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World's Largest Power Plant Dry Cooling Systems Overview

Jessica Shi, Ph.D.

Sr. Project Manager

Technical Lead of Water Use and Availability

Technology Innovation Program

EPRI Brown Bag Lunch Seminar

Palo Alto, CA

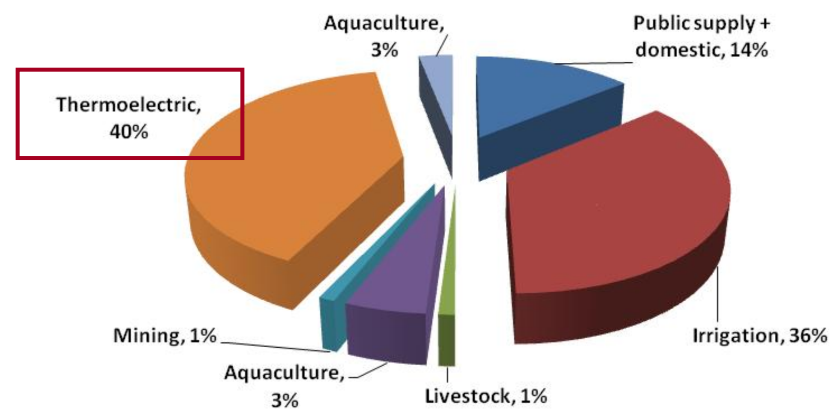
Sep. 3, 2013

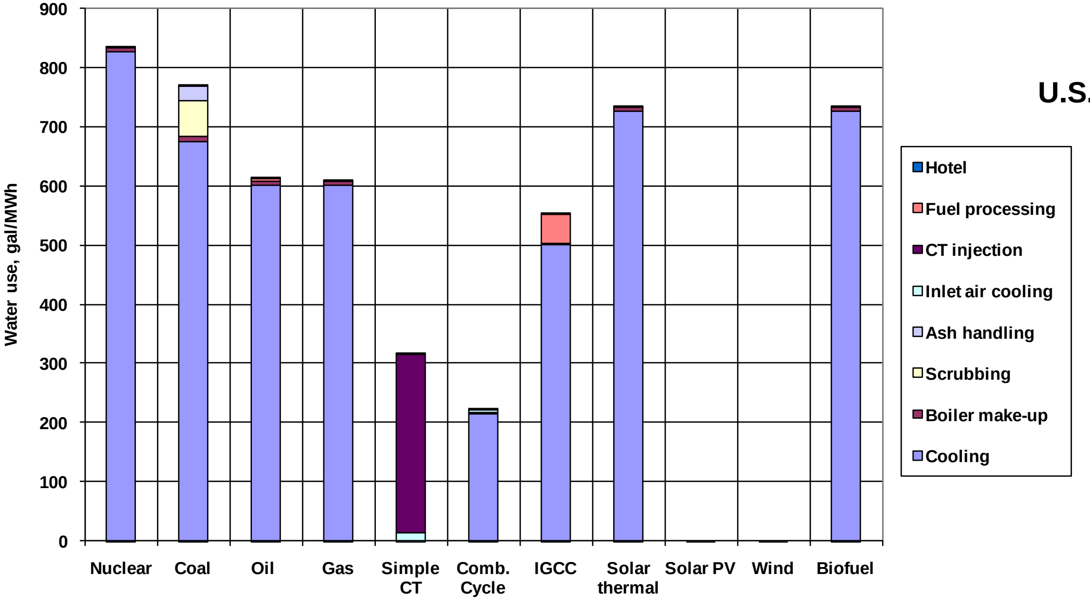
Outline

- Overview
  - Water Use and Availability Technology Innovation Program
  - Power Plant Cooling
  - South Africa and Eskom
- Dry Cooling at Four Eskom's Power Stations in South Africa
- EPRI-NSF Collaboration
- Conclusion

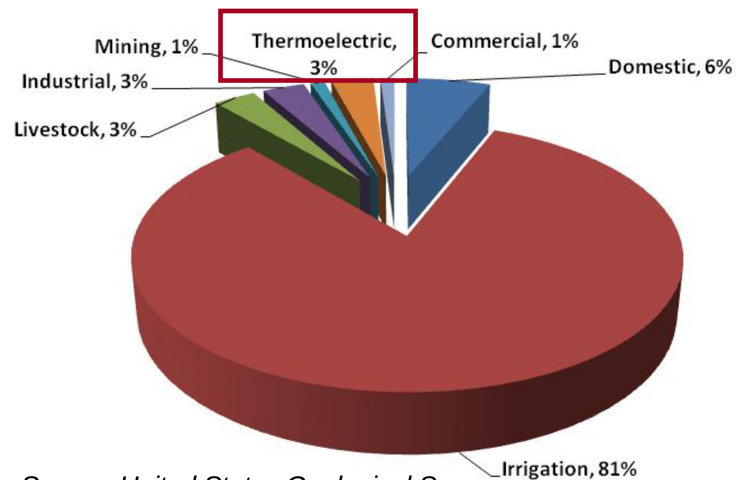
Industry Specific Needs: Strategic Water Management

- Thermal-electric power plants withdraw 40% and consume 3% of US fresh water.
- 90% of power plant water demand is due to cooling systems.





Source: EPRI Report, "Water Use for Electric Power generation", No. 1014026, 2008



Source: United States Geological Survey

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Water Use and Availability Technology Innovation Program Overview and Objective

- Initiated in early 2011
- Collected 168 proposals/white papers from 3 solicitations
  - ✓ Feb., 2011
  - ✓ June, 2012
  - ✓ May, 2013 (jointly with NSF).
- Funded 12 projects

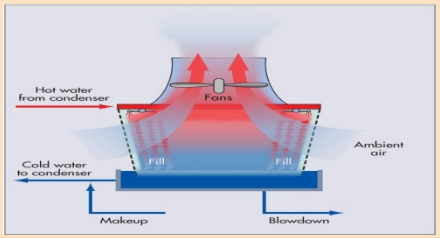
Objective

Seek and develop "out of the box", game changing, early stage, and high risk cooling and water treatment ideas and technologies with high potential for water consumption reduction.

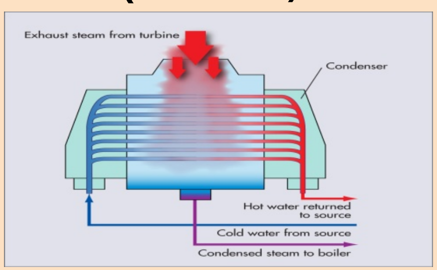
What Cooling System Options are Currently Deployed in the Industry?

Water Cooling

Cooling Tower [1](42% in US)[2]



Once Through Cooling[1] (43% in US) [2]



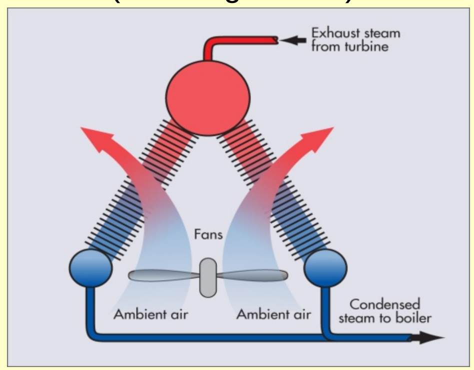
Cooling Pond

(14% in US)[2]

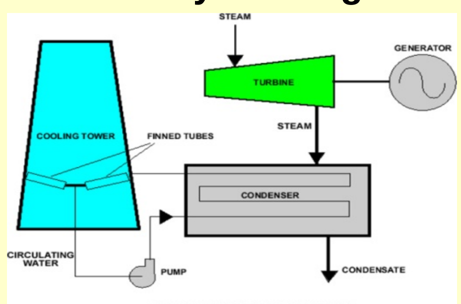
Dry Cooling[1]

Direct Dry Cooling:

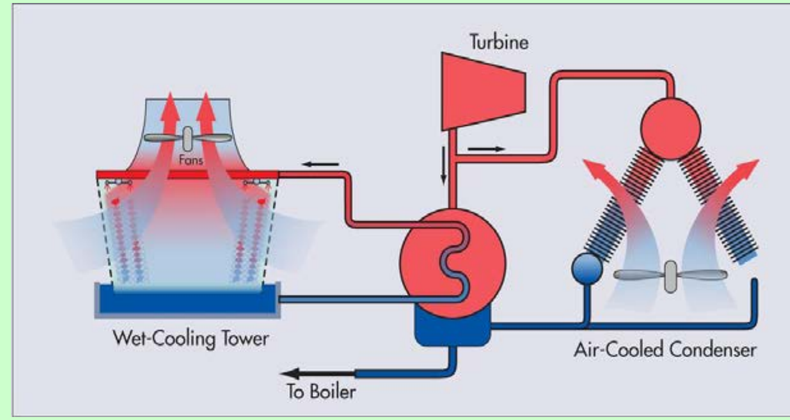
Air Cooled Condenser (1%Usage in US) [2]



Indirect Dry Cooling [3] :



Hybrid Cooling[1]



Increasing demand for dry cooling in water scarcity regions.

1. *EPRI Report, "Water Use for Electric Power generation", No. 1014026, 2008.*
2. *Report of Department of Energy, National Energy Technology Laboratory, "Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements",* DOE/NETL-400/2008/1339, *2008*
3. *http://www.globalccsinstitute.com/publications/evaluation-and-analysis-water-usage-power-plants-co2-capture/online/101181*

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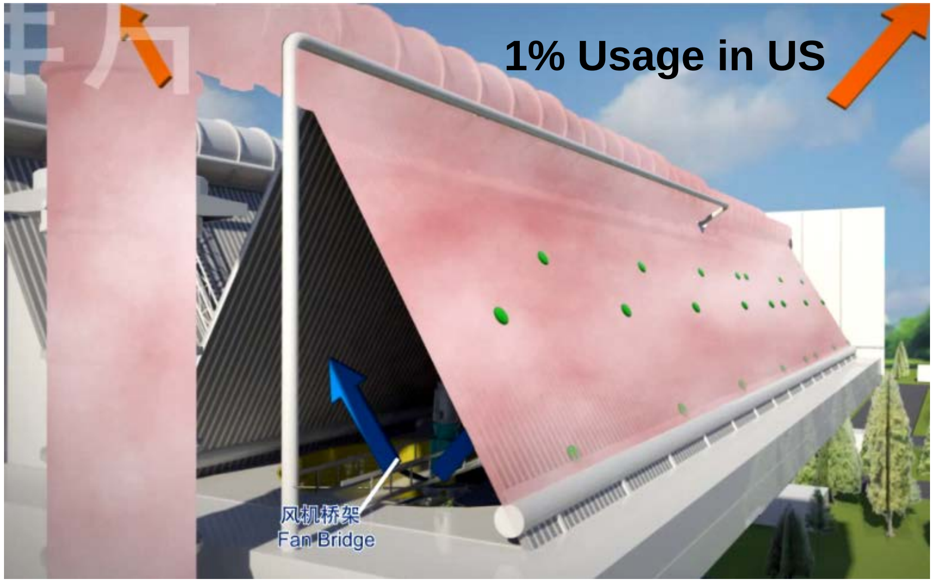
Air Cooled Condenser Pros/Cons

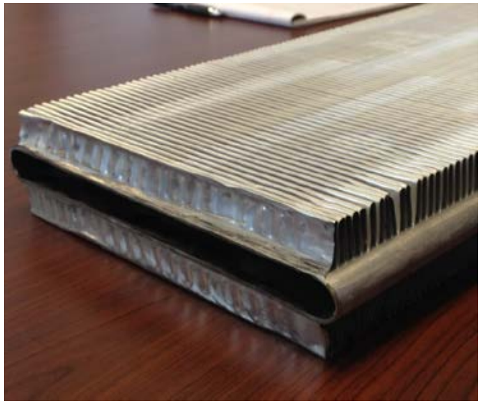
Pros:

- Dry system
  - Zero water consumption and water supply needed

Cons:

- Up to 10% less power production on hot days due to higher steam condensation temperature compared to CT and OTC systems
- Up to five times more expensive than cooling tower systems
- Noise, wind effect, and freezing in cold days





Click Here for Animation

Source:

EVAPCO BLCT Dry Cooling

Challenge: Reduce steam condensation temperature >> more power production

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- Conclusion

Where is South Africa?

Medium-Sized Country:

More than1.221 Mkm^2

– 2 X of France (0.675 Mkm^2)

– 2 X of Texas (0.696 Mkm^2)

Source: Ken Galt, "Reduction of Water Consumption and Increased Water Recycle and Re0Use to Comply with Zero Liquid Effluent Discharge in Eskom", Presentation at EPRI Conference – Water Management Technology, Atlanta, Georgia, March, 2013.

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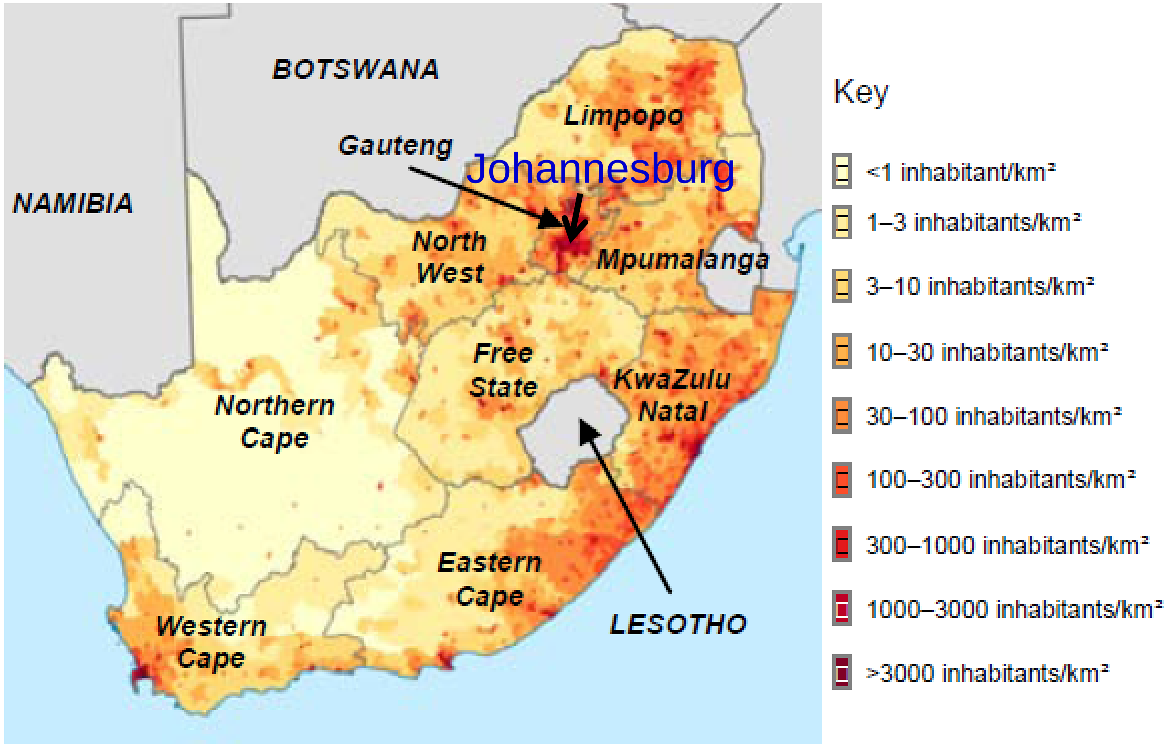
South Africa Population Density



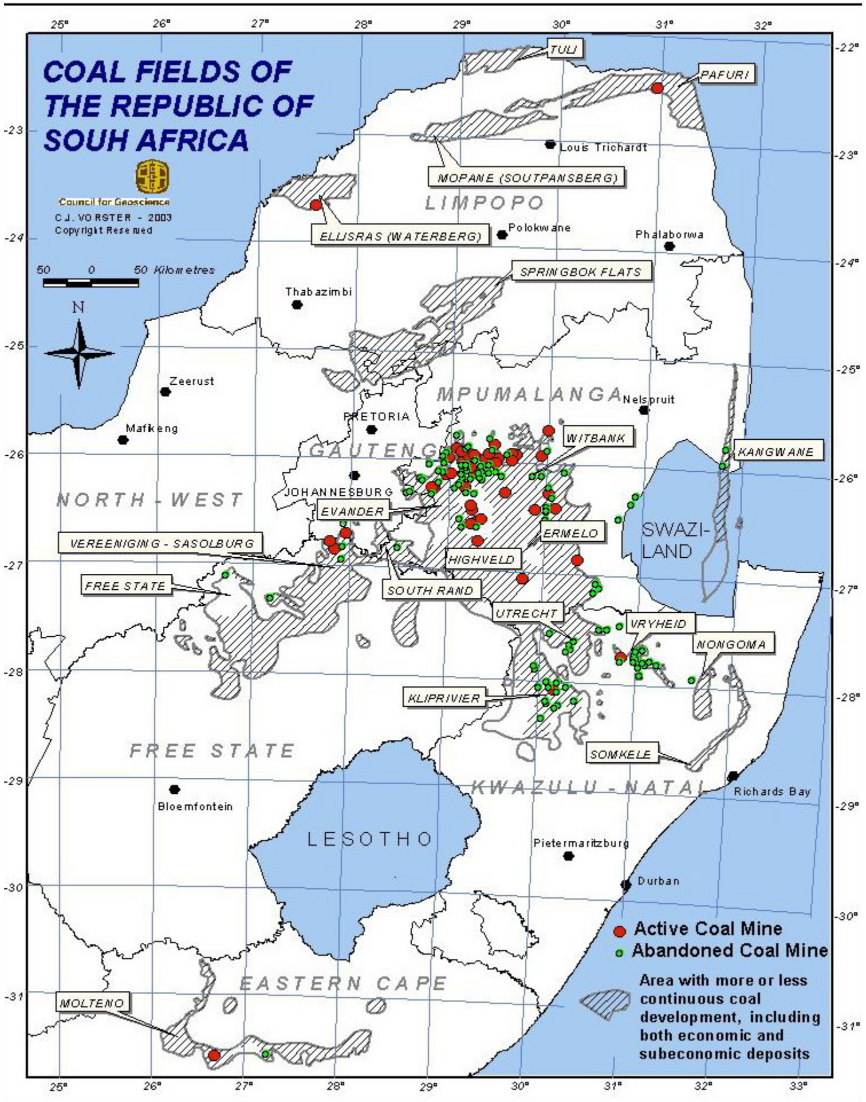
Map of population Density in South Africa
Data Source - Stats SA; map - Wikipedia

Population: 50.8 M (1.221 Mkm^{2})

- France:85.4 M (0.675 Mkm^{2})
- Texas:25.7 M (0.696 Mkm^{2})

Source: Ken Galt, "Reduction of Water Consumption and Increased Water Recycle and Re0Use to Comply with Zero Liquid Effluent Discharge in Eskom", Presentation at EPRI Conference – Water Management Technology, Atlanta, Georgia, March, 2013.

South African Coalfields Locations



- World's 5th largest coal producer
- World's 3rd largest coal exporter

Source: Ken Galt, "Reduction of Water Consumption and Increased Water Recycle and Re0Use to Comply with Zero Liquid Effluent Discharge in Eskom", Presentation at EPRI Conference – Water Management Technology, Atlanta, Georgia, March, 2013.

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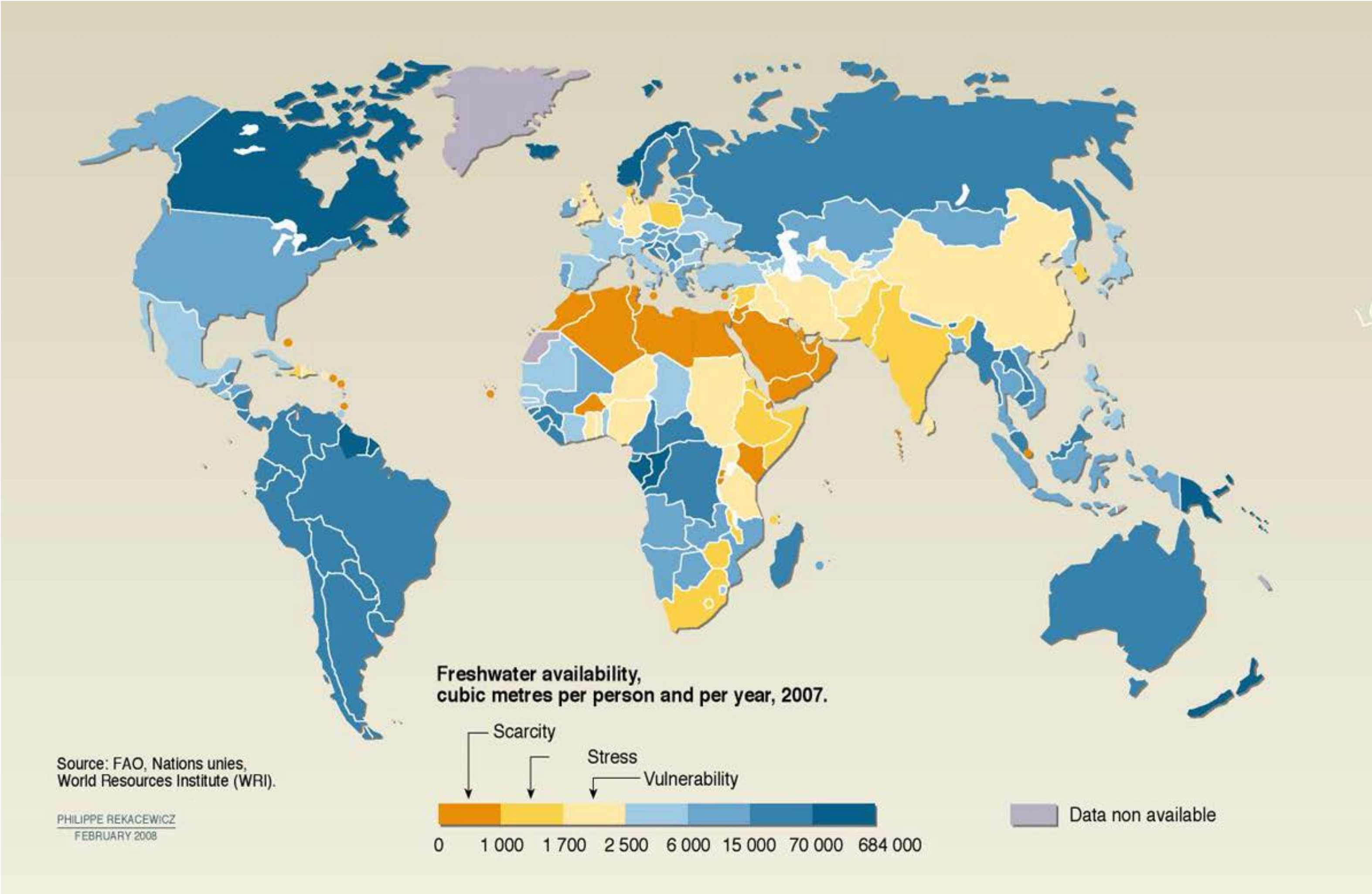
Water Stressed South Africa



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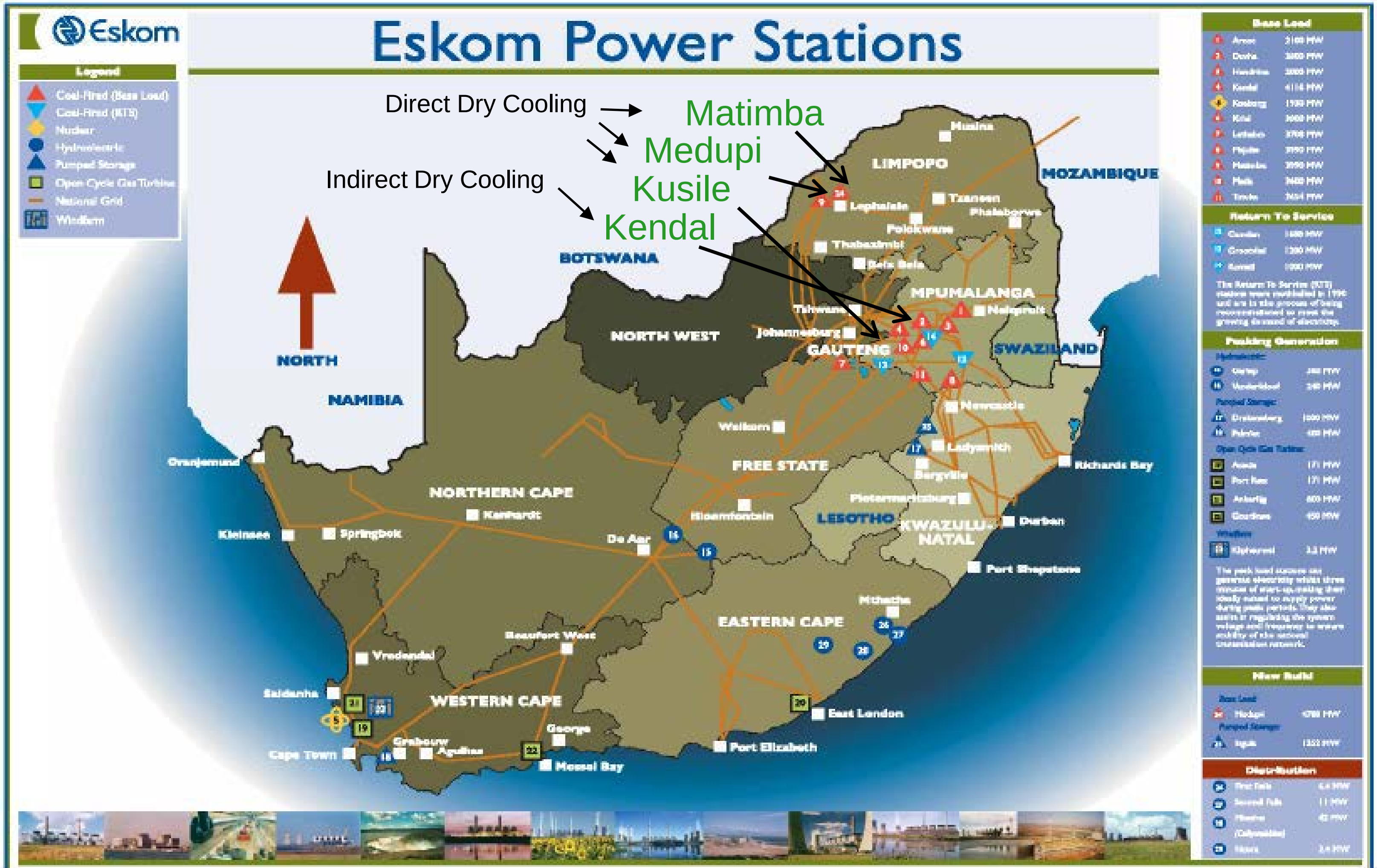
Eskom Introduction

- State-owned electricity supply utility
- Generation total capacity of 44.145 GW:
  - 95% of electricity used in South Africa
  - 45% of electricity used in Africa
- Generation Fleet:
  - 13 Coal Fired
  - 1 Nuclear
  - 4 Hydro & Pumped Storage
  - 4 Gas Turbines

Eskom Power Stations



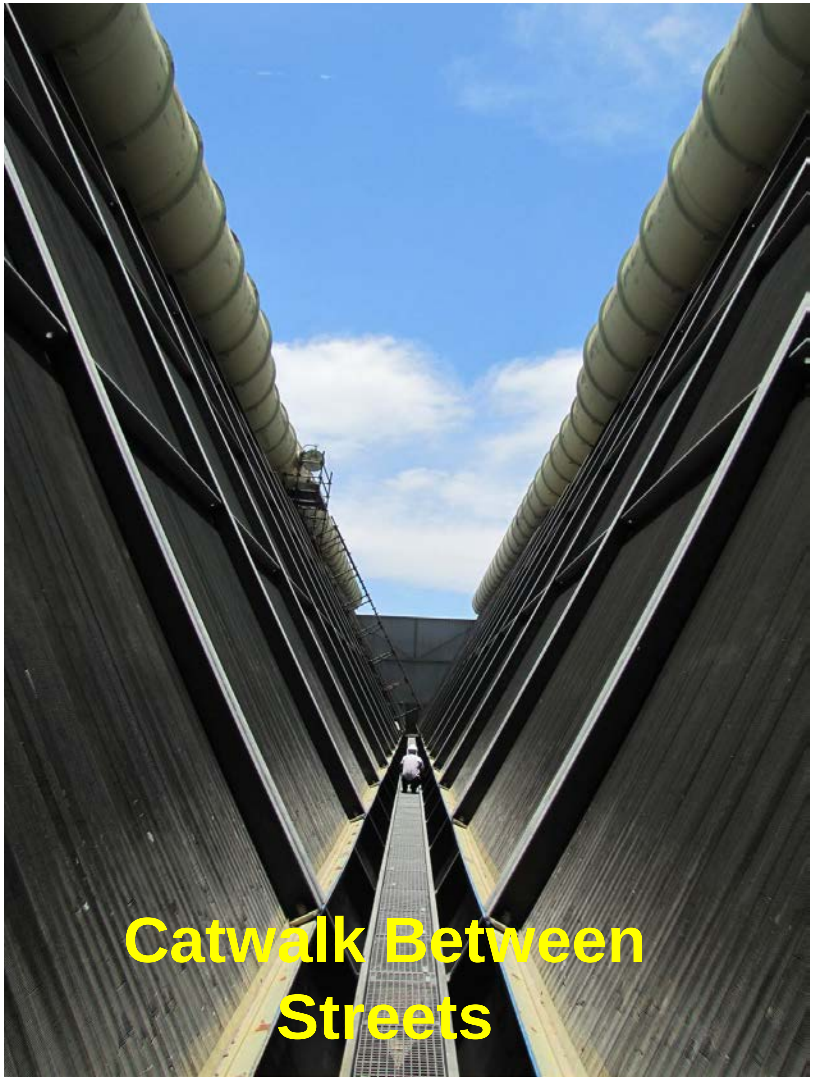
Source: Ken Galt, "Reduction of Water Consumption and Increased Water Recycle and Re0Use to Comply with Zero Liquid Effluent Discharge in Eskom", Presentation at EPRI Conference – Water Management Technology, Atlanta, Georgia, March, 2013.

Air Cooled Condenser at Matimba Power Station (6x 665 MWe = 4.11 GWe)

- The largest operating direct dry cooling system in the world
- Cooling system commissioned by GEA in1987

Top View of Air Cooled Condensers at Matimba Power Station

Air Cooled Condensers at Matimba Power Station



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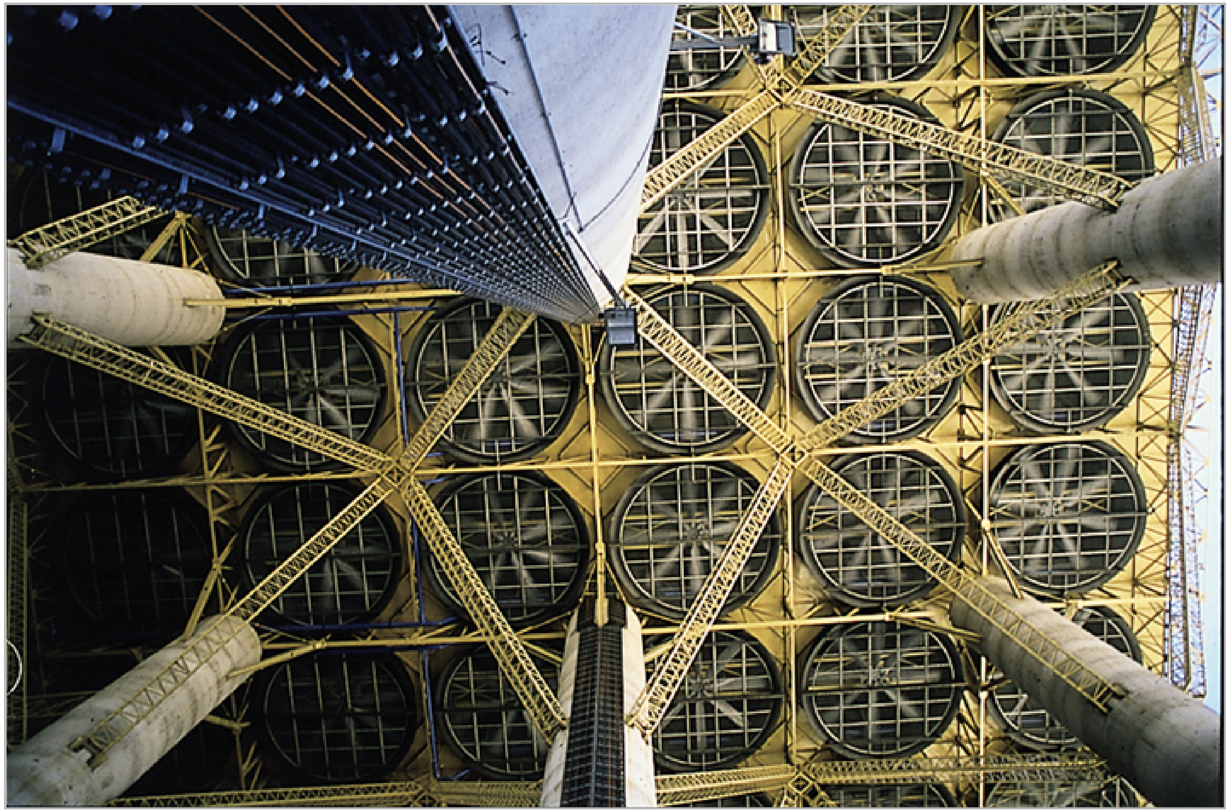
Air Cooled Condenser Fans at Matimba Power Station – 6 fans/street



Air Cooled Condensers at Medupi Power Station (6 X 800 MWe = 4.8 GW)

- Medupi means ‘rain that soaks parched lands, giving economic relief’.
- Contract awarded for in May 2007 (Cooling by GEA)
- Unit 1 to be in operation by end of 2013 and the other units to be commissioned at approximately 8-month intervals

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Major Improvements at Medupi Power Station

- *Based on Lessons Learned from Matimba*

	Matimba	Medupi
Generation (MWe)	6 X 665 MWe	6 x 794 Mwe
Year Built/Awarded	1987	2007
Cooling Vender	GEA	GEA
Fan Bottom Height, m	45	54
Street Length, m	72	100
Length Across Steets/Unit, m	82	112
Steam Tube Length, m	9.4	10.4
Number of Streets/Unit	8	8
Number of Fans/Street	6	8
Number of Steam Tube Rows	2	2
Fan Diameter, m	9.144	10.36

Source: Email communication with Dr. Johannes Pretorius of Eskom with permission for unlimited public release

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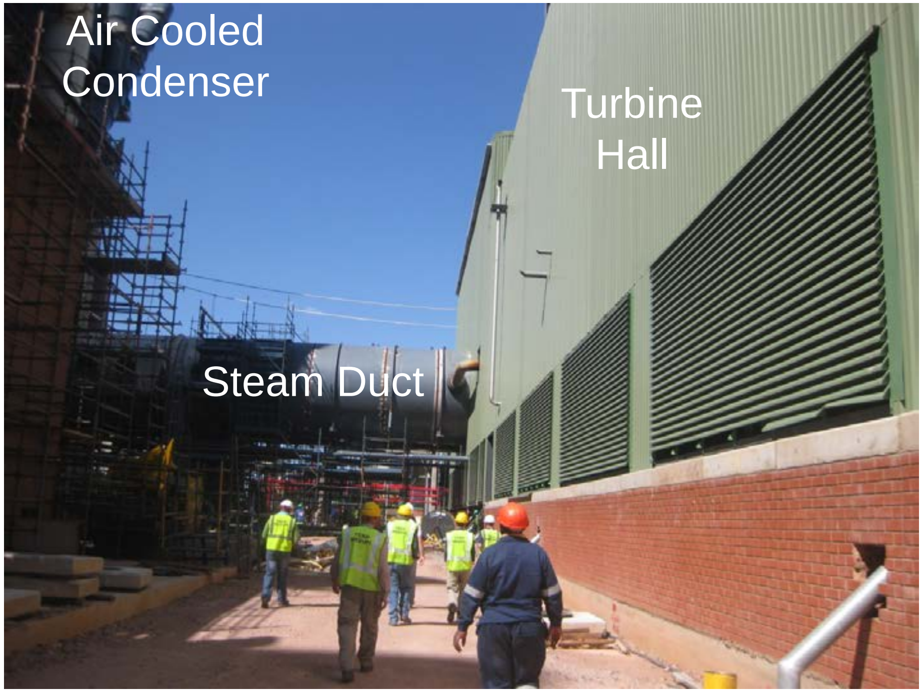
More Improvement at Medupi – Wind Effects Minimization

- Extended spacing between the air cooled condensers and turbine hall to minimize wind issue.

Matimba (26 years old)

Medupi (under construction)



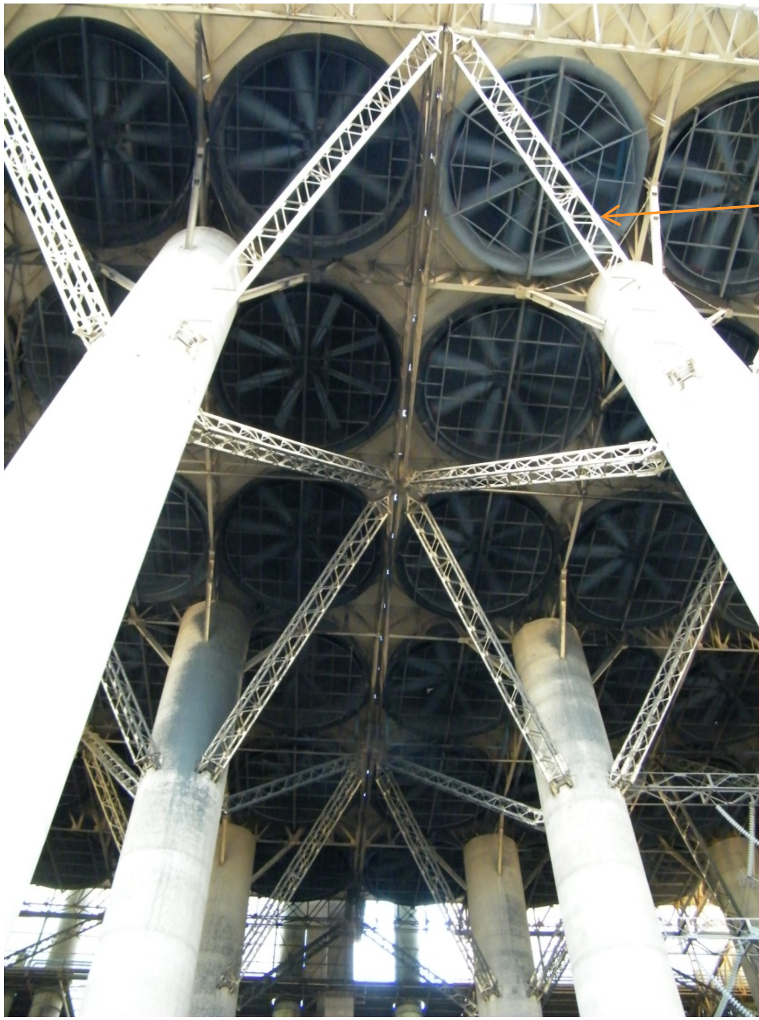
More improvements - Ease of Fan Maintenance

Added screens below the fan

- Access & reachability for maintenance on fans
- Plant & personnel safety – fatigue failures on fans

Beam – Fan Platform Support Difference

Matimba (26 years old)



Medupi (Under Construction)

- More columns per unit area
- No more angled metal frames

Unique Steam Duct Splitting Arrangement at Medupi Power Station

Matimba (26 years old)

Medupi

Air Cooled Condensers at Kusile Power Station (6 X 800 MWe = 4.8 GWe)

- Contract awarded in May 2008 (Cooling by SPX)
- Unit 1 in operation in 2014 and the other units to be commissioned at approximately 8-month intervals

Air Cooled Condenser Modules at Kusile Power Station

Matimba

Steam Pipe being Installed

20 Min.
Later

Fan Casing being Installed

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Fan Shape Comparison

Matimba (26 years old)

Medupi

Kusile

	Matimba	Medupi	Kusile
Fan Diameter, m	9.144	10.36	10.36

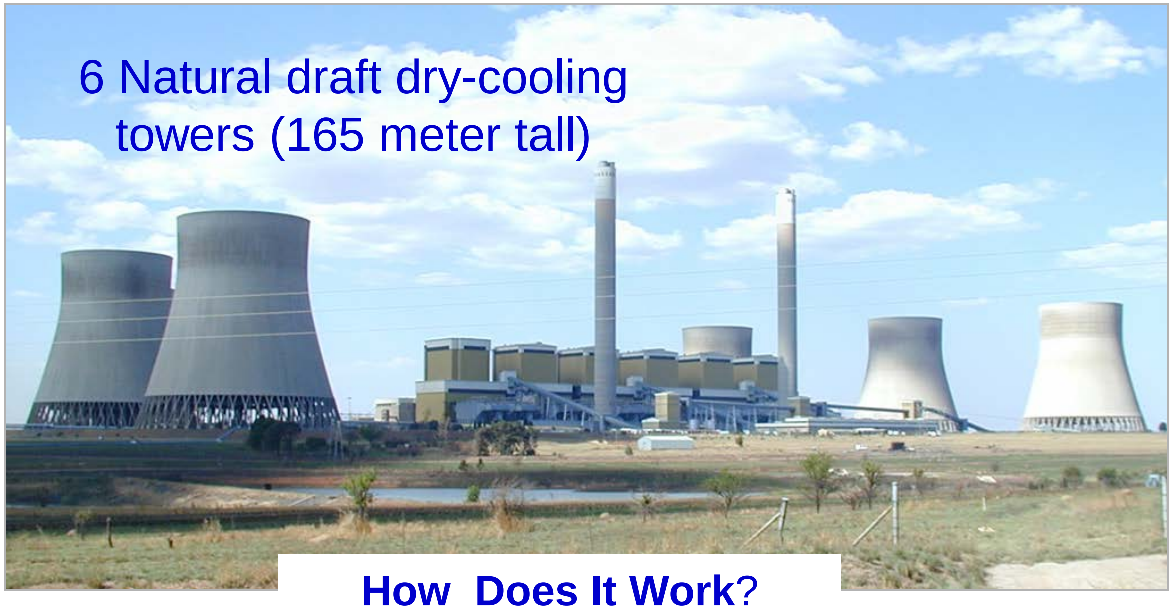
Source: Email communication with Dr. Johannes Pretorius of Eskom with permission for unlimited public release

Cooling System Comparison

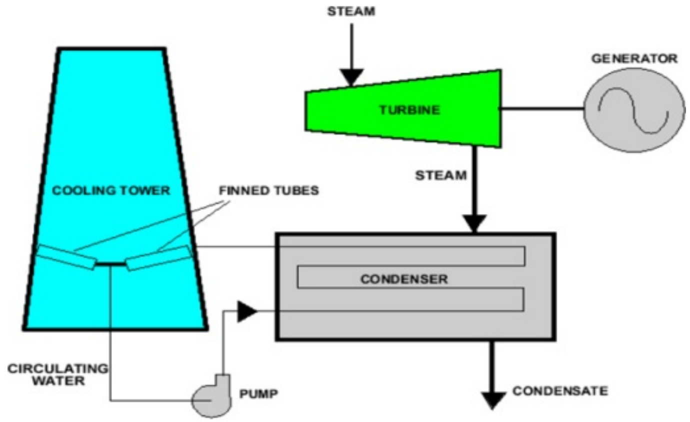
	Matimba	Medupi	Kusile
Generation (MWe)	6 X 665 MWe	6 x 794 MWe	6 x 798 MWe
Year Built/Awarded	1987	2007	2008 (approx.)
Cooling Vender	GEA	GEA	SPX
Fan Bottom Height, m	45	54	60
Street Length, m	72	100	100.8
Length Across Steets/Unit, m	82	112	112
Steam Tube Length, m	9.4	10.4	11
Number of Streets/Unit	8	8	8
Number of Cells/Street	6	8	8
Number of Steam Tube Rows	2	2	3
Number of Blades/Fan	8	8	8 on perimeter fans, 9 on central fans

Source: Email communication with Dr. Johannes Pretorius of Eskom with permission for unlimited public release

Indirect Dry Cooling System at Kendal Power Station (6 x 686 MWe)



How Does It Work?



INDIRECT DRY-COOLING SYSTEM

Data

	Kendal
Cooling Type	Indirect Dry Cooling
Generation (MWe)	6 X 686 MWe
Year Commissioned	1988
Cooling Tower Height, m	165
Cooling Tower Base Diameter, m	161
Heat Exchanger Platform Height Relative to the Ground Level, m	19.7 to 27.3
Vender	SPX
Design Conditions	
Number of Heat Exchangers (HXs)	500
Number of Water Tubes/HX	264
Number of Sectors	11
Number of Water Tube Rows	4

Source: http://www.globalccsinstitute.com/publications/evaluation-and-analysis-water-usage-power-plants-co2-capture/online/101181

Pros and Cons of Indirect Dry Cooling

Compared to air cooled condensers (direct dry cooling):

Pros

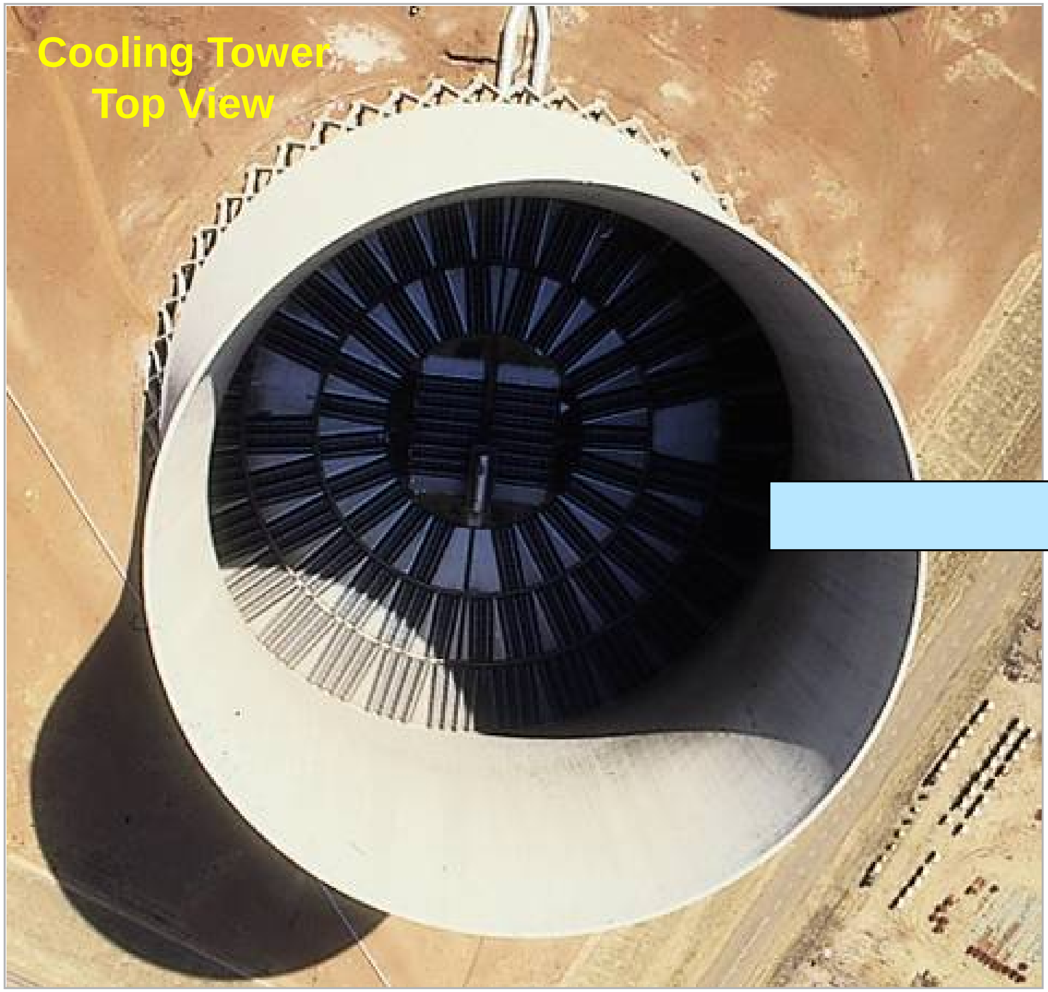
- No fans
- Lower operational costs
- Lower maintenance costs
- Less wind effect
- Possible option for nuclear power plants

Cons

- Higher capital costs
- Higher life-cycle costs

Kendal Power Station (6 x 686 MWe)

- Currently largest dry-cooled power station worldwide



A – frame Air Coolers.

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More Air Cooler Views at Kendal Power Station

Bottom Views

Cooler Tubes with Fins

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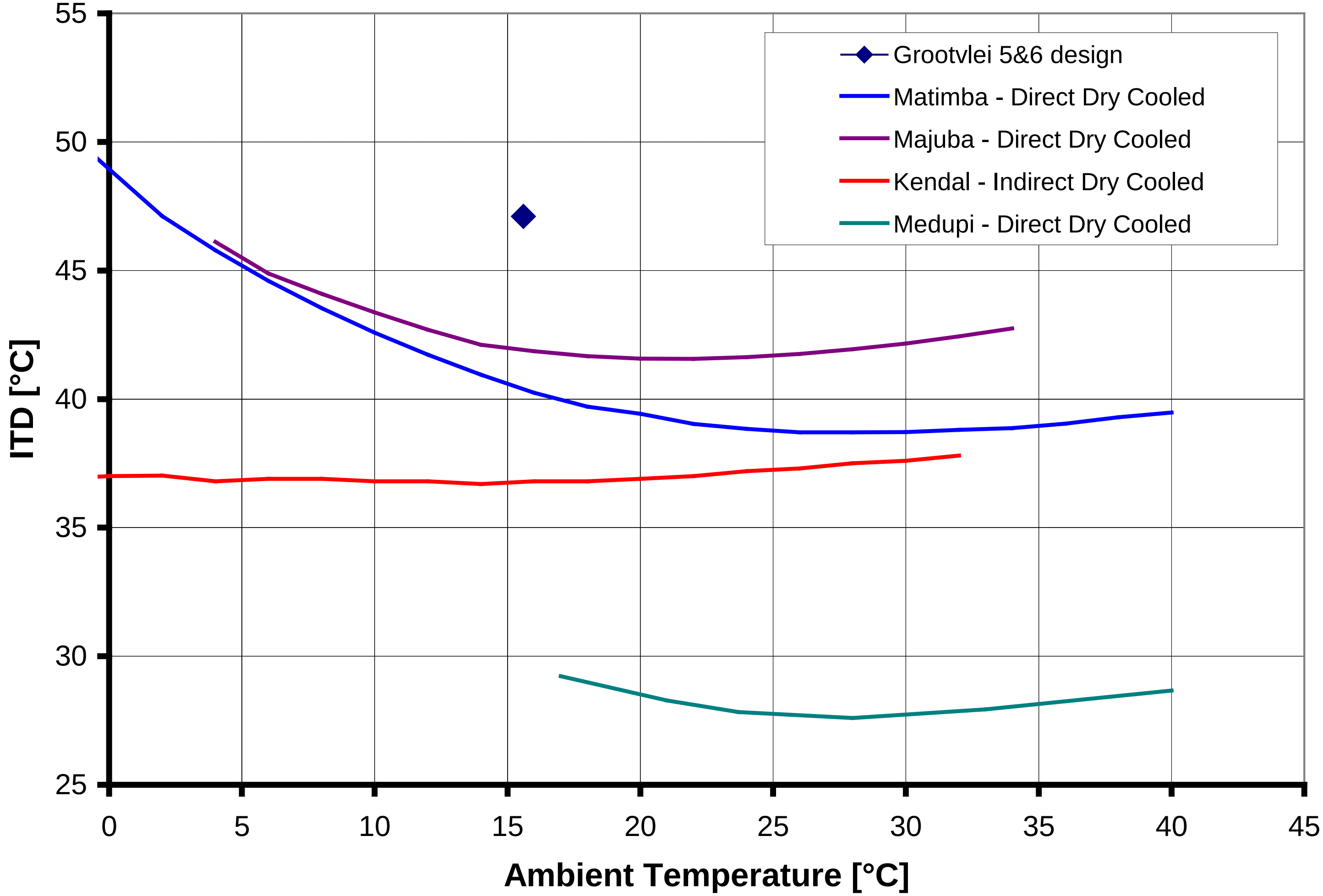
Eskom Dry-Cooling Initial Temperature Difference (ITD) Variation with Ambient Temperature



Source: J.P. Pretorius and A.F. Du Preez, "Eskom Cooling Technologies", 14th IAHR Conference, 2009

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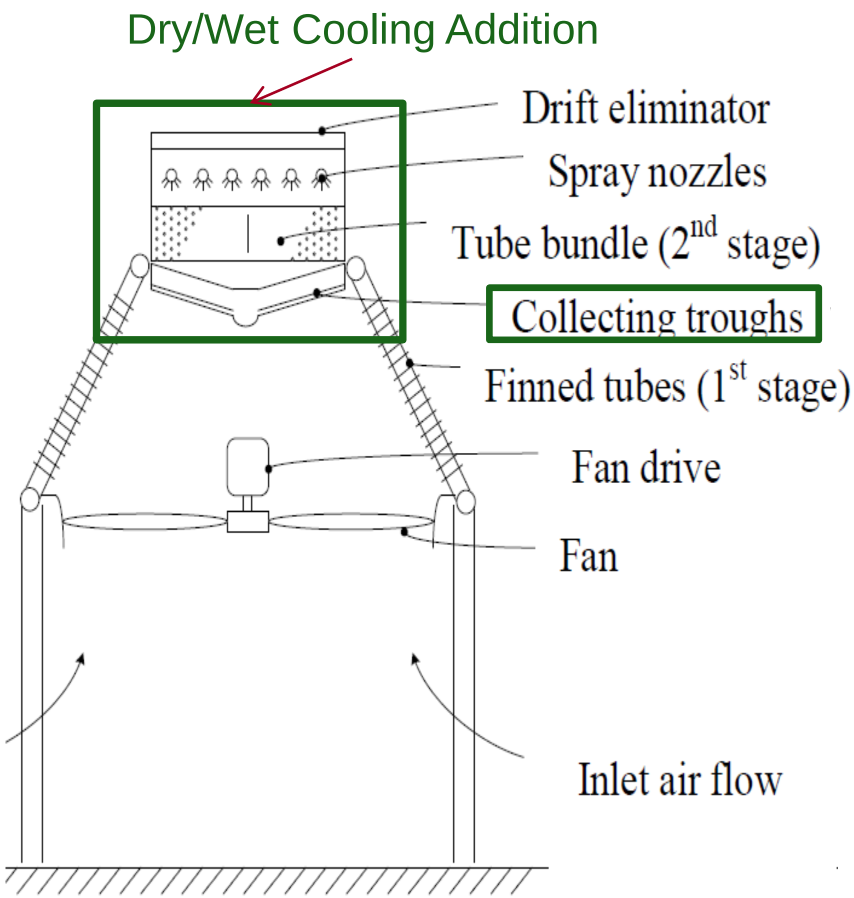
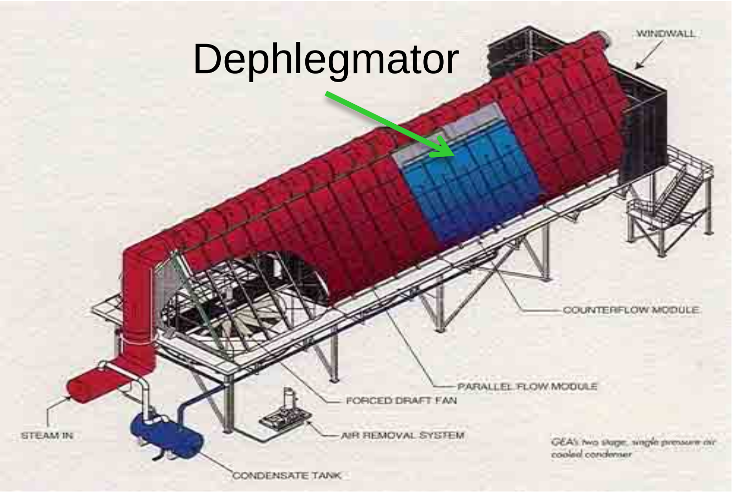
Sample Project of EPRI: Water Spray Enhanced Air Cooled Condensers (Collaboration with University of Stellenbosch in S. Africa)



Hybrid Dry-Wet Dephlegmator Concept



Source: http://www.gea-energytechnology.com/opencms/opencms/gas/en/products/Direct_Air-Cooled_Condensers.html

Key Potential Benefit

Up to 7% more power production on the hottest days than air cooled condensers

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NSF-EPRI Collaboration
on Advancing Dry Cooling Technologies

- **Funding Size**
  - **$6 M Collaboration ($3 M commitment from each of EPRI TI and NSF)**
  - $600 K to $2.1 M for a 3 year project
  - 5 to 10 projects
- **Timing**
  - Solicitation released on May 22, 2013
  - Informational Webcast on 7/24/13 (Slides, Recording)
  - Many proposals collected as of August 19, 2013
  - Award Notification in Dec., 2013
- **Funding Approach**
  - Coordinated but independent funding
    - NSF awards grants.
    - EPRI contracts.
  - Joint funding for most proposals
  - Independent funding for a few proposals if needed

Value

- Leveraged $3M from NSF
- Attracted top talents to power plant cooling innovation.

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Concluding Remarks

- South Africa, with lots of coal and little water, has been the technological leader in dry cooling for 30 to 40 years. The US and other water starving countries may be headed down the same road.
- EPRI's team is benefited from Eskom's knowledge about dry cooling systems.
- Through EPRI's Water Use and Availability Technology Innovation Program, EPRI is pushing the envelope to develop next generation of dry cooling technologies.

Where there's a will, there's a way.

- old English proverb

Thank you so much!

Together…Shaping the Future of Electricity

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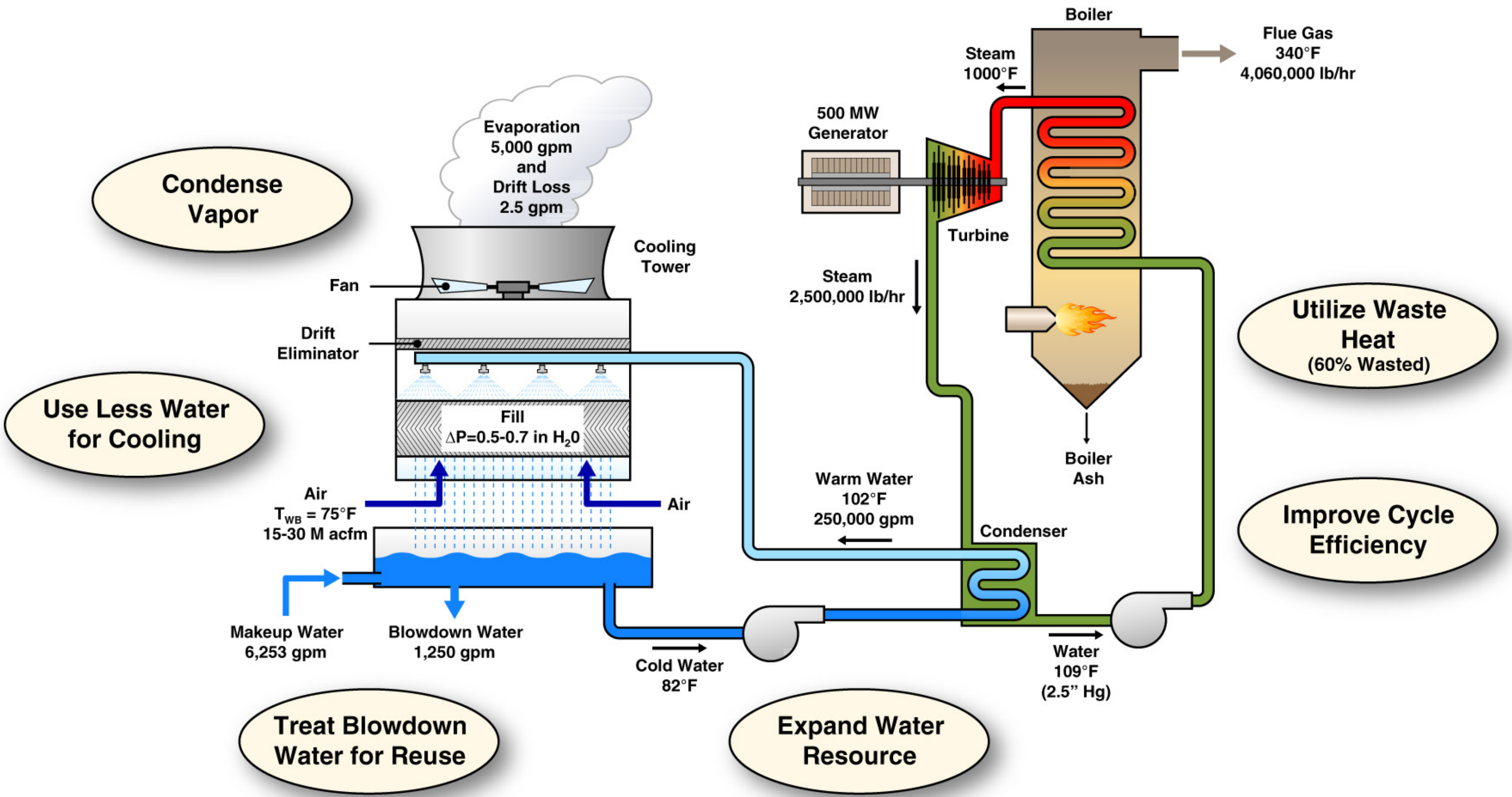
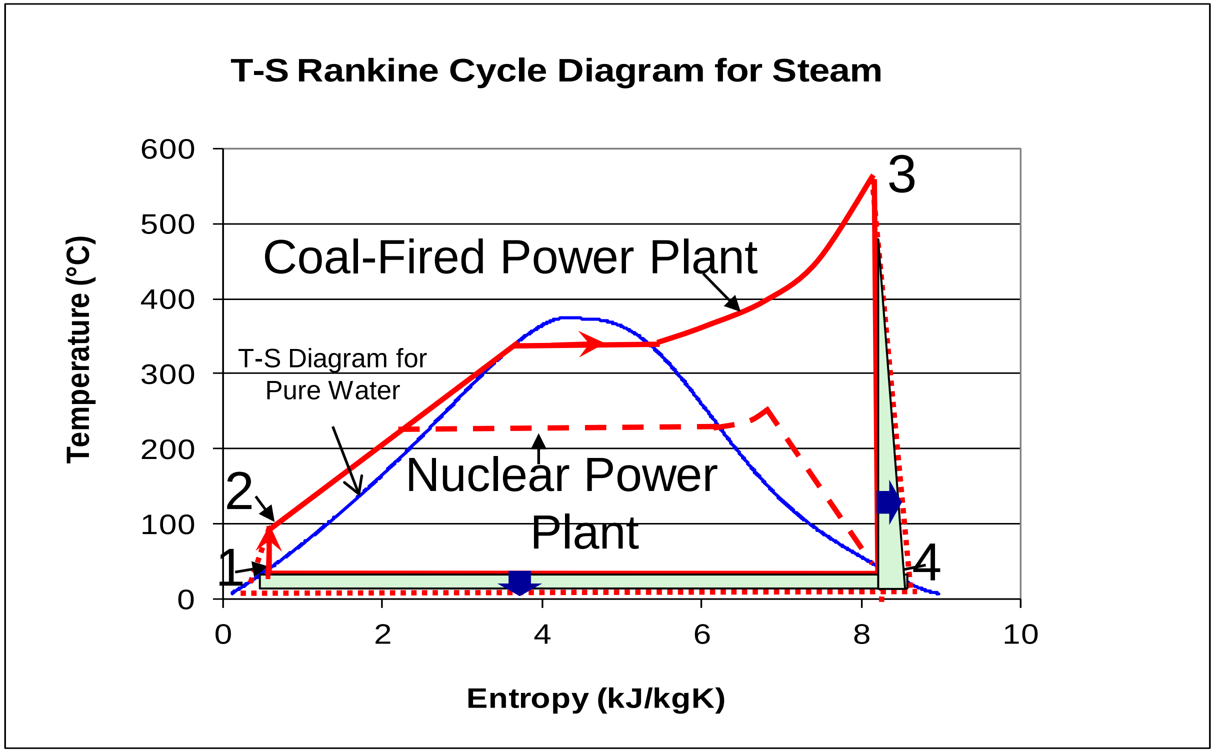
Appendices

Opportunities for Power Plant Water Use Reduction



<u>Innovation Priorities</u>: Advancing cooling technologies, and applying novel water treatment and waste heat concepts to improve efficiency and reduce water use

Effect of Reducing Condensing Temperature on Steam Turbine Rankine Cycle Efficiency



Potential for 5% (1st Order Estimate) more power production or $11M more annual income ($0.05/kWh) for a 500 MW power plant due to reduced steam condensation temperature from 50 ℃ to 35 ℃.

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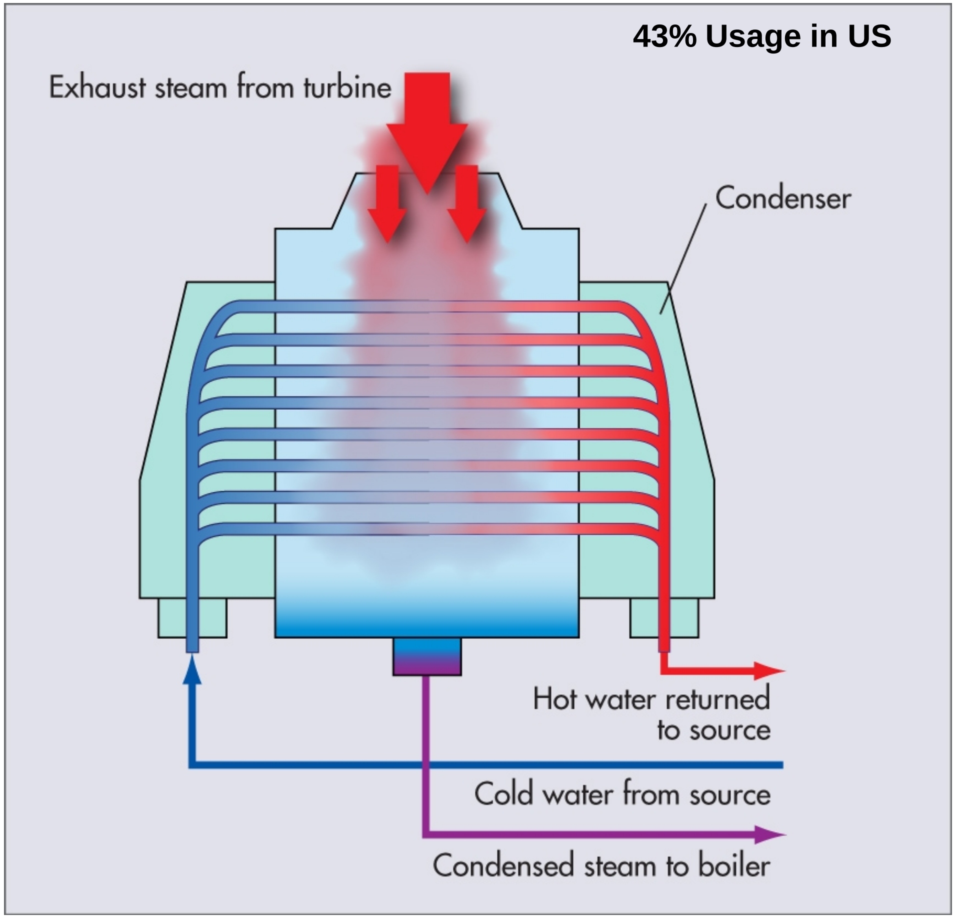
Once Through Cooling Pros/Cons

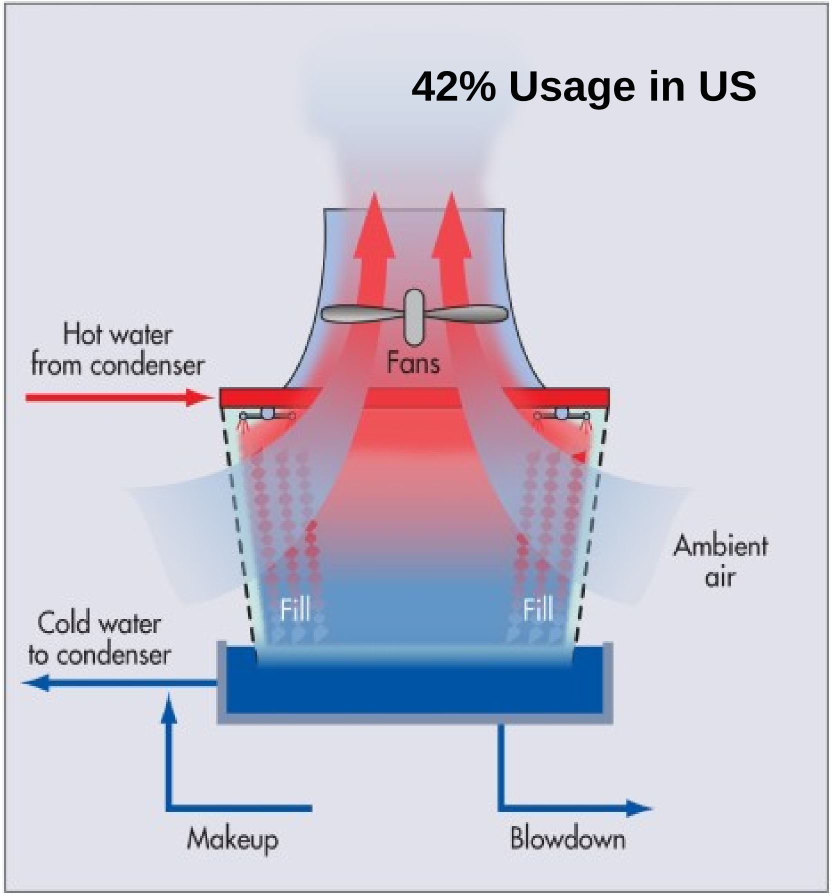
- Pros:
- Most cost effective
- Lowest steam condensate temp.

- Cons:
- Facing tightened EPA rules to minimize once through cooling (OTC) system entrance and discharge disturbance to water eco systems.
- Forced to or increasing pressure to retrofit OTC systems to cooling tower or dry cooling systems (19 power plans already affected by CA retrofitting regulations)



Cooling Tower Cooling System Pros/Cons

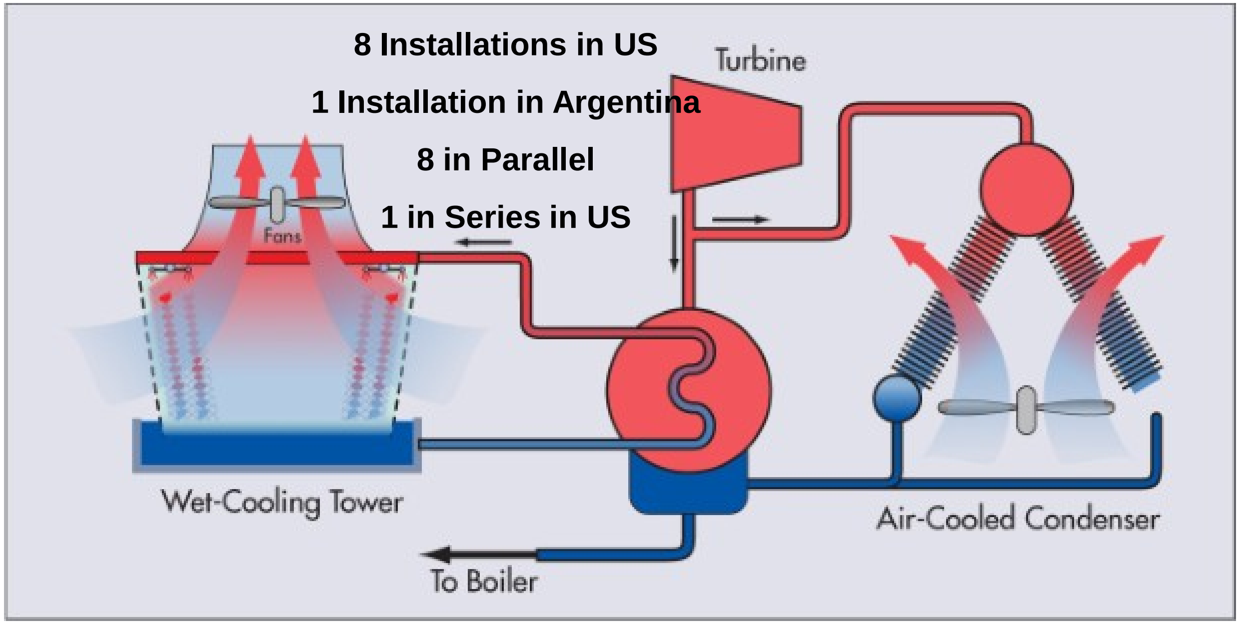
- Pros:
- Most effective cooling system due to evaporative cooling-95% less water withdrawal than once through cooling systems
- Cons:
- Significant vapor loss and makeup water needs
- Shut down in drought seasons
- Twice as expensive as once through cooling systems
- Less power production on hot days due to higher steam condensation temperatures compared to once through systems
- Water treatment cost



Challenges: Vapor Capture and Cooler Steam

Hybrid Cooling Pros/Cons

- Pros:
- Full power output even on hot days due to full operation of cooling tower systems
- Potential for more than 50% less vapor loss compared to cooling tower systems



Challenge:

Develop alternative more cost effective hybrid sys.

Cons:

- Cooling tower shut down in drought seasons
- As expensive as air cooled condensers
- Dual cooling components

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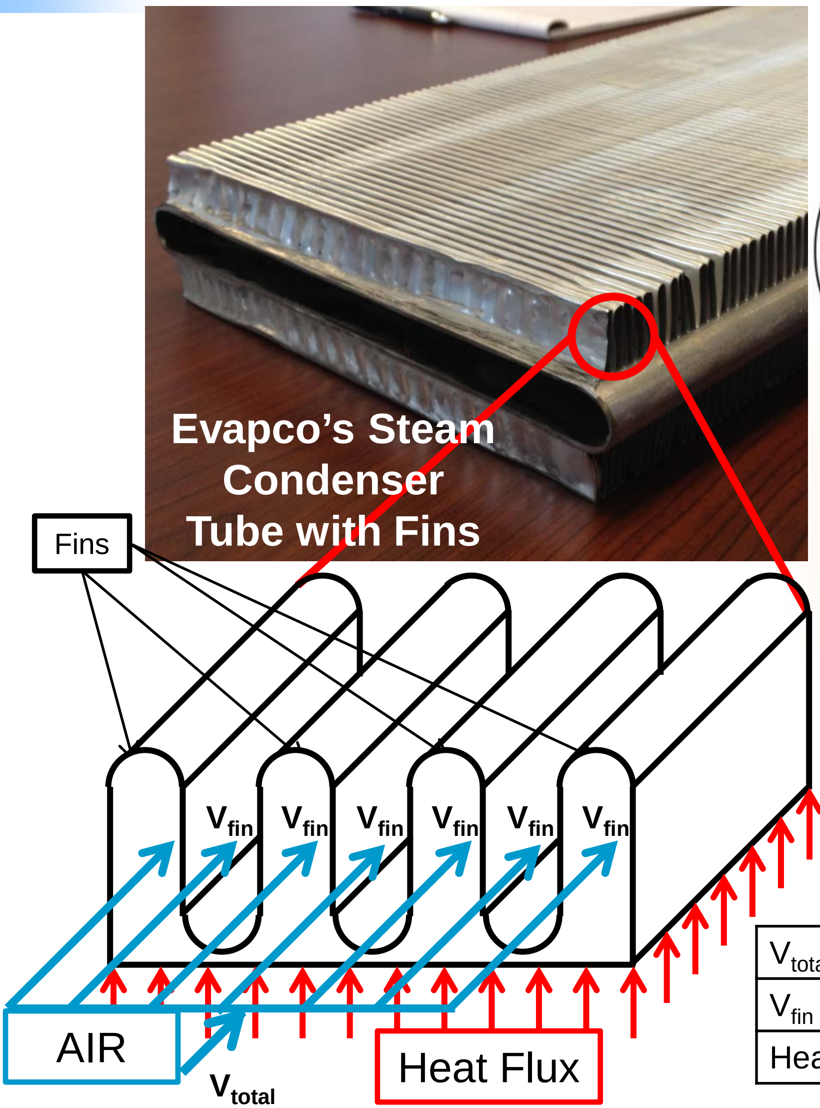
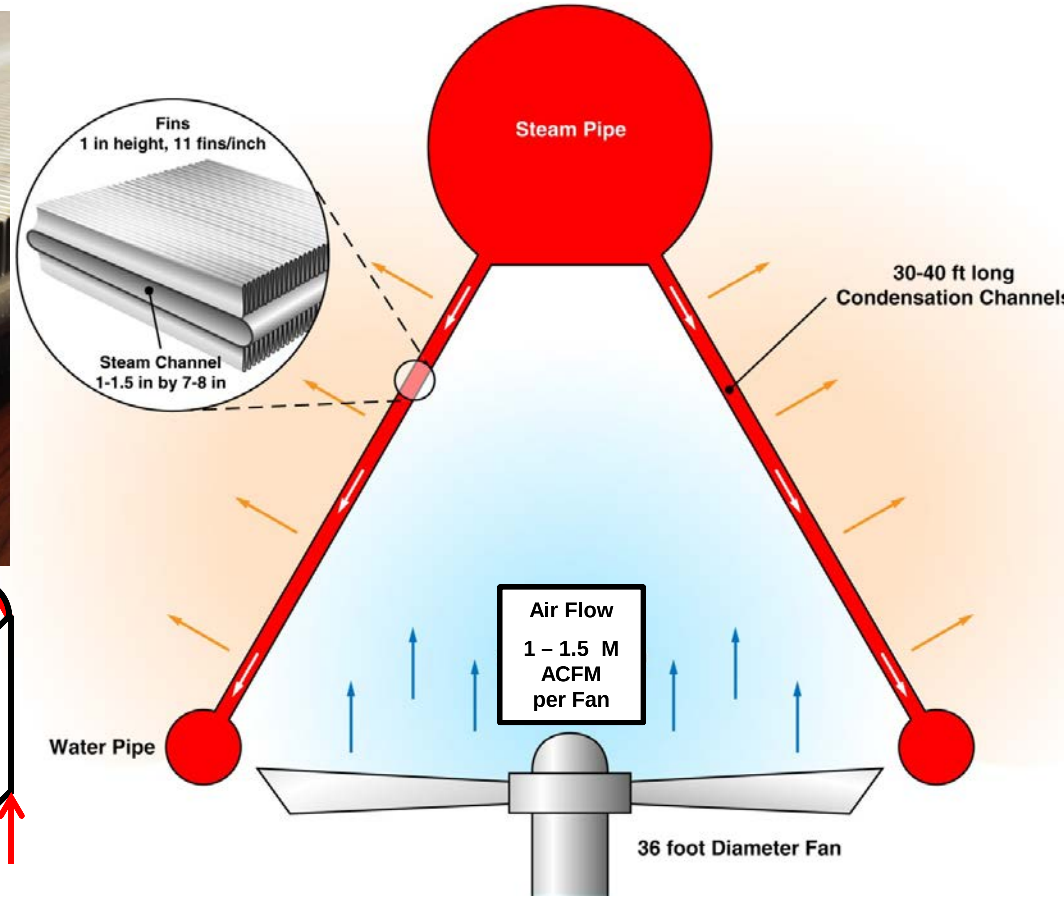
Air Cooled Condenser Dimensions and Air Flow Rate





V_{total}[m/s]	2 – 3
V_{fin} [m/s]	3.5 – 5
Heat Flux [W/m^2]	350-400

Sample Data[1,2,3] for Air Cooled Condensers

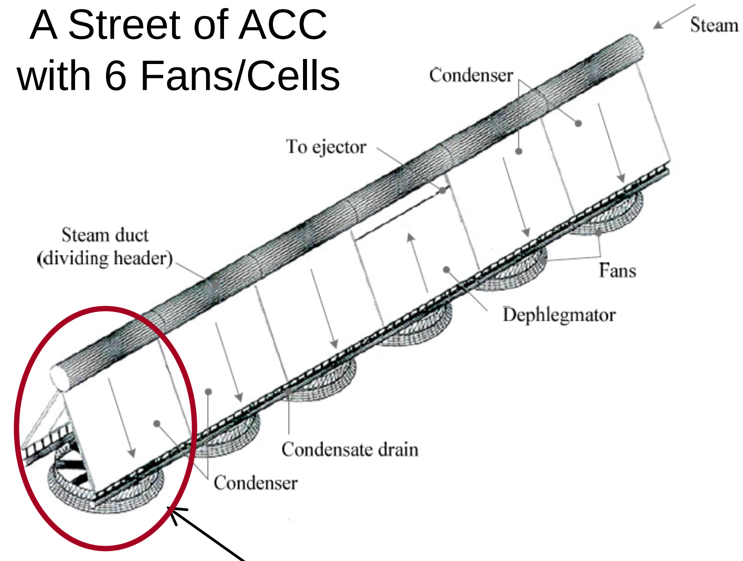
Ambient Air at 40°C and RH50%

ACC Design Parameters	
Cooling Capacity [MW]/Cell	10 – 22
Tube Bundles per cell	8 – 10
Tubes per bundle	40 – 57
Spacing between Tubes [mm]	57
Overall Heat Transfer Coefficient [W/m^{2}K]	35 – 50
Fan Static Pressure [Pa]	120 – 190
Fan Power per cell [kW]	125 – 190
Fan Diameter [m]	9 – 10

Parameter	Air Side	Steam Side
Hydraulic Diameter [mm]	19 – 20	44 – 65
Flow Rate [kg/s]	540 – 750	5 – 9
Reynold's Number	4000 – 6000	NA*
Temperature [°C]	40	60 – 85
Area [m^2]	40,000	930
HTC [W/m^{2}K]	45 – 50	15,000 - 18,000
Pressure Drop [Pa]	75 – 100	125 – 250

** Dependent on flow rate, steam condensation temperature and quality etc.*

A Street of ACC
with 6 Fans/Cells



Cost : $1.5 Million/ ACC cell
(Footprint size: 12x12 m^2/ACC cell)

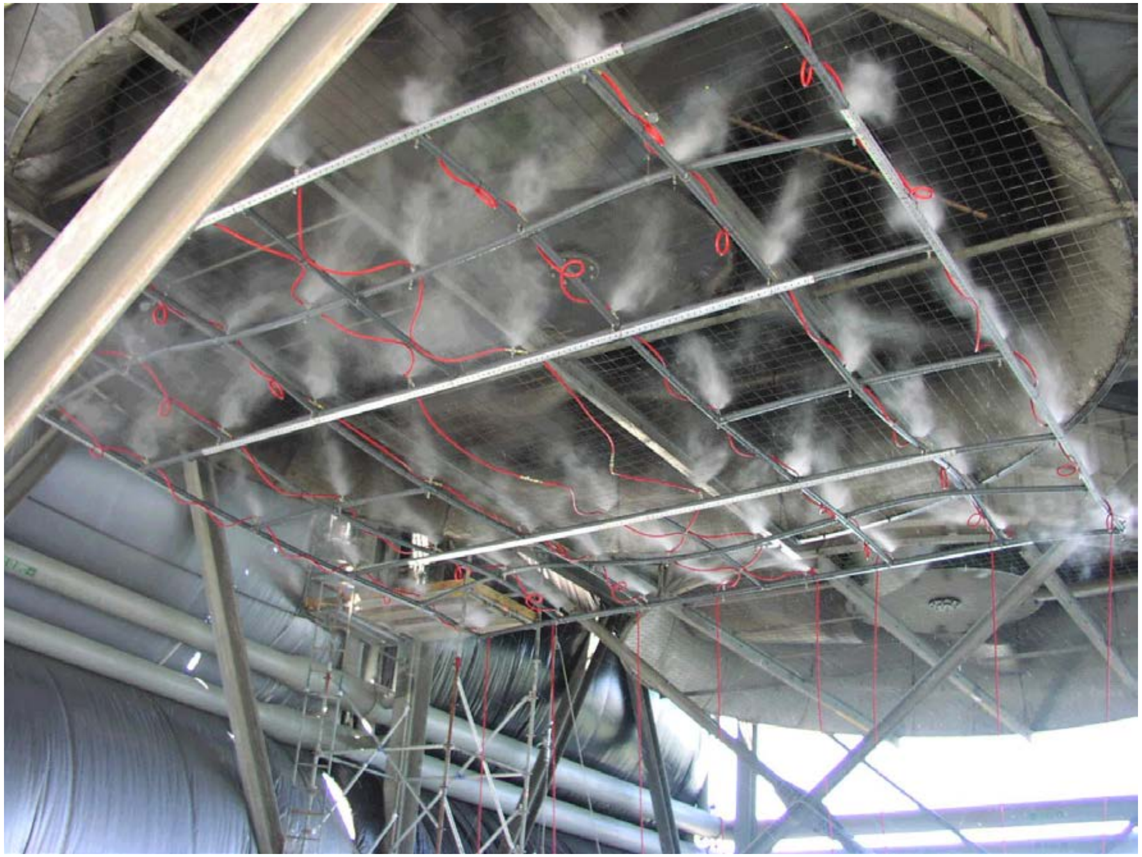
Sources:

1. Heyns, J, A, "Performance Characteristics Of An Air Cooled Steam Condenser Incorporating A Hybrid (Dry/Wet) Dephlegmator", Thesis, 2008.

2. Maulbetsch,J,S, "Water Conserving Cooling Systems - Air-Cooled Condensers", DOE ARPA-E Workshop, Presentation, 2012.

3. Evapco BLCT Dry Cooling

What do you do when it is hot?



Inlet air cooling with sprays

Testing at Crockett Co-Gen plant

Current Cooling System Data Comparison

500 MW Coal Fired Steam Power Plant with Heat Load of 2500 Mbtu/hr and Steam Flow Rate of 2.5 Mlb/hr.

Cooling System	System Cost ($MM)	Cost Ratio Relative to Wet	Evaporative Loss (kgal/MWh)	Steam Condensation Temperature* (°F)	Coolant Flow Rate (gpm)
Wet Cooling Tower and Condenser	20. - 25.	1.00	0.5 - 0.7	116	100,000 - 250,000
Dry Direct	60 - 100	**2.5 - 5**	0.00	155	0
Once Through Cooling	10. - 15.	0.4 - .75	0.2 - 0.3	100	150,000 - 350,000
Hybrid	40 -75	**2 - 4**	0.1 - 0.5	116	50,000 - 150,000

* Steam Condensation Temperatures Based on T_{DB} of 100° F and T_{WB} of 78° F.

	Steam Condenser					Tower/ACC			
Cooling System	**Heat Transfer Area (ft²)**	**Tube Dia. (in)**	**# of Tubes**	**Tube Length (ft)**	**Cost (MM$)**	**No. of Cells**	**Cell Dimensions (ft x ft)**	**Tower/ACC Footprint (ft²)**	**Cost (MM$)**
Wet Cooling Tower and Condenser	175,000 - 350,000	1.125 - 1.25	17,000 - 35,000	30 - 40	1. - 2.5	15 - 20	48 x 48 to 60 x 60	50,000 - 80,000	7. - 10.
Dry Direct	n/a	n/a	n/a	n/a	n/a	40 - 72	40 x 40	64,000 - 120,000	60. - 100.
Once Through Cooling	175,000 - 350,000	1.125 - 1.25	17,000 - 35,000	30 - 40	1. - 2.5	n/a	n/a	n/a	n/a
Hybrid	50,000 - 350,000	1.125 - 1.25	10,000 - 350,000	30 - 40	0.4 - 2.5	4 - 10/ 15- 30	48 x 48 to 60 x 60/ 40 x 40	10,000 - 36,000/ 24,000 - 48,000	30. - 80.

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Eskom's Future Directions

- Two new supercritical coal fired stations: Medupi and Kusile
  - Dry cooling
  - Dry ashing
  - FGD to be equipped in Medupi

- Nuclear generation expansion
  - Increase current 2 x 970 MWe PWRs to 9600 MWe by 2030
  - Cooled by once-through seawater cooling with desalination for portable and demin.

- More nuclear and gas generation mix

- Renewables Initiation
  - 12% renewables (wind and concentrating solar) by 2030
  - Little capacity for expansion of hydro and/or pumped storage

Eskom Power Station Cooling Technologies

Year	Power station	Unit size [MW]	Cooling technology
1962 onwards	Komati 1-5 Komati 6-9	5 x 100 4 x 125	Wet-cooled
1967	Camden	8 x 200	Wet-cooled
1969	Grootvlei 1-4	4 x 200	Wet-cooled
1970	Hendrina	10 x 200	Wet-cooled
1971	Arnot	6 x 350	Wet-cooled
1971, 1977	Grootvlei 5-6	2 x 200	Indirect dry-cooled
1976	Kriel	6 x 500	Wet-cooled
1979	Matla	6 x 600	Wet-cooled
1980	Duvha	6 x 600	Wet-cooled
1981	Koeberg	2 x 965	Once-through (ocean)
1985	Lethabo	6 x 618	Wet-cooled
1985	Tutuka	6 x 609	Wet-cooled
1987	Matimba	6 x 665	Direct dry-cooled
1988	Kendal	6 x 686	Indirect dry-cooled
1991	Majuba 1-3	3 x 657	Direct dry-cooled
1998	Majuba 4-6	3 x 712	Wet-cooled

More improvements at Medupi - Ease of Maintenance

- No more steps onto fan bridge
- Sliding door rather than hinged doors

Matimba Side Walk next to Air Cooled Condenser Rooms

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Advanced Water Research for Power Plants

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EPRI is pursuing and developing potentially game changing, early stage, ideas, concepts, and technologies to reduce power plant freshwater withdrawal and consumption. Such technologies could improve cycle efficiency as well as help address water-related operational and siting constraints facing fossil, nuclear, biomass, and geothermal power generators.

In 2011, EPRI released a broad-based global request for information (RFI) to help identify concepts with breakthrough potential. Since then, EPRI received 114 proposals and several white papers through two RFI rounds and outreach. To date, EPRI has funded five advanced cooling projects and three water treatment projects. Information on these projects can be found here. EPRI is also working on funding an additional hybrid cooling project and three more water treatment projects.

On May 22, 2013, EPRI and the National Science Foundation (NSF) released a joint solicitation to advance dry cooling and dry-wet hybrid cooling technologies for power plant applications. The project is a $6 million joint effort and follows from an EPRI-NSF workshop held on November 13, 2012 during the ASME Congress Conference in Houston, Texas. This workshop engaged experts in discussion of the power industry's water resource management needs, as well as state-of- the-art technologies, innovative concepts, and R&D opportunities related to power plant cooling systems and processes. The joint EPRI-NSF solicitation will remain open until August 19, 2013.

Resources

2013 Joint EPRI-NSF Solicitation
2012 Request for Information Solicitation
Technology Innovation Water Use and Availability Program Overview
Power Plant Cooling System Information and Data

www.epri.com/Pages/Advanced-Water-Research-for-Power-Plants.aspx