Power Plant Cooling
--What are the trade-offs?

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Maulbetsch Consulting
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Power plants use water
Largest use is for condenser cooling
Some cooling systems use less water than others
Tradeoffs are
• Amount of water used
• Cost
• Plant efficiency and output
Water conserving cooling systems are available at a price

✓ Increased capital cost---500 MW plants
  0.4% to 12.5%
✓ Increased cooling system power
  0.5 to 3.0 MW
✓ Increased plant heat rates
  0.4 to 4.0 %
✓ Increased power production costs
  1.9 to 4.9%
Plants

Discussion limited to……

✓ Plants with condenser cooling
  • Combined-cycle plants
  • Steam plants
  • Not simple cycle turbines or reciprocating engines

✓ New plants
  • Not retrofits
Combined Cycle Plant

Diagram showing a combined cycle power plant with labeled components:
- **Fuel**
- **Compressor**
- **Gas Turbine**
- **HRSG**
- **Exhaust**
- **Steam Turbine**
- **Condenser**
- **Pump**
- **Generator**
Steam Plant

Fuel

Boiler

EXHAUST

PUMP

STEAM TURBINE

GENERATOR

CONDENSER
Cooling systems

☑ Commonly used
  • Once-through
  • Wet cooling
  • Dry cooling

☑ Others
  • Hybrid (wet/dry) cooling
  • Spray enhanced dry cooling
Once-through

Exhaust Steam

Hot CW

Cold CW

CW Pump(s)

Water source—ocean, river, lake, etc

to HRSG
Wet Cooling Tower

from condenser

Hot CW

Fans

Ambient air

to condenser

Cold CW

Makeup

Blowdown
Air Cooled Condenser

from steam turbine

Exhaust steam

Ambient air

to boiler or HRSG
Water source

✓ Natural
  ✓ Ocean
  ✓ Fresh surface water
  ✓ Groundwater
    • potable
    • brackish
✓ Reclaimed
  ✓ Municipal discharge
  ✓ Agricultural run-off
Cooling Water Taken In---500 MW Combined Cycle Plant

Water Taken In, gpm

Once-through

Wet

Dry
Cooling Water Consumption---500 MW Combined Cycle Plants

Water Consumed, gpm

<table>
<thead>
<tr>
<th>Water Type</th>
<th>Water Consumed, gpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once-through</td>
<td>100</td>
</tr>
<tr>
<td>Wet</td>
<td>2,000</td>
</tr>
<tr>
<td>Dry</td>
<td>0</td>
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</tbody>
</table>
Capital Cost---500 MW Combined Cycle Plant

- Once-through Wet Dry Cooling System Type
  - Capital Cost, $
  - Base
  - +1.20 %
  - +12.5 %
Normalized Capital Cost---500 MW Combined Cycle

Normalized Capital Cost, $/kW

<table>
<thead>
<tr>
<th>Cooling System Type</th>
<th>Normalized Cost, $/kW</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once-through</td>
<td>Base</td>
<td></td>
</tr>
<tr>
<td>Wet</td>
<td>+1.2%</td>
<td></td>
</tr>
<tr>
<td>Dry</td>
<td>+12.5%</td>
<td></td>
</tr>
</tbody>
</table>
Design Heat Rate---500 MW Combined Cycle Plant

Heat Rate, Btu/kWh

<table>
<thead>
<tr>
<th>Cooling System Type</th>
<th>Heat Rate</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once-through</td>
<td>Base</td>
<td>+0.37%</td>
</tr>
<tr>
<td>Wet</td>
<td>+0.71%</td>
<td></td>
</tr>
<tr>
<td>Dry</td>
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</tbody>
</table>
Hot Day Output

Hot Day Capacity Loss---500 MW Combined Cycle Plants
(Includes Effect on Combustion Turbines)
Cooling Water Taken In---500 MW Steam Plant

Cooling Water Taken In, gpm

- Once-through
- Wet
- Dry

Y-axis: Cooling Water Taken In, gpm
- 0
- 20,000
- 40,000
- 60,000
- 80,000
- 100,000
- 120,000
- 140,000
- 160,000
- 180,000
- 200,000
Cooling Water Consumed---500 MW Steam Plant

- Water Consumed, gpm

- Once-through
- Wet
- Dry

Chart showing water consumption for different cooling methods.
Capital Cost---500 MW Steam Plant

Cooling System Type

<table>
<thead>
<tr>
<th>Type</th>
<th>Capital Cost, $</th>
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</thead>
<tbody>
<tr>
<td>Base</td>
<td>280,000,000</td>
</tr>
<tr>
<td>+.43 %</td>
<td>290,000,000</td>
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<tr>
<td>+12.6 %</td>
<td>300,000,000</td>
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<tr>
<td>Dry</td>
<td>320,000,000</td>
</tr>
</tbody>
</table>
Normalized Capital Cost---500 MW Steam Plant

Cooling System Type

Normalized Capital Cost, $/kW

- Once-through
  - Base
  - .47%

- Wet
  - +.47%

- Dry
  - +12.8%
Design Heat Rate---500 MW Steam Plant

Heat Rate, Btu/kWh

Cooling System Type

- Once-through
- Wet
- Dry

Base
+3.7%
+4.2%
Hot Day Heat Rate Increase---500 MW Steam Plants

- Once-through
- Wet
- Dry

Heat Rate Increase, %

Cooling System Type

- 0%
- 1%
- 2%
- 3%
- 4%
- 5%
- 6%
- 7%
- 8%
- 9%
- 10%
Power for Cooling System Pumps and Fans

- Combined Cycle
- Steam

Cooling System Power, kW

- Once-through
- Wet
- Dry

Cooling System Type
Maintenance Costs

✓ Labor, chemicals and equipment
✓ Highly site-specific
✓ Estimated at 1 to 3% of cooling system capital cost
✓ 10’s to 100’s of k$ per year---negligible in comparison to other cost items
Levelized Cost Components for Sample Combined-Cycle Natural Gas Power Plant

Levelized Cost Components By Percent

- Fuel Costs 75%
- Capital & Financing - Construction 16%
- Variable O&M 2%
- Corporate Taxes (w/Credits) 4%
- Fixed O&M Costs 1%
- Insurance & Ad Valorem Costs 2%
Production Cost Breakdown---Dry Cooling
500 MW Combined-Cycle Plant

- Fuel: 88.16%
- Capital: 10.86%
- Cooling power: 0.78%
- Cooling Maintenance: 0.19%
Cost of Electricity---500 MW Combined-Cycle Plant

Annualization factor--0.075; Cost of fuel--$6/MMBtu; Capacity factor--8,100 hours/year

<table>
<thead>
<tr>
<th>Type of Cooling System</th>
<th>Cost due to Capital</th>
<th>Cost due to fuel</th>
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</thead>
<tbody>
<tr>
<td>Once through</td>
<td>+1.86 %</td>
<td>+3.30 %</td>
</tr>
<tr>
<td>Base</td>
<td>43.05 $/MWh</td>
<td>43.85 $/MWh</td>
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<tr>
<td>Wet</td>
<td>44.47 $/MWh</td>
<td></td>
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<tr>
<td>Dry</td>
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</table>
Cost of Electricity---500 MW Steam Plant

- Cost due to Capital
- Cost due to fuel

Annualization factor--0.075; Cost of fuel--$6/MMBtu; Capacity factor--8,100 hours/year

<table>
<thead>
<tr>
<th>Type of Cooling System</th>
<th>Base</th>
<th>+3.08%</th>
<th>+4.86%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Once through</td>
<td>52.60 $/MWh</td>
<td>54.22 $/MWh</td>
<td>55.16 $/MWh</td>
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<tr>
<td>Wet</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Dry</td>
<td></td>
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</table>
Additional considerations

✓ Benefit of “a little bit” of water
  – Hybrid (wet/dry) systems
  – Spray enhancement
Hybrid (wet/dry) system
Tucuman 450 MW Combined Cycle (Argentina)
PAC SYSTEM®
(Air Cooled Condenser & Wet Cooling System)
Hybrid System Cost Estimate

Capital Cost of Cooling System

Water Conservation

Plume Abatement

Hybrid System Range of Water Use

0% 15% 85% 100% (All Wet)
Spray enhancement

- Spray water into inlet air stream of air-cooled condenser
- Low capital cost approach
- Low annual water use
- Reduce inlet temperature by 5 to 10 F
- Restore “hot day” capacity loss
### Summary—Combined-Cycle Plants

#### 500 MW Combined-Cycle Plant

<table>
<thead>
<tr>
<th>Items for comparison</th>
<th>Cooling System</th>
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<tbody>
<tr>
<td></td>
<td>Once-through</td>
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<tr>
<td><strong>Plant Cost</strong></td>
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<tr>
<td>Capital, $</td>
<td>198,800,000</td>
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<tr>
<td>Normalized Capital Cost, $/kW</td>
<td>405.7</td>
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<tr>
<td><strong>Performance</strong></td>
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<tr>
<td>Cooling System Power, kW</td>
<td>2,075</td>
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<tr>
<td>Design Heat Rate, Btu/kWh</td>
<td>6,549</td>
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<tr>
<td>Hot day Capacity Loss, MW</td>
<td>Base</td>
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<tr>
<td><strong>Water</strong></td>
<td></td>
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<tr>
<td>Water taken in, gpm</td>
<td>132,410</td>
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<tr>
<td>Water consumed, gpm</td>
<td>De minimis ??</td>
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<tr>
<td>Items for comparison</td>
<td>Cooling System</td>
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<tr>
<td>----------------------</td>
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<td>Once-through</td>
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<td>Plant Cost</td>
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<tr>
<td>Capital, $</td>
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<td>Normalized Capital Cost, $/kW</td>
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<td>Base</td>
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<td>Water</td>
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<td>Water taken in, gpm</td>
<td>180,500</td>
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<td>Water consumed, gpm</td>
<td>De minimis??</td>
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