

**NSF-EPRI Workshop on Advanced Power Plant Cooling: Reducing Water Consumption**  
**November 13 Tuesday, 800a.m-400p.m**  
**Grand Ballroom B, Hilton Americas, Houston**

**Coordinators: Dr. Sumanta Acharya, National Science Foundation; Dr. Jessica Shi, Electric Power Research Institute; Dr. Srinivas Garimella, Georgia Institute of Technology.**

**Background:**

In the U.S. power generation industry, steam-electric plants account for approximately 40% of the nation's total freshwater withdrawals and approximately 3% of the nation's total freshwater consumption. Power plants rely on condensers that use either once-through cooling, recirculating wet-cooling towers, or air-cooling to condense the steam discharge from the turbine. The rate of water use in power-stations with recirculating wet cooling systems, currently estimated to be 42% of the U.S steam power plants, may not be sustainable at some locations across the country. Further, thermal discharges from once-through cooling, used in 43% U.S. steam power plants, face increasing regulatory challenges. Therefore developing cost effective options for reducing water use for power plant cooling has emerged as a widespread national need.

Air cooled steam condensers (installed in only 1% of U.S. steam plants) are a water-efficient option but can have up to a 10% power production penalty on hot days, and up to five times higher capital costs compared to current cooling tower and water cooled surface condenser systems (Figure 1). Innovations in air-cooled condensers (Figure 2) and in hybrid wet-dry cooling technologies are needed to reduce these penalties and capital costs.

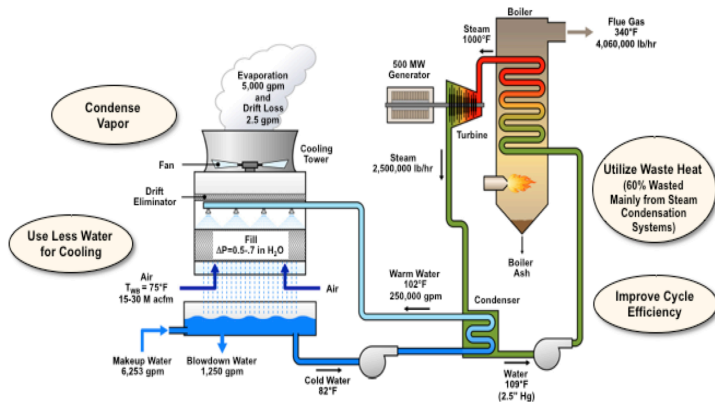


Figure 1. Illustration of a 500 MW Power Plant Steam and Cooling Water Flow System

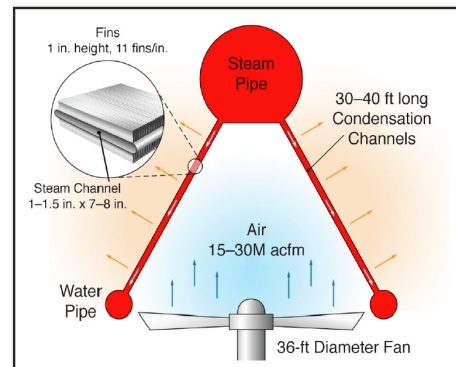


Figure 2. Illustration of a Typical Air Cooled Condenser for Power Plants

**Workshop Objectives:**

This workshop will bring together experts from academia and industry to define a research roadmap to advance power plant cooling with a focus on reducing water-use, and to build a foundation for a possible NSF-EPRI joint solicitation in 2013. A key driver for research, as noted above, is the increased concern regarding the availability of water and the environmental impact of water consumption and withdrawal. Therefore, higher effectiveness recirculating wet- or air-cooled condensers and hybrid wet-dry cooling are needed.

The workshop will include a review of the state of the art in current technology, operating conditions and requirements, related emerging technologies being developed for other industries, NSF and EPRI program overview, and the advances needed in these areas. This will be followed by breakout sessions in selected topics to discuss the research issues and to identify high impact directions.

## **Workshop Agenda:**

### **Introduction: 800a.m -830a.m**

Robert Goldstein, Sr. Technical Executive, EPRI/Sean Bushart, Sr. Program Manager, EPRI, Water-Energy Nexus Overview

Jessica Shi, Sr. Project Manager, EPRI, Overview of EPRI's Current Research in Power Plant Cooling

Sumanta Acharya, Program Director, NSF —Overview of NSF's Current Research in Cooling Technologies

### **Wet and Hybrid Wet-Dry Cooling Systems: 830a.m-1000a.m**

**Moderator:** Jean-Pierre Libert, Evapco, Review of where things stand with closed-cycle wet cooling & what's needed

Rich Aull, Brentwood, Cooling-Tower Technology-Advances

Tom Lestina, HTRI, Challenges of process condenser design

John Thome, EPFL, Advances in condensation technology

Srinivas Garimella, Ga Tech, Compact condensers: Advances in Miniaturization and Implementation

Kripa Varanasi, MIT, Innovations in condensation using nanostructured surfaces

### **Break: 1000a.m-1015a.m**

### **Break Out Sessions: 1015a.m-1145a.m**

Wet and Hybrid Wet-Dry Cooling Systems— Jean-Pierre Libert & Srinivas Garimella (co-Leads)

### **Lunch: 1145a.m-1245p.m**

### **Report out by Libert & Garimella: 1245p.m-100p.m**

### **Air Cooled Condensers 100p.m-200p.m**

**Moderator:** Ken Mortensen, SPX, Dry and wet/dry and water recovery, What research do we need?

John Maulbetsch, Maulbetsch Consulting, Air-cooled condensers: A State of the Art Primer

Olivier LeGaludec, Alstom, From low to zero water consumption cooling system: impact of ACC on Plant performances

Kevin Kelly, MezzoTech, Air-cooled & Liquid-Cooled HX-high effectiveness, meso-scale devices

### **Break: 200p.m-215p.m**

### **Break Out Sessions: 215p.m-345p.m**

Air Cooled Condensers, Ken Mortensen

### **Report by Mortensen: 345p.m-400p.m**

## Biographies

### **SUMANTA ACHARYA**

Program Director, Thermal Transport Program  
National Science Foundation (NSF)



Sumanta Acharya holds the L. R. Daniel professorship and the Fritz & Francis Blumer professorship in the department of Mechanical Engineering at Louisiana State University (LSU). He is the director of the Center for Turbine Innovation and Energy Research (TIER) which focuses on energy generation and propulsion research. He is currently at National Science Foundation (NSF) as the Program Director of the Thermal Transport Program.

Professor Acharya is a PhD from the University of Minnesota (PhD) following which he joined the faculty of mechanical engineering at LSU. During his career at LSU, Prof. Acharya has developed a multifaceted research program in heat transfer with a focus on gas turbine heat transfer and computational heat transfer. He is an ASME Fellow, and previous Associate Editor of ASME Journal of Heat Transfer and ASME Journal of Energy Resources Technology. He was recently awarded the 2011 ASME Heat Transfer Memorial Award in the Science category.

### **Richard Aull**

Director of Engineering, Water Group  
Brentwood Industries



Richard (Rich) J. Aull, PE is Director of Engineering of the Water Group at Brentwood Industries with 33 years experience in the cooling tower industry. With Brentwood since 1993, he is responsible for new product development, product testing, product quality assurance standards and application engineering.

Before joining Brentwood, he held a variety of engineering positions with Research Cottrell's Hamon Cooling Tower Division and Ecodyne Cooling Tower Services Group, specializing in the thermal upgrading of natural draft cooling towers.

Rich is active in the Cooling Technology Institute (CTI), having served as a board member and currently serving as the Software Publishing Task Group Chair, and as Vice Chair of the Performance and Technology (P&T) and Multi-Agency Testing committees. In addition he is a voting member of various P&T standards developing task groups. He has published technical papers and conducted seminars on a variety of cooling tower topics for the Cooling Technology Institute, Electric Power Research Institute and American Society of Mechanical Engineers.

Rich received his B.S. & M.S. Degrees in Mechanical Engineering from the New Jersey Institute of Technology specializing in thermodynamics and heat transfer and is a registered Professional Engineer in the States of New Jersey & Pennsylvania.

## **Srinivas Garimella**

Hightower Chair in Engineering  
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Dr. Srinivas Garimella is the Hightower Chair in Engineering and Director of the Sustainable Thermal Systems Laboratory at Georgia Institute of Technology. He received M. S. and Ph.D. degrees from The Ohio State University, and a Bachelor's degree from the Indian Institute of Technology, Kanpur. He has held prior positions as Research Scientist at Battelle Memorial Institute, Senior Engineer at General Motors Corp., and Associate Professor at Western Michigan University and Iowa State University. He is a Fellow of the American Society of Mechanical Engineers, an Associate Editor of the *ASME Journal of Heat Transfer*, and Editor of the *International Journal of Air-conditioning and Refrigeration*. He has also served as Associate Editor of the *ASME Journal of Energy Resources Technology*, and Past Chair of the Advanced Energy Systems Division of ASME. He was an Associate Editor of the *ASHRAE HVAC&R Research Journal* and Chair of the ASHRAE Technical Committee on Absorption and Heat Operated Machines, and is on the ASHRAE Research Administration Committee. He held the William and Virginia Binger Associate Professorship of Mechanical Engineering at ISU from 1999-2001. He has mentored over 50 graduate students, with his research resulting in over 150 archival journal and conference publications, and he has been awarded five patents. He is the recipient of the NSF CAREER Award (1999), the ASHRAE New Investigator Award (1998), the SAE Ralph E. Teetor Educational Award for Engineering Educators (1998), and was the Iowa State University Miller Faculty Fellow (1999-2000) and Woodruff Faculty Fellow (2003-2008) at Georgia Tech.

## **Robert Goldstein**

Technical Executive, Water and Ecosystems  
Electric Power Research Institute (EPRI)



Dr. Robert Goldstein is Senior Technical Executive, Water and Ecosystems, in EPRI's Environment Sector. His current activities include managing the Water Availability and Resource Risk Management Program. Prior to joining EPRI in 1975, Bob was a Systems Ecologist with the Oak Ridge National Laboratory. He holds a Doctor of Engineering Science degree from Columbia University. Bob is the author of numerous papers on environmental subjects and has served on many government and NGO research advisory committees. He is also the co-editor of a book, *Sulfur Dioxide and Vegetation: Physiology, Ecology, and Policy Issues*.

## **Kevin W. Kelly**

President, Mezzo Technologies  
7167 Florida Boulevard  
Baton Rouge, LA 70806  
kelly@mezzotech.com

Dr. Kelly graduated with a B. S. in Mechanical Engineering from Duke University in 1980. He worked as a Design Engineer for Duke Power Company from 1980 until 1985. He received his Ph. D. degree in Mechanical Engineering from the Massachusetts Institute of Technology in 1991, and joined the Louisiana State University Mechanical Engineering faculty in 1993. In 2000, Dr. Kelly co-founded Mezzo Technologies, which specializes in micro channel heat exchangers. Since 2006, Dr. Kelly has been the President of Mezzo Technologies and in 2008 he left LSU to become a full time employee of Mezzo. The company now focuses on manufacturing, for a variety of applications, micro tube heat exchangers, which typically consist of thousands of stainless steel tubes with diameters in the range of 0.5-2.0 mm.

## **Oliver Le-Galudec**

ALSTOM



Olivier Le Galudec graduated in Mechanical engineering and Energetics in 1987 from ENSEM in France, after which he joined French Naval Aviation as Air Traffic Controller Officer. Early 1989 he returned to Lorraine region in France and started a PhD on turbulent diffusivity within nuclear reactor under a contract shared by CNRS ( national research facility ) , CEA ( commissariat à l'énergie atomique) and EDF ( French utility) while also teaching mechanics and fluid mechanics in Nancy 1 University .

Early 1990 he joined Gec Alsthom – later ALSTOM – in Belfort as Thermodynamical Calculation Engineer within new Plants EPC business, then shifted to Performance test activities 18 months later. In 1999 Olivier took over the management of the performance group in Belfort, then in 2001 the global performance group colated between Belfort (Fr) and Baden (CH) while still contributing to Plant performance test campaigns : he cumulated experience over 140 guarantee verification campaigns on GT open cycles, Combined Cycles, add-ons, Steam turbines and conventional Steam Plants . He now covers all technical gurantees for thermal performances and acoustics of new Plants within ALSTOM.

## **Thomas G. Lestina,**

Vice President, Research & Engineering Services  
Heat Transfer Research Inc.



Thomas has over 25 years of engineering and project management experience. He earned a B.S. in Mechanical Engineering from Union College, Schenectady, New York, USA, and an M.S. in Mechanical Engineering from Rensselaer Polytechnic Institute, Troy, NY. He is a member of ASME and serves on the technical committee for the ASME Performance Test Code 12.5, Single Phase Heat Exchangers. Prior to joining HTRI, he worked as a Lead Engineer for MPR Associates, Inc., Alexandria, Virginia, USA. Lestina oversees research, contract services, training and technical support activities at HTRI. He also routinely teaches workshops and courses as part of the HTRI training program. Lestina is a licensed Professional Engineer (P.E.) in Texas.

## **Jean-Pierre Libert**

Vice-President of Advanced Technology  
Evapco Inc.



As Vice-President of Advanced Technology with Evapco Inc., Jean-Pierre Libert oversees the R&D, product development and rating activities of field-erected cooling towers and air cooled steam condensers.

Jean-Pierre holds a M.S. Degree in Mechanical Engineering from Faculté Polytechnique de Mons, Belgium. He has been an active Member of the Cooling Technology Institute since 1985 and a Member in good standing of the American Society of Mechanical Engineers.

Since 1979, through a variety of assignments in Belgium, Mexico and the U.S.A., Jean-Pierre has acquired extensive cooling technology experience. He and his wife live in Frederick, Maryland.

## **John S. Maulbetsch**

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Since 1999, Dr. Maulbetsch has been a private consultant to government and industry. Most of his work has been on water use and conservation in electric power production. He has published two major studies on alternative cooling systems for power plants for the California Energy Commission and the Electric Power Research Institute. Other studies have included the costs of retrofitting once-through cooled plants with closed-cycle cooling; the assessment of water conservation options for plants in arid regions; the effect of wind on air-cooled condenser performance; and the use of spray enhancement to augment the performance of air-cooled condensers on hot days.

Prior to establishing his consulting practice, he was at the Electric Power Research Institute for 23 years. Before joining EPRI, Dr. Maulbetsch was the Director of the Energy Technology Center of Dynatech Corporation in Cambridge, Massachusetts and before that on the faculty of the Massachusetts Institute of Technology.

Dr. Maulbetsch received his S.B., S.M. and Ph.D. degrees from M.I.T. in 1960, 1962 and 1965 respectively.

## **Kenneth P. Mortensen**

R&D Project Manager  
SPX Cooling Technologies

Ken is a Research and Development Project Manager for SPX Cooling Technologies. Has managed several engineering and operations departments responsible for water quality, material selection, and physical application criteria for cooling towers and components, as well as design, manufacture and servicing of water treatment equipment and installations. Ken has been with SPX/Marley for 34 years.

Ken graduated in 1977 with a Bachelor of Science Degree in Chemical Engineering from Massachusetts Institute of Technology and completed an MBA at Rockhurst University in Kansas City, Missouri in 2000.

Ken is the author of a number technical papers on subjects including "Use of Low Clog Film Fill in Cooling Towers", "Use of Recycled Water in Cooling Towers", "Cooling Tower Technology for Geothermal Application", and "Use of Ozone Water Treatment for Cooling Water". Ken holds Patents for Fire-resistant Fiberglass Cooling Tower Design, Low-Fouling Cooling Tower Film Fills, and plastic joining techniques. He is a Registered engineer in the State of Kansas.

## **Eric K. Rasmussen, PE, State of Kansas**

Director of Research and Development  
SPX Cooling Technologies, Inc.



Mr. Rasmussen has over 18 years of experience, 16 in the cooling tower industry. He has worked with all aspects of cooling towers including thermal analysis, structural design, manufacturing, construction, and research and development. His broad range of experience gives him a unique understanding of the various challenges associated with the cooling tower market.

Mr. Rasmussen's project management experience includes designing, planning, and supervising the manufacturing and construction of multiple new and existing cooling tower products. Currently, Mr. Rasmussen leads Product Development at SPX CT. In this role he helped develop and currently maintains the New Product Introduction (NPI) process.

Mr. Rasmussen is a registered professional engineer in the state of Kansas. He holds a Bachelor's of Science Degree in Mechanical Engineering and a Secondary Degree in Natural Resources and Environmental Science from Kansas State University.

## **Jessica Shi**

Senior Project Manager  
Electric Power Research Institute (EPRI)



Dr. Jessica Shi is a Senior Project Manager at the Electric Power Research Institute (EPRI). She heads EPRI's research on developing innovative water conservation cooling technologies.

Before joining EPRI in 2010, Dr. Shi was a Principal Aero/Thermal Engineer at Northrop Grumman Electronic Systems. Her responsibilities included developing thermal fluid modeling and design for Laser Weapon thermal energy storage systems and other thermal management systems, as well as performing compressor and steam turbine airfoil aero and steam valve designs and analysis for naval submarine and surface ship propulsion and generation systems. Prior to that, she worked as a Lead Engineer in General Electric's Aircraft Engine Division, where she designed and analyzed turbine airfoil cooling systems and performed life assessment analyses of turbine airfoils. She also has worked on various thermal-cooling R&D projects at BAE Systems, Argonne National Labs, Research Associates, and National Institute of Metrology in Beijing.

Dr. Shi is a lead inventor of several patents for gas turbine airfoil cooling designs and of patent applications for power plant cooling technologies. In addition, she published numerous papers and reports. She has also served as Conference session or topic co-chairs and has been a paper reviewer for prestigious journals. She has also received many awards both in school and at work for her outstanding achievements.

Dr. Shi received a Bachelor of Science degree in Thermal-Fluid Sciences from Tsinghua University in Beijing, China. She also received a Ph.D. in



Thermal-Fluid Sciences from the University of Illinois at Urbana-Champaign.

### **John R. Thome**

Professor, Ecole Polytechnique Fédérale de Lausanne (EPFL)



John R. Thome is Professor of Heat and Mass Transfer at the Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland since 1998. An American citizen, he received his Ph.D. at Oxford University in 1978 and was then Assistant/Associate Professor at Michigan State University, until leaving to start his own consulting company at the age of 31, which he operated for the next 15 years before joining the EPFL. He has authored four books on boiling, condensation and two-phase flow, widely used in the fields of refrigeration/air conditioning, electronics cooling, nuclear, and chemical engineering. He received the ASME Heat Transfer Division's Best Paper Award (1998), the UK Institute of Refrigeration's J.E. Hall Gold Medal (2008), the 2010 ASME Heat Transfer Memorial Award and the *International Journal of Refrigeration* Best Paper Award for 2011-12. He directs the Laboratory of Heat and Mass with more than 20 PhD's and post-docs. He hosts a highly popular Microscale Heat Transfer Summer School each June in Lausanne.

### **Kripa K. Varanasi**

Professor, Mechanical Engineering, Massachusetts Institute of Technology  
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Kripa Varanasi is a Doherty Associate Professor in the Department of Mechanical Engineering at MIT. He received his B.Tech from IIT, Madras, India and his MS (ME and EECS) and Ph.D from MIT. Prior to joining MIT, Dr. Varanasi was a lead research scientist and project leader in the Energy & Propulsion and Nanotechnology programs at the GE Global Research Center, Niskayuna, NY, and was the PI for the DARPA Advanced Electronics Cooling program. The primary focus of his research is in the development of nano-engineered surface, interface, and coating technologies that can dramatically enhance performance in energy, water, agriculture, transportation, buildings, and electronics cooling systems. He is enabling this approach via highly interdisciplinary research focused on a nanoengineered surfaces and interfaces, thermal-fluid science and new materials discovery combined with scalable nanomanufacturing. His work spans various thermal-fluid and interfacial phenomena including phase transitions (condensation, boiling, freezing), nanoscale thermal transport, separation, wetting, catalysis, flow assurance in oil and gas, nanofabrication, and synthesis of inorganic bulk and nanoscale materials guided via computational materials design. Dr. Varanasi has filed more than 50 patents in this area. He was awarded the First Prize at the 2008 ASME Nanotechnology Symposium and won several awards at GE Research Labs including Technology Project of the Year, Best Patent Award, Inventor Award, and Leadership Award. He has received the MIT Energy Initiative award, 2010 IEEE-ASME ITherm best paper award, NSF Career Award, DARPA Young Faculty Award. He is commercializing some of the slippery coating technology under LiquiGlide for which his team received the audience choice award and 100K award at the MIT 100K and MassChallenge Entrepreneurship competitions. Time Magazine has named his invention LiquiGlide one of the Best Inventions of the Year.