Crosscutting Research Program: Power Plant Water Usage

Water Management Program Workshop

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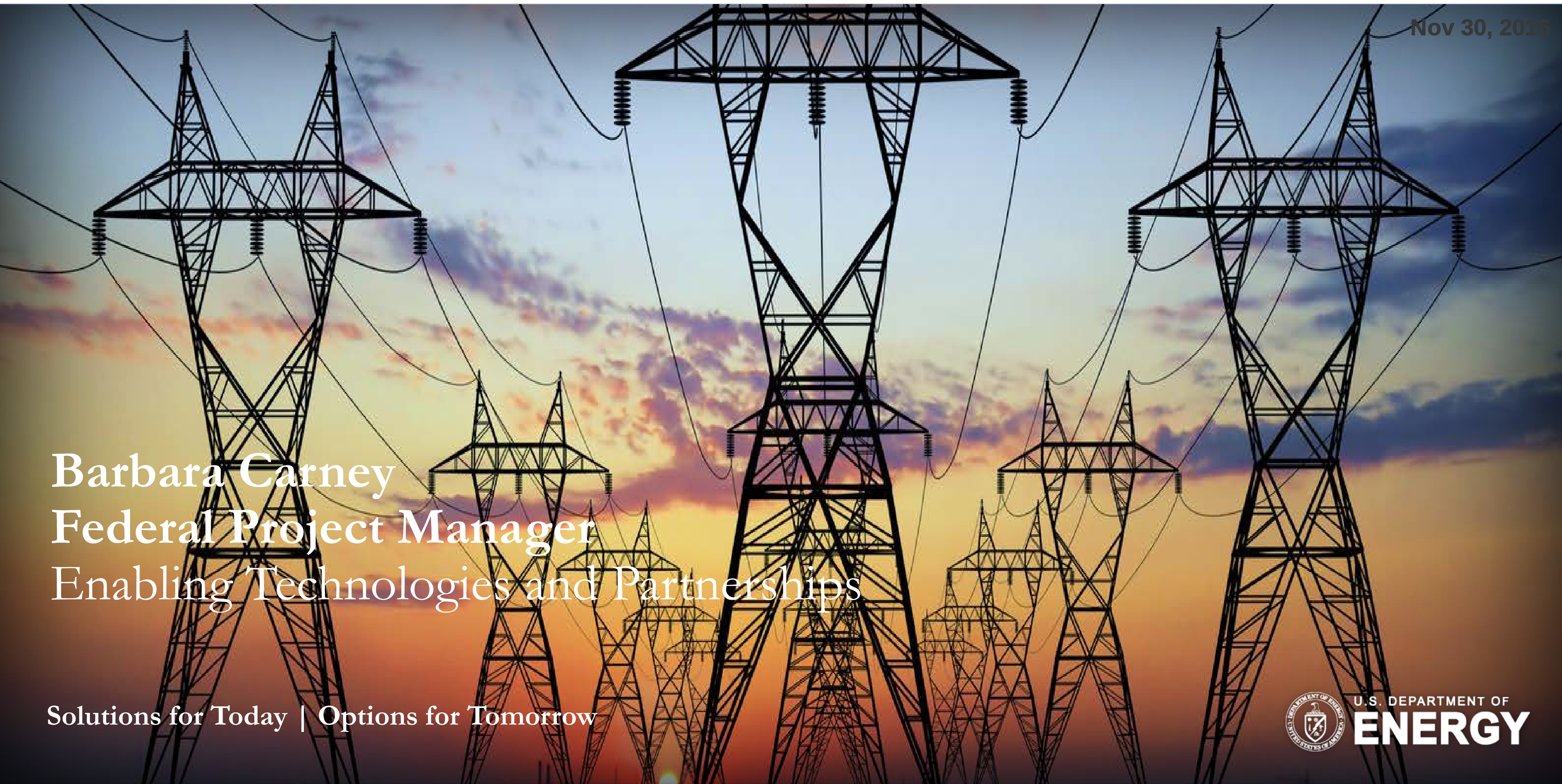


Nov 30, 2016

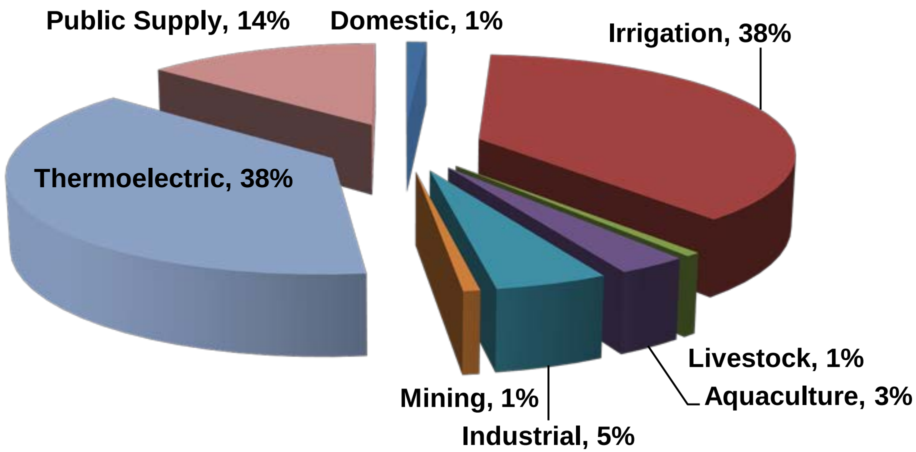
Barbara Carney
Federal Project Manager
Enabling Technologies and Partnerships

Solutions for Today | Options for Tomorrow

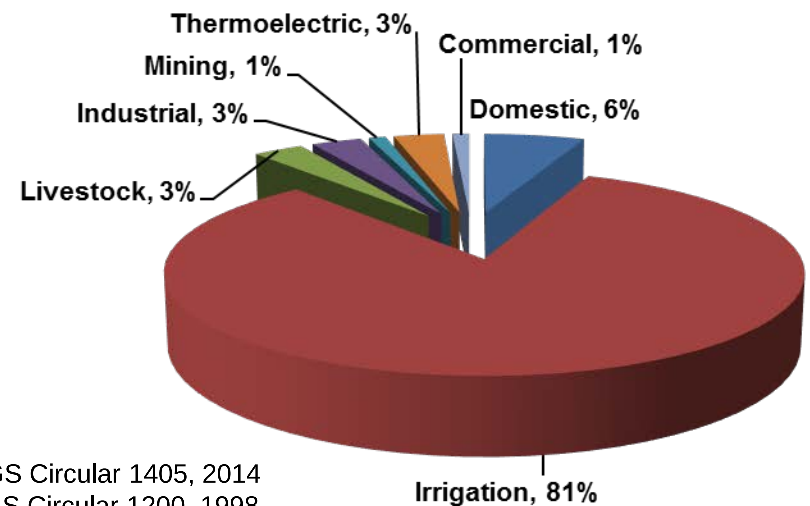
U.S. DEPARTMENT OF ENERGY

Competing Water Demands

U.S. Freshwater Withdrawal[1]



U.S. Freshwater Consumption[2]



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
[2]USGS, Estimated Use of Water in the United States in 1995, USGS Circular 1200, 1998

What *is* Thermo-Electric Power Generation?

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- 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

US Electricity Generation 2015

In 2015, the United States generated about 4 trillion kilowatthours of electricity.[1] About 67% of the electricity generated was from fossil fuels (coal, natural gas, and petroleum).

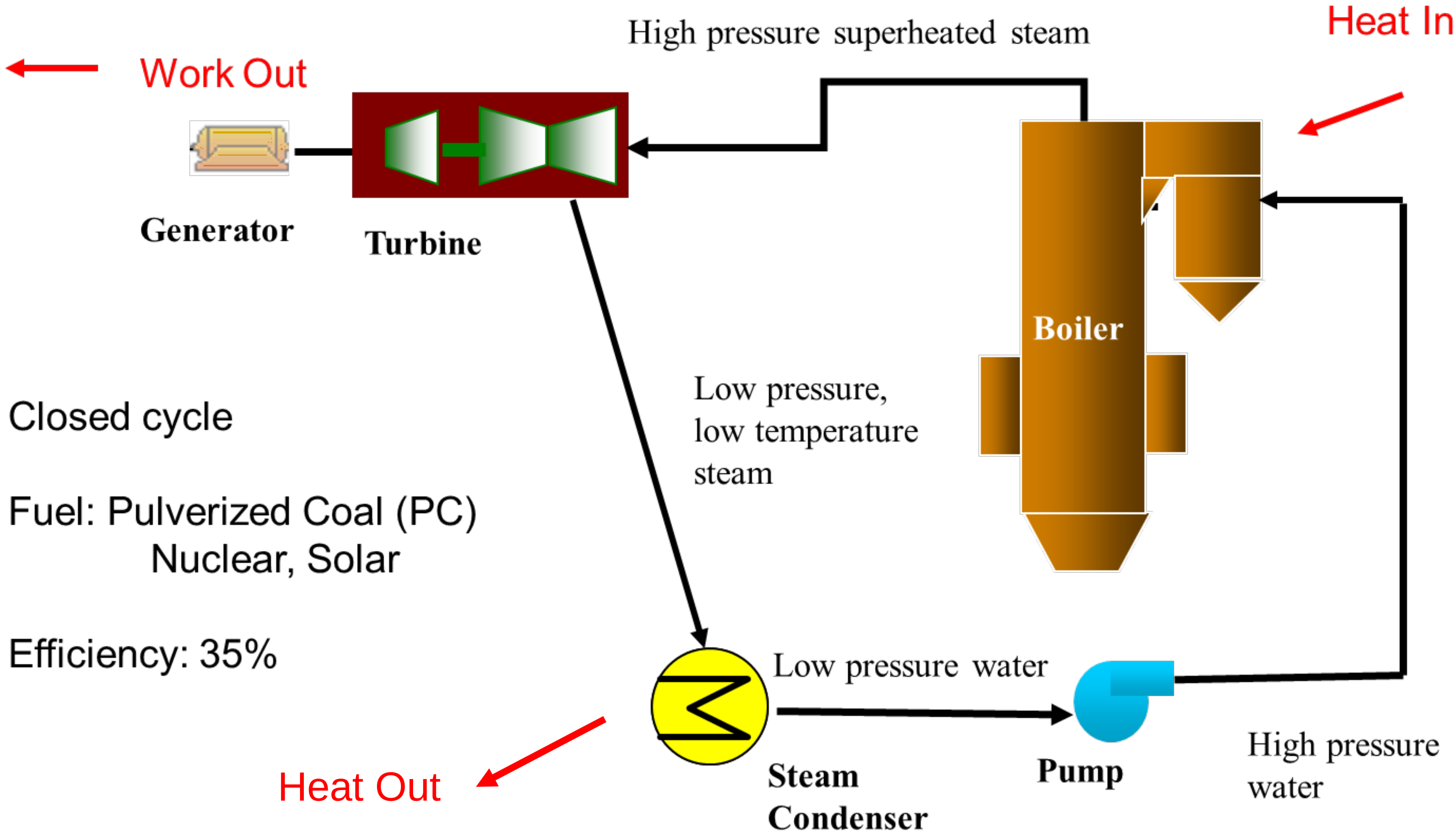
Major energy sources and percent share of total U.S. electricity generation in 2015:[1]

- 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

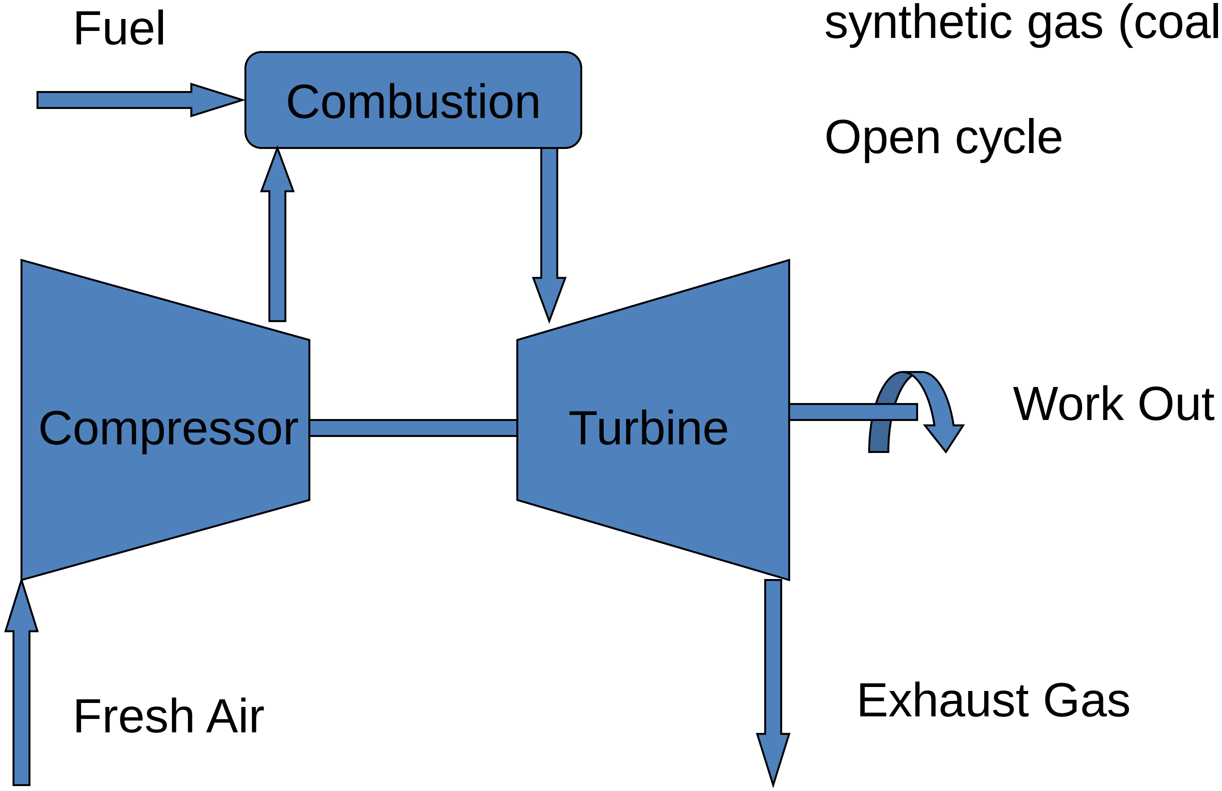


Closed cycle

Fuel: Pulverized Coal (PC)
Nuclear, Solar

Efficiency: 35%

Brayton (Joule) Cycle-Gas Turbine



Fuel: natural gas or
synthetic gas (coal gasification)

Open cycle

To Steam Cycle for Combined Cycle (59% efficient)

2x1 Natural Gas Combined Cycle (NGCC)

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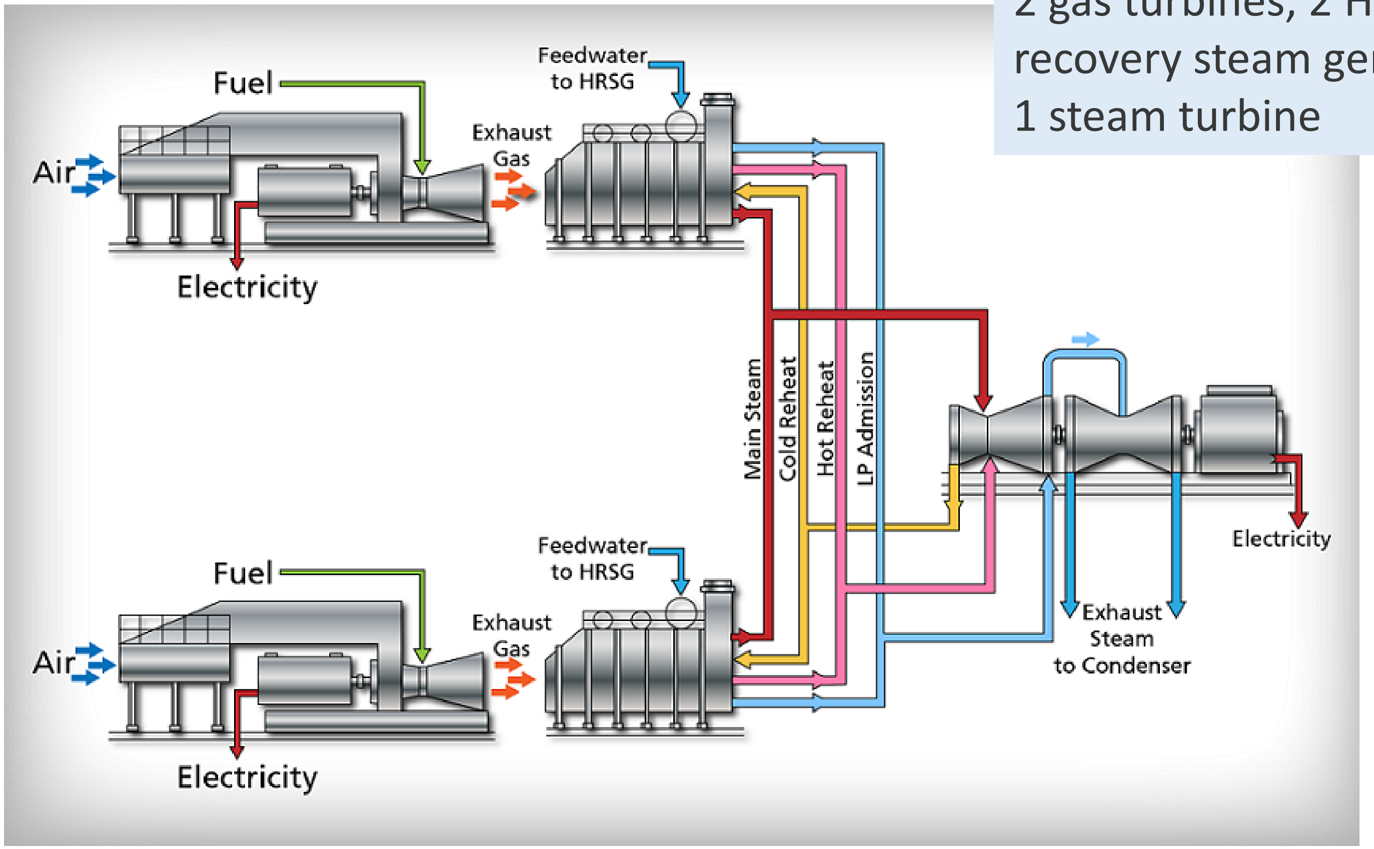
2 gas turbines, 2 HRSGs (heat recovery steam generators), 1 steam turbine



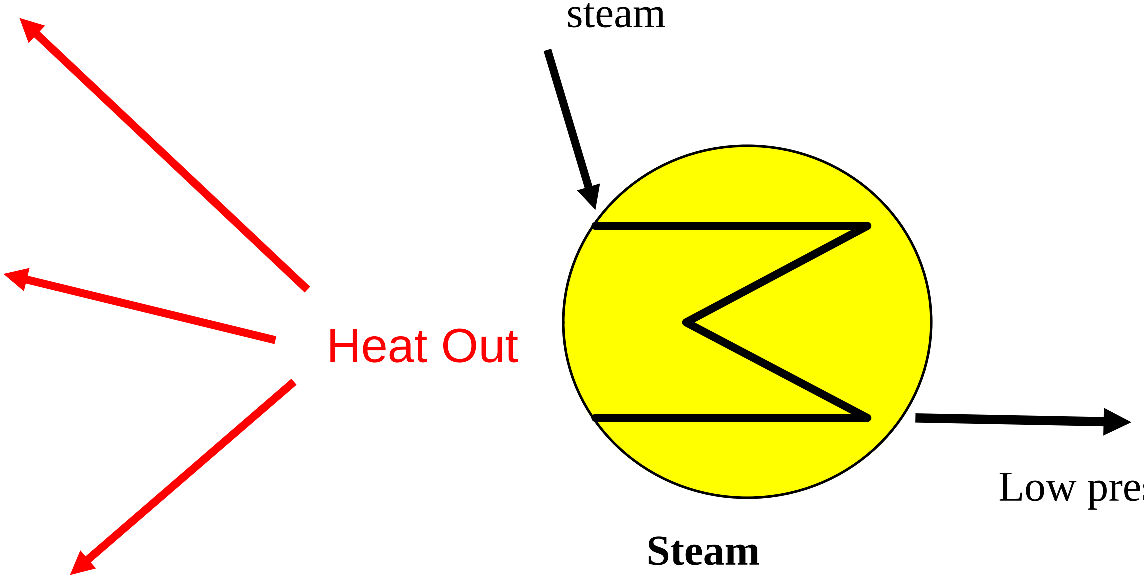
Efficiency
HHV (Higher Heating Value) 54%
LHV (Lower Heating Value) 60%

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)



Cooling Systems

Cooling system types by primary energy source (2012)

Primary energy source	Once-through	Recirculating	Dry cooling	Wet & dry hybrid cooling	Total cooling systems
coal	398	368	4	1	771
natural gas	197	422	51	4	674
nuclear	50	44	0	0	94
other	74	41	1	0	116
total	719	875	56	5	1,655

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

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

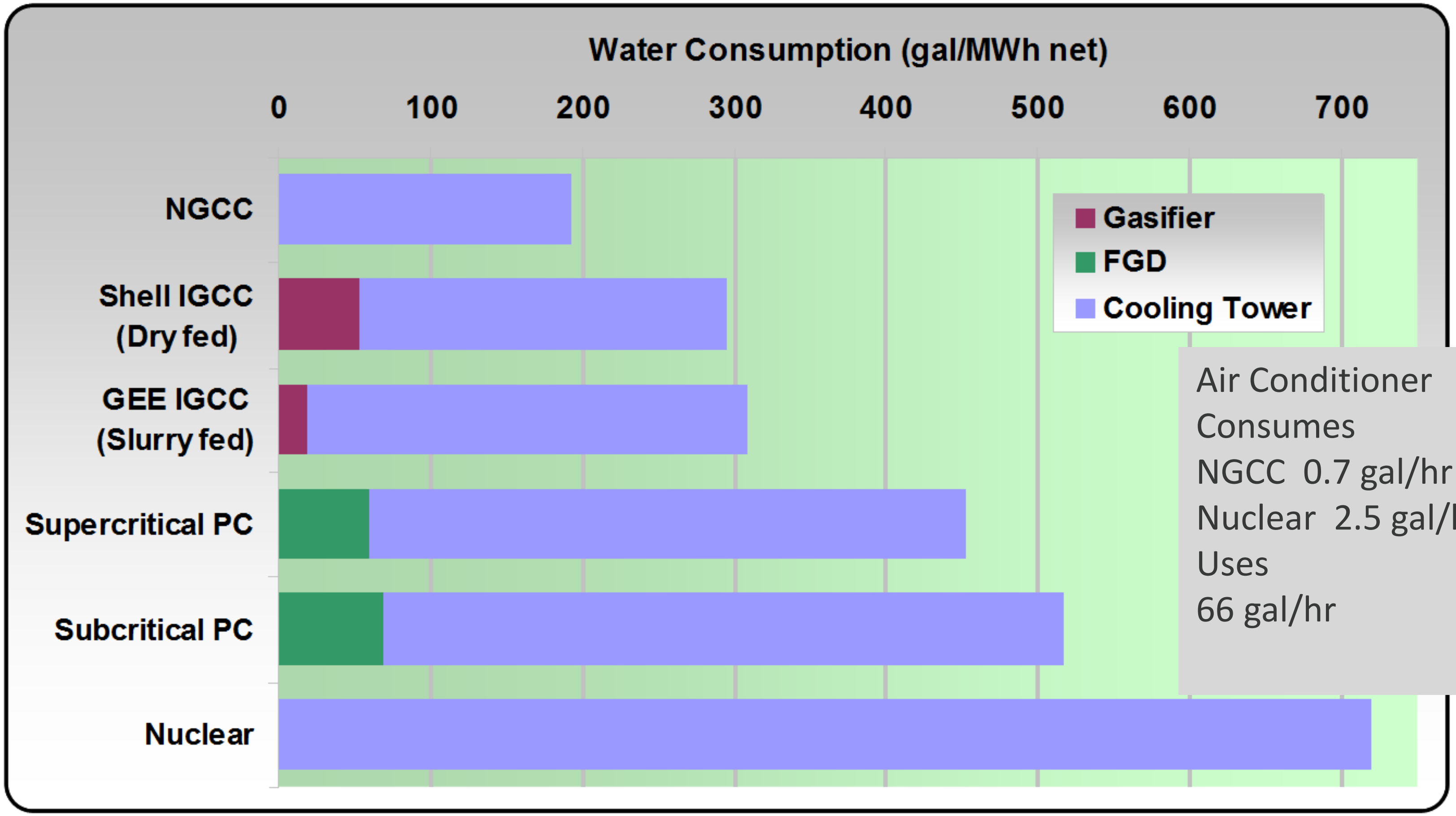
161 billion gallons per day (bgd) withdrawn; >99% surface water withdrawal, 73% of surface water freshwater sources, 44 bgd saline water withdrawn, 97% of saline withdrawal surface water

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

Light Bulbs		
Incandescent	***100 W***	***1.9 gallons/hour***
Halogen	***72 W***	***1.4 gallons/hour***
Compact Flourescent	***26 W***	***0.49 gallons/hour***
Light emitting diode (LED)	***16-22 W***	***0.36 gallons/hour***
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**



Air Conditioner
Consumes
NGCC 0.7 gal/hr
Nuclear 2.5 gal/hr
Uses
66 gal/hr

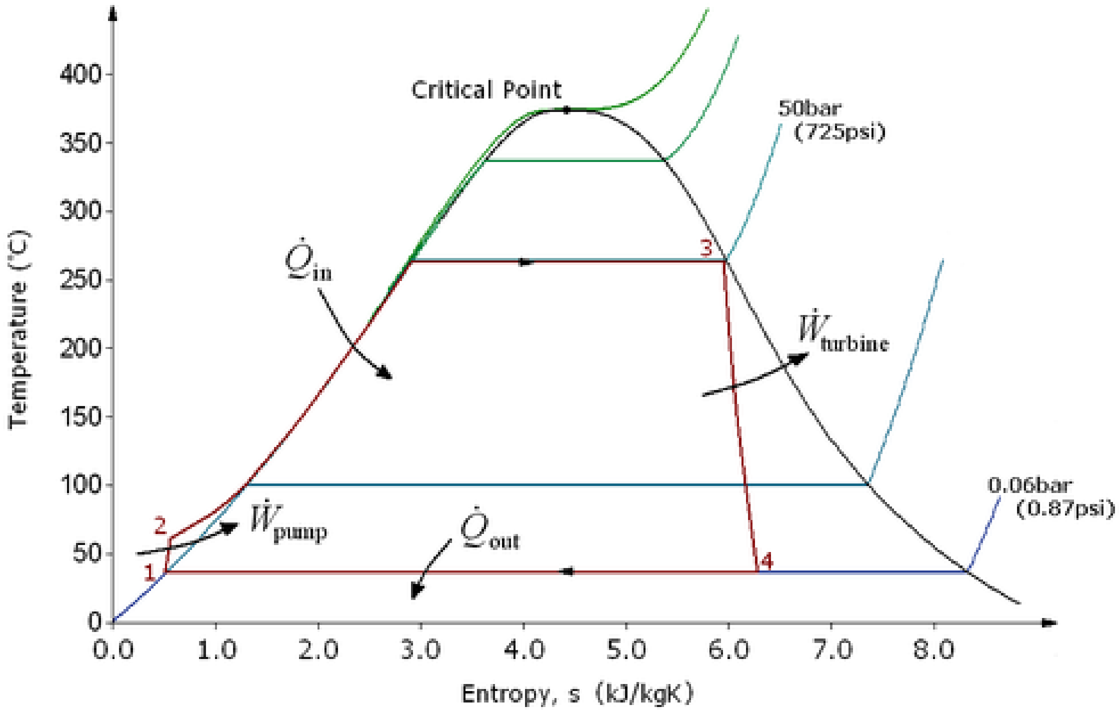
Plants equipped with wet re-circulating cooling towers, from "Water Requirements for Existing and Emerging Thermoelectric Plant Technologies"

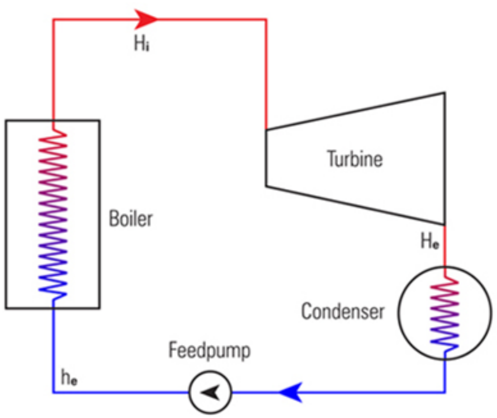
Rankine Cycle Efficiency-Thermodynamics

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

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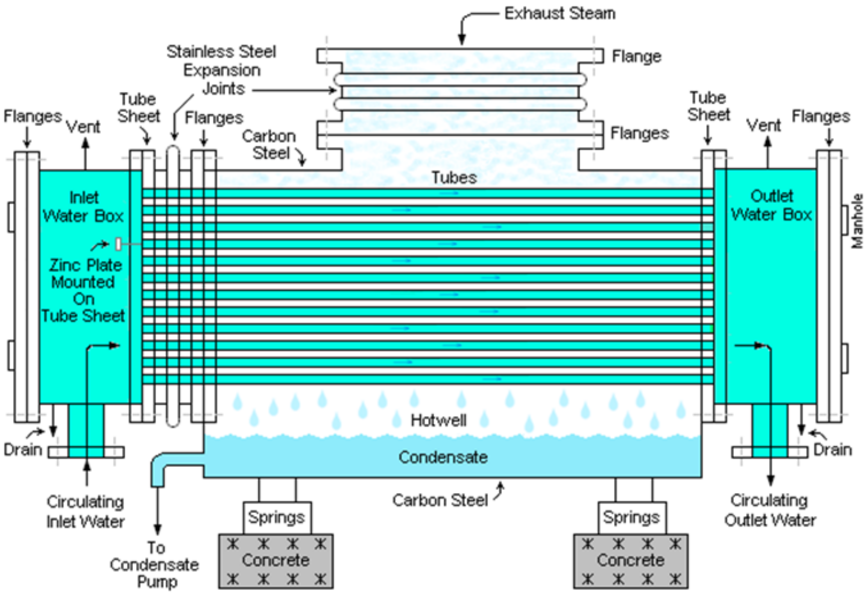

Note: Tubes are brass, cupro nickel, titanium or stainless steel. The tubes are expanded or rolled and bell mouthed at the ends in the tubesheets.

Typical Power Plant Condenser

Saturated Steam

100 F 0.95 psia

120 F 1.2 psia

140 F 2.8 psia

Thermo-electric Power Generation

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NETL Power Plant Water Program- Commercial Successes

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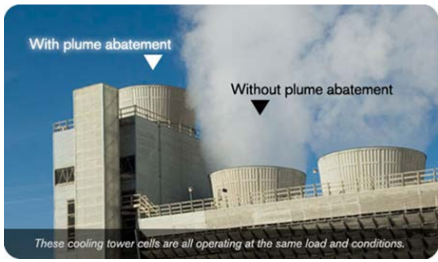
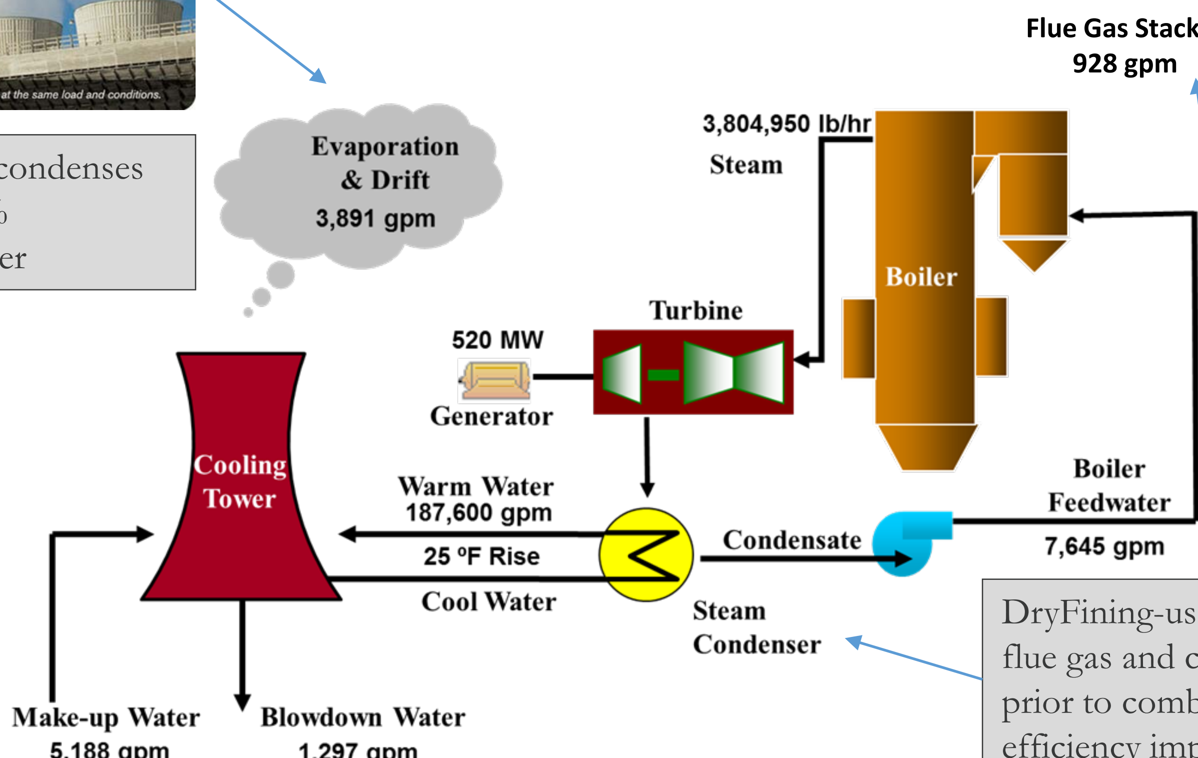
The average US Coal Plant is 33% efficient at generating electricity. The other 67% of heat from coal is waste heat, which is released from boiler in flue gas and dissipated to water from steam condenser.



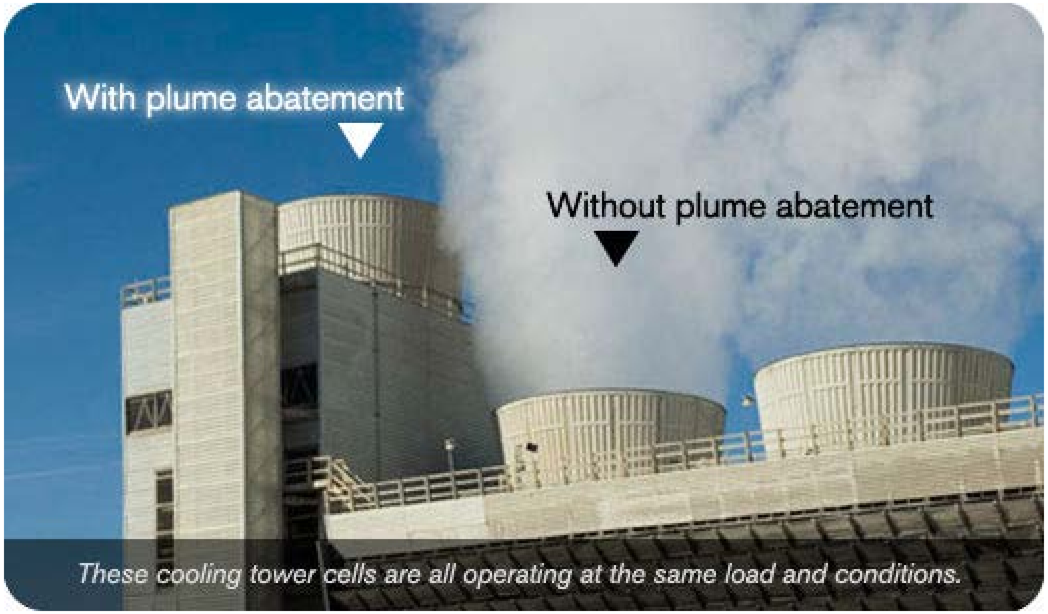
SPX ClearSky-condenses average of 19% evaporated water



Spiritwood, Great River Energy, North Dakota, Combined Heat and Power for bio-refinery, 60% efficiency.

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

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.

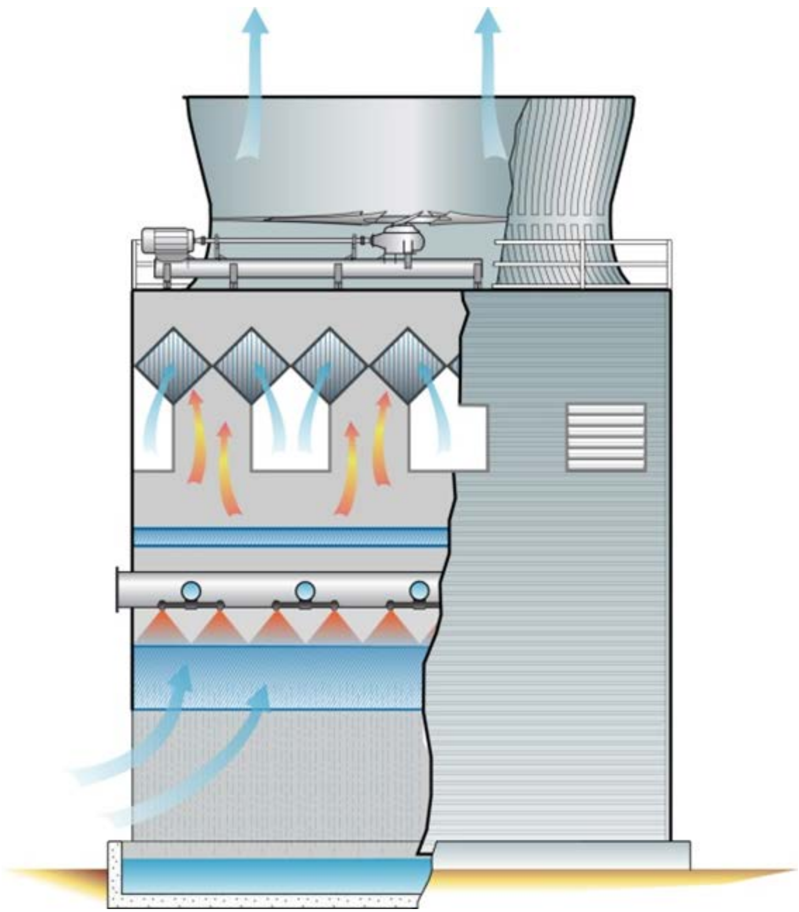
- **Lower Installation Cost**
  Less piping means less investment than conventional systems
- **Greater Design Flexibility**
  Back-to-back design allows for easy installation, including retrofits
- **Reduced Maintenance Costs**
  Unique patented design and materials means less need for maintenance
- **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

DryFining - Great River Energy – Coal Creek Station

- 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.

http://www.powermag.com November 2014

DryFining: Path to Commercialization

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

"Lignite Fuel Enhancement Final Technical Report," DOE Award Number: DE-FC26-04NT41763, released June 2010.

- 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)

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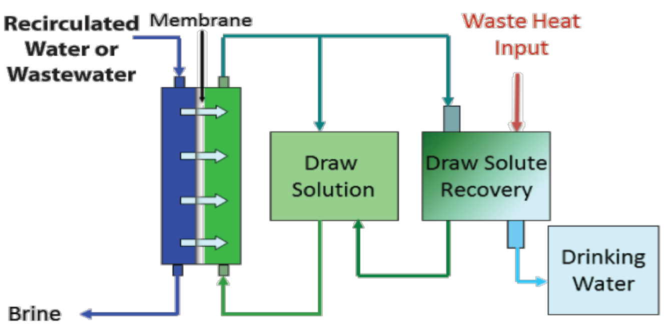
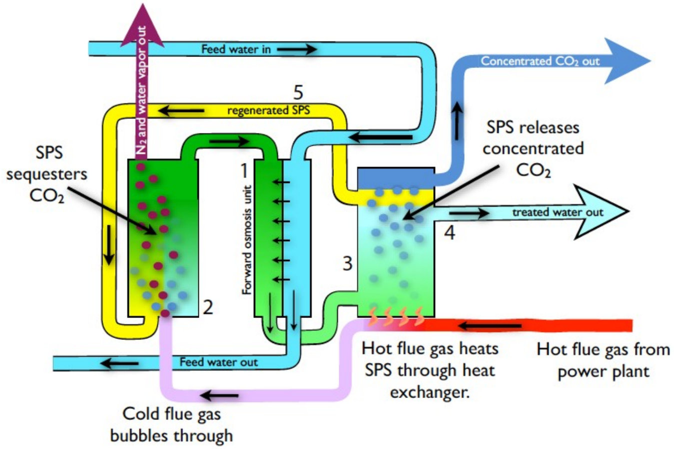
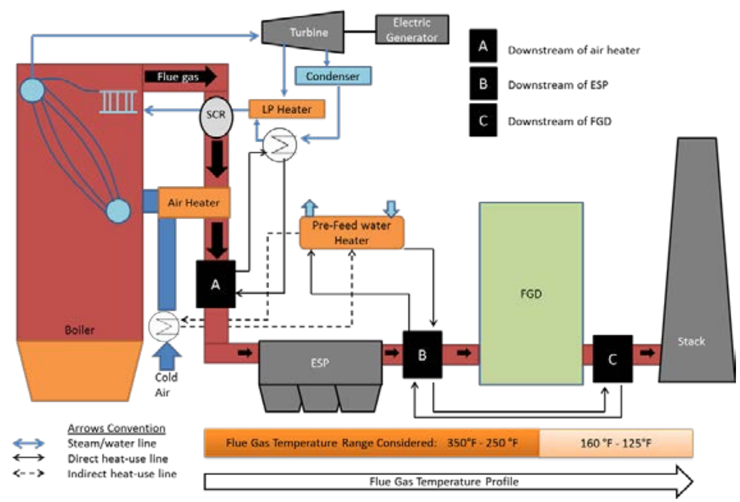
Forward Osmosis (FO) Process Utilizing Low Grade Heat: Applications in Power Plants Carnegie Mellon University



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



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

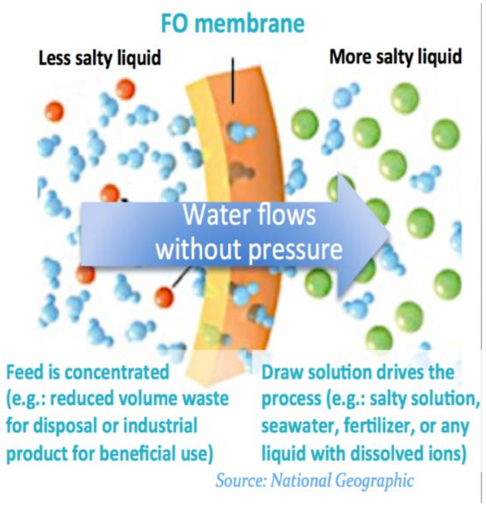


Development of a Field Demonstration for Cost-Effective Low-Grade Heat Recovery and Use Technology Designed to Improve Efficiency and Reduce Water Usage Rates for a Coal-Fired Power Plant Southern Company

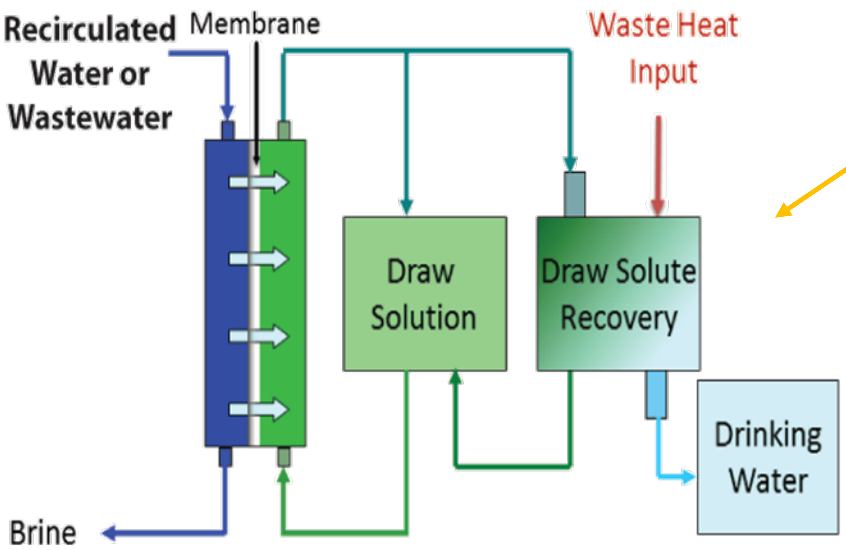
Transport Membrane Condenser (TMC)- nanoporous ceramic membrane

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

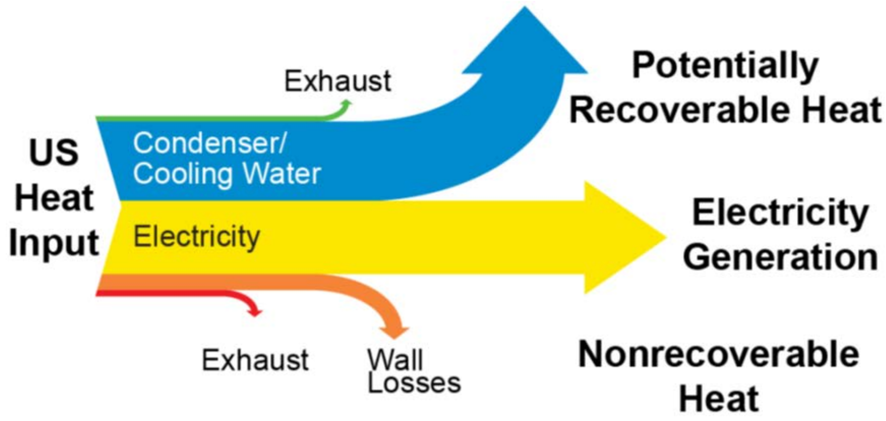


Oasys Water's forward osmosis technology is installed to treat flue gas desulfurization wastewater at the Changxing Power Plant in China.



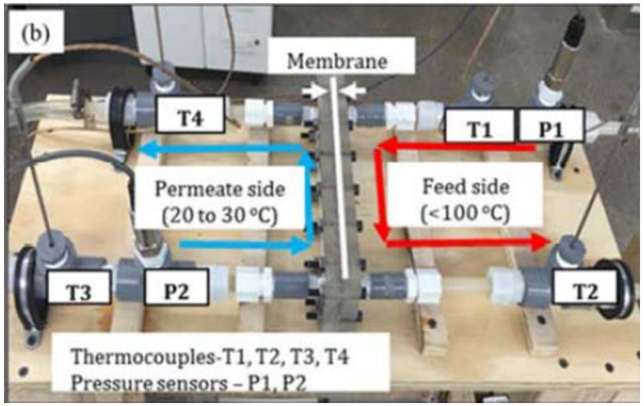
Generalized FO system design

Draw solute—ammonia bicarbonate (baking soda), waste heat regenerates weak draw solute



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.

Gingerich, D. and Mauter, M.S., Quantity, Quality, and Availability of Waste Heat from United States Thermal Power Generation, Environmental Science & Technology.



University of Pittsburgh test apparatus

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.

Transport Membrane Condenser (TMC)

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

Current Project Focus

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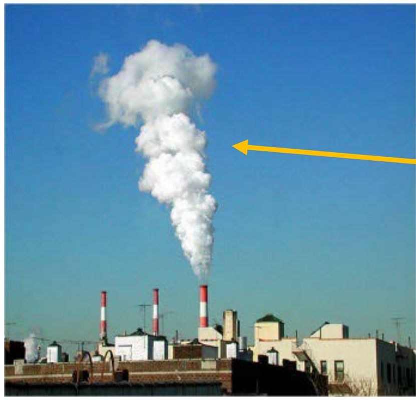


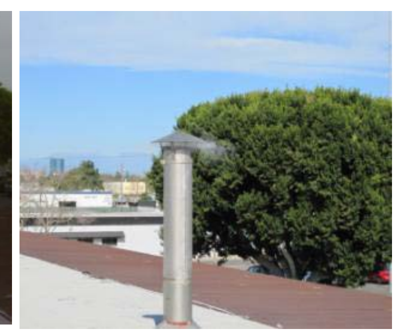
Eliminate plume of condensing water from stack

- 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

Southern Company Services, Inc. , Electric Power Research Institute, AECOM (URS Group)

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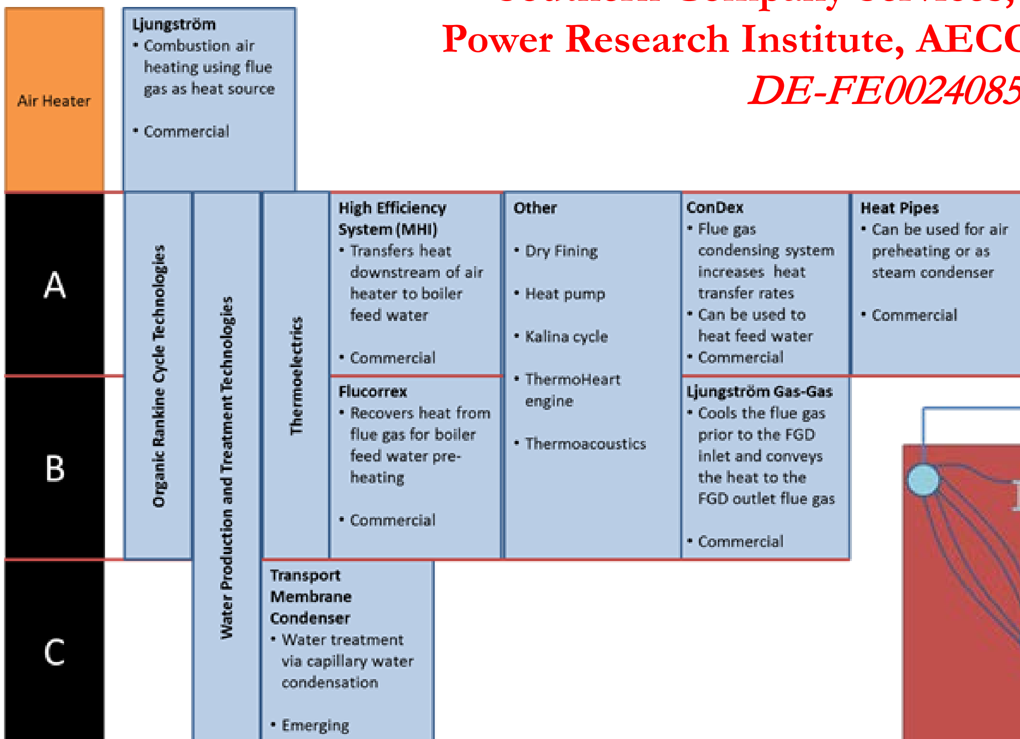
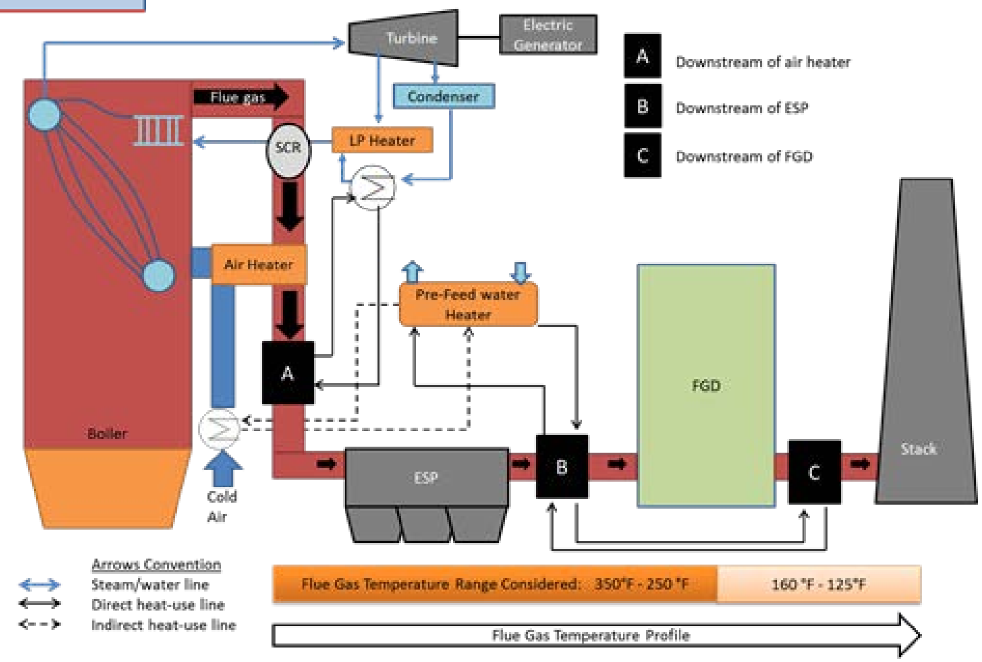




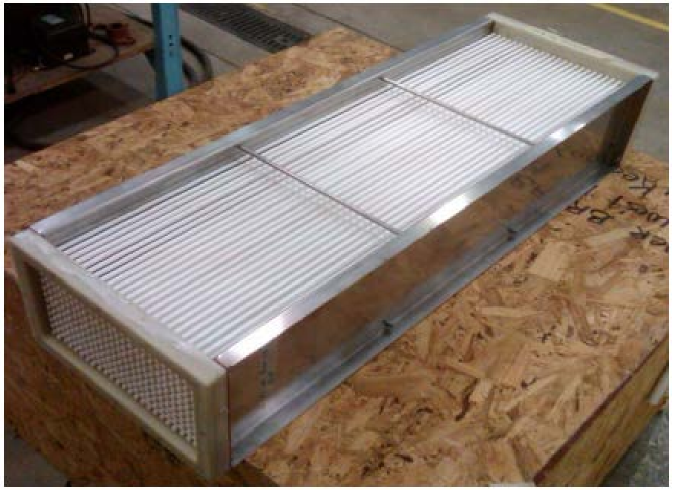
Potential uses of low-grade heat

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

Question: Is boiler feedwater or combustion air pre-heating better for LTHR?

GTI's Transport Membrane Condenser (TMC) captures water and heat

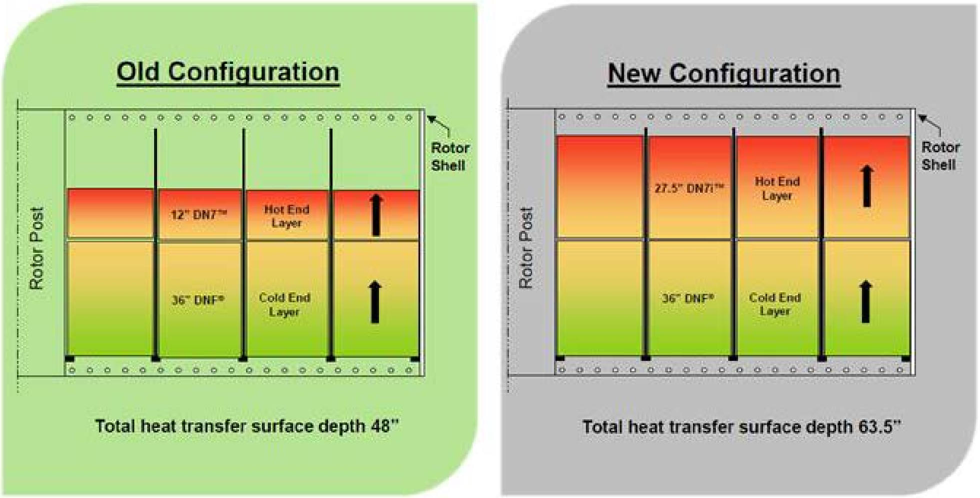
- Uses a nano-porous ceramic membrane to extract water vapor and its latent heat via capillary condensation from flue gas after the FGD
- Mineral-free water is created and passed back to the feedwater at 180°F or as cooling water makeup
- Advantages
  - Organization stated relatively low cost
  - Can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



GTI's TMC [3]

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 SO_3
- SCR operating temperature can be reduced due to reduced SO_3



Before and after Ljungström technology update

Future Direction-Discussion

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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