume abatement markets, it was found that a more economical approach for the use of the technology was needed.

To improve value, research to develop a more efficient heat transfer pack and geometrical efficiency of the overall tower, including pack orientation, production process quality, and superstructure was undertaken in this Award, NT05647. Investigation prior to acceptance of this Award had identified a promising pack joining and sealing technique and enhanced surface geometry, which are essential to improved design value.

The project objective of Award NT05647 was to further enable Air2Air® becoming a commercially viable water savings and plume abatement technology by researching a re-engineered pack, testing improvement provided by modification, and prototyping the pack manufacture to improve pack economy, as it relates to superstructure volume, cost, pack orientation, and ducting details. A more efficient heat transfer pack with watertight wet path seals is the result.

Conclusions:

1. A re-engineered sheet/module including improvements to pack structure, wet path seal, and condensing surface was created
2. Testing confirmed the improvements provided by the sheet design modification and prototype module manufacturing, improved economy of Air2Air, also known as ClearSky for plume abatement application
3. The tower superstructure, pack orientation, and ducting details were also re-engineered providing better economy
4. A competitive commercial product utilizing a more efficient heat exchange module is the result, and the first commercial sale has been realized and is being built

Background

The production of electricity requires a reliable, abundant, and predictable source of freshwater—a resource that is limited in many parts of the United States and throughout the world. The process of thermoelectric generation from fossil fuels such as coal, oil, and natural gas is water intensive. According to the U.S. Geological Survey in year 2000, thermoelectric-power withdrawals accounted for 48 percent of total water use, 39 percent of total freshwater withdrawals (136 billion gallons per day) for all categories, and 52 percent of fresh surface-water withdrawals [1]. See figure 1.

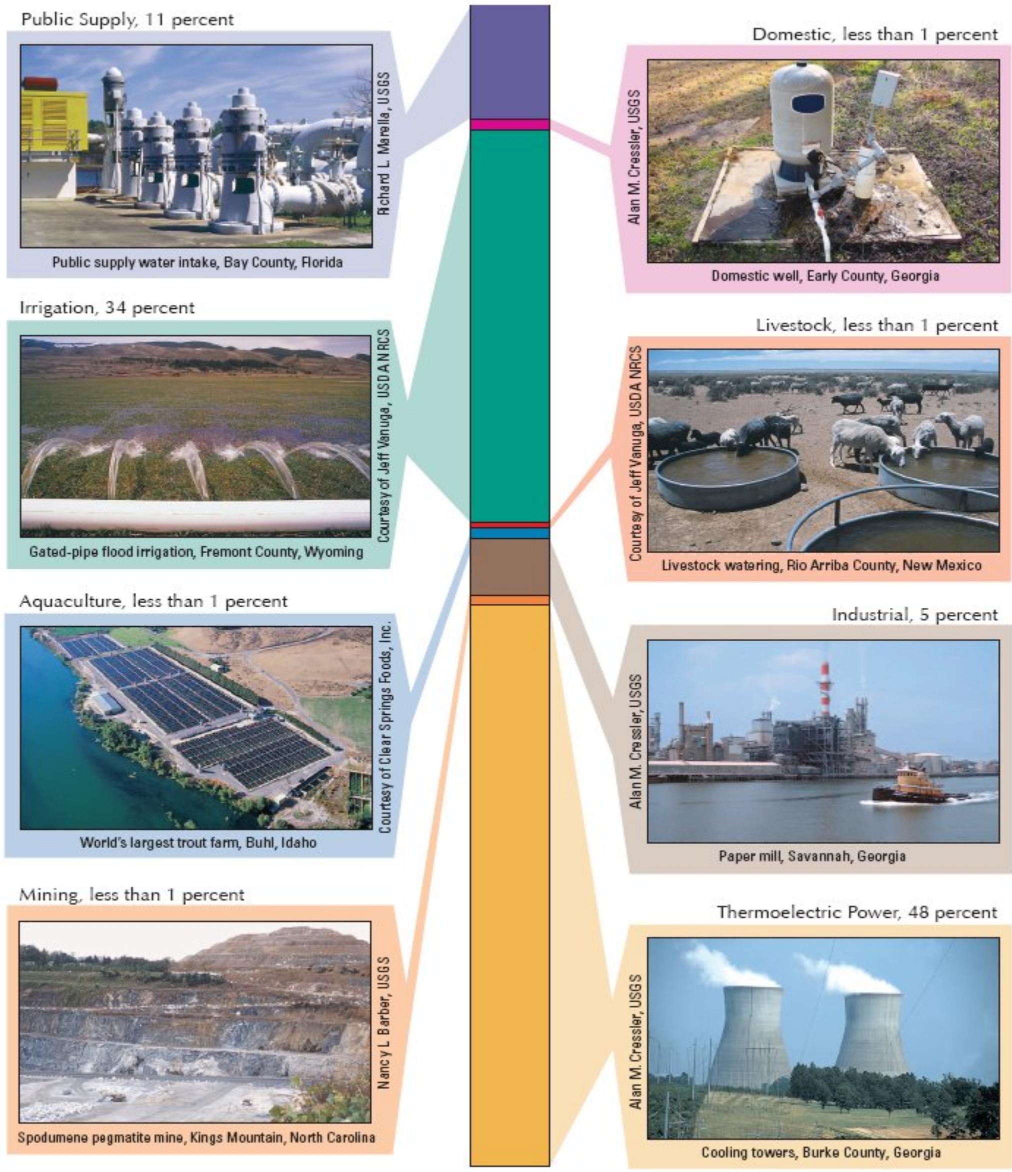


Figure 1: Category of water withdrawals for year 2000

In all fairness, one should not discuss the withdrawal of freshwater by thermoelectric plants without discussing consumption. As illustrated in Figure 2, the 1995 consumption (through evaporation) was approximately 3 billion gallons each day [2].

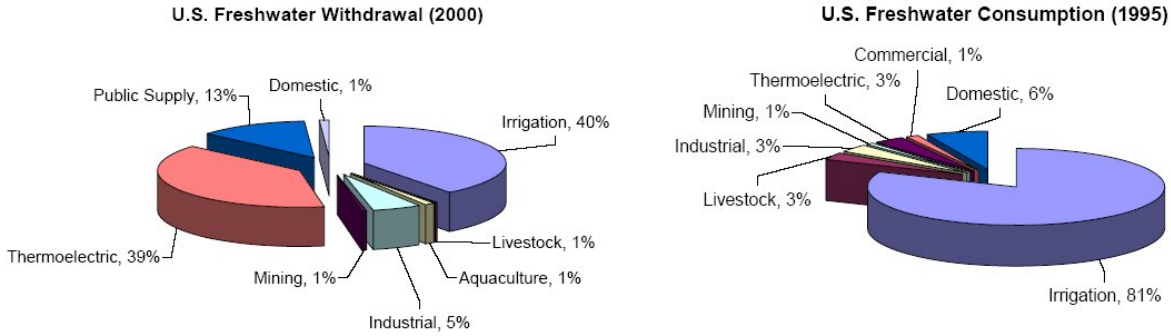
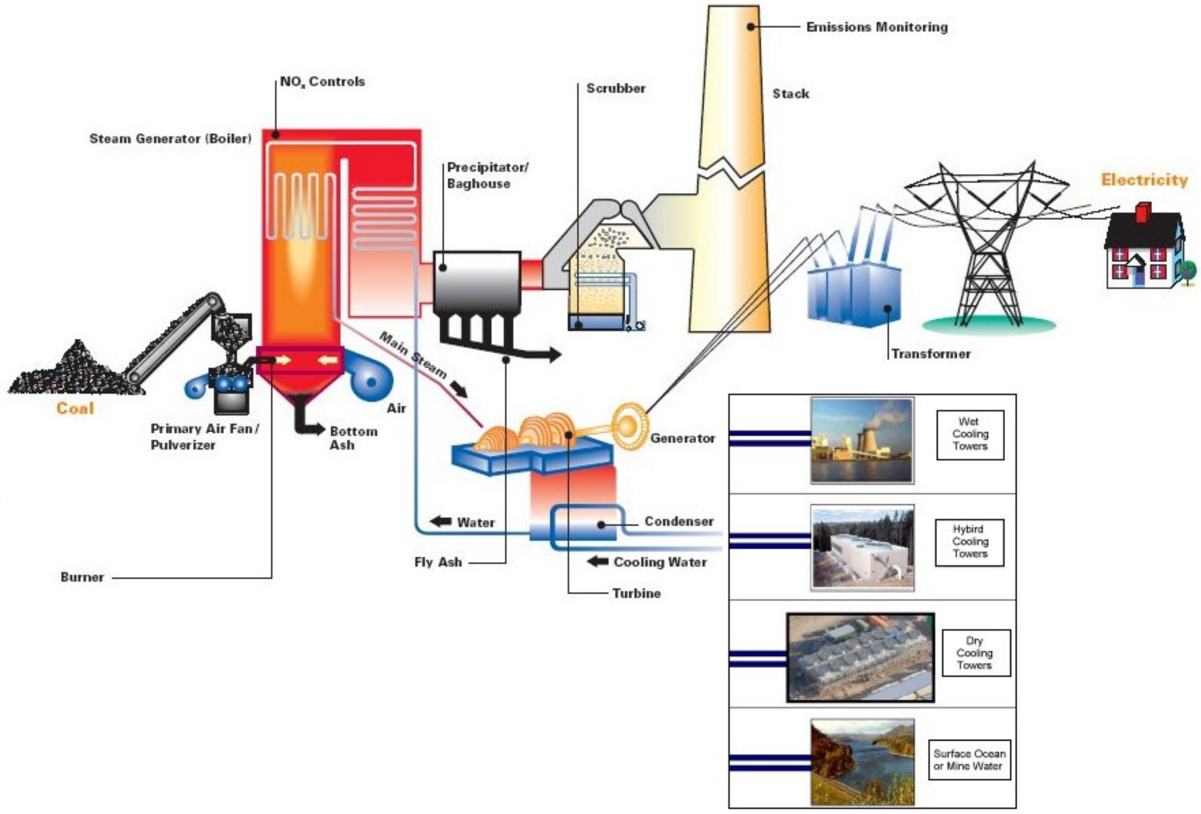


Figure 2: Comparison of domestic freshwater withdrawals and consumption

As a growing economy drives the need for more electricity, demands on freshwater supplies for thermoelectric power generation will also grow. However, electric utilities will have to compete with demands from other off-stream-use sectors such as public supply, domestic, commercial, irrigation, industrial, and mining. In addition, the need to leave water in streams and rivers to achieve environmental, ecological, and recreational goals will further complicate the future allocation of the nation's freshwater resources. As such, the availability of adequate supplies of freshwater to produce electricity as well as the potential impact of power plant operations on freshwater quality are receiving increased attention [3].

Water use in thermoelectric power plants

The generation of electricity from steam requires that the process steam be condensed at the aft end of a turbine. This is achieved most frequently through the use of cooling water. The process is greatly simplified in the Figure 3 illustration, although it is more typically a fossil fuel turbine exhaust, oil, gas, coal or nuclear power. The heat energy flows through a steam generator (boiler) where water is converted to steam and forced to build up pressures up to 3000-psi. This high-pressure steam is channeled through a turbine which rotates at 3600-rpm. The turbine drives an electric generator which feeds power to the grid. Critical to the operating efficiency of a power plant, is the pressure differential between steam turbine inlet and outlet. Steam, as it condenses, reduces its volume 1700 times. This compaction creates suction on the exit end of the turbine which draws steam through the turbine from the inlet.



Adapted from http://www.eei.org/industry_issues/environment/air/New_Source_Review/coal1.pdf

Figure 3: Simplified power plant cooling system

The primary purpose of a thermoelectric plant cooling loop is condensation of steam at the turbine exit to increase the draw. The most prominent cooling technologies used today are once-through systems and recirculating wet cooling towers. Recently, dry cooling systems have seen tremendous growth. While all three systems require some kind of cooling fluid, typically water, the amount of water withdrawal needed for each technology varies. Although once-through systems have the largest volume of water withdrawal, they are one of the most efficient cooling systems for power generation and tend to have the lowest capital investment costs. Wet cooling towers require lower water withdrawals than once through systems, but may require significant pretreatment for makeup water and have higher capital costs. Moreover, water vapor plumes exiting the tower can present aesthetic concerns as well as other issues. While dry cooling systems have negligible water withdrawals, they are the least efficient of the three systems because of the higher ancillary power required to operate pumps, fans, and other equipment. Dry systems also tend to have higher capital costs and larger footprints than most other cooling options. Because of the higher capital and operation costs for dry systems, wet cooling towers are often preferred provided sufficient water can be resourced. This is true even in areas where water resources may be limited. In such areas water conservation can be very important in determining the cooling system required.

Technical Approach: Previous DOE Grant DEFC2606NT42725 -

In response to the DOE funding opportunity DE-PS26-08NT00233-01 Area of Interest 1: Advanced Cooling Technology SPX Cooling Technologies Inc. (SPX) proposes to research enhancements the Air2Air® innovative water conservation technology.

Traditional wet cooling tower

As illustrated in Figure 4, a traditional evaporative cooling tower uses the latent heat of vaporization to transfer heat. By evaporating a small portion of the circulating water flow through the tower, the remaining water is cooled. The tower's exit air stream is saturated with water vapor that is typically discharged.

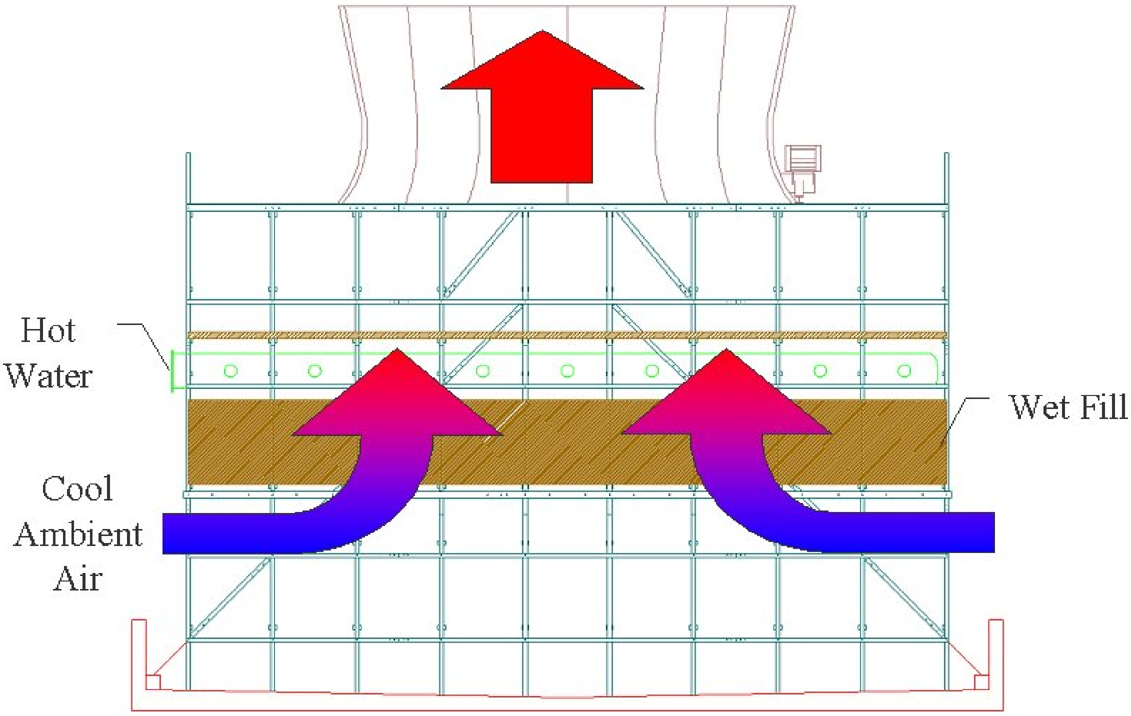


Figure 4: Sketch of a traditional wet cooling tower

Air2Air® water conservation cooling tower

An Air2Air® water conservation cooling tower as shown in Figure 5 recovers part of the evaporate by using relatively cool ambient air to condense evaporate and retain water that would otherwise be lost to the atmosphere.

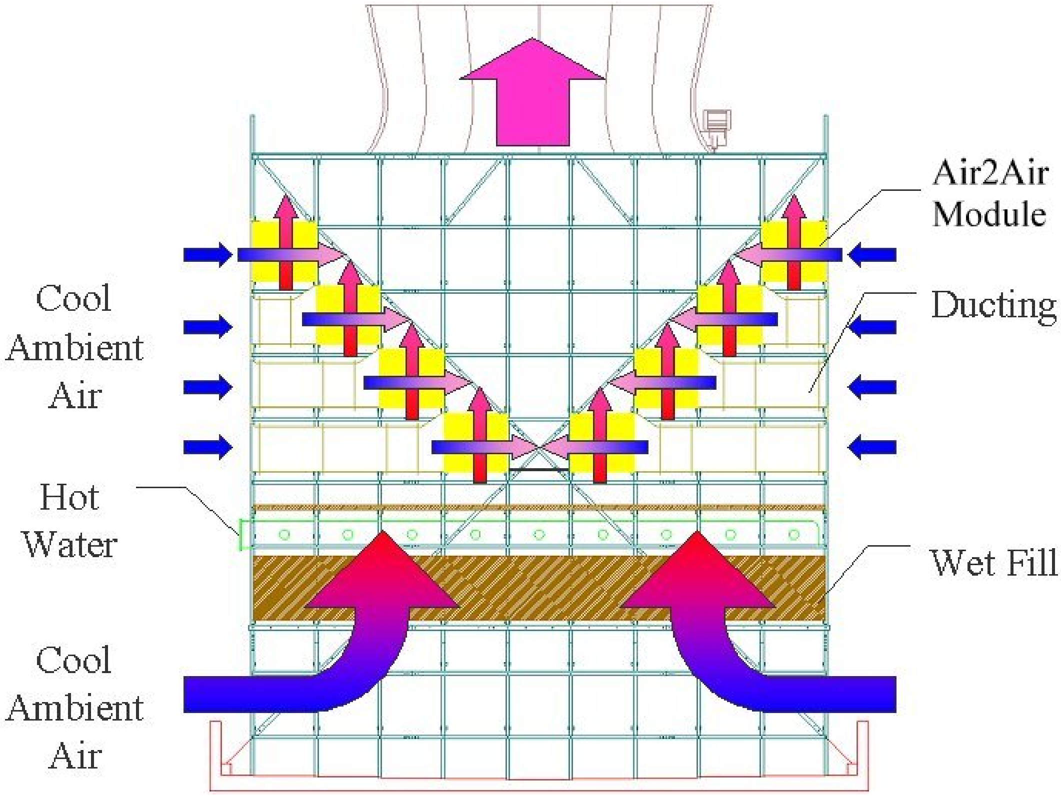


Figure 5: Sketch of Air2Air™ Water Conservation Cooling Tower

The Air2Air® Condensing Module (Figure 6) serves as a heat exchanger above the wet fill media in the cooling tower. The temperatures noted in Figure 6 demonstrate theoretical temperatures for a typical evaporative cooling tower used in a thermo-electric power plant. The cool ambient air ducted from outside extracts the heat from the hot saturated moist air leaving the wet fill media. Part of the moisture will condense out in the Air2Air™ modules and be returned to the cooling tower. The condensate is high purity water – approaching distilled water quality. It can be collected for other power plant use or return back to the cooling tower. The rate of evaporate water recovery is typically 15% - 25% annually, depending on the cooing tower location (climate).

SPX Air2Air® Condensing Module technology was developed over a two-and-a-half year period, originally seeking a means of plume abatement for cooling towers near roadways and airports. The Air2Air® technology reduces the discharge plume from an evaporative cooling tower by reducing the amount of water in the saturated effluent discharge air. The Air2Air® technology also will theoretically reduce the consumption of water by the power plant's cooling towers by recovering 15% to 25% of the evaporate, depending on the climate.

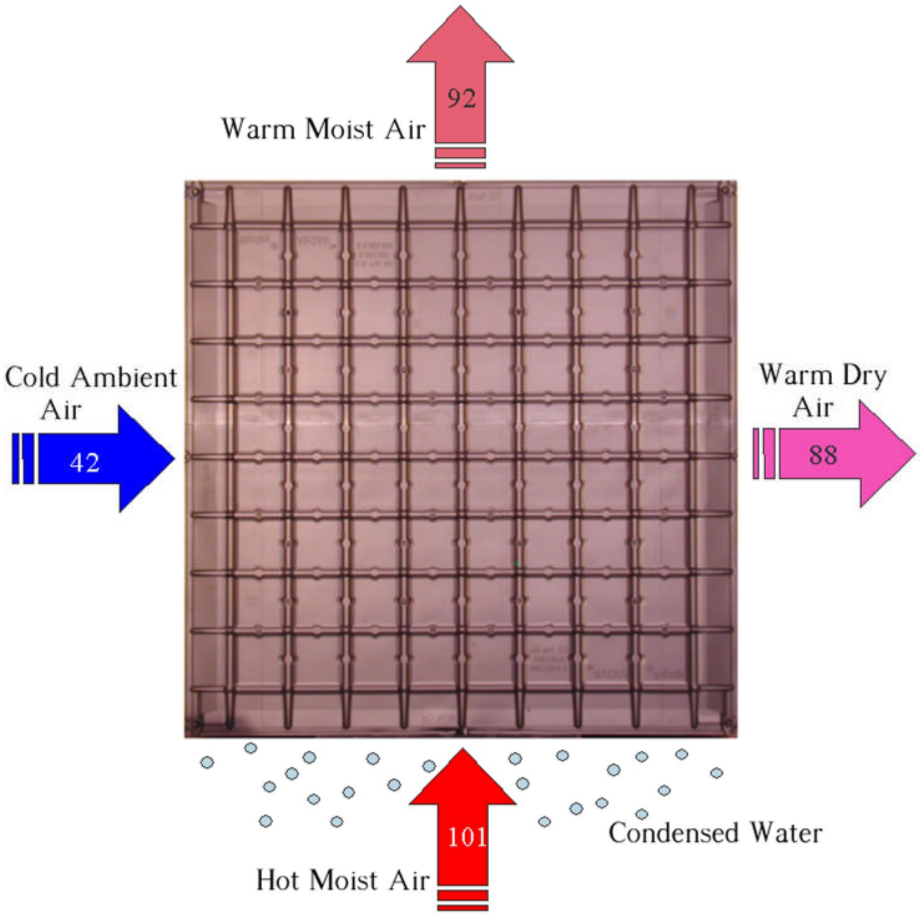


Figure 6: Air2Air™ Condensing Module

The configuration in Figure 5 shows individual ducts servicing each level in each bay. This ducting scheme was abandoned in favor of what was believed to be a more economical scheme as shown in Figure 7.

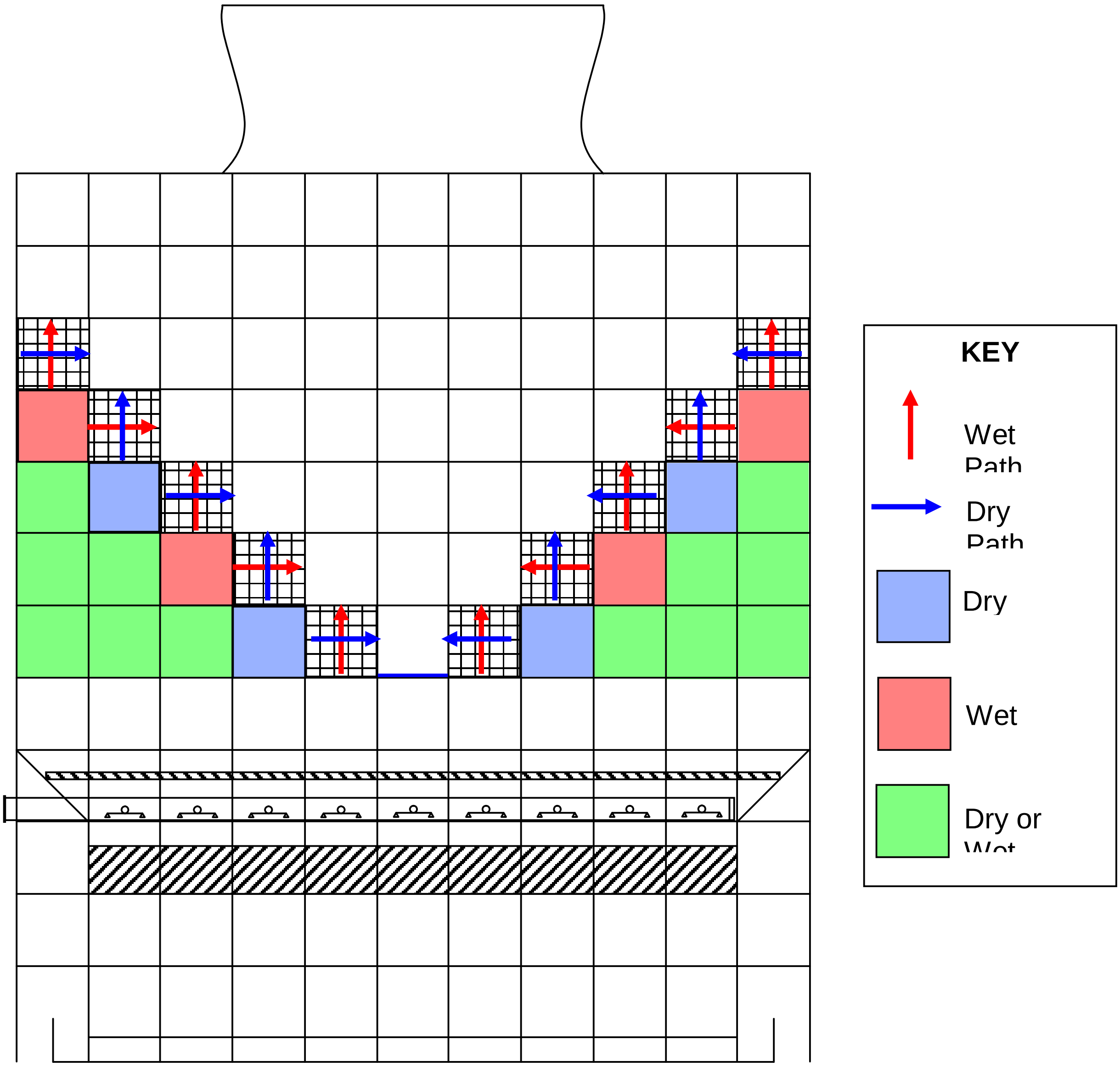


Figure 7 – Air2Air® Design with Horizontal and Vertical A2A® Pack Wet Paths

Under DOE Grant No. DEFC2606NT42725, the Figure 7 design went forward for the Air2Air® validation cell until it was discover that a reliable seal at the bottom of the tubes defining the horizontal wet path could not be made. The seal permitted a substantial portion of the condensate to leak into the dry path ducting. In addition to losing water conservation, ice formation during cold weather would be severe and unacceptable. The vertical wet path tubes were deemed acceptable because the vertical seals did not have standing, condensate exerting pressure against the seals, but rather the condensate fell through the bottom of the packs and back into the wet section of the tower. Thus water conservation would be preserved with the vertical wet path packs.

Therefore, the design as shown in Figure 7 was modified to orient all the Air2Air® packs to have vertical wet paths. See Figure 8.

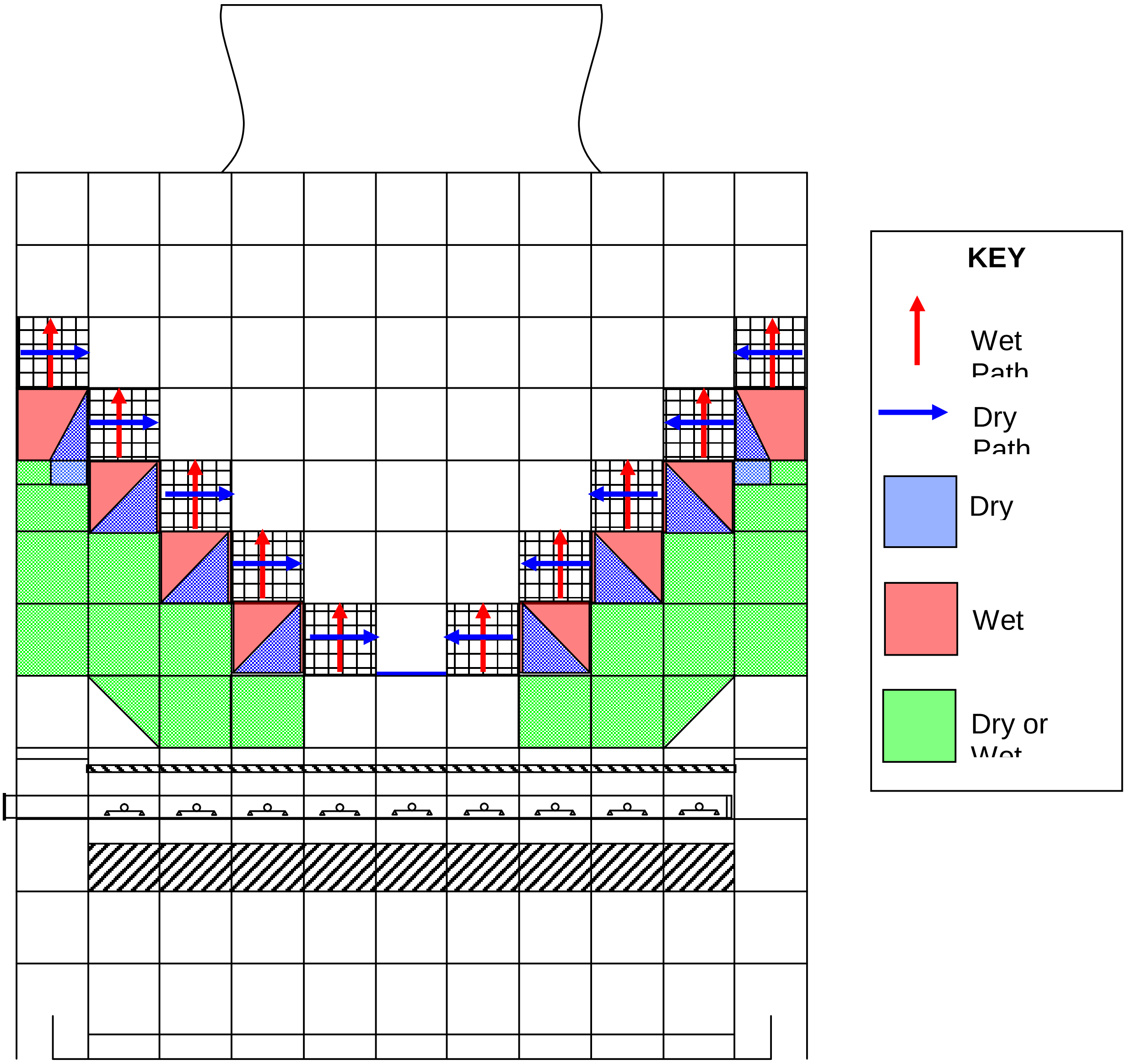


Figure 8 – Validation Cell Design with All Vertical Air2Air® Pack Wet Paths

As can be seen by comparing Figures 7 and 8, the ducting is substantially more complicated when accommodating all vertical A2A® pack wet paths. More material was required to split the longitudinal ducts into dry and wet portions (triangular regions adjacent to the A2A® packs) and to drop the dry duct floor down to supply dry air to the lowest level A2A® packs. More importantly, however, was the increased labor required to execute the additional complexity in this modified design.

The advantages of Air2Air™ technology

Air2Air™ technology has superior advantages over a dry cooling tower and a traditional coil-type plume abated cooling tower.

Comparing to a dry cooling tower, an Air2Air® water conservation tower has:

- Less initial capital cost
- Less plan area requirement (footprint)
- Lower pump head and less operating cost
- Colder water temperature
- Ability to be retrofitted to existing wet cooling towers in power plants
- Ability to generate high quality water for other power plant use
- Ability to create high quality fresh water if wet cooling tower uses seawater as process water.

A cooling tower out-fitted with the Air2Air® water conservation technology has following advantages over a traditional coil-type plume abated cooling tower.

- Lower pump head
- Less piping cost
- Simplicity of operation
- Easier to retrofit existing cooling towers
- Better plume abatement result due to higher surface area of Air2Air® Condensing Module
- Ability to generate high quality water for other power plant use
- Ability to create high quality fresh water if wet cooling tower uses seawater as process water.

Technical basis and feasibility of Air2Air® technology

The Air2Air™ Condensing Module serves as a crossflow-type heat exchanger. The hot saturated moist air enters the wet pass of Air2Air® Condensing Module. It loses heat to the cool ambient air entering on the dry pass of the module. Part of the moisture in the wet pass condenses out on the surface of the module. The condensate is high purity water, approaching distilled water quality. In the meantime, cool ambient air is heated and becomes warm dry air. The reduced moist air discharged from wet pass mixes with the warm dry air discharged from dry pass to result in a less saturated effluent air. Plume abatement is achieved.

SPX Cooling Technologies (SPX) spent two and half years conducting research on the Air2Air® Condensing Modules in a laboratory-scale test setup. Tests have been conducted in all four seasons, and test data has a good agreement with the prediction. Figure 9 shows some of the laboratory test data and the agreement with the prediction.

Date and Test ID	Season	Ambient WB/DB, (°F) Temperature	Mass Balance Condensation, GPM	Volumetric Condensation, GPM	Agreement of Methods
5/7/2004, AAHE14-2	Spring	65.8/73.1	0.578	0.573	99.1%
5/7/2004, AAHE14-6	Spring	71.0/85.4	0.408	0.399	97.8%
5/20/2004, AAHE14-20	Spring	74.6/84.5	0.525	0.506	96.3%
6/26/2004, AAHE14-27	Summer	57.6/68.4	0.605	0.615	101.6%

Figure 9: Laboratory test data

Research is presently being conducted under DOE Grant DE-PS26-05NT42411 at Public Service of New Mexico's San Juan Generating Station. A validation cell with Air2Air® replaced one of the existing cooling tower cells on Unit 4. Preliminary data indicates the Air2Air® heat exchange packs are condensing a considerable amount of water from the effluent air stream.

Four patents have issued on the Air2Air® condensing technology. SPX requested and received DOE waiver of rights on these patents. A rating program has been developed to size an Air2Air® water conservation tower. SPX claims priority to this software and declares this software outside the scope of this project.

Anticipated public benefits of Air2Air® technology

Thermoelectric generation is water intensive, whether it is derived from fossil fuels such as coal, oil, and natural gas, or from nuclear power. In fact, each kilowatt-hour (kWh) generated requires an average of 25 gallons of water. This means that U.S. citizens may indirectly depend on water to turn on lights and run appliances as much as they may directly use water to take showers and water their lawns [8]. As the nation's growing economy drives the need for more electricity, demands on the use of water for power generation also will grow. The direct and indirect demand for water for energy production will increasingly compete with demands from other sectors of the economy. As a result, increased attention is being paid to the availability of adequate water supplies required to produce electricity, and to the potential impact of energy operations on water quality.

Additionally, several areas in the United States are presently experiencing drought conditions, which heightens awareness of water usage. Figure 10 displays a map showing drought stricken areas of the US [9].

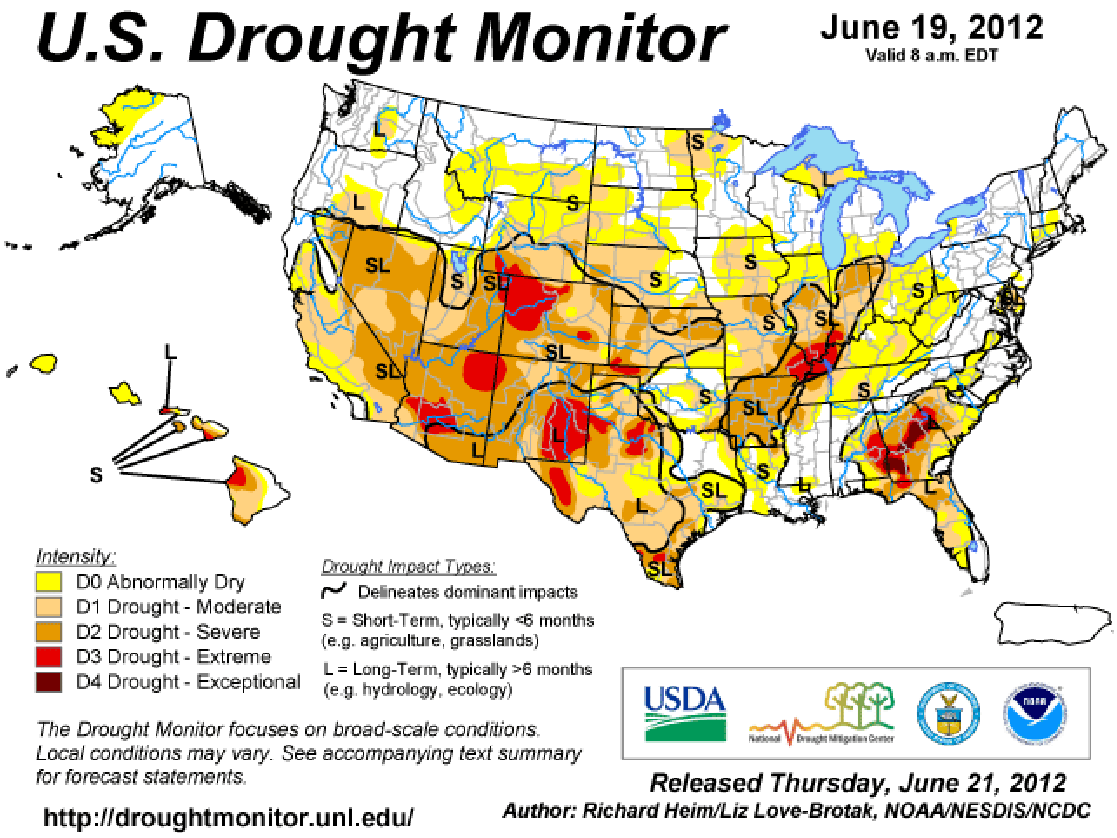


Figure 10 – U.S. Drought Monitor

The implementation of Air2Air® technology on existing cooling towers (retrofit) and new cooling towers would reduce freshwater consumption by thermoelectric power plants. In the case of salt-water cooling towers, high quality freshwater can be generated for other uses.

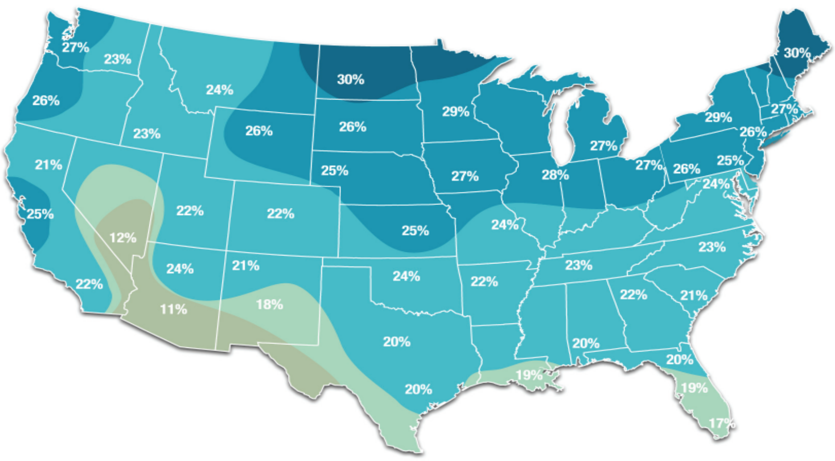
Take a typical 300 MW coal-fired power plant as an example, its cooling tower recirculates 140,000 GPM of water at a cooling range of 20 °F. The water consumption due to evaporation is about 3 million gallons per day. By using the Air2Air® condensing technology, 15% to 25% of the evaporation can be recovered. If assuming 20% water conservation, that is 600,000 gallons per day.

If all of the industrial cooling towers in California were retrofitted with the Air2Air® condensing technology, roughly 188 million gallons of high quality freshwater can be conserved in one day. This is equivalent to a 7.6% residential water capacity increase in California.

Base on the laboratory test data, SPX has estimated the water saving potentials throughout the United States. The color map shown in Figure 11 illustrates a water savings percentage for each state based on the climate in the area. Take Los Angeles as an example, the water saving is roughly 22%. The water saving potential for the state of Wyoming is 26%.

In addition to water conservation, following benefits also apply.

- Plume abatement
- Possible other uses of conserved high quality water within the power plant, such as reducing outside purchase or on-site demineralized water production



Water Savings – Gallons per Day			
A typical 500 MW combined cycle power plant	12%	18%	21%
	345,000	515,000	600,000
	24%	27%	30%
	685,000	770,000	865,000

Figure 11: Potential water saving percentage in the United States

Project Description

Technical objectives of proposed project

The overall project objective is to further enable Air2Air® to become a commercially viable water savings technology by solving issues of economy as they relate to superstructure volume, pack cost, and costly ducting details. Specific technical objects supporting this overall objective are as follows:

(a) More efficient heat transfer pack
(b) Watertight wet path seals to enable orientation other than vertical
(c) Remove height from structure without compromising performance to remove material and labor
(d) Simplify ducting details to remove material and labor

Technical Approach and Understanding

"Improvement to Air2Air® Technology to Reduce Fresh-Water Evaporative Cooling Loss at Coal-Based Thermoelectric Power Plants**"**

Objectives -

The technical objectives are presented in more detail below.

(a) More efficient heat transfer pack – The present pack design as shown in Figure 5 has large areas of smooth surfaces originally designed to manage the balance between air flow and pressure drop. Surface enhancements will be added to enhance heat transfer particularly in the dry air passages. As can be seen by the example inlet and outlet temperatures shown on Figure 5, the wet path temperature change is much smaller than the dry path temperature change. Moisture in the wet air changing from vapor to liquid explains this phenomenon because of the latent heat required for the phase change. In this example the temperature difference between the entering dry ambient air temperature (42 ºF) and the exiting wet path temperature (92º F) is 50 Fº, which represents a significant driving potential to condense more vapor from the effluent air stream. However, the temperature difference between the exiting dry air temperature (88 ºF) and the exiting wet air temperature (92 ºF) is only 4 Fº, which represents very little driving potential. This example illustrates that the dry path should probably be shorter and the wet path should probably be longer.

(b) Watertight wet path seals to enable orientation other than vertical – Water tight wet path tube seals are crucial to having the flexibility to orient the Air2Air® pack modules in a direction other than vertical. For example a diamond pattern pack orientation is shown in Figure 12. Water will collect on the bottom of the wet tubes at the seal and run downward to the bottom points of the diamonds. Leakage at the seal will enter into the dry path ducting resulting in loss of condensate and icing in cold weather. This behavior is unacceptable in the commercial market place.

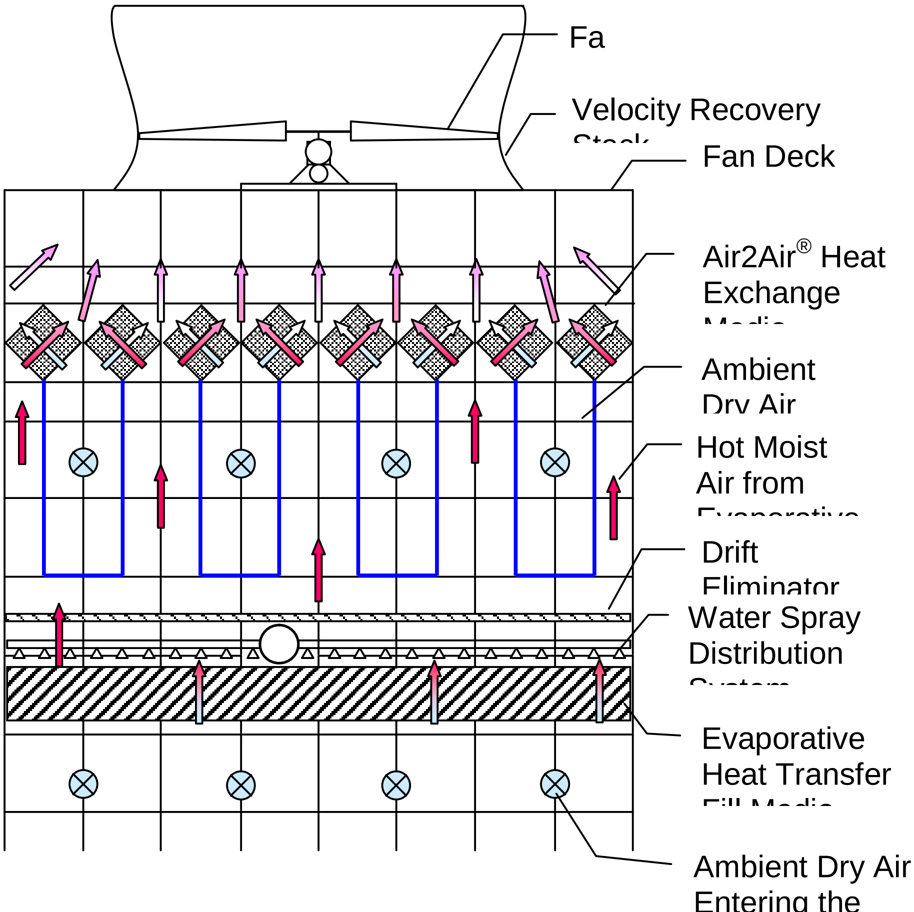


Figure 12 - Air2Air® Diamond Pack Orientation

(c) Remove height from structure without compromising performance to remove material and labor – Again the validation cell experience taught that the very tall structure as shown in Figure 8 (approximately 80 feet to the fan deck) is very costly to build. Taller structures naturally have to resist more wind (and / or seismic) loads than shorter structures. So, not only does a larger structure have more structural elements proportional to height (or volume), but those members often must be sized heavier to resist higher loads. For example special columns had to be procured for the validation cell rather than standard columns. Therefore, it is very important to reduce the height and/or volume of the structure to achieve structural economy. If the general configuration shown in Figure 11 were adapted to the validation cell, an estimated 12 feet would be removed, which is a 15% reduction in height and volume. Thus in this objective we will be studying alternatives to achieve structural economy.

(d) Simplify ducting details to remove material and labor - Complicated ducting details evolved out of necessity when it was discovered that the only acceptable Air2Air® wet path orientation was vertical because of insufficient seals. Obviously a robust seal would make possible horizontal wet path orientation of the Air2Air® packs and the design shown in Figure 7. However, more economy is desired than the Figure 7 configuration can provide. For example Figure 11 with the diamond orientation of the Air2Air® packs has only transverse direction ducts whereas Figures 7 and 8 have transverse ducts that feed longitudinal ducts. Therefore, overall ducting economy will be the focus of this objective.

Report Details for Technical Objectives of Project

Project Milestones:

Task	Milestone Description – DE-NT0005647	Date
1	A2A Tower Configuration Analysis	12/08 COMPLETE
2	A2A Heat Exchanger Enhancement Analysis	12/08 COMPLETE
3	Pack Seal Development	9/10 COMPLETE
4	Evaluate Resulting A2A Pack	03/12 COMPLETE
5	Reporting	06/12 COMPLETE
6	Commercialization	09/11+

Approach: SPX Cooling Technologies proceeded with methods and design configurations during the last quarter of 2008, prior to Award NT05647, at no charge to the DOE, as outlined below. This work advanced the project towards the final objective of a tested, quality, commercially available Air2Air® Tower and Air2Air®Heat Exchanger solution at the best overall economy possible. An optimized Air2Air®Cooling Tower design, with defined and effective component systems, has resulted.

Task 1 - Air2Air® Tower Configuration Analysis – The focus of this task was on the general arrangement of the cooling tower that could include the Air2Air® technology in the most commercially viable configuration. Research and design work in 2008 resulted in a concept for an overall geometrical design of the tower, including A2A packing, ducting support, and plenum. This concept shown in an early form in Figure 12 in the Project Description section, is not as tall as previous “stair-step” designs shown in Figure 5, 7, and 8,and places the A2A packing in a “diamond” single layer configuration. The ducting is much simpler and more uniform and requires less labor to construct. Design details for the new tower configuration were completed during this award and evaluated for simplicity and better economy. The design’s progression to commercialization is followed in this report.

Task 2 - Air2Air® Heat Exchanger Enhancement Study - Substantial research work resulted in a preliminary and then final design of a more effective Air2Air® surface geometry and sheet spacing for assembly into modules. CFD has been used to evaluate the heat transfer and pressure characteristics of these features as the design was completed. Enhanced heat transfer surface and spacings were evaluated to confirm heat exchanger economy during the award. The Air2Air® surface mold was then designed for full size thermal, seal, and structural testing in tasks 3 and 4.

Task 3 - Air2Air® Pack Seal – Technologies, including heat bonding and RF welding, were investigated to determine an economical and effective method of sealing the wet path tubes. Laboratory prototyping for this process was conducted. The successful technology provided a continuous full-length edge seal, preventing loss of moisture migration through the seal, provide internal bonding for internal structural integrity, and provide seal capable of sustaining long-term load bearing of the pack. Full sized testing of this seal design and the manufacturing technology confirmed the actual full-scale feasibility of the method was completed. Seal equipment specification was completed and Full size Air2Air® Heat Exchanger seal process equipment produced.

Sealing Machine Manufacture

Task 3A - Air2Air® Heat Exchanger Identify Design Improvement – The finished CFD evaluation of an improved heat transfer surface and seal configuration was used to complete the design of the improved Air2Air® module surface. This design includes seal features identified in SPX laboratory prototyping, see Task 2 and 3 above. The full improved Air2Air® surface design was prototyped by mold vendors

Close-up of A2A Mold with Ribbing

Task 4 - Evaluate Resulting A2A Pack - Full size Air2Air® Heat Exchanger parts were produced, RF welded at the vendor's facility, seal leak tested, and assembled into modules. Adjustments to the support geometry of the final parts are planned based on that testing. These parts were also thermally tested. Adjustments to the final design are planned based on that testing.

Initial RF Pairs being Tested

First A2A Module from the Prototype RF Pairs Run

SPX asked for a Schedule Extension through 2011 on Project “Improvement to Air2AirTM Technology to Recover Fresh-Water from the Normal Evaporative Cooling Loss at Coal-Based Thermoelectric Power Plants”, Award, NT05647.

Research and prototyping by their nature teach us about final requirements for such a complex product. SPX saw results that were not initially expected in several area and have had to adjust our design and propose new experiments as we proceeded in the program. A couple of areas needed more work were module structural support in the diamond configuration and RF welding application/tune-in on very large plan area parts. These tests have extended the schedule for Task 3A and 4 - Air2Air® Heat Exchanger Design and Evaluate Resulting A2A Pack. Adding some detail to the last progress report, here were the extended and added process steps, with the completion status for each at the time of the request noted:

A. Tooling / Machine Design I, Tooling Manufacture I [COMPLETE]
B. Seal Process Machine Feature Requirements [COMPLETE]
C. Manufacture Seal Machine [COMPLETE]
D. RF Tooling [COMPLETE]
E. Setup of Prototype Air2Air® Heat Exchanger Tool I and Prototype Seal Machine [COMPLETE]
F. RF Test Run [COMPLETE]
G. Testing Seal [Short-term COMPLETE, Long term Ongoing]
H. Testing Materials/Structural [Design I COMPLETE], Results required design changes
I. Thermal Testing Design I [COMPLETE], Results required design changes
J. Tooling / Machine Design II Added step
K. Tooling Manufacture II, Added step
L. Testing Materials/Structural [Design II] Added step
M. Thermal Testing [Design II] Added step

Mold modification were made including Structural Design II of the corner geometry identified by module temperature and load testing to the Air2Air® Heat Exchanger final tooling followed by structural testing and Thermal Testing of the resultant parts.

Structural Testing at 3X Design Load 100degF of the Corner Re-design

Sample sheet were formed, RF welding die modifications were completed, and pairs were re-sampled, see picture below. From this point, final prototype modules build, and final materials/structural and thermal testing were undertaken.

Sealed Air2Air Pair

Task 5 – Reporting – This information is contained in this document.

Task 6 – Commercialization -Sample of the re-designed RF pairs of the Air2Air heat exchanger for various test were made and modules were assembled. A mock-up of the constructed plenum was completed and support and drain details finalized. Material tests were initiated.


Assembly of Air2Air Pairs into a Module


Mockup of Tower Plenum

Plant production seal training was completed prior to the first commercial production of parts starting in 2012.

Conclusions:

1. A re-engineered sheet/module including improvements to pack structure, wet path seal, and condensing surface was created
2. Testing confirmed the improvements provided by the sheet design modification and prototype module manufacturing, improved economy of Air2Air, also known as ClearSky for plume abatement application
3. The tower superstructure, pack orientation, and ducting details were also re-engineered providing better economy
4. A competitive commercial product utilizing a more efficient heat exchange module is the result, and the first commercial sale has been realized and is being built

Appendix

Results During the Period, 10/1/11-12/31/11:

SPX Cooling is in the process of completing Steps 12 and 13, Testing Materials, Structural Capability, and Thermal for the production Design II parts.

12. Testing Materials/Structural [Design II] Added step
13. Thermal Testing [Design II] Added step

Sample RF pairs of the Air2Air heat exchanger for various tests were made. Drain details were finalized in the thermal test cell. Material tests were reviewed. Plant production seal training was planned. Results of testing will be included in the final report due 3/31/11.

Previous Results for the Period, 7/1/11-9/30/11:

SPX Cooling made progress making parts and setting up for Steps 12 and 13 below, Testing Materials, Structural Capability, and Thermal for the production Design II parts during the period.

12. Testing Materials/Structural [Design II] Added step
13. Thermal Testing [Design II] Added step

Sample RF pairs of the Air2Air heat exchanger for various tests were made and modules were assembled. A mock-up of the constructed plenum was completed and support and drain details finalized. Material tests were initialized.

Assembly of Air2Air Pairs into a Module

Mockup of Tower Plenum

Previous Results for the Period, 4/1/11-6/30/11:

SPX Cooling Technologies completed the Tooling Manufacture Step, item 11 below.

With the return of the thermoforming tooling, sample sheet were formed, RF welding die modifications were completed, and pairs were sampled, see picture below. From this point, prototype module will be build, and final materials and thermal testing will be completed and reported.

1. Tooling / Machine Design I, Tooling Manufacture I [COMPLETE]

2. Seal Process Machine Feature Requirements [COMPLETE]
3. Manufacture Seal Machine [COMPLETE], Delays in this step
4. RF Tooling [COMPLETE], Delays in this step
5. Setup of Prototype Air2Air® Heat Exchanger Tool I and Prototype Seal Machine [COMPLETE]
6. RF Test Run [COMPLETED]
7. Testing Seal [Short-term COMPLETE, Long term Ongoing]
8. Testing Materials/Structural [Design I COMPLETE], Results required design changes
9. Thermal Testing Design I [COMPLETE], Results required design changes
10. Tooling / Machine Design II [COMPLETE], Added step
11. Tooling Manufacture II, [COMPLETE] Added step
12. **Testing Materials/Structural [Design II] Added step**
13. **Thermal Testing [Design II] Added step**

Sealed Air2Air Pair

Previous Period Results, 1/1/11-3/31/11:

SPX Cooling Technologies is working to complete the added Tooling Manufacture Step, item 11 below, identified by Module temperature and load testing. Mold Re-work design went to the vendor in January, 2011. Tooling work proceeded during the period.

With the return of the tooling in mid-April, sample sheet forming, RF welding modifications, pairs sampling, sample module building, and final materials and thermal testing will proceed

Previous Period Results, 10/1/10-12/31/10:

SPX has asked for a Schedule Extension for an Additional Year on Project "Improvement to Air2AirTM Technology to Recover Fresh-Water from the Normal Evaporative Cooling Loss at Coal-Based Thermoelectric Power Plants", Award, NT05647.

We are asking so that we can properly complete the project objective of further enabling Air2Air becoming a commercially viable water savings and plume abatement technology by **researching a re-engineered pack**, **testing improvement** provided by modification, and **prototyping the pack manufacture**. The results of these processes determine the revised A2A tower superstructure volume, cost, and enable the optimum pack orientation and ducting details.

Research and prototyping by their nature teach us about final requirements for such a complex product. We have seen results that we did not initially expect in several areas and have had to adjust our design and propose new experiments as we proceeded in the program. A couple of areas we needed to do more work were module structural support in the diamond configuration and RF welding application/tune-in on very large plan area parts. These tests have extended the schedule for Task 3A - Air2Air® Heat Exchanger Design. Adding some detail to the last progress report, here are the extended and added process steps:

14. Tooling / Machine Design I, Tooling Manufacture I [COMPLETE]
15. Seal Process Machine Feature Requirements [COMPLETE]
16. Manufacture Seal Machine [COMPLETE], Delays in this step
17. RF Tooling [COMPLETE], Delays in this step
18. Setup of Prototype Air2Air® Heat Exchanger Tool I and Prototype Seal Machine [COMPLETE]
19. RF Test Run [COMPLETED]
20. Testing Seal [Short-term COMPLETE, Long term Ongoing]
21. Testing Materials/Structural [Design I COMPLETE], Results required design changes
22. Thermal Testing Design I [COMPLETE], Results required design changes
23. **Tooling / Machine Design II [COMPLETE], Added step**
24. **Tooling Manufacture II, [COMPLETE] Added step**

25. **Testing Materials/Structural [Design II]** **Added step**
26. **Thermal Testing [Design II]** **Added step**

Per the original Milestone Schedule we are executing Task 3A - Air2Air® Heat Exchanger Identify Methods - Air2Air® Heat Exchanger mold modification Structural Design II of the corner geometry for build into the Air2Air® Heat Exchanger final tooling **[Completed during the period]**, structural testing [in process through January, 2011], and Thermal Testing of the resultant parts are being or will be run, per the extended schedule.

Structural Testing at 3X Design Load 100degF of the Corner Re-design

Previous Period Results, 7/1/10-9/30/10:

Task 3A - Air2Air® Heat Exchanger Identify Methods - Full size Air2Air® Heat Exchanger parts were fabricated using RF welding, seal leak tested, and assembled into modules during the period. Adjustments to the support geometry of the final parts are planned based on that testing. Full size Air2Air® Heat Exchanger seal process equipment has been manufactured and test run at the SPX Plant during the period.

Steps in these evaluation processes: Tooling / Machine Design I [COMPLETE], Tooling Manufacture I [COMPLETE], specifying Seal Process Machine Feature Requirements [COMPLETE], Manufacture Seal Machine [COMPLETE], followed by Setup of Prototype Air2Air® Heat Exchanger Tool I and Prototype Seal Machine [**COMPLETED this period**] and RF Test Run [**COMPLETED this period**], and RF Tooling [COMPLETE]. Finally, tasks related to Seal [**In Process this period**], Materials [in process through November, 2010], and Thermal Testing of the resultant parts are being run, as adjusted. Revised support geometry will be built into the Air2Air® Heat Exchanger final tooling.

Above right, RF Sealing machine in SPX Olathe Plant; Above, A2A module; Right, Materials Testing at 100 to 120 degF.

Previous Period Results, 4/1/10-6/30/10:

Task 3A - Air2Air® Heat Exchanger Identify Methods - Full size Air2Air® Heat Exchanger parts were thermally tested and checked during the period. Adjustments to the final design are planned based on that testing. Full size Air2Air® Heat Exchanger seal process equipment has been manufactured and test run at the vendor's facility during the period.

Steps in these evaluation processes: Tooling / Machine Design [COMPLETE], Tooling Manufacture [COMPLETE], specifying Seal Process Machine Feature Requirements [COMPLETE], Manufacture Seal Machine [COMPLETE], followed by Setup of Prototype Air2Air® Heat Exchanger Tool and Prototype Seal Machine [in vendor plant] and RF Test Run [planned August, 2010], and for Tooling [COMPLETE]. Finally, Seal [planned August, 2010], Materials [planned August, 2010], and Thermal Testing of the resultant parts as adjusted.

Initial RF Pairs being Set for Test

Previous Period Results, 1/1/10-3/31/10:

Task 3A - Air2Air® Heat Exchanger Identify Methods - Full size Air2Air® Heat Exchanger test mold with improvements was run and parts checked during the period. Full size Air2Air® Heat Exchanger seal process equipment has been ordered and manufacture is in process during the period. Pictures of the complete A2A Mold and the Sealing Equipment in process are provided below.

Steps in these evaluation processes: Tooling / Machine Design [COMPLETE], Tooling Manufacture [COMPLETE], specifying Seal Process Machine Feature Requirements [COMPLETE], Manufacture Seal Machine [in process], followed by Setup of Prototype Air2Air® Heat Exchanger Tool and Prototype Seal Machine and Test Run for each, scheduled for January, 2010 for Tooling [COMPLETE], and May, 2010 for Sealing Machinery. Finally, Seal and Thermal Testing of the resultant parts scheduled for March-May, 2010 [setup completed].

Close-up of A2A Mold with Ribbing

Sealing Machine in Manufacturing Process

Previous Period Results, 10/1/09-12/31/09:

Task 3A - Air2Air® Heat Exchanger Identify Methods - Full size Air2Air® Heat Exchanger test mold with improvements was manufactured and received during the period. It was checked to specification. This mold will be run and parts checked during the next period. Full size Air2Air® Heat Exchanger seal process equipment has been ordered and manufacture is in process during the period. Manufacture will be complete during the next period. Steps in these evaluation processes: Tooling / Machine Design [COMPLETE], Tooling Manufacture [COMPLETE], specifying Seal Process Machine Feature Requirements [COMPLETE], Manufacture Seal Machine [in process], followed by Setup of Prototype Air2Air® Heat Exchanger Tool and Prototype Seal Machine and Test Run for each, scheduled for January, 2010 for Tooling, and March, 2010 for Sealing Machinery. Finally, Seal and Thermal Testing of the resultant parts scheduled for March-May, 2010.

Previous Period Results, 7/1/09-9/30/09:

Task 3A - Air2Air® Heat Exchanger Identify Methods - Full size Air2Air® Heat Exchanger test mold has been specified, ordered and manufacturing is in process for this item. Steps in this evaluation process include Tooling / Machine Design [COMPLETE], followed by Setup of Prototype Air2Air® Heat Exchanger Tool and Test Run, scheduled for November and December 2009.

Task 3A - Air2Air® Heat Exchanger Identify Methods – Full size Air2Air® Heat Exchanger seal process equipment has been ordered and manufacture is in process. Steps in this evaluation process include specifying Machine Feature Requirements [COMPLETE], followed by Setup of Prototype Machine, Test Run, and Seal Testing scheduled for February and March, 2010.

Previous Period Results, 3/31/09-6/30/09:

Task 3A - Air2Air® Heat Exchanger Identify Methods – The finished CFD evaluation of an improved heat transfer surface and seal configuration was used to complete the design of the improved Air2Air® module surface. This design includes seal features identified in SPX laboratory prototyping, see Task 3 below. The full improved Air2Air® surface design was forwarded to mold vendors for quote of full Air2Air® surface. Full size test mold will be ordered and produced next. Steps in this evaluation process include Tooling / Machine Design [COMPLETE], Setup of Prototype Tool / Machine, Test Run, and Seal Testing.

Task 3A - Air2Air® Heat Exchanger Identify Methods – A technology has been investigated and a complete study determined it to be an economical and effective method of sealing the wet path tubes. Laboratory prototyping for this process was previously conducted by SPX in 2008. This technology is expected to provide continuous full-length edge seal, prevent long-term moisture migration through the seal, provide internal bonding for internal structural integrity, and provide seal capable of sustaining long-term load bearing of the pack.

Full sized testing of this seal design and the manufacturing technology to confirm the actual full-scale feasibility of the method is now in process. Seal equipment specification was completed and equipment quoted during the quarter. Full size manufacturing process equipment will be ordered and produced next. Steps in this evaluation process include Machine Feature Requirements [COMPLETE], Setup of Prototype Machine, Test Run, and Seal Testing.

Conclusion: SPX Cooling Technologies is completing the required investigation steps in the proper sequence to result in the final objective of a tested and commercially available Air2Air® Tower and Air2Air®Heat Exchanger solution.

Previous Period Results, 1/1/09-3/31/09:

Task 2 - Air2Air® Heat Exchanger Enhancement Study – Substantial progress has been made on design of the Air2Air® module surface. CFD was used to evaluate the heat transfer and pressure characteristics of these features as the design was completed. The Air2Air® surface mold will be designed for full size seal testing next.

Previous Result, 2008: The following research has been completed at this point:

Task 1 - General Air2Air® Tower Configuration Study - General Arrangement – Preliminary research work has resulted in a concept for an overall geometrical design of the tower, including A2A packing, ducting support, and plenum. Design details for the new tower configuration are being completed and evaluated for simplicity and better economy.

Task 2 - Air2Air® Heat Exchanger Enhancement Study - Research work has resulted in a preliminary design of an Effective Surface Treatment and Spacing for the Air2Air® modules. CFD has been used to evaluate the heat transfer and pressure characteristics of these features before implementation. Enhanced heat transfer surface requirements and spacings are being evaluated to confirm heat exchanger economy.

Task 3 - Air2Air® Pack Seal - A technology is being investigated to determine an economical and effective method of sealing the wet path tubes. Laboratory prototyping for this process has been conducted. This technology may provide continuous full-length edge seal, prevent long-term moisture migration through the seal, provide internal bonding for internal structural integrity, and provide seal capable of sustaining long-term load bearing of the pack. Full sized testing of this technology to confirm the actual feasibility of the method will follow.

Task 3A - Identify Methods - An investigation is being conducted to identify from 1 to 3 other methods to seal the sheets. Steps in this evaluation process include Tooling / Machine Design, Setup of Prototype Tool / Machine, Test Run, Seal Testing.