Asia-Pacific
Economic Cooperation

APEC Water-Energy Nexus Expert Workshop Report

31 October-1 November 2017, USA

APEC Energy Working Group

December 2017

APEC Project: EWG 07 2015A

Produced by
Washington CORE
4340 East-West Highway Suite 1110
Bethesda, Maryland 20814 U.S.
Telephone: 301-654-2915 Ext. 136 or 127
E-mail: nanako@wcore.com, chris@wcore.com

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org

© 2017 APEC Secretariat

APEC#217-RE-04.6

APEC Water-Energy Nexus Expert Workshop

31 October – 1 November 2017, USA

Table of Contents

1 Executive Summary

The Asia-Pacific Economy Cooperation (APEC) Water-Energy Nexus Expert Workshop was held by the APEC Expert Group on Clean Fossil Energy (EGCFE) - under the APEC Energy Working Group (EWG) - in Atlanta, United States on 31 October 31 – 1 November 2017, to share information on policy measures, latest technology developments, capacity building needs, international cooperation, economic considerations, and best practices related to water use for coal-based power generation and conversion in the APEC region.

1.1 Overview of workshop

Building on the EWG 08/2014A report "Water Energy Nexus: Coal-Based Power Generation and Conversion – Saving Water," this workshop was proposed to address the critical need for governments and industry in the APEC region to better understand the links between water and energy production and consumption, termed the water-energy nexus. In particular, proactively addressing potential energy system vulnerabilities stemming from water resource dependency is important for all economies reliant on coal to meet their energy and economic development needs.

By fostering discussion on these important topics, the workshop sought to identify priorities for further research and collaboration on water-energy nexus issues in the APEC region, and explore possible future directions for the EGCFE to pursue.

34 people attended the 2-day workshop, including speakers and participants from eight APEC economies, split equally between developing and developed members (Canada, Indonesia, Japan, Korea, Malaysia, the Philippines, the United States, and Viet Nam) were:

- Government officials from energy agencies in Indonesia, Malaysia, the Philippines, and the United States with technical and economic expertise relevant to the use of water for fossil energy-based industries, and on the environmental and regulatory issues specific to the water-energy nexus.
- Research institutes and academia involved in R&D activities for water conservation technologies, and economic and policy analysis relating to the water-energy nexus: Electric Power Research Institute (EPRI - United States), Carnegie Mellon University (CMU - United States), Gas Technology Institute (GTI - United States), U.S. Department of Energy's National Energy Technology Laboratory (DOE/NETL), the University of North Dakota's Energy & Environmental Research Institute (UNDEERC - United States), New Energy and Industrial Technology Development Organization (NEDO - Japan), and Southern Research Institute (SRI - United States).
- Representatives of relevant industry sectors with interests in this topic: Duke Energy Corporation, Oglethorpe Power Corporation, Purestream Services, Southern Company (all from the United States), Tenaga Nasional Berhad (Malaysia), and Electricity of Viet Nam. In addition, the International Energy Agency's Clean Coal Centre (IEACCC) participated and supported the workshop development.

The context for the event's discussions was to add to the body of knowledge begun by the EWG 08/2014A project on technical developments to make coal-based power generation and conversion less-water intensive, and on policy and regulatory developments in APEC member economies. Significant attention was paid to sharing information to support the capacity building needs of developing APEC economies to make their coal-based energy systems more efficient both in themselves and in their use of water. The workshop featured presentations and discussions on:

- Overview of the Global Coal Utilization-Water Nexus
- Research findings: Water-Energy Nexus: Coal-Based Power Generation and Conversion – Saving Water
- Water conservation technologies for coal-fired power plants: User perspective and R&D activity
- Policy making, implementation and International cooperation on water-energy nexus

In addition, breakout group discussions were held so that all attendees could share experiences and best practices from their economies, and a concluding panel discussion was held to review preliminary findings and suggest possible future directions for EGCFE. The workshop also included a field trip to the nearby EPRI/Georgia Power/Southern Company Water Research Center, so that attendees could observe research being conducted on the latest water technology solutions at a coal-fired power plant.

1.2 Main findings

1.2.1 Water conservation technologies for coal-fired power plants: User perspective and R&D activity

1. Key challenges

a. "One size does not fit all" when it comes to technology solutions for water-energy nexus issues in APEC economies. Each economy/region/site has specific needs requiring customized technology solutions.
b. Economies and utilities face difficulty with selecting the right technology solutions for their needs. Each solution comes with different sets of pros and cons that need to be carefully evaluated.
c. The high cost to implement some technologies restricts their adoption. Many R&D organizations, such as DOE/NETL, EPRI, and NEDO, are supporting development of state-of-the-art technologies, but these solutions might not be economically feasible for some, especially developing, APEC economies.

2. Potential solutions

a. Development of decision-making tools could help key decision makers to assess the impact of water conservation, as well as to potentially identify suitable technology solutions.

b. Industry collaboration for knowledge sharing on best practices and lessons learned and accelerating commercialization of innovative technologies would help to increase understanding and availability of technology solutions.
c. Conduct techno-economic analysis from earlier phase of the technology development to make sure technologies being developed are financially feasible solutions for utilities in APEC economies.
d. Identify potential early adopters for water conservation technologies: Non-profit utilities, such as rural electric cooperatives in the United States, may be good targets for early implementation of technology solutions.
e. An R&D prize competition program to promote innovative technology solutions, sponsored by the private sector or/and government could help accelerate the development of water conservation technologies for APEC economies.

1.2.2 Policy making, implementation and International cooperation on water-energy nexus

1. Key challenges

a. There is a lack of integrated policy making and government coordination to manage water usage in power generation sector at local and national level.
b. There is a lack of regulatory incentives for utilities to work on water-energy nexus. In the United States, the priorities of utilities are to provide electricity in a reliable and cost-efficient manner to meet regulatory requirements and stockholder earning expectations. Water conservation is not a must.
c. There is low awareness of water-energy nexus issues at high levels of government. This is exacerbated by the fact that many power plants do not closely monitor water use so data on the scope of water-energy nexus challenges may be incomplete.

2. Potential solutions

a. Establish a coordinating body at the national level to facilitate water-energy nexus efforts. It is important to involve key stakeholders from early phases on new initiatives on water conservation.
b. Implement regulatory requirements and/or government subsidies to encourage water conservation efforts
c. Develop standards/guidelines for water conservation efforts at coal fired power plants to optimize efforts. For example, information should be shared to establish a common understanding of BAT (best available technology) for APEC economies.
d. Introduce framework to address water scarcity issues during the early phase of energy infrastructure planning.

1.2.3 International cooperation on water-energy nexus

1. Key challenges

a. Lack of awareness of water-energy nexus issues in the APEC region and of APEC's related activities.
b. Each economy faces a different degree of water scarcity risk. Some economies face immediate, severe problems while others do not. Regionwide proactive action is necessary despite differences in urgency.
c. Intellectual property (IP) rights can be an obstacle to information sharing.
d. It is challenging to obtain funding to support R&D on coal-related technologies from development organizations, such as the World Bank and the Asian Development Bank, and various developed countries' foreign assistance organizations.

2. Potential solutions

a. Establish/strengthen the roles of existing water-energy nexus expert organizations, such as APEC EGCFE, IEACCC, and EPRI, as contact points to disseminate resources to enhance awareness of issues concerning the water usage in coal-fired power generation among key decisionmakers.
b. Establish training programs to foster technical capabilities to conserve water
c. Encourage cross-cutting research at the international level (such as the United States - China bilateral cooperation on the U.S.-China Clean Energy Research Center's Water-Energy Technologies (CERC-WET) initiative, and collaborative projects by EPRI and the European Union (EU).
d. Develop technology management plan for IP rights.
e. Establish an international working group with interested government authorities and industry representatives.

1.3 Participant feedback

Verbal feedback from attendees about the workshop was highly positive and enthusiastic. Participants favorably mentioned the diverse mix of critical stakeholders, engaging discussions, and unique opportunity to observe technologies at the Water Research Center.

An onsite multiple-choice survey was conducted during the workshop to solicit attendee views on the value and effectiveness of the workshop. Of the 21 attendees who completed the survey, 100% agreed or strongly agreed that the workshop:

- Achieved its intended objectives
- Included a diversity of viewpoints across economies and professions
- Established a good foundation for future international cooperation and discussion among APEC economies on water-energy nexus issues

1.4 Conclusion and future steps

The workshop fostered very active and enthusiastic discussion among the attendees, illustrating how critical the water-energy nexus is to APEC economies and the many things still be discussed and learned. All attendees expressed interest in further activities by the EWG/EGCFE in this area, including technology and regulatory capacity building.

Based on the ideas and opinions of the speakers and participants, there appears to be broad support for APEC to consider the following next steps:

1. Develop a decision support tool to help key decision makers to assess the impact of water conservation as well as to potentially identify suitable technology solutions.

2. Hold a regular meeting or workshop to continue knowledge sharing on water-energy nexus with a wide group of stakeholders, especially concerning experiences with water management technology implementation.

3. Promote industry collaboration on reducing costs of technology development and seek funding for a technology development competition prize to accelerate commercialization of new technologies.

4. Key R&D areas for further study:

    a. Technologies to extract and reuse water vapor from flue gas as a way of providing financial incentive to utilities to adopt conservation technologies
    b. Alternative dry cooling technology, such as hybrid cooling, indirect cooling technologies
    c. Technologies to reduce energy consumption and lower costs of wastewater treatment

5. Establish a cross-cutting water-energy nexus steering committee or task force to set priorities for further discussion, policy measures, and research.

6. Create a knowledge sharing database with information from APEC and other economies on local water costs, volume of water used by energy sector, and water conservation technology acquisition and implementation costs and performance.

7. Development of APEC guidelines for water conservation efforts at coal-fired power plants to optimize efforts. These guidelines can provide APEC economies with the general concepts and strategies to address water-energy nexus issues.

2 Agenda

The workshop agenda follows below with a list of all sessions and speakers.

	Session	Speakers
DAY 1 - Tuesday, October 31st		
7:30 - 8:30	**Registration and Breakfast**	
8:45 - 9:05	**1) Introduction**	• **Mr Scott Smouse** U.S. Department of Energy, APEC Expert Group on Clean Fossil Energy • **Ms Aya Matsune** Washington CORE
9:05 – 9:50	**2) Overview of the Global Coal Utilisation-Water Nexus**	• **Dr Andrew Minchener OBE** International Energy Agency Clean Coal Centre
9:50 - 10:15	**Group Photo and Coffee Break**	
10:15 – 11:15	**3) Research findings: Water-Energy Nexus: Coal-Based Power Generation and Conversion – Saving Water**	• **Mr Ludwin Daal** Sweco Netherlands B.V.
11:15 - 13:00	**4) Water conservation technologies for coal-fired power plants: User perspective**	• **Mr Neil Kern** Duke Energy Corporation • **Mr Jeffery Preece** Electric Power Research Institute • **Mr Quang PhamLe** Electricity of Viet Nam • **Mr Max Ball** Independent Clean Energy Advisor • **Mr Ahmad Rosly Abbas** Tenaga Nasional Berhad
13:00 - 14:00	**Lunch**	
14:00 – 15:25	**5) Water conservation technologies for coal-fired power plants: R&D activity**	• **Ms Patricia Rawls** National Energy Technology Laboratory, U.S. Department of Energy • **Dr Vincent Tidwell** Sandia National Laboratories, U.S. Department of Energy • **Dr Haibo Zhai** Carnegie Mellon University • **Mr Yasuro Yamanaka** New Energy and Industrial Technology Development Organization (NEDO)
15:25 – 15:45	**Coffee Break**	
15:45 – 17:05	**6) Breakout discussions**	Group leaders presented their findings.

	Session	Speakers
DAY 2 - Wednesday, November 1st		
7:30 – 8:30	**Breakfast**	
8:45 – 10:15	**7) Policy making, implementation and International cooperation on water-energy nexus**	• **Mr Scott Smouse** U.S. Department of Energy & APEC Expert Group on Clean Fossil Energy • **Mr Ahmad Rizal Khalit** Ministry of Energy, Green Technology and Water of Malaysia • **Mr Andi Novianto** Coordinating Ministry for Economic Affairs of the Republic of Indonesia • **Ms Anne Carpenter** International Energy Agency Clean Coal Centre
10:15 – 10:30	**Break**	
10:30 – 11:30	**8) Panel Discussion: Preliminary findings and future directions**	**Panel members:** • **Mr Ahmad Rosly Abbas** Tenaga Nasional Berhad • **Mr Andi Novianto** Coordinating Ministry for Economic Affairs of the Republic of Indonesia • **Mr Jeffery Preece** Electric Power Research Institute • **Ms Patricia Rawls** National Energy Technology Laboratory, U.S. Department of Energy • **Dr Andrew Minchener OBE** International Energy Agency Clean Coal Centre **Closing remarks:** • **Mr Scott Smouse** U.S. Department of Energy & APEC Expert Group on Clean Fossil Energy
11:30 – 12:30	**Lunch**	
12:45 – 17:00	**Field trip: Tour of Water Research Center** The Water Research Center, located at Georgia Power's coal-fired Plant Bowen, established by Southern Company, Georgia Power, and the Electric Power Research Institute, tests the latest technologies to reduce, conserve, and improve the quality of water returned to the environment from coal power generation.	

3 Workshop Methodology

Planning for the workshop sought to ensure an event that would:

- Bring together a wide range of knowledgeable key stakeholders working on water-energy nexus issues in the APEC region
- Facilitate discussion of the EWG 08/2014 A report "Water Energy Nexus: Coal-Based Power Generation and Conversion – Saving Water" and of the experiences and activities of the speakers and participants
- Strengthen relationships and knowledge sharing between different types of stakeholders and different economies
- Provide an opportunity to observe the latest research on water management technology development at a coal-based power plant.
- Elicit valuable observations and insights from attendees that will guide future steps on water-energy nexus activities for EGCFE.

To ensure a diverse group of knowledgeable speakers, the project team sought candidates with policy, technology, research, and/or hands-on experience with water-energy nexus issues and especially water conservation on coal-based power generation; while attempting to achieve a balanced representation of government, academic and private sectors; developing and developed economies; and genders.

The session topics were chosen to cover the most important topics pertaining to the objectives of the project and the EWG 08/2014 A report. Thus, the agenda covered:

- Current state of water-energy nexus issues in the APEC region
- Water management technology development and implementation in coal-based power generation
- Policy frameworks and governance
- International cooperation on research and capacity building

Breakout Discussions were held at the end of Day 1 to foster more in-depth exchange of experiences and best practices. Attendees were divided into four groups of roughly eight people each and assigned to discuss viewpoints and experiences concerning a provided list of topics. Each group discussed technology issues, policy and international cooperation issues. The members of each group were selected to ensure a diversity of stakeholders and backgrounds relevant to the assigned issues. Each group was asked to designate a discussion leader to moderate and a note-taker so that the products of the discussion could be presented to the whole group at the end of the session.

The formal program concluded with a review of common priorities, challenges, and solutions voiced by attendees during the workshop, and subsequent reflections by an expert panel and all attendees on these findings, additional issues still to be addressed, and possible next water-energy nexus activities for EGCFE.

Following this, a field trip was provided to the EPRI/Southern Company Water Research Center at Georgia Power's coal-fired Plant Bowen. This tour gave attendees the chance to observe in person the testing of several technologies discussed during the workshop.

4 Attendance

The workshop was attended by 34 people from eight APEC economies, as seen in the tables below.

Figure 1: Attendee group photo

Source: Washington CORE

Table 1: List of speakers

Economy	Name	Organization	Gender
CDA	Mr Maxwell Ball	Independent Clean Energy Advisor	M
INA	Mr Andi Novianto	Coordinating Ministry for Economic Affairs of the Republic of Indonesia	M
JPN	Mr Yasuro Yamanaka	New Energy and Industrial Technology Development Organization	M
MAS	Mr Ahmad Rizal Khalit	Ministry of Energy, Green Technology and Water of Malaysia	M
	Mr Ahmad Rosly Abbas	Tenaga Nasional Berhad	M
US	Mr Scott Smouse	U.S. Department of Energy	M
	Ms Patricia Rawls		F
	Mr Vincent Tidwell		M
	Mr Neil Kern	Duke Energy Corporation	M
	Mr Jeffery Preece	Electric Power Research Institute	M
	Dr Haibo Zhai	Carnegie Mellon University	M
VN	Mr Quang Le Pham	Electricity of Viet Nam	M
Other	Dr Andrew Minchener OBE	International Energy Agency Clean Coal Centre	M
	Ms Anne Carpenter		F
	Mr Ludwin Daal	Sweco Nederland B.V.	M

Table 2: List of participants

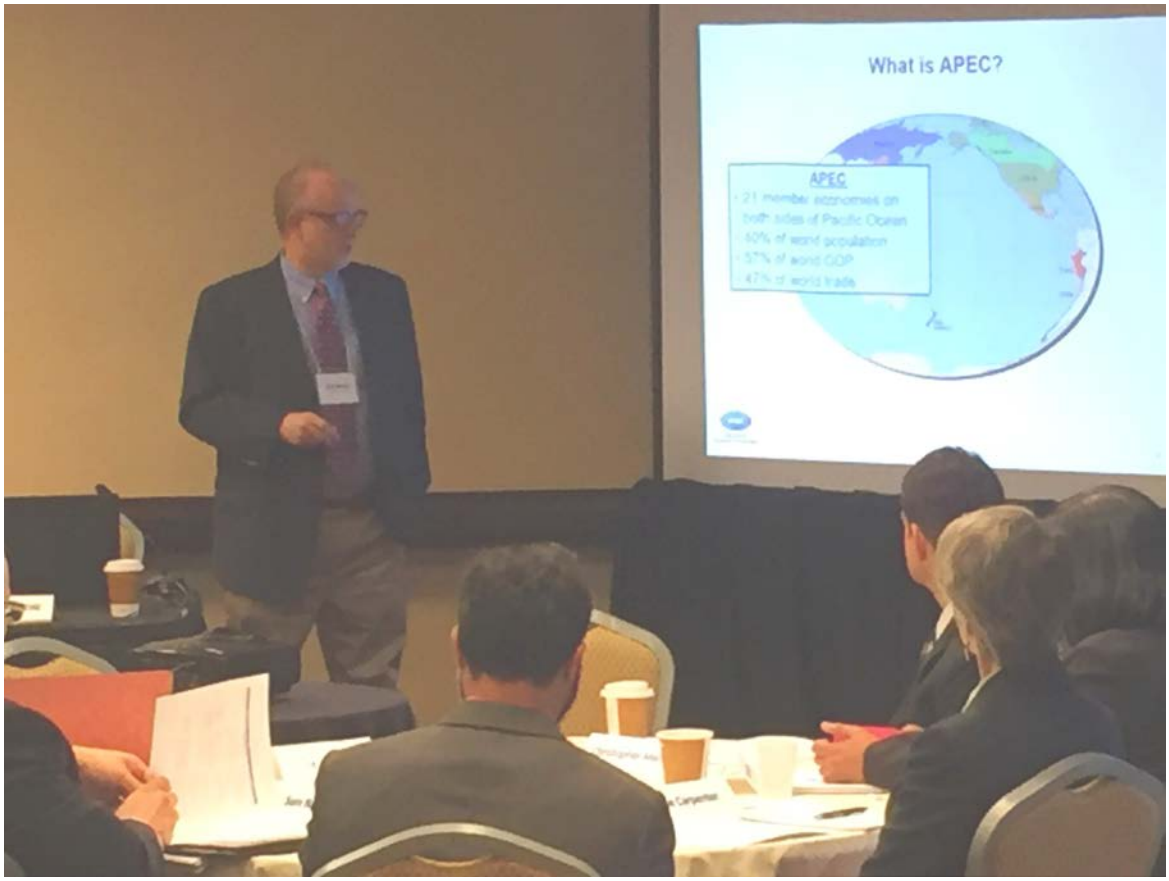
Economy	Attendee name	Organization	Gender
CDA	Ms Kimberly King	Consulate General of Canada	F
JPN	Ms Misa Suzuki	New Energy and Industrial Technology Development Organization	F
ROK	Ms Koeun Lee	Korean Consulate in Atlanta	F
	Mr Myungwoo Nam		M
RP	Ms Melita Obillo	Philippine Department of Energy	F
US	Mr Donald W. Collins	Western Research Institute	M
	Mr Clark Harrison	Purestream Services	M
	Mr Ryan Klapperich	University of North Dakota	M
	DrChristopher Martin		M
	Mr David LaMont	Gas Technology Institute	M
	Mr Gary Madden	Techinomics Inc.	M
	Mr Sam Najim	Oglethorpe Power Corporation	M
	Ms Rebecca Osteen	Southern Company	F
	Dr Jay Renew	Southern Research	M
	Dr Carlos Romero	Lehigh University	M
	Ms Aya Matsune	Washington CORE	F
	Ms Nanako Hisamichi		F
	Mr Chris Wood		M
	Ms Linglan Guan		F

5 Speaker presentations and discussion

5.1 Session 1: Introduction

This opening session provided an overview of the workshop's background, objectives, and agenda.

Figure 2: Session 1 presentation



Source: Washington CORE

Moderator: Ms Aya Matsune
Vice President, Washington CORE

1. **Expert Group on Clean Fossil Energy (EGCFE) Water-Energy Nexus: Saving Water**

Speaker: Mr Scott Smouse
Senior Advisor to Deputy Assistant Secretary, Office of Clean Coal and Carbon Management/ Office of Fossil Energy, U.S. Department of Energy & Chair, APEC Expert Group on Clean Fossil Energy

Bio:
Mr Scott Smouse provides advice on a broad range of technical, policy, and regulatory issues and activities, especially related to bilateral and multilateral cooperation with foreign partners on various research, development, and demonstration (RD&D) and technology deployment activities. From 1996- 2014, Mr Smouse coordinated the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) international bilateral and multilateral activities. From 2013-2014, drawing on his early career in combustion, he additionally assumed a management position in NETL's RD&D programs as Technology Manager for Advanced Combustion.

Mr Smouse has held senior-level positions in several international organizations/initiatives, including the APEC and the Asia Pacific Partnership on Clean Development and Climate (APP). Since 2001, he has chaired the Expert Group on Clean Fossil Energy (EGCFE) under the APEC Energy Working Group (EWG). He is a member of the DOE management team for the U.S. Advanced Coal Technology Consortium under the U.S.–CERC program). Mr Smouse was the lead author on the international sections of the 2010 Interagency Task Force Report on Carbon Capture and Storage to President Barack Obama. He holds a BS in Chemistry from Fairmont State College and a MS in Fuel Science (Combustion) from Penn State University.

Presentation overview:
Mr Smouse provided general background information and recent activities for APEC, the EWG, and the EGCFE. The mission of APEC's 21-member economies is to promote trade growth and harmonization, in which the group plays an important role given its large shares of global population and gross domestic product (GDP). The EWG and EGCFE regularly sponsor research studies, workshops, and seminars. This APEC Water-Energy Nexus Expert Workshop is the first such EGCFE event to focus on water usage in power generation.

Mr Smouse concluded by introducing some future EGCFE projects and upcoming proposals concerning:

- High efficiency low emission coal-fired power generation
- Peer review in efficient power generation (PREP)
- Water-energy nexus, continue work in 2018

5.2 Session 2: Overview of the Global Coal Utilisation-Water Nexus

Session 2 reviewed the current global situation of water conservation challenges and related efforts and relevant key policy, regulatory developments as well as the water saving technology options.

Figure 3: Session 2 presentation

Source: Washington CORE

Moderator: Mr Donald W. Collins
Chief Executive Officer of Western Research Institute

1. **Overview of the Global Coal Utilisation – Water Nexus**

Speaker: Dr Andrew Minchener OBE
General Manager, International Energy Agency Clean Coal Centre

Bio:
General Manager of the IEA Clean Coal Centre (IEACCC) since July 2013, DrMinchener is responsible for all aspects of the Centre's activities with special emphasis on maintaining a strong international profile for all aspects of clean coal utilization. Dr Minchener is a Fellow of the Energy Institute and a Chartered Engineer. He has over 40 years' experience in fossil fuel and biomass/waste utilization, systems development, energy and environmental consultancy, and contract research and development, with particular emphasis on clean coal and Carbon Capture and Storage (CCS) issues in Europe and the Far East. This includes specific expertise in policy/institutional/regulatory analysis, techno/socio-economic analysis, training/capacity building, knowledge transfer and international business development.

Dr Minchener has undertaken numerous overseas assignments, including over 160 missions to the People's Republic of China and other parts of Asia, where he has worked with a number of organizations including the UK Department of Energy and Climate Change, the World Bank, the Asian Development Bank, the International Energy Agency, the European Commission and the IEACCC. Dr Minchener has degrees in

Chemistry and Combustion Studies, a DPhil in clean coal issues and a DSc in energy and environment studies from the University of Leeds.

Presentation overview:
Dr Minchener provided an overview of global coal utilization and water-energy nexus issues, covering the following main topics:

- Water availability worldwide
- Water related policies for the coal power sector plus regulations for development and implementation worldwide
- Introduction to potential sources of non-fresh water for use in power and industry applications
- Prospects for water conservation in coal-fired power plants, including techniques being developed and applied for more efficient water usage and recycling

Global water demand in the energy sector is rising due to economic growth and population increase, increasing urbanization and industrialization, higher standards of living, and greater food demand. Many parts of the APEC region are experiencing serious water stress, as well as parts of Europe and Africa. In the APEC region, China particularly faces an imminent water scarcity risk.

Coal-based power generation is one of the primary factors that contributes to water resource constraints in the APEC region. Coal users are concentrated in developing economies, which creates demand for capacity building to address the water-energy nexus issue in coal-based power generation. However, each region and economy faces different water issues, thus there is no “one size fits all” solution.

For example, China and the United States have considerably different landscapes. China, the largest coal producer and consumer in the world, is characterized as a heavily populated economy and the second largest water user in the world. In China, water resources are unevenly distributed - Northern China has a particularly high level of water risk. It is projected that China faces a water deficit of 200 billion m^3 by 2030. China has implemented a water allocation plan, which sets a quota on water usage at the province level, but it still needs more work to conserve water, such as seeking non-fresh water sources for cooling in the coal-based power generation sector.

The United States is a highly populated yet relatively water-rich economy. However, the coal-based power generation sector primarily depends on fresh water withdrawals for cooling, and nearly every region of the United States has experienced water constraints. The United States has a sustainability goal in place, but there is a need to implement coordinated efforts to achieve an effective and comprehensive approach to address water-energy nexus issues.

The challenges are where to source water from, how to reduce the amount of water consumption, and how to limit the wastewater discharge. One of the key water conservation solutions is to identify potential alternatives to using fresh water for cooling, such as municipal wastewater, mine water, and seawater. Another solution is to reduce consumption of water by implementing technologies such as dry cooling. The

dry-cooling solution helps minimize wastewater generation within the plant while supporting environmental sustainability.

The availability of fresh water is becoming an issue in many parts of the world. It is important to reduce the burden on fresh water supplies by reducing their consumption and utilizing alternative water resources. The coal-based power generation sector is the key focus for reducing water consumption. In certain cases, with a suitably designed on-site water treatment plant, a coal-fired power plant has the potential to become a supplier of both electricity and fresh water.

Q&A:

- Mr Daal asked how economies can learn from each other on water-energy nexus policy. Dr Minchener responded that there is great variance in water issues from one economy to the next. Economies can learn a lot from one another but may need to adapt other economies best practices to match their own circumstances and targets.

- Mr Collins asked about the effects of low-rank coal use on water conservation. Dr Minchener cited efforts in the United States and the EU to extract water from lignite before the coal goes into the boiler so that it can be reused. There is also potential to change low-rank coal into hydrogen through gasification for use in clean energy, which a Japanese project has been doing in Australia.

5.3 Session 3: Research findings: Water-Energy Nexus: Coal-Based Power Generation and Conversion – Saving Water

Session 3 provided a summary of findings and lessons learned from the 2016 APEC report Water-Energy Nexus: Coal-Based Power Generation and Conversion - Saving Water (EWG 08 2014A).

Figure 4: Session 3 presentation

Source: Washington CORE

Moderator: Ms Lily Guan
Project coordinator, Washington CORE

1. **Water Energy Nexus: Coal-Based Power Generation and Conversion – Saving Water**

Speaker: Mr Ludwin Daal
Senior Consultant and Project Manager of Water Capture Technology, Sweco Netherlands B.V. (formerly part of DNV NL)

Bio:
Mr Daal is the main author of the 2016 APEC study Water-Energy Nexus: Coal-Based Power Generation and Conversion - Saving Water. He has a chemical and environmental engineering background, and has worked as a consultant for over 15 years. He currently works in the Process and Cooling water group within Sweco where he is a water chemist.

His activities in the past include, among others, chairman of the working group on sample preparation for the CEN standards on Solid Biofuels and International Standards expert within the ISO group. He was project manager of the EU project: evaporated water capture with novel membranes – abbreviated CapWa. The project has received global media attention and has been recognized by the EU as one of its project success stories. Mr Daal is currently a work package leader in the EU project MATChING, which focuses on reducing cooling water use for geothermal and thermal power plants. He has been an invited speaker at many conferences in locations including Qatar, India, Australia, China and Europe.

Presentation overview:
Many economies around the world suffer from water scarcity including the APEC region. At the same time, economies like Thailand are continuing to invest in new power plants, which increases strain on water resources. Flue gas cleaning and cooling are the main sources of water strain in power generation. The Paris climate accord has led to an increase in wet flue-gas desulfurization (FGD).

There is discussion about reusing wastewater for process water, but the latter needs to be very pure. The manufacturers of the plant turbines set strict standards for process water, and a purity level equivalent to drinking water is preferred. Water needs to be purified, then sent to the water steam cycle. It costs US$1 per cubic meter of water to achieve high purity makeup water. Power plant operators won't reuse wastewater unless there is a regulatory requirement in effect. Using effluent for makeup water creates technical problems and safety concerns.

Meanwhile, there is increasing evidence that dry cooling can be economically feasible. South Africa utility Eskom has found a way to optimize dry cooling to reduce the energy penalty to a range of 3.5 – 5.5%, below the 7% cited by a 2011 U.S. Environmental Protection Agency (EPA) study. On the other hand, dry cooling reduces the quality of the makeup water, and the equipment requires a large physical footprint. Dry cooling has not taken off on a large scale yet because water prices are not high enough to drive

the implementation of dry cooling technologies in most economies, although prices are rising in Israel and Australia. In the Netherlands industry users of water have strongly resisted proposals for an increase in the price of water.

Amongst other technologies related to water conservation, use of cooling towers is growing. Reuse of water from power plants for district heat is gaining popularity in Japan, Korea and the EU as a way to save money. Coal fired power plants could also save costs by capturing the large quantity of water vapor they produce. Principal water capture saves energy due to less need for heaters.

Zero liquid discharge (ZLD) projects are big in Italy, where there is a convergence of water scarcity and a lot of coal resources. ZLD generates distillate – the more this can be reduced the less water is needed. Some distillate like salt can be sold for revenue to offset costs. Meanwhile, Israel abandoned a ZLD plant due to many operational problems. ZLD works well with gas-fired plants, and may have potential in the United States, where many power plants are transitioning from coal to gas.

Q&A:

- Dr Zhai asked about Mr Daal's research with membrane technology. Mr Daal said that a selective layer of polyetheretherketone is being used on an ultrafiltration membrane to remove water vapor molecules and CO_2 from coal-fired power generation. He said that trials in Norway were successful, and that it appears the United States is starting to experiment with using membranes for water vapor removal in coal-fired power plants.

- Mr Collins commented about a project with the U.S. National Coal Council about analyzing the net economic benefit of using carbon capture and utilization technologies across a national supply chain. Mr Daal agreed that there is a great benefit to doing this kind of life cycle analysis, but said that such studies can be very difficult and expensive.

5.4 Session 4: Water conservation technologies for coal-fired power plants: User perspective

In Session 4, utilities shared experiences with technical and economic challenges for water management at their coal-fired power plants, factors affecting decisions on implementation of water management technology solutions, lessons learned, and policy/regulatory issues related to water use at coal fired power plants.

Figure 5: Session 4 presentation

Source: Washington CORE

Moderator: Dr Andrew Minchener OBE
General Manager, International Energy Agency Clean Coal Centre

1. **Water Management in the Power Generation Sector**

Speaker: Mr Neil Kern
Technology Development Manager, Emerging Technology Office, Duke Energy Corporation

Bio:
Mr Kern is responsible for assessing and selecting new generation-related technologies for further development and deployment. His current areas of focus include advanced power generation cycles, water management technologies, environmental control technologies, and advanced sensors. He is also responsible for managing technical relationships with government, industry, and academic entities to support necessary research needs for the energy sector. Mr Kern earned a Bachelor of Science degree in Chemical Engineering with a concentration in Green Chemistry from North Carolina State University. He is a registered Professional Engineer in the state of North Carolina.

Presentation overview:
Duke Energy's energy mix is still 90% coal in the Midwest region, but other regions are mostly gas and nuclear power. For the future, Duke Energy is focused on more gas plants and cooling towers.

Maintaining reliability and cost efficiency in power plant operation is the highest priority for U.S. utility companies. There are no incentives to take extra steps such as water conservation, except for effluent discharge control for regulatory compliance and to promote local sustainability. Up until now, water efficiency has only become a priority at Duke during periods of drought, but there is movement toward making it a standard part of planning.

In general, the energy industry has been slow to consider water use in planning, and this is unlikely to change much unless the true cost of water is established. New regulatory requirements are important to incentivize more efficient water use, but should be balanced with the added cost and risk to utilities.

Duke's Crystal River plant in Florida is using reclaimed wastewater from a local treatment facility in the plant's FGD system as makeup water. The US $8-million project was jointly funded by the Southwest Florida Water Management District, the City of Crystal River and the Florida Department of Environmental Protection. Duke Energy provided additional funds for construction within the power plant complex.

Duke Energy controls the water pump, and the municipal wastewater facility conducts water treatment. Duke Energy pays the facility a small fee for the treatment service. The power plant normally uses groundwater for cooling, but past 3.45 million gallons per day it is required by regulation to use alternate water source, so it switches over to wastewater. This contributes to savings of approximately 750,000 gallons per day of groundwater.

2. Water Management in Coal-Fired Power Plants

Speaker: Mr Jeffery Preece
Senior Technical Leader, Water Management Technology Generation, Electric Power Research Institute

Bio:
Mr Preece is responsible for planning and managing power plant water management R&D projects for the Electric Power Research Institute's (EPRI) Water Management Technology program. Focus areas include water requirements for environmental controls; increasing efficiency of water use; and addressing water treatment issues. Prior to joining EPRI in 2014, Mr Preece provided technical support for flue gas desulfurization wastewater treatment systems at a U.S. electric utility company. In previous roles, he supported boiler/steam cycle chemistry, demineralized water treatment systems, and cooling water chemistry applications for coal-fired and combined-cycle facilities. Mr Preece has a Bachelor of Science degree in chemical engineering from North Carolina State University.

Presentation overview:
The amount of accessible fresh water on Earth is very small. Hence drought is a growing concern around the world and across many U.S. states. The location of water scarcity is not static – it is expanding to a wide variety of locations over time.

Regulatory pressures are needed to reduce fresh water use in power generation in the United States. Given the current availability of water for use in cooling, there is no economic incentive to implement dry cooling, which imposes a significant efficiency penalty. The U.S. EPA recently introduced new effluent discharge requirements to establish numeric limits on internal water treatment processes and related best available technologies for utilities, and it is still unclear what further steps the new EPA administrator may take.

Any significant new regulations will have a serious impact on the economic viability of coal-fired power plants, so it is important to conduct techno-economic analysis and strike a balance between what technology is effective for conserving water and what is financially feasible for utilities to implement. Therefore, it is important to include the regulatory agency in industry discussions to ensure mutual understanding of what kinds of solutions would be realistic.

There are several water conservation technology solutions available to coal-fired power plants. For example, dry cooling can help to cut water use in power generation, but it significantly reduces plant energy efficiency in warmer months. A hybrid-cooling system that used wet cooling during the summer and dry cooling the rest of the year could be an attractive option, but more research is needed. EPRI is looking into improving heat transfer by using new materials developed through additive manufacturing.

In general, operating costs need to be reduced to make such technology solutions economically viable for power plants. There is a lot of research being done by EPRI and the U.S. government on new technologies for membrane structures, alternate heat sources, and chemical treatments; but resources available to commercialize new technologies are limited, so for now utilities need to work with existing commercially available technologies.

3. Coal-fired power plant development and water usage – Utility's point of view

Speaker: Mr Quang PhamLe
Project Officer of Investment Management Department, Electricity of Viet Nam

Bio:
Mr Quang PhamLe began his career as an engineer at the Technical & IT division of Electricity Power Trading Company (a subsidiary company of Electricity of Viet Nam (EVN)), where he managed metering systems of power plants and transmission substations. After completing a Master program, he joined the Nihn Thuan nuclear power project Management Board (an EVN affiliate), where he was in charge of technology selection, and reviewing technical issues of nuclear power plant projects.

He joined the EVN headquarters office in 2015 where he managed the investment stage (pre-project) of nuclear projects, and after the nuclear program was canceled, he has managed thermal power projects (coal-fired and combined cycle gas turbine (CCGT)) and his main responsibilities are to review and/or evaluate the feasibility of each project for submission or approval, including technology, technical issues, project schedule and financing.

Presentation overview:
Coal-fired power represents a large share of total power generation in Viet Nam and will continue to do so. Two new coal-fired plants are currently under construction, although they may be converted to liquefied natural gas (LNG) due to local government resistance to coal. Coal-fired power plants in Viet Nam use sea water for cooling, so water scarcity is not an issue.

However, due to Vietnamese law on water resource and wastewater management, utilities are required to consider water use and wastewater discharge during power plant construction. Mr PhamLe mentioned that one challenge faced is the difficulty of identifying the best available technologies for increasing the efficiency of water management at a plant.

4. Saskatchewan Perspective on the Water-Energy Nexus

Speaker: Mr Max Ball
Independent Clean Energy Advisor

Bio:
Mr Max Ball has extensive experience in siting power plants, optimization of power conversion, water use and project licensing. During his 40 years of employment at SaskPower, Mr Ball participated in all aspects of power generation including managing a full portfolio of supply options for the company. Specific project work included development and permitting of coal and gas thermal generation facilities, developing clean coal technologies, advancing the understanding of grid integration. Mr Ball initiated the world leading commercial deployment of carbon capture at Boundary Dam Power Station (commissioned 2014). Following his retirement from SaskPower in early 2017, Mr Ball provides advisory services supporting deployment of clean energy.

Presentation overview:
Today, there is not much remaining coal-fired power generation in Canada, but still some significant presence in Saskatchewan Province. Even there however it is under increasing pressure from gas.

Any water conservation solution needs to be socially and economically beneficial. Perhaps an incentive needs to be provided to incentivize utilities to adopt effective technologies. Cool temperatures in Saskatchewan make dry cooling economically viable at coal-fired power plants. The Boundary Dam coal-fired power plant, which is the world's first post-combustion coal-fired power plant to capture and store CO2 emissions, has been very successful at recovering water vapor from flue gas. This is an important technology solution, as recovering water in this way could substantially reduce or even eliminate the need for off-plant sources of water.

5. Groundwater Exploration Initiatives at TNB's Coal-fired Power Station in Kapar, Malaysia: Issues and Challenges

Speaker: Mr Ahmad Rosly Abbas
Head of Unit, Built Environment & Climate Change Research Group, Tenaga Nasional Berhad

Bio:
Mr Abbas joined Tenaga Nasional Berhad (TNB) Research in 1999 as a researcher in built environment, and is currently the Head of the Built Environment & Climate Change Unit. Mr Abbas has successfully lead various built environment-related research projects and services. Most recently, he managed a team of researchers to successfully complete projects on zero water discharge and on groundwater as alternative town water for TNB thermal power plants. Mr Abbas has worked under various organizations in the area of business development, research and consultancy, construction and project management. Mr Abbas graduated with a Bachelor of Architecture degree in 1988 from Oklahoma State University, USA. He is a Certified Building Energy Manager.

Presentation overview:
In Malaysia, power plants tend to be located in highly populated areas along the coast. These areas have a lot of groundwater that coal-fired power plants use as an alternative to fresh water for cooling. However, the groundwater quality is not very good due to salt water penetration, so it is costly to use. Moreover, soil subsidence has become a major problem near power plants to due to heavy groundwater extraction.

Although not a major problem yet, Malaysia is facing a growing water scarcity risk that may become an issue in the near future. A recent study by the National Hydraulic Institute of Malaysia (NAHRIM) concluded that Peninsular Malaysia will become increasingly exposed to global warming effects due to a projected decrease in annual rainfall in several states with extremely dry years expected in 2020, 2029, 2034 and 2044. Additionally, river flow in several states is expected to decrease by between 3% to 93% by 2050, and the water quality of several major rivers - currently the main sources of municipal water supplies - has deteriorated over time due to contamination from surrounding land use.

As a response to these issues, Kapar Power Station in Malaysia is focused on using tube wells for groundwater extraction along with a monitoring system to try to minimize soli subsidence, as well as water purification technology to improve the brackish groundwater quality and make its reuse more practical. A water treatment plant is planned using single pass reverse osmosis and filters to remove iron and carbon.

Q&A:

- Mr Novianto asked about U.S. regulatory requirements for fly ash. Mr Preece responded that the fly ash itself is considered nonhazardous, but there is a no discharge requirement for water used with fly ash. Most power plants use dry handling of the ash, and can sell the dry ash.

- Mr Preece was asked about EPRI's work on additive manufacturing and advanced water technologies. He said EPRI is developing new materials for water treatment membranes to increase surface area without sacrificing the pore sizes of the amount of pressure that needs to be applied to the membrane surface. EPRI is also looking for opportunities to increase efficiency of heat transfer by increasing surface area and using smaller volume.

- Mr Preece mentioned EPRI has recently begun a water quality training program to incentivize industry decisionmakers to think about water usage and how it affects others and the environment.

- Dr Daal asked if any utilities had developed a way to calculate the cost of water scarcity reducing power availability. Mr Kern said Duke Energy has not calculated a financial value for this risk but is working on this issue.

5.5 Session 5: Water conservation technologies for coal-fired power plants: R&D activity

In Session 5 technology institutes provided an in-depth look at R&D activity on technology solutions relating to water management and conservation for coal-fired power plants.

Figure 6: Session 5 presentation

Source: Washington CORE

Moderator: Dr Andrew Minchener OBE
General Manager, International Energy Agency Clean Coal Centre

1. **Crosscutting Research Program: Water Management Research & development**

Speaker: Ms Patricia Rawls
Supervisor for the Enabling Technologies and Partnerships Team, National Energy Technology Laboratory, U.S. Department of Energy

Bio:
Ms Rawls is responsible for leading the implementation of the Crosscutting Research and Rare Earth Elements Program at the National Energy Technology Laboratory (NETL). This includes managing a portfolio of research projects in water management, sensors and controls, simulation based engineering, high performance materials and rare earth elements from coal. During her over 25 years at NETL, she has held several positions in Project Management, Systems Engineering & Analysis and Evaluation & Planning. In these positions, she has worked in a variety of technology areas including Coal Preparation, Gas Turbines, Gasification, and Advanced Materials Research.

Presentation overview:
NETL's mission is to reduce the cost of clean coal technologies, maintaining balance between capabilities in CO_2 reduction, water usage and cost. It is important to assess the techno-economic aspects of each technology developed to make certain that it would be practical to implement. Current NETL research funding is focused on the themes of:

- Advanced energy systems (US$129 million)
- Carbon capture (US$101 million)
- Carbon storage (US$95.3 million)
- Domestic supply of rare earth elements (US$15 million)

NETL encompasses above research themes through Crosscutting research program (US $45.5 million) to focus on R&D activities for water management research, developing advanced materials, sensors and controls, and simulation-based engineering.
There is no single technology solution for all situations, so NETL works to provide a range of options that people can choose from. This involves analyzing regional, or even plant specific characteristics to develop appropriate solutions. Current NETL technology focus areas include:

The NETL Water Management Program is working to develop technologies for power plants that can reduce the levels of water effluent discharge, fresh water consumption, and water treatment costs. Research is focused on developing new materials for advanced heat transfer and cooling systems; water treatment and reuse solutions using waste heat and carbon dioxide to treat water; process efficiency and heat utilization; and data modeling/analysis using wireless networked sensors to monitor water quality and detect heavy metals.

2. Integrated Energy-Water Planning

Speaker: Dr Vincent Tidwell
Distinguished Member of the Technical Staff, Sandia National Laboratories, U.S. Department of Energy

Bio:
Dr Tidwell has over 20 years of experience conducting and managing research on basic and applied projects in water resource management, collaborative modeling and the energy-water nexus. He played a lead role in realizing a new Crosscut Program on the Energy-Water Nexus within the U.S. Department of Energy. Recently he led a multi-

institutional team to integrate water into long-term transmission planning in the United States and identified potential pinch points where water stress could impact energy production internationally. He and colleagues are combining critical infrastructure protection models with climate integrated assessment models to evaluate the resilience of U.S. infrastructure.

Dr Tidwell is an adjunct professor at the University of New Mexico, New Mexico Institute of Mining and Technology, and the University of Arizona. He served on New Mexico Governor Richardson's Blue Ribbon Task Force on water and is a Lead Author for the Water, Energy and Land Use chapter in the 2014 National Climate Assessment (NCA) and the Energy Chapter in the 2018 NCA.

Presentation overview:
The United States and China both have high water scarcity risks, and power generation is a major contributor to water stress. Accurate modeling and assessment tools are critical to understanding water-energy nexus needs and how to deal with the issue. There is no universally applicable modeling approach – customization is necessary based on circumstances.

Sandia National Laboratory collaborated with the Western Electricity Coordinating Council (WECC) to consider water resources during the planning phase for the transmission expansion project in the Electric Reliability Council of Texas (ERCOT) region. The project resulted in the creation of an integrated energy-water dataset and modeling tool that allow transmission project planners to assess the implications of water resources during energy infrastructure planning.

Sandia National Laboratory conducted a study commissioned by APEC titled "Mapping Water Consumption for Energy Production Around the Pacific Rim," in order to identify water resource constraints in the energy sector. Among many findings, the study identified that coal-fired power plants are responsible for a huge amount of water use - thermoelectric power accounts for 49% of total water usage by the energy sector, and 70% of this figure is for coal-fired power generation.

3. Water Use at Coal-fired Power Plants: Technological and Regulatory Factors

Speaker: Dr Haibo Zhai
Associate Research Professor, Engineering and Public Policy, Carnegie Mellon University

Bio:
Dr Zhai is an Associate Research Professor in the Department of Engineering and Public Policy at Carnegie Mellon University (CMU), and manager of the Integrated Environmental Control Model, a widely-used computer tool for power plant modeling and analysis. His research focuses on low-carbon energy systems and associated environmental control technologies and involves the combination of systems modeling and analysis with engineering-economics, risk analysis, and policy analysis. Dr Zhai's current research mainly focuses on electric power generation systems, carbon capture and storage, advanced cooling technologies, and the energy-water nexus. He received

his PhD in environmental engineering from North Carolina State University and did his postdoctoral fellowship research at CMU.

Presentation overview:
There is a need for careful coordination of energy, climate change, and water resource policies to avoid a possible conflict between water supply and demand. For example, amine-based CO_2 capture technology is an effective way to reduce emissions from coal-fired power plants, but large amounts of cooling water are required to support the capture process operation, significantly increasing plant water use.

CMU has developed an assessment tool called the Integrated Environment Control Model (IECM), which can be used to quantify and characterize water use at pulverized-coal (PC) power plants that use wet cooling towers. IECM is a computer-modeling program that performs systematic cost and performance analysis of various emissions control technologies at coal-fired power plants to aid engineers, policy makers, and researchers with preliminary design and analysis of electricity generation options.

The cooling system is the largest source of water use at PC power plants with wet towers, accounting for 80% of a plant's total water consumption. Improving plant efficiency can remarkably decrease water use; as a plant becomes more efficient (supercritical, ultra-supercritical plants), it can reduce the amount of makeup water required. Dry cooling requires no makeup water at all, but incurs the highest levelized cost of electricity (LCOE).

4. Japanese technology for coal-fired power plants: R&D activity

Speaker: Mr Yasuro Yamanaka
Project Coordinator, Environment Department, Clean Coal Group, New Energy and Industrial Technology Development Organization

Bio:
Mr Yamanaka is the project manager for many of the national development projects in Japan at New Energy and Industrial Technology Development Organization (NEDO). Previously he worked for over twenty years at IHI Corporation, one of the major boiler suppliers for coal-fired power plants. Mr Yamanaka has extensive working experience as a process and system engineer and has managed many projects related to Molten Carbonate Fuel Cell (MCFC) Power Generation System, Polymer Electrolyte Fuel Cell (PEFC), Hydrogen generator which reforms Natural Gas, Naphtha and Kerosene to Hydrogen, Post-Combustion CO2 Capture (PCC) system. He established a program team organization from the beginning to the end for the PEFC and PCC system projects. He was also a project manager at IHI for an international collaboration project of PCC demonstration with an Australian organization, and this project is still progressing as envisioned. He has extensive experience in project management for new development projects.

Presentation overview:
Japan mainly relies on imported coal and uses sea water for cooling in its coal-fired power plants on the coastline, so water scarcity is not a concern in coal-fired power generation.

The dry-cooled integrated gasification combined cycle (IGCC) Nakoso demonstration plant will be the first in Japan when it starts operating in 2020. IGCC has 10% higher performance than conventional ultra-supercritical (USC) plants, and IGCC emissions are 60% lower than USC plants. Water usage in dry-cooled IGCC is 30% lower than in conventional coal-fired power plants due to higher efficiency and less water used for gas clean up.

Oxyfuel, which uses oxygen as a combustion for coal, makes it easier to capture pure CO_2 and water vapor from flue gas.

Advanced Humid Air Turbines (AHAT) will be a useful technology solution for capturing the water from humid air. So AHAT can provide high efficiency without a steam combined cycle - they do not have steam condensers. AHAT is suitable for a dry climate region as it does not get easily affected by the cooling temperature.

Q&A:

- Mr Khalit asked Ms Rawls how NETL is trying to reduce water treatment costs. Ms Rawls said that there are currently no set goals for reducing costs, but NETL's efforts are generally focused on increasing plant efficiency to help reduce operational costs.

- Dr Minchener asked Dr Tidwell if the United States faces a disaster if action is not taken on water use for power generation. Dr Tidwell said that the energy mix in the United States is shifting toward, gas, nuclear, and renewables, and this is helping to reduce water use. On the other hand, he pointed out that energy use for transporting and treating water is increasing, and it is important to capture more energy from wastewater treatment.

- Mr Ball observed that in his experience it is possible to do carbon capture and storage using only water vapor captured from flue gas, although costs do increase. Dr Zhai agreed this approach should be studied further.

- Mr Daal asked Mr Tidwell if all potential water sources, including rainfall capture and reuse, are considered when modeling water use at potential locations for new power plants in the United States. Mr Tidwell said that a variety of water sources are considered but not rainfall at this time, but the effects of climate change are beginning to be analyzed.

- Dr Minchener asked Mr Yamanaka which of the technologies he presented are most likely to see commercialization first. Mr Yamanaka said that IGCC technology is likely to be a good approach to increasing plant efficiency and reducing water usage.

- Mr Collins asked Mr Tidwell if his models consider the water present in low-rank coal as potential water source for power plants. Mr Tidwell said they do not currently, but it is an interesting idea.

5.6 Session 6: Breakout discussions

In Session 6 attendees divided into groups to discuss technology, policy, and international cooperation issues concerning the water-energy nexus.

Figure 7: Session 6 discussion

Source: Washington CORE

The summary of findings presented by each group are shown in the table below.

Table 3: Session 6 Overview

Group 1: Leader – Mr Don Collins, Western Research Institute	
Findings	• China is highly integrated across different utility sectors. • Regulated energy utilities in United States and Malaysia are inhibited from coordinated strategic planning with other sectors such as water due to the rate case and other issues. • EPRI water training model could provide model that would provide financial incentive for utilities to implement water conservation technologies. • Integration is lacking in government, which handicaps decision-making on water-energy nexus issues. • Modeling tools could be helpful • Economies with low coal costs and ample water have less incentive to invest

	in water conservation technology. • Need to collaborate between economies • Need to upgrade municipal water infrastructure – opportunity to upgrade water quality. • Prize competitions, such as X Prize could be useful for driving innovation for water-energy nexus R&D.
Group 2: Leader – Mr Ludwin Daal, Sweco Netherlands B.V.	
Findings	• The United States, EU, and the Philippines have major policy integration issues. This is particularly a problem in the United States due to having different authorities in each state. In EU, the policy of one economy may directly impact policy of another, so there are sometimes unintended consequences. • In the Philippines, access to capital is a challenge for power plant operators. Information campaigns are needed to educate policymakers on the situation and encourage government funding for energy infrastructure. • It is very helpful to have a central point for information on water-energy nexus issues – EPRI and its Water Research Center (WRC) perform this function in the United States, and the IEACCC does the same on a global level.
Group 3: Leader – Mr Scott Smouse, U.S. Department of Energy	
Findings	• Most workshop attendees were unaware of APEC EWG 08/2014 A report, so it has not been adequately publicized. This report and recent relevant reports by IEACCC, such as the upcoming effluent standards study should be distributed to attendees. • Need a decision support tool for water allocation between different uses. Try to work with utilities or other organizations to develop this. • Need standards to guide utility technology procurement decisions.
Group 4: Leader – Dr Vincent Tidwell, U.S. Department of Energy	
Findings	• Investment in water conservation technologies is already happening – testing is happening at WRC. • Water has always been an important issue in the western part of the United States, but in the east it is still more of a longtime strategic move. • Regulation greatly impacts incentive for utilities to invest in water conservation technologies. No one wants to be first to invest in new technology. Support is needed with commercializing technology. Also, plant managers often do not conduct water monitoring, so they don't have good data on water use. • Each economy has different needs, so it is hard to integrate technology • Coal extraction uses a lot of water – could be reused.

5.7 Session 7: Policy making, implementation and International cooperation on water-energy nexus

In Session 7, government officials and policy experts discussed policy measures, frameworks, and international cooperation efforts on the water-energy nexus,

integration of energy and water policymaking, promotion of technological innovation, and international cooperation on clean coal technology and research.

Figure 8: Session 7 presentation

Source: Washington CORE

Moderator: Mr Chris Wood
Senior Research Analyst, Washington CORE

1. **Water and Energy: Technology, Policy and Regulation**

Speaker: Mr Scott Smouse
Senior Advisor to Deputy Assistant Secretary, Office of Clean Coal and Carbon Management/Office of Fossil Energy, U.S. Department of Energy & Chair, APEC Expert Group on Clean Fossil Energy

Bio:
*Please see Session 1 for bio.

Presentation overview:
Reviewing U.S. government efforts to address water-energy nexus issues, Mr Smouse said that the U.S. Department of Energy's 2017 Quadrennial Energy Review recommended launching an electricity-related Energy-Water Nexus Policy Partnership with Federal, state, and local partners to address nexus challenges affecting the electricity generation. In 2015 the U.S. EPA established effluent limitation guidelines (ELG) for limiting toxic metal discharges within steam electric power plants. Mr Smouse said that the limitation goals set by the ELG are very difficult for power plants to achieve, regardless of how much they invest in solutions. In September 2017 the EPA issued stay of certain ELG compliance deadlines for FGD wastewater and bottom ash technologies in response industry concerns, and new rulemaking is pending.

The U.S. Department of Energy Office of Clean Coal is working on water management R&D concerning:

- Process efficiency – It is important to reduce water needs for improved heat transfer technology and better thermal integration of power plant systems (particularly new plants that include carbon capture technologies).
- Water treatment - Developing advanced technologies to reuse power plant cooling water and associated waste heat and to investigate methods to recover water from power plant flue gas.
- Data collection, modeling, and analysis – Working to improve the quality and amount of data collected, conduct comprehensive modeling efforts of complex systems, and provide crosscutting analyses to help inform decision-makers and support policy development.

On the topic of international cooperation, the U.S.-CERC Water and Energy Technologies Consortium (CERC WET) is an important vehicle for bilateral U.S.-China cooperation on water technology R&D. The University of California at Berkeley leads the U.S. consortium, and the Research Institute of Petroleum Exploration & Development (RIPED) leads the Chinese consortium. The program was extended in 2015 to run through 2020. CERC is looking at a broad range of power plant issues, including water use reduction and water treatment management, and is soliciting input from U.S. members such as Duke Energy, General Electric, and the California Energy Commission; and Chinese members, such as Shenhua Group and the National Climate Centre.

2. Water Policy in Malaysia: The Water-Energy Nexus

Speaker: Mr Ahmad Rizal Khalit
Under Secretary, Water Services Industry Division, Ministry of Energy, Green Technology and Water of Malaysia

Bio:
Mr Khalit entered public service in 2000 with a first posting at the Ministry of Natural Resources and Environment in charge of the Forestry Development and Environmental Conservation Divisions. In 2009 he was promoted to Head of the Planning and Evaluation Division in the National Hydraulic Research Institute Malaysia, involved in the management of water resources research activities as well as other development affairs. From 2011-2014, he was a member of the Economic Planning Unit, in the Prime Minister's Department as Principal Assistant Director of the Water Economic and R&D Division. Since 2015, Mr Khalit serves as Under Secretary of the Water Services Industry Division at the Ministry of Energy, Green Technology and Water of Malaysia.

Presentation overview:
Water stress in Malaysia is low. 82.4% of water used is surface water, with groundwater making up only 1.5%.

The Ministry of Energy Green Technology and Water of Malaysia has been working on the water-energy nexus and water conservation efforts are being pursued based on a

coordinated water management strategy. Multiple ministries are responsible for water management. The government's current 5-year plan, which prioritizes sustainable use of energy and increasing efficiency of water services, is now under midterm review, and may change course afterward.

Malaysia has a green technology master plan, but this lacks clear commitments to implement water efficient technologies. Not enough progress has been made on wastewater recycling. Currently the wastewater is discharged into rivers, which is a very harmful situation. The plan is to get wastewater treatment started by 2018, including lower river water treatment - right now only water from the upper river is used.

Malaysia needs to reduce the cost and improve performance of water treatment in power plants. More attention is being paid now to reducing the amount of energy used in water treatment.

3. Water-Energy Nexus in Indonesia

Speaker: Mr Andi Novianto
Assistant to the Deputy Minister for Energy Management, Environment, and Natural Resources, Coordinating Ministry for Economic Affairs of the Republic of Indonesia

Bio:
Mr Novianto's work is focused on developing energy for human life, and making energy more efficient and cleaner for a better environment. His current tasks involve relations with several public and private institutions, local government, and bilateral and multilateral organizations, such as Asian Development Bank (ADB), World Bank (WB), Japan International Cooperation Agency (JICA), IEA, and APEC. He received a PhD from Tohoku University in Japan in 2001, majoring in Agriculture and Resource Economics.

Presentation overview:
Indonesia has a top-down approach to governance of water-energy nexus issues, from the national to regional to district governments.

Renewable energy makes up 12% of energy production in Indonesia. Reliance on coal is expected to drop from 55.6% to 50.4% over 2017 to 2026. Indonesia produces a lot of coal, and exports around 400 million tons to other economies, such as Malaysia. Indonesia want to improve the energy efficiency of coal-fired power generation, and increase renewable energy's share of total energy production to 23% by 2025.

Energy technology is very expensive. Japan, China, and ADB are helping Indonesia with technology development, and financing coal power plants.

4. Research Collaboration on Water Conservation in Coal-fired Power Plants

Speaker: Ms Anne Carpenter
Senior Author and Analyst, International Energy Agency Clean Coal Centre

Bio:
Ms Anne Carpenter has worked at the IEA Clean Coal Centre (IEACCC) for over 30 years, working on a number of projects. These include the emissions database, and over 20 reports on a variety of topics. Recent reports include low water FGD systems, water availability and policies for the coal power sector, potential water sources and water conservation in coal-fired power plants, and wastewater regulations and issues for coal-fired power plants. Ms Carpenter graduated from Leicester University with a Combined Studies degree in Chemistry, Geology and Archaeology, and received an MSc in Information Science at City University in London.

Presentation overview:
IEACCC works with many economies on water-energy nexus issues. Australia, Japan, Korea, the United States and other APEC members are IEA members. IEA is also collaborating with China, Russia and Thailand, and believes even more international collaboration is necessary to conduct technology development to address global water-energy nexus issues as water scarcity rises around the globe. Such collaboration can reduce development costs and time to market of solutions for lowering water use and consumption in thermal power plants.

The EU MATChING project, composed of organizations from six EU economies, is working to reduce freshwater use by 13% in thermal power plants. Meanwhile the United States is conducting research on dry cooling technologies through projects led by the U.S. Department of Energy and National Science Foundation/EPRI. Some economies are now mandating dry cooling.

More development is needed for technology solutions, such as ZLD, to reduce energy consumption and lower the cost of wastewater treatment.

Q&A:
- The moderator asked the panel what they would suggest as a model for effective international cooperation efforts. Ms Carpenter said that the U.S.-China CERC-WET cooperation program is working well. Mr Smouse said that some successful aspects of this program include the funding approach - through which industry must match government funding – and a technology management plan that has helped with intellectual property (IP) concerns, at least in the early stages of R&D.
- The moderator asked Mr Khalit how Malaysia plans to work toward integration of energy and water policymaking. Mr Khalit said that the Malaysian government has just recently begun to consider the water-energy nexus, so it is still at a very early stage. So far, the government has been mostly concerned with drinking water, but is now taking an interest in water use in coal-fired power plants and would be interested in international cooperation in the future.
- Mr Novianto suggested working with international development organizations such as the ADB to fund CCS R&D and infrastructure development.
- DrMinchener seconded the suggestion that cooperation should be sought with

international development organizations, saying that he has worked with the ADB on projects in China before.

- Mr Collins asked Mr Khalit if biosolids from water treatment are used in Malaysia to produce energy to offset the energy used for treatment. Mr Khalit said there is currently a pilot project that has had positive results, and it remains to be seen if a larger effort is feasible. Mr Collins said there are some case studies on this practice in California that he could share.

5.8 Session 8: Panel Discussion: Preliminary findings and future directions

In Session 8, preliminary findings of the workshop were reviewed by a panel of experts in coal water-energy nexus topics, and suggestions made for APEC water-energy nexus priorities and possible future EGCFE activities.

Figure 9: Session 8 presentation

Source: Washington CORE

1. **APEC Water-Energy Nexus Expert Workshop – Key Findings from Workshop Discussions and Next Steps**

Speaker: Ms Nanako Hisamichi
Project Manager, Washington CORE

Bio:
Ms Hisamichi focuses on energy and environment policy research and industry trends, in Asia, North America, and Europe. She provides consulting services and in-depth analysis to assist government, utility, and R&D organizations with the development of policy and business strategies. She has recently completed a project to analyze the market and the state of R&D for carbon capture technologies in APEC economies and

Europe. Ms Hisamichi earned a B.A. in Business Administration, with a concentration in International Business and a minor in sociology, from Washington State University in Washington, U.S.

Presentation overview:
Ms Hisamichi reviewed the preliminary findings on common water-energy nexus challenges, priorities, and best practices emphasized by speakers and participants during the workshop. These findings were divided amongst the event's three major themes of technology development and implementation, policy frameworks, and international cooperation.

A. Water conservation technologies for coal-fired power plants

1. Key challenges

a. "One size does not fit all" when it comes to technology solutions for water-energy nexus issues in APEC economies. Each economy/region/site has specific needs. This creates much complexity as it requires customized technology solutions. For example, each economy has different circumstances in terms of water scarcity, energy mix, climate, and regulatory/economic constraints. Even within economies, there may be differences in technology needs between existing and new power plants, the former of which may be constrained by current systems and infrastructure.

b. Economies and utilities face difficulties with selecting the right technology solutions for their needs. Each solution comes with different sets of pros and cons that need to be carefully evaluated. In some cases, it is difficult to discern which solution represents the best available technology, or best handles the tradeoff between efficiency and water conservation. For example, the tradeoff between energy efficiency and water conservation was discussed for dry cooling technology, particularly on hot summer months. The issue of potential increase in water usage for implementing CCS technologies was also identified.

c. The high costs of implementing water conservation technologies restrict adoption by utilities. Many R&D organizations, such as NETL, EPRI, and NEDO, are developing state of the art technologies but these solutions might not always be economically feasible for APEC economies. In many cases, utility investors are wary of large investments that don't contribute to profits or fulfilling current regulatory obligations.

2. Potential solutions

a. Development of decision making tools (such as modeling) could help key decision makers to assess the impact of water conservation as well as to potentially identify suitable technology solutions. In the case of the United States, Sandia National Laboratory, as well as CMU, are developing assessment tools, which enables the integration of water resource management in power generation planning.

b. Industry collaboration for knowledge sharing on best practices and lessons learned on water conservation efforts and accelerating commercialization of innovative technologies (EPRI/WRC) would help to increase understanding and availability of technology solutions. For example, APEC economies in particularly dry region can reference South African utility company, Eskom's research and operational experience with dry cooling technology. Also, Duke Energy's experience in utilizing municipal wastewater to reduce the usage of ground water for cooling presents a useful case study on the benefit and challenges associated with the technologies as well as the cost-sharing mechanism with the local partners.

c. Conduct techno-economic analysis from earlier phase of the technology development to make sure technologies being developed are financially feasible solutions for utilities in the APEC economies.

d. Identify potential early adopters for water conservation technologies: Non-profit utilities, such as rural electric cooperatives in the United States, may be a good target for early implementation of technology solutions. As the owners of cooperatives are members of the local community served by the cooperative, it is more likely to obtain consensus among them on technology investment than among stockholders focused only on profits.

e. An R&D prize competition program, such as NRG COSIA Carbon X-PRIZE, to promote innovative technology solutions., sponsored by the private sector or/and government could help accelerate the development of water conservation technologies for APEC economies. NRG COSIA Carbon XPRIZE is a US$20 million R&D competition supported by industry partners to promote the development of innovative CO2 conversion technologies.

B. Effective policy making to address water-energy nexus issues

1. Key challenges

a. There is a lack of integrated policy making and government coordination to manage water usage in power generation sector at local and national level.

b. There is a lack of regulatory incentives for utilities to work on water-energy nexus. It was observed that in the United States, the priorities of utilities are to provide electricity in a reliable and cost-efficient manner to meet regulatory requirements and shareholder earning expectations. Water conservation is not a must.

c. There is low awareness of water-energy nexus issues at the high level of government. This is exacerbated by the fact that many power plants do not closely monitor water use so data on the scope of water-energy nexus

challenges may be incomplete.

2. Potential solutions

a. Establish a coordinating body at the national level to facilitate water-energy nexus efforts.

   For example, Malaysia has been working on water management and energy under the same roof through Ministry of Energy Green Technology and Water of Malaysia and actions for water conservation are being implemented based on the water management strategy through coordinated approach.

   It is important to have the key stakeholders' involvement from early phases on new initiatives on water conservation to provide the opportunity for the industry to provide feedback on the expected impact and feasibility of implementing any new regulatory requirements. The case of United States regarding the effluent limitations guidelines and standards (ELG) demonstrated the importance of having industry's involvement on the issue. U.S. EPA announced the agency's decision to postpone the implementation of ELG final rule from original compliance date of November 1, 2018 to November 1, 2020, due to the petitions from industry stakeholders to reconsider the rule, which is estimated to cost US$480 million per year for regulatory compliance.[1].

b. Implement regulatory requirements and/or government subsidies (e.g., tax credit) to encourage water conservation efforts

c. Develop standards/guidelines for water conservation efforts at coal-fired power plants to optimize efforts. For example, the definition of BAT (best available technology) varies among APEC economies. Information should be shared to communicate the implication of BAT for water conservation in APEC economies. IEACCC will be releasing a relevant report on this issue.

d. Introduce framework to address water scarcity issues during the early phase of infrastructure planning. For example, Sandia National Laboratories collaborated with NETL and the water managers from Western Electricity Coordinating Council (WECC) to consider water resource during the planning phase for the transmission expansion project in ERCOT region. The project resulted in the creation of integrated energy-water dataset and modeling tool that allow transmission project planners to assess the implication of water resource during energy infrastructure planning. In addition, utility companies in Viet Nam consider water resource and wastewater management during power plant design phase.

[1] "Pending Litigation & Rule Reconsideration." EPA. September 18, 2017. https://www.federalregister.gov/documents/2017/09/18/2017-19821/postponement-of-certain-compliance-dates-for-the-effluent-limitations-guidelines-and-standards-for

C. International cooperation for water-energy nexus for coal

1. Key challenges

a. Lack of awareness of water-energy nexus issues in the APEC region and of APEC's related activities.

b. Each economy faces a different degree of water scarcity risk. Some economies face immediate, severe problems while others do not. APEC regionwide proactive action is necessary despite differences in urgency.

c. IP rights can be an obstacle to information sharing.

d. It is difficult to obtain funding to support R&D for coal-related technologies from development organizations, such as World Bank and Asian Development Bank.

2. Potential solutions

a. Establish/strengthen the roles of existing water-energy nexus expert organization, such as EGCFE, IEACCC, and EPRI to be contact points to disseminate resources to enhance awareness of issues concerning the water usage in coal-fired power generation among key decision makers.

b. Establish training programs to foster technical capabilities to conserve water

c. Encourage cross-cutting research at the international level (such as the U.S.-China bilateral cooperation on the CERC-WET initiative, and collaborative projects by EPRI and the EU.

d. Develop technology management plan for IP rights. For example, CERC-WET received high level buy-in, therefore enabling it to agree on a technology management plan for IP.

e. Establish an international working group with interested government authorities and industry representatives. It is important to define the role and purpose of the partnership.

2. Panel Discussion

Panelists:

- **Mr Ahmad Rosly Abbas, Tenaga Nasional Berhad**
- **Mr Andi Novianto, Coordinating Ministry for Economic Affairs of the Republic of Indonesia**
- **Mr Jeffery Preece, Electric Power Research Institute**
- **Ms Patricia Rawls, National Energy Technology Laboratory, U.S. Department of Energy**
- **Dr Andrew Minchener OBE, International Energy Agency Clean Coal Centre**

Moderator: Ms Nanako Hisamichi
The panel discussion was held to review preliminary findings and suggest possible future directions for EGCFE. After reviewing key findings from the two-day workshop, the moderator asked the panelists as well as audience for additional insights on the key challenges and potential solutions as well as suggestions for EGCFE to consider undertaking to work toward mutually beneficial solutions for the APEC economies.

Overview of discussions:

1. **The panel was asked to share their perspectives on the preliminary findings and suggest additional priorities**

- Dr Minchener said it would be helpful to have collaboration amongst economies on effective polices and regulations, which differ by economy according to the local water stress level and other factors. Economies should be willing to share information on successful polices and how other economies could implement them. Maybe a policy discussion workshop would be useful way to have this dialogue.

- Mr Novianto suggested that the APEC EWG should pay special attention to the water-energy nexus, either through EGCFE or another working group. Along the lines of Dr Minchener's idea, he said that developing economies can learn from developed economies (like the United States) a model on water-energy nexus. APEC could approach funding originations, such as the World Bank or the Asian Development Bank, to support water-energy nexus policy development.

- Ms Rawls suggested bilateral agreements for technology development, matching economies with similar issues and needs. She also supported holding more meetings like this workshop.

- Mr Abbas said a committee should be created to set an agenda for priorities on developing water conservation and integrated governance. He emphasized that action must be taken before water demand outstrips supply.

- Mr Preece also supported continuing collaboration activates activities to get a consensus, and suggested bringing in financial institutions as well. As an example of financial institution interest, he mentioned a World Bank project helping to reduce the cost of cooling water in South Africa. He suggested beginning collaboration with small achievable goals. The first step could be knowledge sharing - economies could share important reports and make sure water-energy nexus economic drivers in all economies are clearly defined. Eventually the group could work toward technical metrics.

- Dr Daal suggested that water-vapor capture from flue gases can make power plants into net water producers, and this could provide revenue to incentivize utilities to invest in water conservation.

- Mr Preece said the water vapor idea is attractive and EPRI has considered this kind of technology, but the current U.S. regulatory environment focuses research

on wastewater treatment, so there wouldn't be much support from utilities. Mr Preece said events like this workshop are very helpful because it is possible to learn about technology applications in other economies that could be useful in the future.

- Ms Rawls also said the idea is attractive but very high risk. Maybe better to look at incremental improvements of more proven technologies for now.

- Mr Sam Najim added that it would be helpful to have data on water costs around the world to better understand conversations about which technologies are feasible.

2. The moderator asked what next steps for APEC the panelists would suggest based on this workshop's findings

- Mr Novianto said there is a need for a model for water regulations and technology adoption that other economies can refer to.

- Mr Preece suggested that South Africa and China should be involved in future collaborative activities given their deep interest and experience with the subject. He suggested having more workshops more frequently to maintain knowledge sharing.

- Mr Abbas said that economies should be given the chance to suggest content for the next workshop based on their priorities.

- Agreeing with Mr Preece, Dr Minchener mentioned that the China National Energy Administration is very serious about the water-energy nexus and should be included in further meetings.

- Mr Clark Harrison observed that all economies are "developing" the policy/regulatory water-energy nexus issue. He suggested that if an economy, such as Malaysia, was willing to share its experience as it implements a new policy/governance approach, APEC could create a committee to support an economy on provide guidance for this effort.

- Dr Zhai suggested APEC establish a database to share technology water costs and performance.

- Mr Khalit suggested creating a database to share information about much water is used by the energy sector in APEC economies, for comparative purposes.

- Mr Collins and Dr Zhai suggested that more effort should be placed on making water vapor capture from flue gas cost effective.

- Mr Ball said there is a need to calculate the levelized cost of water (and levelized social cost). Need this to justify regulations and investment in better technology for water conservation

- Mr Collins suggested water be considered as a source for hydrogen for industry applications.

3. Mr Smouse closing comments:

- APEC reports need to be promoted and distributed more widely
- There is an opportunity to create a Water Energy Nexus Taskforce – will discuss with US EWG representative
- APEC could conduct study to collect data on cost of implementing technologies
- APEC could develop a worldwide decision support tool with support from WB, ADB
- X Prize contest could be a possibility to help develop technology
- Environmental NGOs supporting CCS might also support water-energy nexus projects.

6 Field Trip: Water Research Center

On the afternoon of November 1st, workshop attendees participated in a tour of the nearby Water Research Center (WRC), established by EPRI and Southern Company at Georgia Power's coal-fired Plant Bowen.

The WRC provides utilities, research organizations, and vendors with access to scalable testing infrastructure, treatable water from an operating power plant, monitoring and analysis facilities, and specialist staff to investigate advanced water management technologies and holistically address issues related to water consumption, discharge quality and management of solids residues.

Southern Company initiated the concept for the WRC and requested that EPRI assemble and manage a consortium of electric generation companies to help support and guide development of the center. Georgia Power offered Plant Bowen near Cartersville, Georgia, as a host site and provided approximately 60 percent of the total funding, plus substantial plant staff time. EPRI assembled a consortium of 13 other power companies to participate in development of the WRC. The creation of the WRC contributed to the successful launch of EPRI's new Water Management Technology Program (P185) by supplying key R&D needs and ideas and establishing a facility that reduces the program's costs for testing new technologies. To date, research conducted at the WRC has yielded useful results in several areas and more than 30 individual technologies have been involved in projects at the facility.

During the WRC tour, led by Mr Jeffery Preece of EPRI, the attendees observed the research lab and highlights from past projects that have been conducted at the site, as well as learned about currently operating projects, such as two membrane treatment systems, a thermal evaporation/concentration system, a physical/chemical treatment system, a biological treatment system, and a solids fixation/encapsulation system. Attendee interest in these projects were very keen, and a variety of technical questions were discussed with the WRC staff.

Figure 10: Georgia Power's Plant Bowen - site of the WRC

Source: Washington CORE

7 Recommendations for follow-on APEC water-energy nexus activities

Based on the preliminary workshop findings presented in Session 8 and the subsequent feedback from the expert panel and other attendees, the following steps are recommended for consideration by the EGCFE and EWG to accelerate progress on effective responses to water-energy nexus challenges:

1. Develop a decision support tool (or model) to help key decision makers to assess the impact of water conservation as well as to potentially identify suitable technology solutions. It was proposed by Dr Zhai of CMU that APEC develop this tool for evaluating/prioritizing water-saving technologies and alternative water supplies, not just for coal-fired power generation, but also natural gas, nuclear, and other forms of power. This would include integrating power generation with municipal and industrial water treatment and supply. Mr Preece of EPRI said that they have started work on a similar concept. There is an opportunity for collaboration. Other attendees suggested that we approach the ADB, environmental foundations, and other similar organizations for funding.

2. Hold a regular meeting or workshop to continue knowledge sharing on water-energy nexus. The workshop participants highly praised the diverse mix of critical stakeholders and engaging discussions and encouraged holding the workshops of similar scale in the future to facilitate active discussion. Multiple participants have requested opportunities to discuss water-energy nexus issues, especially water conservation technologies in depth. For future meetings/workshops, it is recommended to provide a combination of sessions to introduce the general concept and issue as well as more in-depth technical sessions on technologies R&D, policy measures, and utility operational experiences.

   It may be advantageous to include additional economies with deep interest and knowledge of the subject, even some outside of APEC. For example, the South African utility company, Eskom could share their experiences with advanced implementations of dry cooling technologies, The EU consortium, MATChING, led by Enel, could share information from its multiple R&D and demonstration projects for material technologies for performance improvement of cooling systems in power plants.

3. Promote industry collaboration on technology development and testing to reduce costs of existing technologies and accelerate commercialization of innovative technologies. A technology development prize, such as the X Prize in the United States, could be one way to accelerate technology development.

4. Key R&D focus areas identified during the workshop for further study:

   a. Technologies to extract and reuse water vapor from flue gas as a way of providing a financial incentive to utilities to adopt conservation

technologies
   b. Alternative to wet and dry cooling technology, such as hybrid cooling, indirect cooling technologies
   c. Technologies to reduce energy consumption and lower costs of wastewater treatment

5. Establish a cross-cutting water-energy nexus steering committee or task force to set priorities for further discussion, policy measures, and research. The committee should include representatives from government, industry, and academia to promote consensus from key stakeholders on approaches to address water-energy nexus as well as to encourage collaborative efforts. Such a committee could also help to put economies with similar needs in touch so they could learn from each other on a bilateral basis. The committee could also help an economy as a test case to implement technologies or governance reforms.

6. Create a knowledge sharing database with information from APEC and other economies on local water costs, volume of water used by energy sector, and water conservation technology acquisition and implementation costs and performance. The database should encourage more holistic approaches to address water-nexus issues. Understanding the water scarcity risk and associated cost can potentially incentivize utilities to engage in water conservation efforts.

7. Development of APEC guidelines for water conservation efforts at coal-fired power plants to optimize efforts. These guidelines can provide APEC economies with the general concepts and strategies to address water-energy nexus issues. Some of the suggested topics for the guidelines include water conservation technologies, water management tools (monitoring and assessment) as well as how to model water resource availability and needs during the planning phase for energy infrastructure.