Crosscutting Research Program: Power Plant Water Usage

Water Management Program Workshop

Barbara Carney
Federal Project Manager
Enabling Technologies and Partnerships
Competing Water Demands

U.S. Freshwater Withdrawal\(^1\)

- Thermoelectric, 38%
- Public Supply, 14%
- Domestic, 1%
- Irrigation, 38%
- Livestock, 1%
- Aquaculture, 3%
- Industrial, 5%
- Mining, 1%

U.S. Freshwater Consumption\(^2\)

- Thermoelectric, 3%
- Commercial, 1%
- Domestic, 6%
- Irrigation, 81%
- Livestock, 3%
- Industrial, 3%
- Mining, 1%

2010 Thermoelectric freshwater requirements:
- Withdrawal: ~ 117 BGD
- Consumption: ~ 4 BGD

Sources:
\(^1\)USGS, Estimated Use of Water in the United States in 2010, USGS Circular 1405, 2014
What is Thermo-Electric Power Generation?

• Converting thermal energy to electrical energy
• Chemical-to-Mechanical-to-Electrical energy
• Use a hot fluid to SPIN a TURBINE
• Turbine spins a generator--makes electricity
• Heat source--coal, natural gas, synthetic gas, nuclear, solar, geothermal
In 2015, the United States generated about 4 trillion kilowatthours of electricity. About 67% of the electricity generated was from fossil fuels (coal, natural gas, and petroleum).

Major energy sources and percent share of total U.S. electricity generation in 2015:

- Coal = 33%
- Natural gas = 33%
- Nuclear = 20%
- Hydropower = 6%
- Other renewables = 7%
  - Biomass = 1.6%
  - Geothermal = 0.4%
  - Solar = 0.6%
  - Wind = 4.7%
- Petroleum = 1%
- Other gases = <1%

1 Preliminary data; based on generation by utility-scale facilities.

Thermoelectric Electricity Generation 89%
Rankine (Steam) Cycle

- **Heat In**
- **Work Out**
- **Generator**
- **Turbine**
- **Boiler**
- **Steam Condenser**
- **Pump**

**Closed cycle**

**Fuel:** Pulverized Coal (PC)
- Nuclear, Solar

**Efficiency:** 35%
Brayton (Joule) Cycle - Gas Turbine

Fuel: natural gas or synthetic gas (coal gasification)

Open cycle

Compressor

Turbine

Fuel

Combustion

Work Out

Fresh Air

Exhaust Gas

To Steam Cycle for Combined Cycle (59% efficient)
2x1 Natural Gas Combined Cycle (NGCC)

2 gas turbines, 2 HRSGs (heat recovery steam generators), 1 steam turbine

Efficiency
HHV (Higher Heating Value) 54%
LHV (Lower Heating Value) 60%
Water usually gets rid of Waste Heat

**Once-through**
High use, low consumption

**Recirculating**
Natural draft or Forced air (fan)
Lower use, high consumption

**Dry cooling**
High capital cost, high backpressure (energy penalty)

Low pressure, low temperature steam

Heat Out

Steam Condenser

Low pressure water
## Cooling Systems

### Cooling system types by primary energy source (2012)

<table>
<thead>
<tr>
<th>Primary energy source</th>
<th>Once-through</th>
<th>Recirculating</th>
<th>Dry cooling</th>
<th>Wet &amp; dry hybrid cooling</th>
<th>Total cooling systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>coal</td>
<td>398</td>
<td>368</td>
<td>4</td>
<td>1</td>
<td>771</td>
</tr>
<tr>
<td>natural gas</td>
<td>197</td>
<td>422</td>
<td>51</td>
<td>4</td>
<td>674</td>
</tr>
<tr>
<td>nuclear</td>
<td>50</td>
<td>44</td>
<td>0</td>
<td>0</td>
<td>94</td>
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<tr>
<td>other</td>
<td>74</td>
<td>41</td>
<td>1</td>
<td>0</td>
<td>116</td>
</tr>
<tr>
<td>total</td>
<td>719</td>
<td>875</td>
<td>56</td>
<td>5</td>
<td>1,655</td>
</tr>
</tbody>
</table>

**Source:** U.S. Energy Information Administration, Form EIA-860, Annual Electric Generator Report

Recirculating 53%
Once-through 43%
Dry 3%
US Water Use Estimate 2010
Thermoelectric Power

1,290 thermoelectric power plants; 3,130,000 gWh (gigawatt-hours)

161 billion gallons per day (bgd) withdrawn; >99% surface water withdrawal, 73% of surface water freshwater sources, 44 bgd saline water withdrawn, 97% of saline withdrawal surface water

19 gallons of water were used to produce 1 kWh (kilowatt-hour) of electricity in 2010*

<table>
<thead>
<tr>
<th>Light Bulbs</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent</td>
<td>100 W</td>
<td>1.9 gallons/hour</td>
</tr>
<tr>
<td>Halogen</td>
<td>72 W</td>
<td>1.4 gallons/hour</td>
</tr>
<tr>
<td>Compact Fluorescent</td>
<td>26 W</td>
<td>0.49 gallons/hour</td>
</tr>
<tr>
<td>Light emitting diode (LED)</td>
<td>16-22 W</td>
<td>0.36 gallons/hour</td>
</tr>
</tbody>
</table>

Central air conditioner 3500 W uses 66 gallons/hour
Vacuum cleaner 1200 W uses 23 gallons/hour

*USGS, Estimated Use of Water in the United States in 2010, USGS Circular 1405, 2014
Thermoelectric Power Plant Water Consumption

Plants equipped with wet re-circulating cooling towers, from “Water Requirements for Existing and Emerging Thermoelectric Plant Technologies”

Air Conditioner
Consumes
NGCC 0.7 gal/hr
Nuclear 2.5 gal/hr
Uses
66 gal/hr
Rankine Cycle Efficiency - Thermodynamics

- Isentropic process -- constant entropy -- pump and turbine
- Isothermal expansion -- boiler $T_H$
- Isothermal compression -- condenser $T_C$

$$\eta = \frac{W_{turbine}}{Q_{in}}$$

1-2 feedwater pump
2-3 boiler
3-4 turbine
4-1 condenser
**Low Temperature Side Power Plant Steam Condenser**

Saturated Steam
100 °F  0.95 psia
120 °F  1.2 psia
140 °F  2.8 psia
Thermo-electric Power Generation
NETL Power Plant Water Program - Commercial Successes

The average US Coal Plant is 33% efficient at generating electricity. The other 67% of heat from coal is waste heat, which is released from boiler in flue gas and dissipated to water from steam condenser.

SPX ClearSky-condenses average of 19% evaporated water

DryFining-uses waste heat from flue gas and condenser to dry coal prior to combustion, 5.8% efficiency improvement.

Spiritwood, Great River Energy, North Dakota, Combined Heat and Power for bio-refinery, 60% efficiency.
ClearSky Plume Abatement Cooling Tower

SPX Cooling Technologies has more than 80 plume-abatement installations worldwide, and the story continues based on technology funded in part by the U.S. Department of Energy as well as hundreds of thousands of hours of real-world operation.

- **Lower Installation Cost**
  Less piping means less investment than conventional systems

- **Greater Design Flexibility**
  Back-to-back design allows for easy installation, including retrofits

- **Reduced Maintenance Costs**
  Unique patented design and materials means less need for maintenance

- **Reduced Auxiliary Power Usage**
  Driven by pump head, ClearSky towers can effectively reduce auxiliary power usage when compared to coil type hybrid towers.
Constructed at San Juan Generating Station, NM
San Juan Generating Station, New Mexico

• 2/09/09 Temperature 35 deg F, Relative Humidity 50%
Second project—Redesign to make smaller
Commercial 12 Cell Installation

ClearSky Plume Abatement Tower Construction Complete
Hess Newark Energy Center in New Jersey
• Low-rank, high-moisture coals constitute about 50% of the U.S. and world coal reserves.

• For high-moisture coals burned in utility boilers, 7% of the fuel heat input used to evaporate and superheat fuel moisture that leaves with the flue gas (mostly latent heat of evaporation).

• Higher fuel and flue gas flow rates, higher auxiliary power use, higher net unit heat rate, and higher mill, coal pipe, and burner maintenance compared to bituminous coals.

• Coal-drying thermal processes mechanically complex or require costly primary energy or steam to remove moisture from the coal—main barrier to industry acceptance.

• DryFining – fluidized bed dryer (FBD) uses waste heat to decrease moisture.
DryFining: Path to Commercialization

“Use of Coal Drying to Reduce Water Consumed in Pulverized Coal Power Plants”: DE-FC26-03NT41729, March, 2006


• DryFining has been in continuous commercial operation at Coal Creek Station for over four years, achieving availability higher than 95%, and not causing a single unit outage. The station net generation has also increased since implementing DryFining.

• SOx emissions were reduced by 44% to 46%, while NOx emissions were reduced by 24% to 25%.

• Average annual improvement in net unit heat rate for Unit 1 is 3.4%, Unit 2 is 5.8% (includes steam turbine upgrade).

• Station auxiliary power use by each unit has decreased 5 MW.

• Paid back $580,000 to U.S. taxpayers
Process Efficiency and Heat Utilization Projects (Began 2014)

Forward Osmosis (FO) Process Utilizing Low Grade Heat: Applications in Power Plants  Carnegie Mellon University

Simultaneous Waste Heat and Water Recovery from Power Plant Flue Gases  Institute of Gas Technology

The COHO – Utilizing Low-Grade Heat and Carbon Dioxide at Power Plants for Water Treatment  Porifera

Development of a Field Demonstration for Cost-Effective Low-Grade Heat Recovery and Use Technology Designed to Improve Efficiency and Reduce Water Usage Rates for a Coal-Fired Power Plant  Southern Company
Forward Osmosis (FO)

- FO is uniquely suited to concentrate high fouling waters that clog up other membranes.
- FO technologies can treat water up to 150,000 ppm of total dissolved solids—four times the maximum for conventional RO systems—and concentrate it to over 280,000 ppm.

Oasys Water’s forward osmosis technology is installed to treat flue gas desulfurization wastewater at the Changxing Power Plant in China.
Establish rigorous models of the temperature and heat duty of the draw solute recovery system integrated with power plant waste heat to determine FO feasibility.
Membrane distillation

Membrane distillation is a thermally driven separation enabled due to a phase change. A hydrophobic membrane creates a barrier for the liquid phase, allowing the vapor phase (e.g. water vapor) to pass through the membrane's pores. The driving force of the process is given by a partial vapor pressure difference commonly triggered by a temperature difference.
Simultaneous Waste Heat and Water Recovery from Power Plant Flue Gases

Institute of Gas Technology, Media and Process Technology, SmartBurn, Florida International University   DE-FC0024092

Transport Membrane Condenser (TMC)

*Media & Process Technology* ceramic nanoporous membrane to remove waste heat and water from flue gas.
Current Project Focus

- Greatly improve TMC water vapor transport flux and system efficiency, ready for high moisture content flue gases from future advanced power generation system, and evaluate membranes for low pH flue gas applications,

- Explore low cost TMC unit fabrication and control methods to reduce capital and installation costs.

TMC Field Demo for Coal Power Plant

Before TMC

After TMC

Eliminate plume of condensing water from stack
Development of a Field Demonstration for Cost-Effective Low-Grade Heat Recovery and Use Technology Designed to Improve Efficiency and Reduce Water Usage Rates for a Coal-Fired Power Plant

Southern Company Services, Inc., Electric Power Research Institute, AECOM (URS Group)  
DE-FE0024085
## Potential uses of low-grade heat

<table>
<thead>
<tr>
<th>Use</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler feedwater heating</td>
<td>Increase efficiency / capacity</td>
</tr>
<tr>
<td>Combustion air pre-heating</td>
<td>Increase efficiency / capacity</td>
</tr>
<tr>
<td>Cogeneration (e.g., district water heating)</td>
<td>Increase overall thermal efficiency</td>
</tr>
<tr>
<td>Convert heat to electricity</td>
<td>Increase unit output</td>
</tr>
<tr>
<td>CT or FGD wastewater treatment</td>
<td>Remove waste (e.g., total dissolvable solids [TDS]) to reduce makeup water and process thermal load / aux power</td>
</tr>
<tr>
<td>Flue gas or FGD exhaust water recovery</td>
<td>Reduce water consumption</td>
</tr>
<tr>
<td>Fuel drying</td>
<td>Increase boiler efficiency and reduce emissions</td>
</tr>
<tr>
<td>Refrigeration cycle</td>
<td>Increase unit efficiency</td>
</tr>
<tr>
<td>Water generation (e.g., desalination)</td>
<td>Cogeneration and sale / use opportunities</td>
</tr>
</tbody>
</table>

**Question:** Is boiler feedwater or combustion air pre-heating better for LTHR?
GTI’s Transport Membrane Condenser (TMC) captures water and heat

- Uses a nano-porous ceramic membrane to extract water vapor and its latent heat via capillary condensation from flue gas after the FGD
- Mineral-free water is created and passed back to the feedwater at 180°F or as cooling water makeup

Advantages
- Organization stated relatively low cost
- Can increase MW output
- Good operational performance
- Tested on coal flue gas

Disadvantages
- Works better on high-moisture flue gas
- May not be tolerant of high SOx levels
- Has not been tested at large scale
Ljungström improves boiler efficiency by increasing AH effectiveness

- Extends AH heat-transfer surface, increasing air temperatures
- Sulfuric acid condensation mitigated via SBS™ (sodium-based solution) injection upstream of the AH
- Reduces FGD water use due to reduced gas temperature and removal of acid gases via alkaline solution injection
- ESP removal improved due to reduced gas temperature and SO₃
- SCR operating temperature can be reduced due to reduced SO₃
Future Direction Discussion

Cooling Technology

Dry Cooling

Water Recovery-condense, membranes, desiccant

Water Treatment-condense, membranes (forward osmosis, membrane distillation)

Water sensors

Cogeneration-use recovered heat

Bottoming cycles, thermoelectrics, heat pipes