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

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# Overview

- ✓ **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**

# The conclusions- in advance

**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**

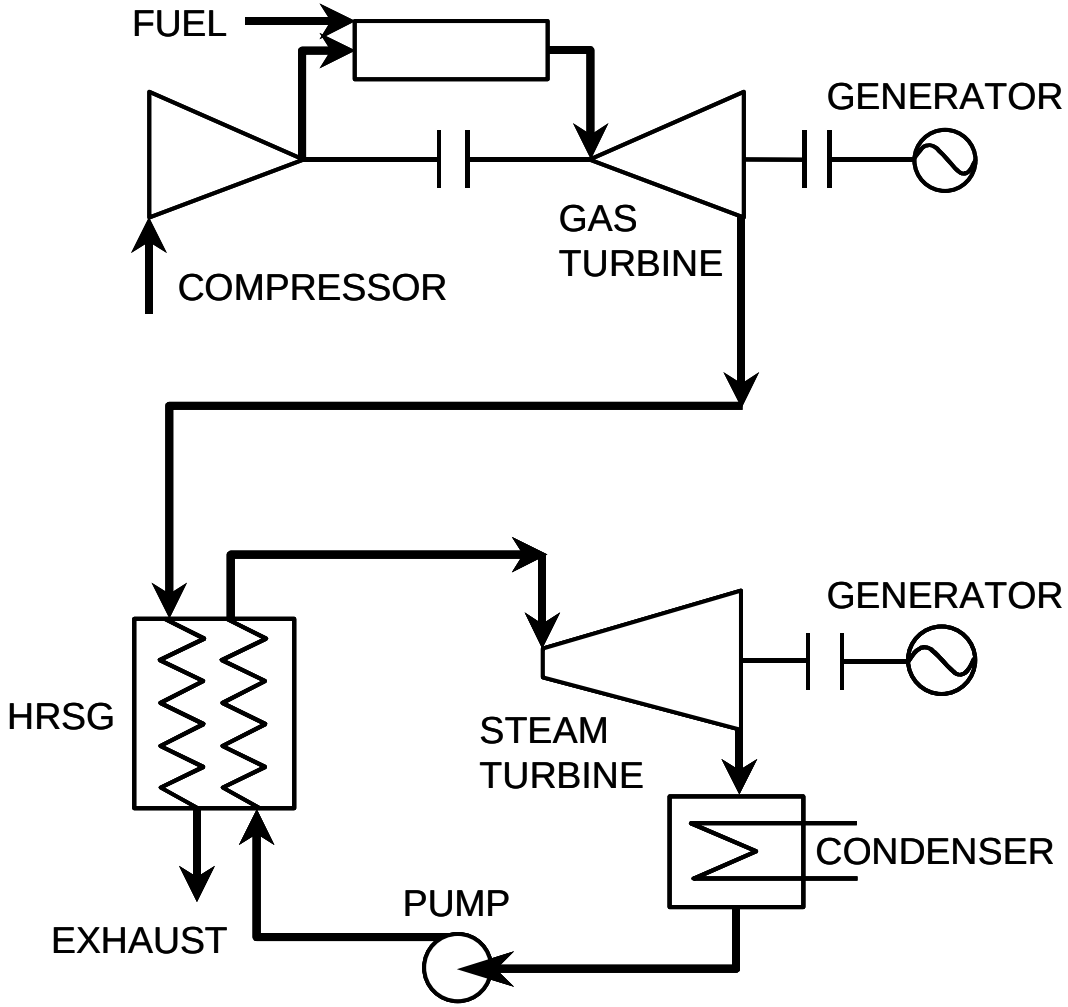
  **1.9 to 4.9%**

# Plants

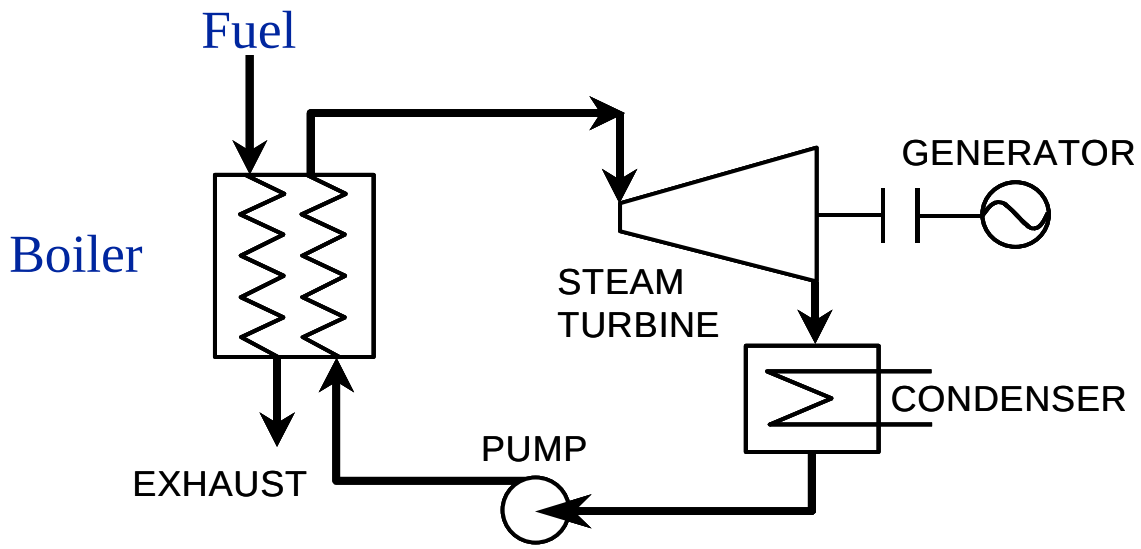
**Discussion limited to…….**

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

# Combined Cycle Plant



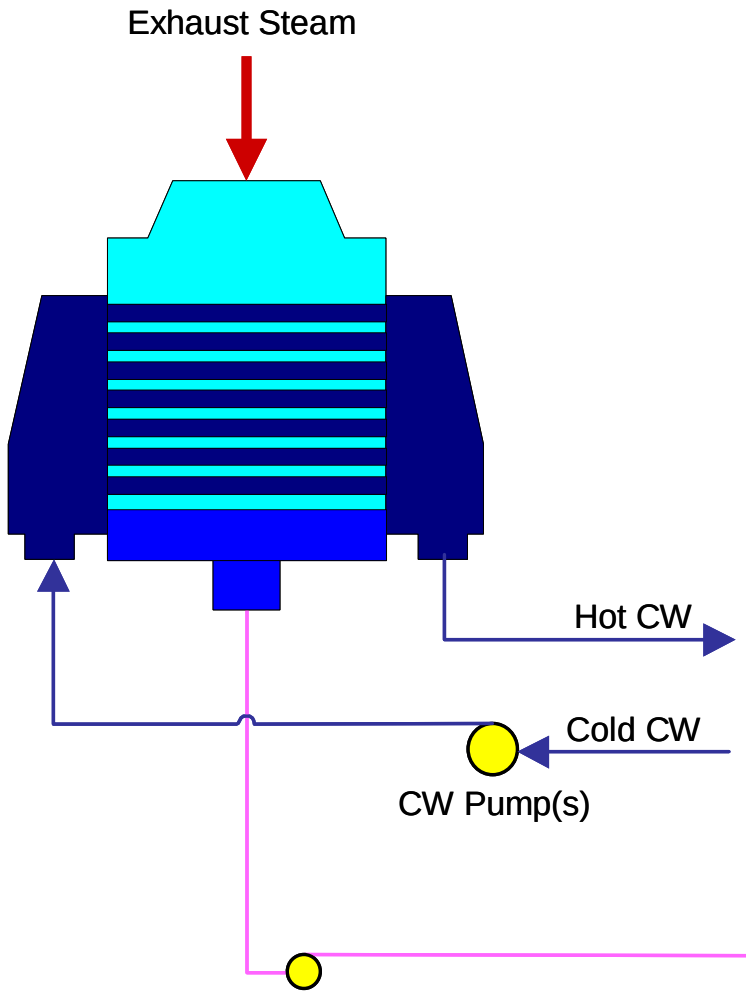
# Steam Plant


Fuel
Boiler
GENERATOR
STEAM
TURBINE
CONDENSER
PUMP
EXHAUST

# Cooling systems

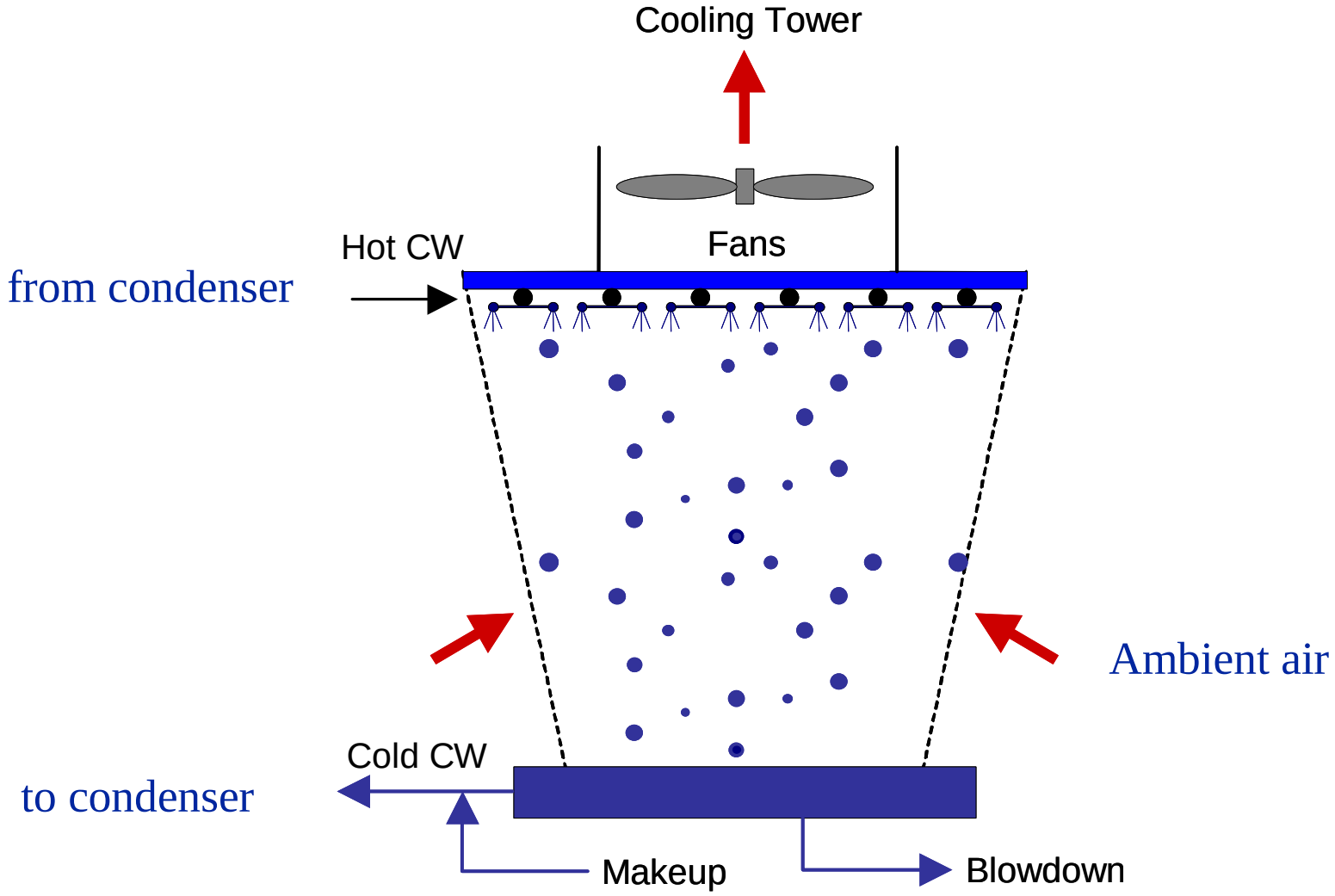
- ✓ **Commonly used**
  - **Once-through**
  - **Wet cooling**
  - **Dry cooling**
- ✓ **Others**
  - **Hybrid (wet/dry) cooling**
  - **Spray enhanced dry cooling**

# Once-through

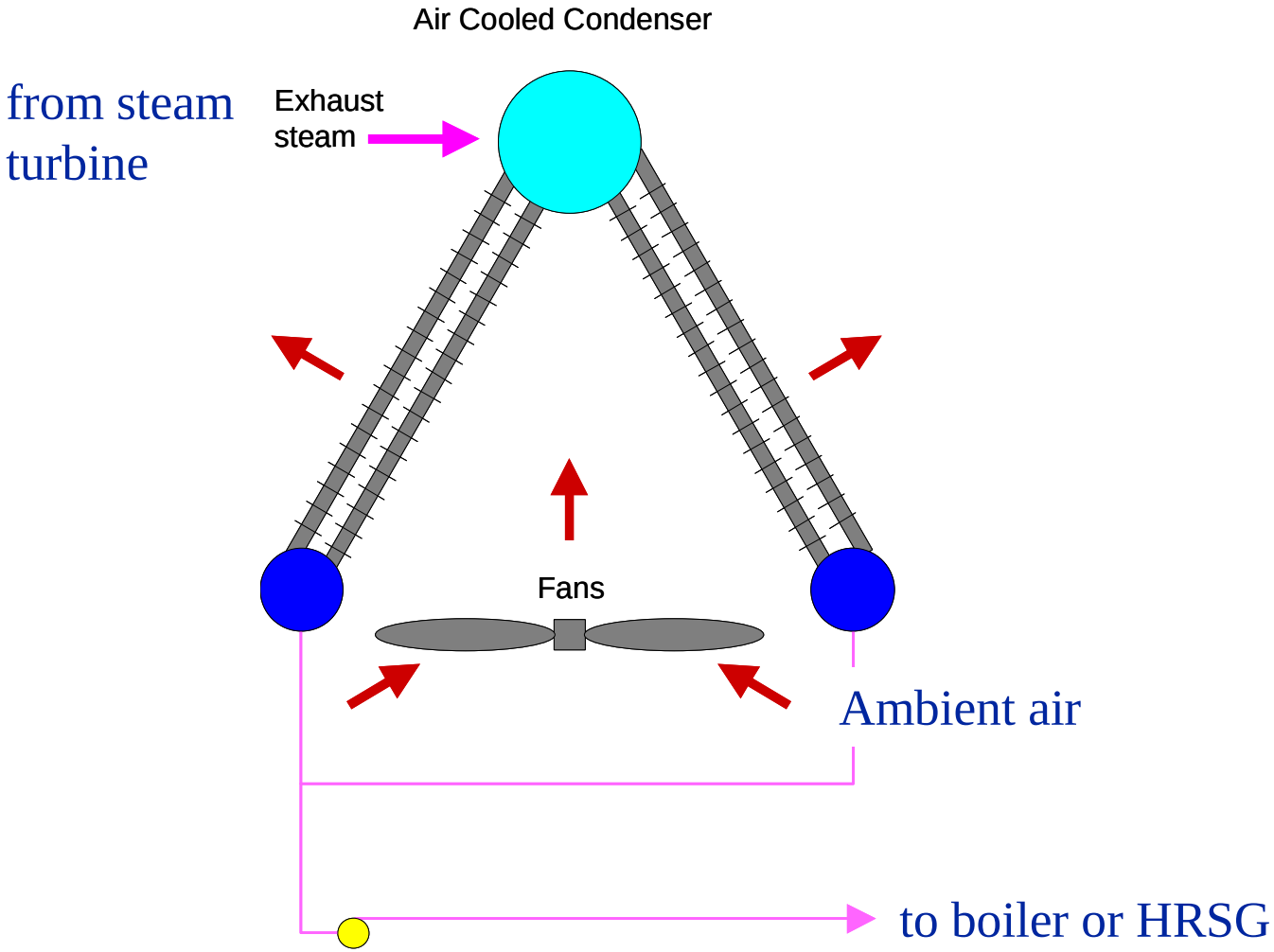



Water source— ocean, river, lake, etc

# Wet Cooling Tower

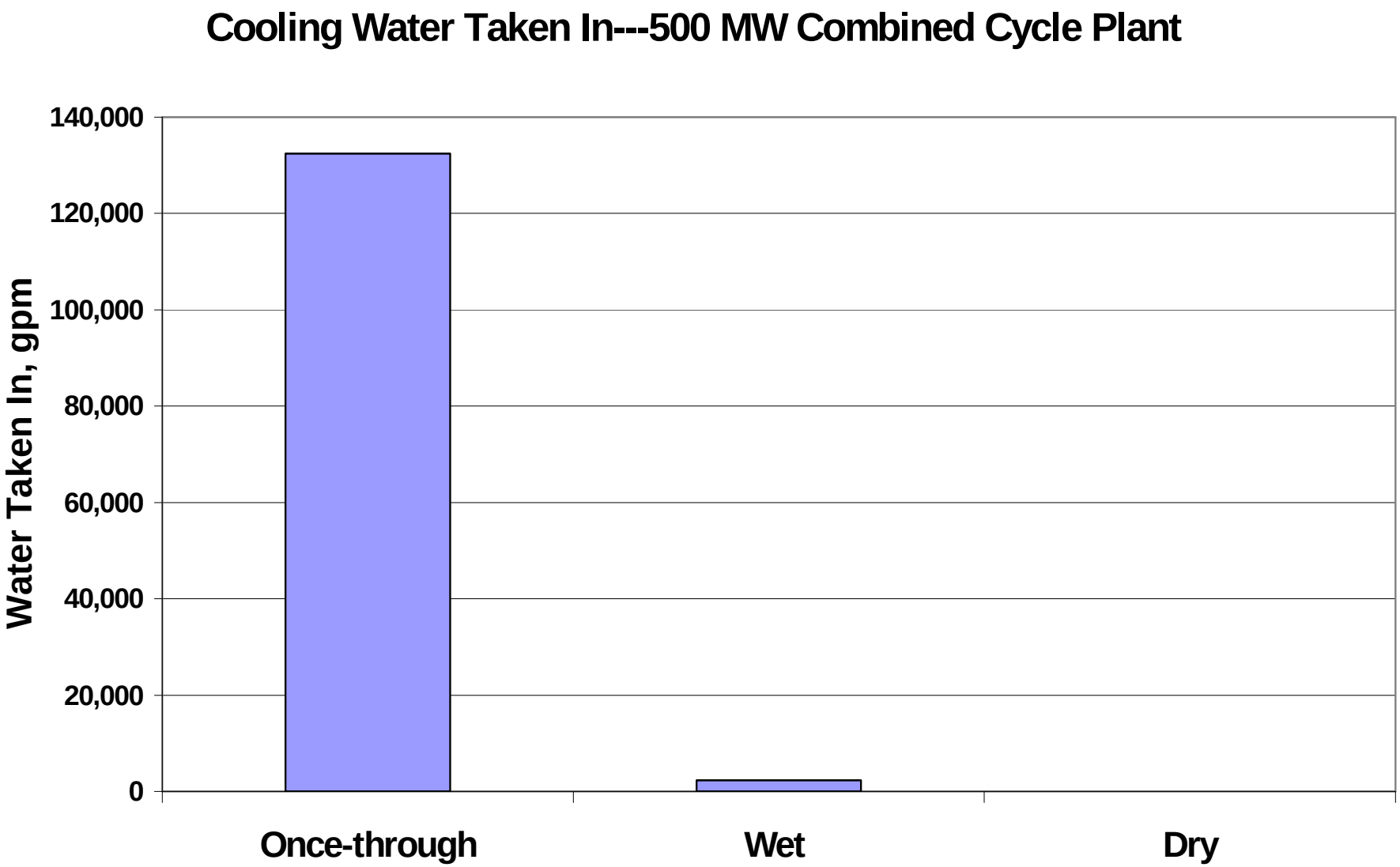


# Air Cooled Condenser

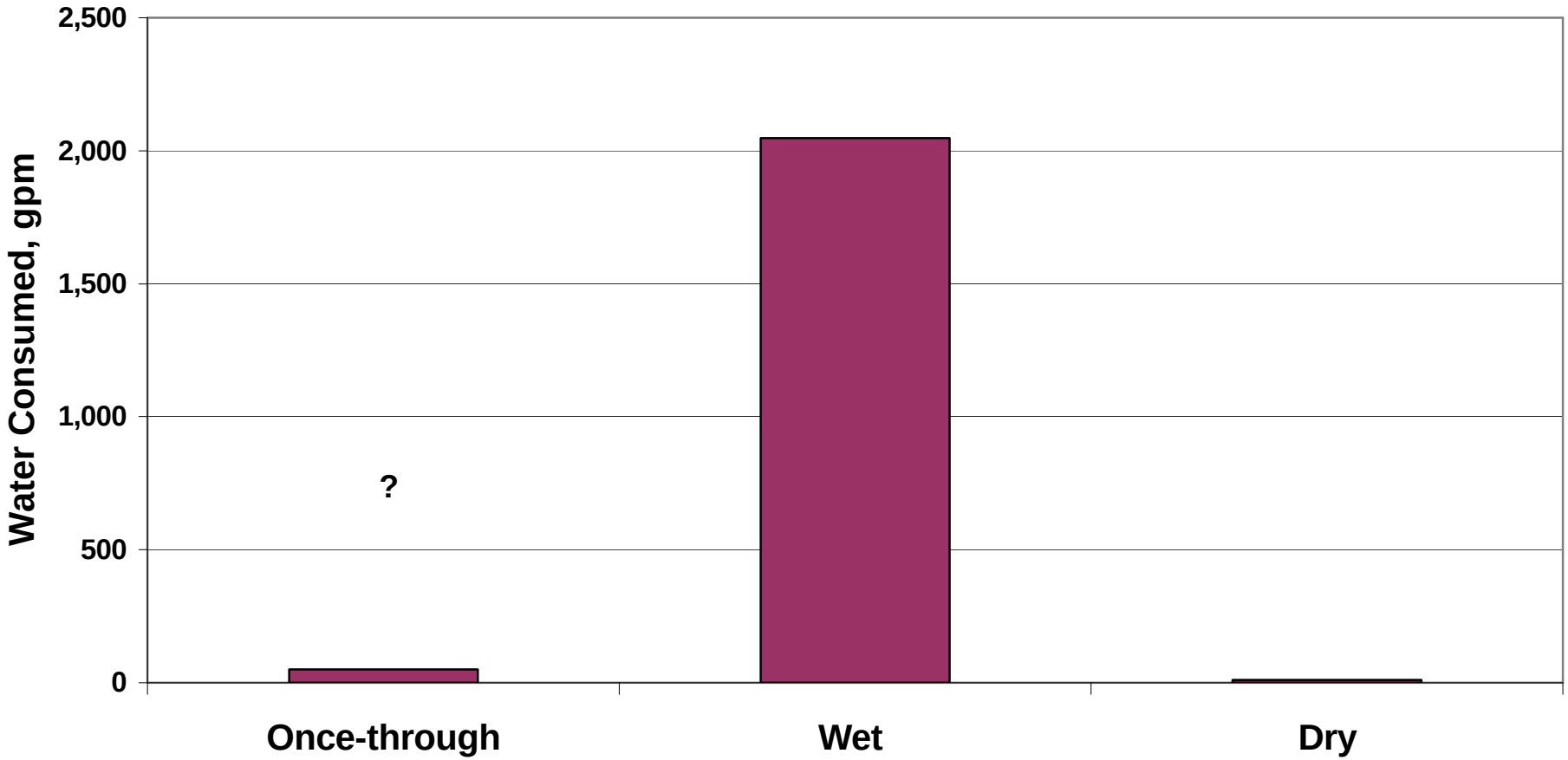


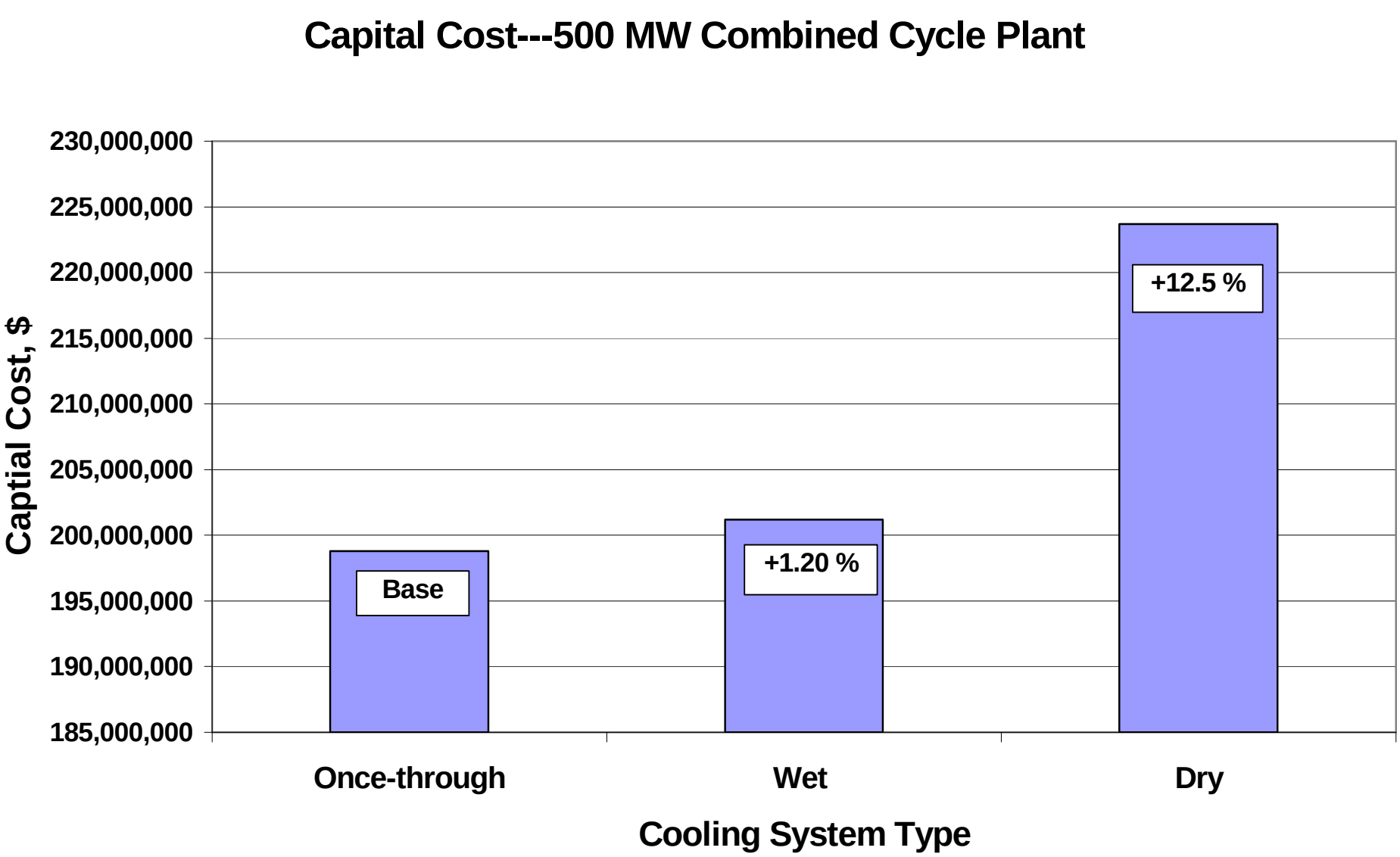
# Water source

- ✓ Natural
  - ✓ Ocean
  - ✓ Fresh surface water
  - ✓ Groundwater
    - potable
    - brackish
- ✓ Reclaimed
  - ✓ Municipal discharge
  - ✓ Agricultural run-off

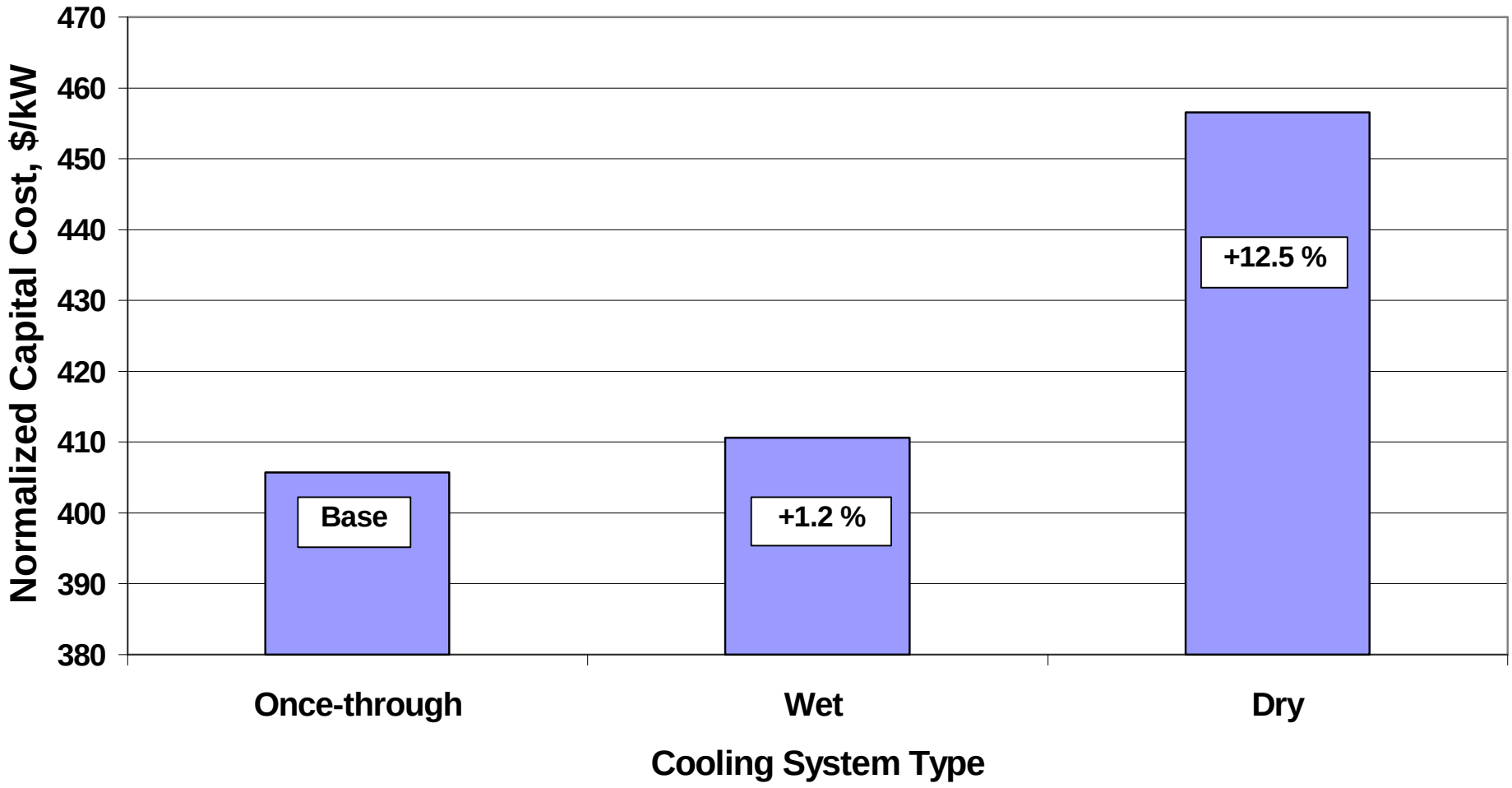

Cooling Water Taken In---500 MW Combined Cycle Plant
Water Taken In, gpm
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Once-through
Wet
Dry

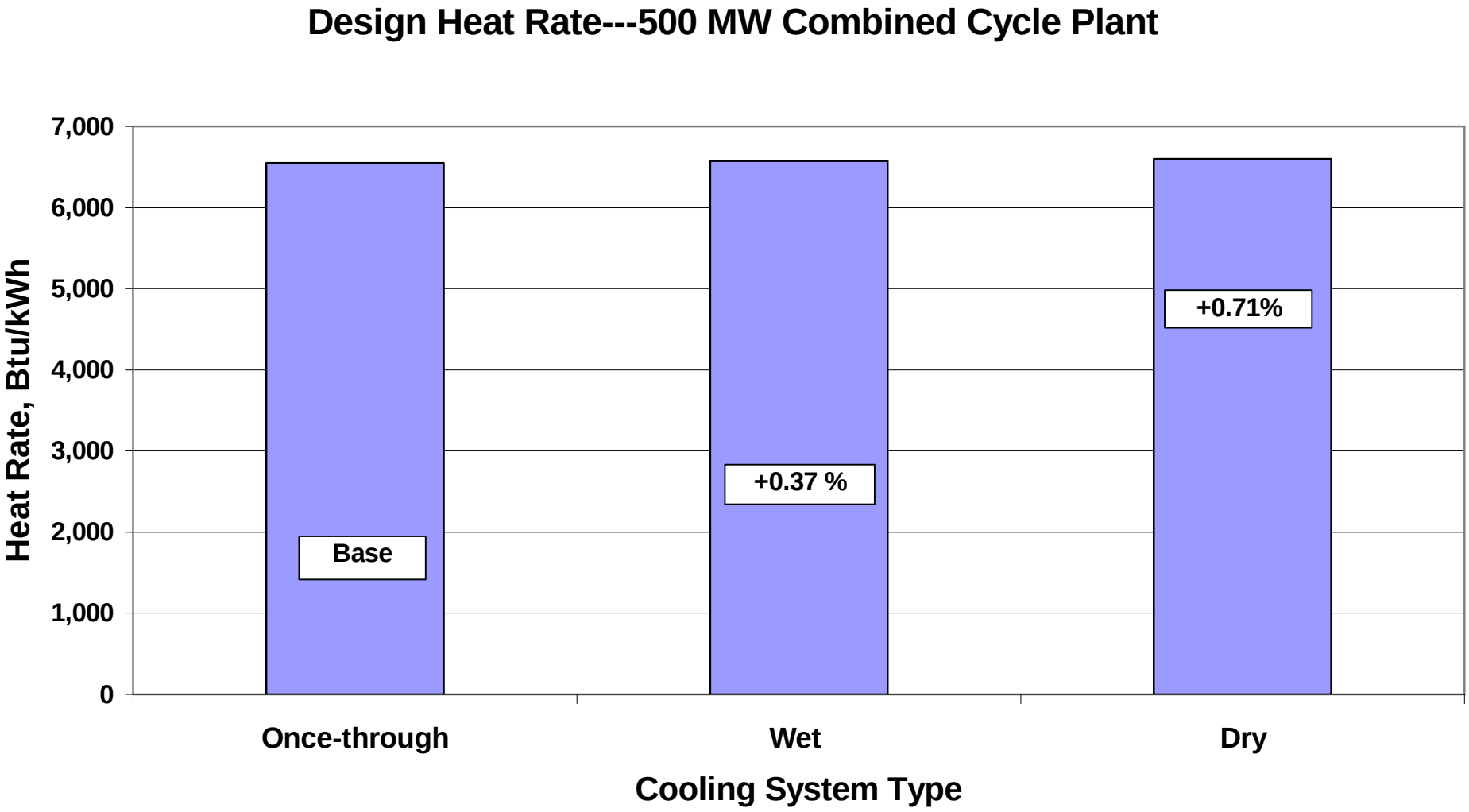
## Cooling Water Consumption---500 MW Combined Cycle Plants

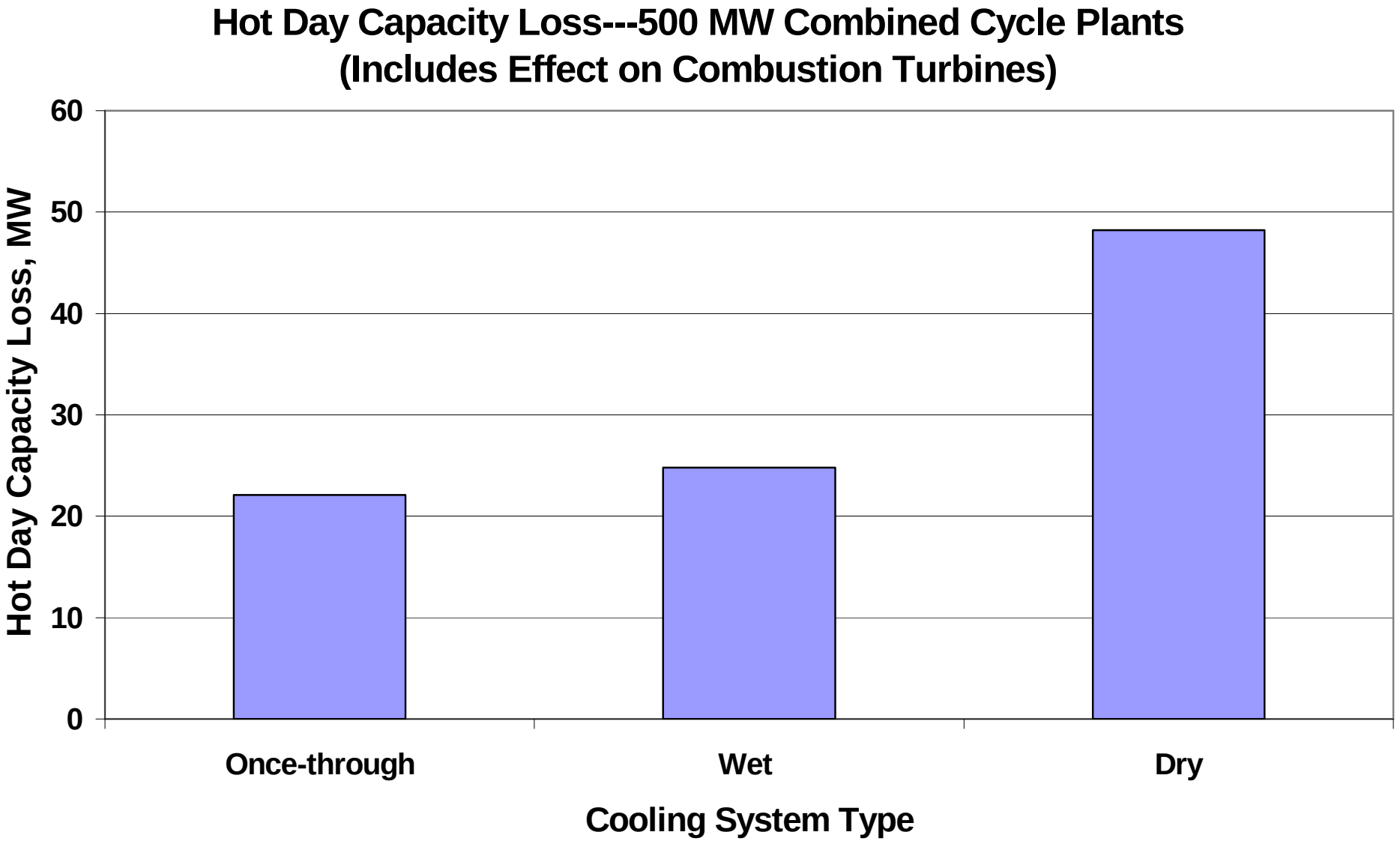


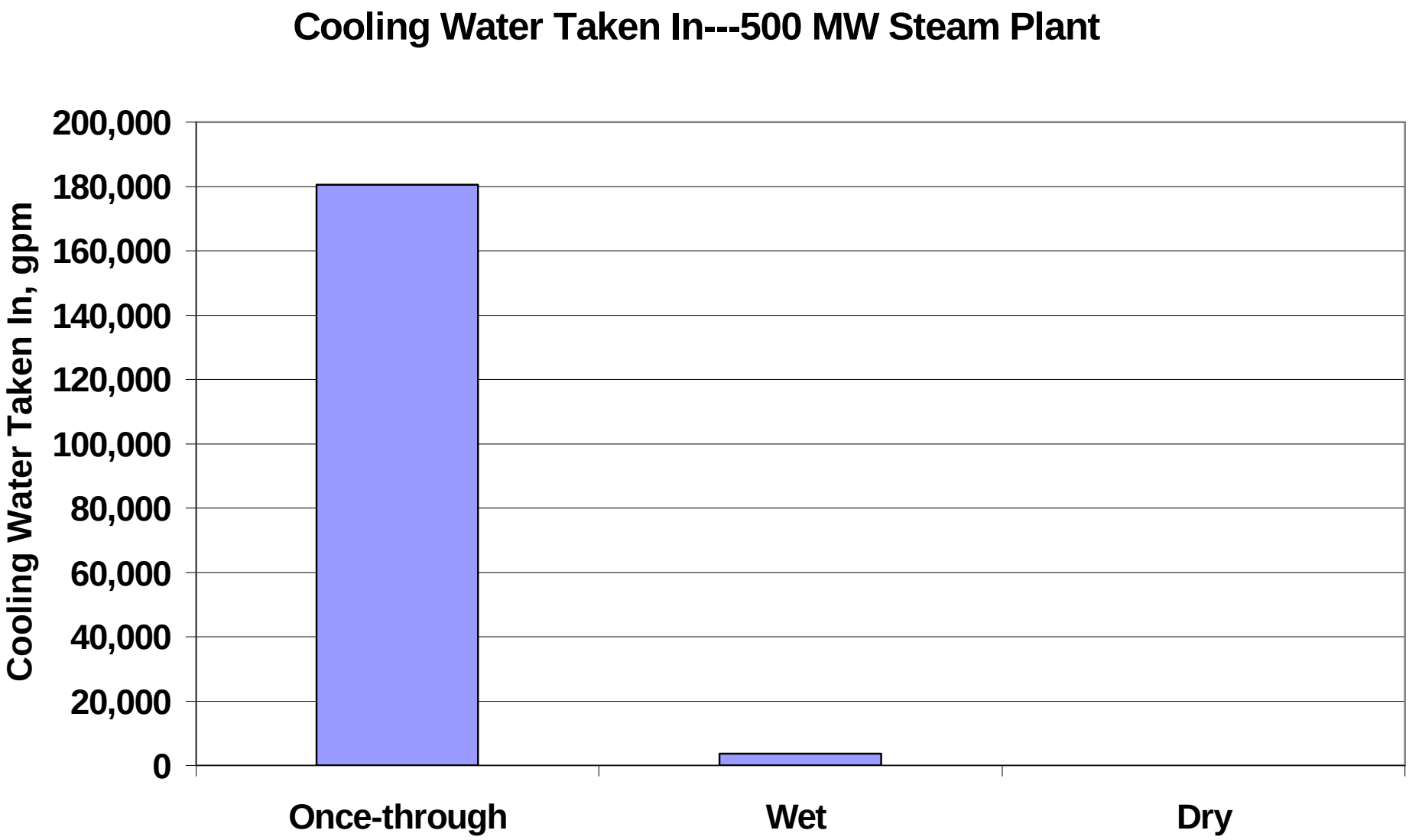

Capital Cost---500 MW Combined Cycle Plant
230,000,000
225,000,000
220,000,000
215,000,000
210,000,000
205,000,000
200,000,000
195,000,000
190,000,000
185,000,000
Captial Cost, $
Base
+1.20 %
+12.5 %
Once-through
Wet
Dry
Cooling System Type

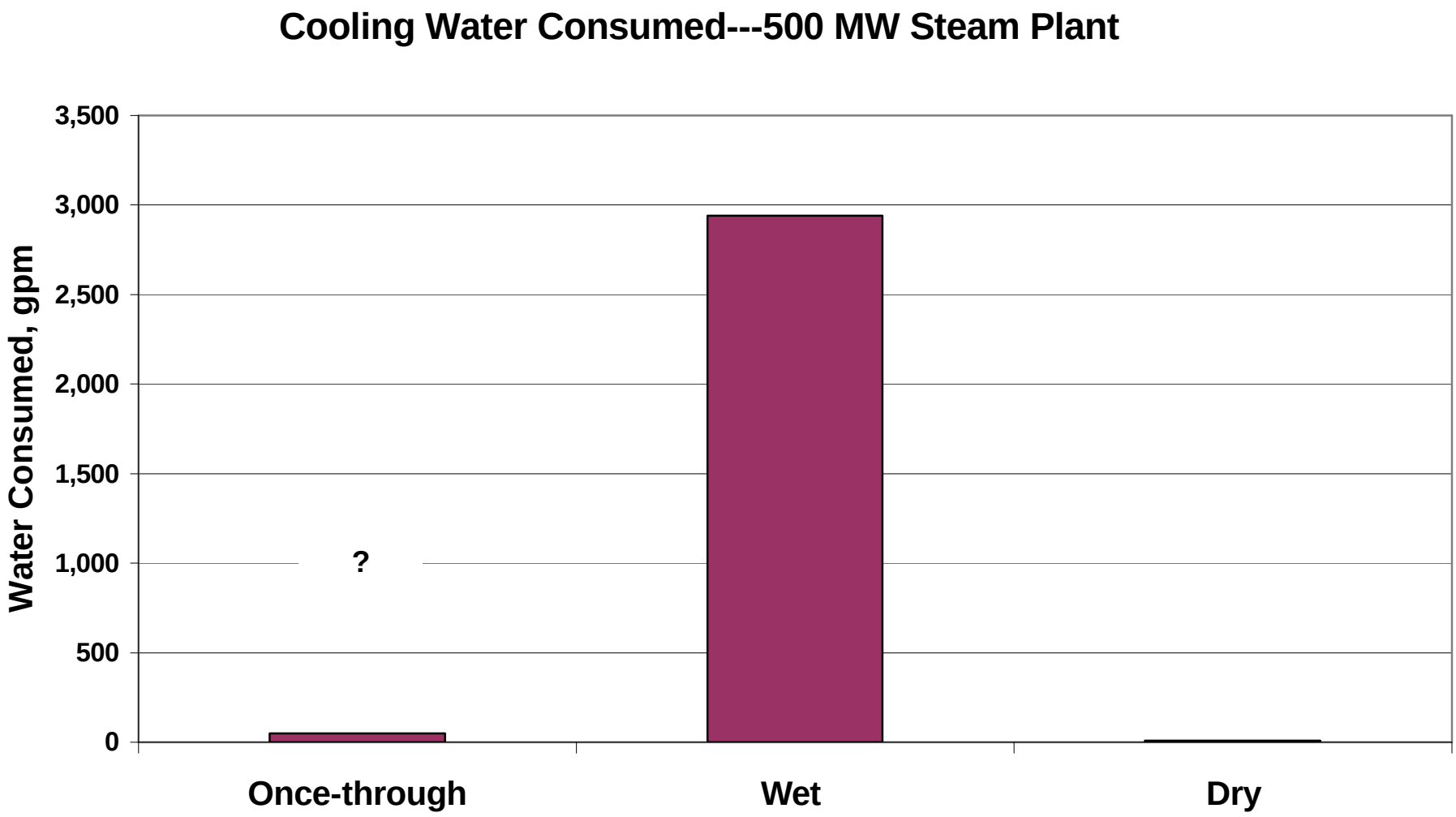
# Normalized Capital Cost---500 MW Combined Cycle



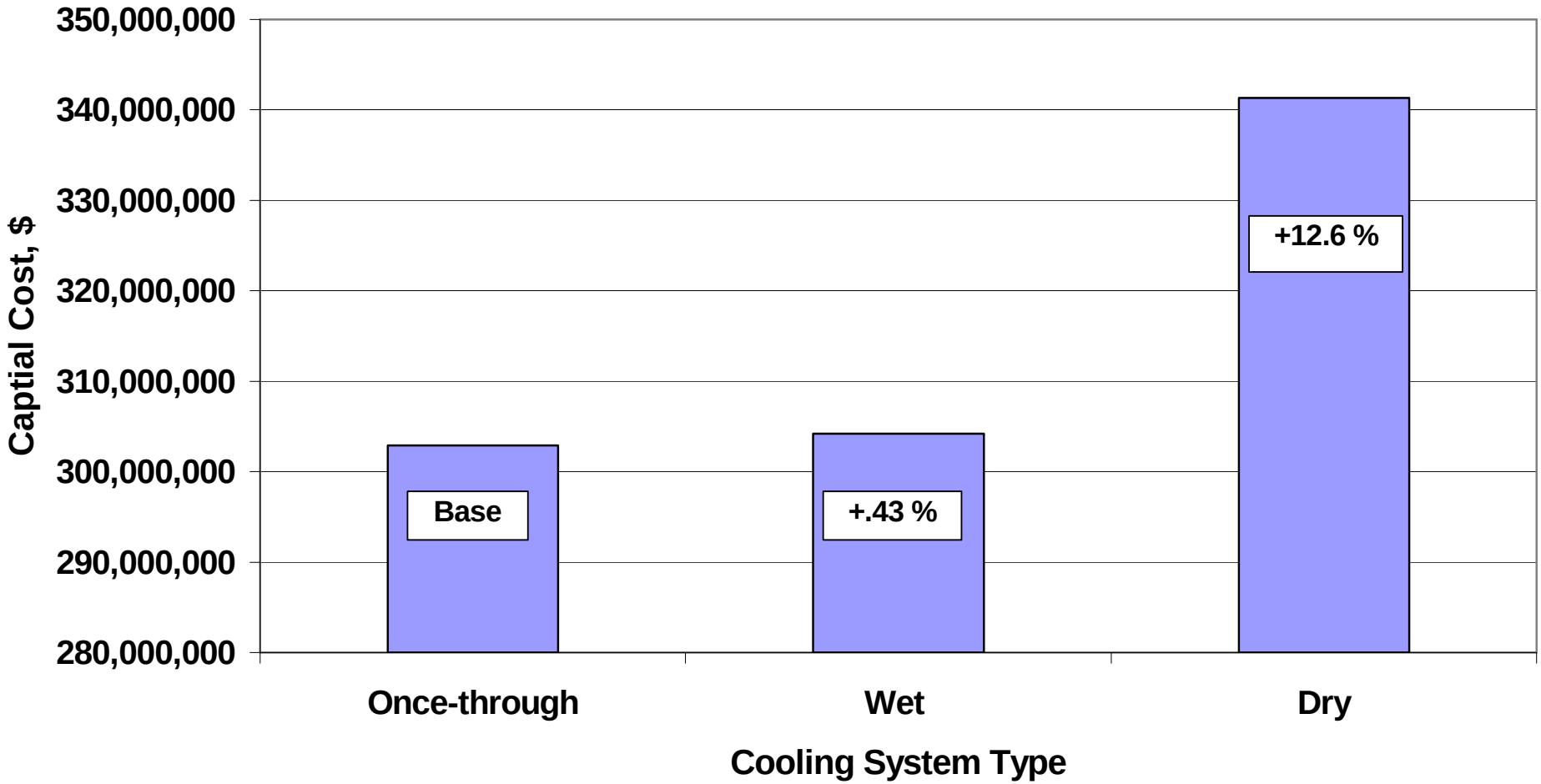

Design Heat Rate---500 MW Combined Cycle Plant
Heat Rate, Btu/kWh
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Base
+0.37 %
+0.71%
Once-through
Wet
Dry
Cooling System Type


Hot Day Capacity Loss---500 MW Combined Cycle Plants
(Includes Effect on Combustion Turbines)
Hot Day Capacity Loss, MW
60
50
40
30
20
10
0
Once-through
Wet
Dry
Cooling System Type

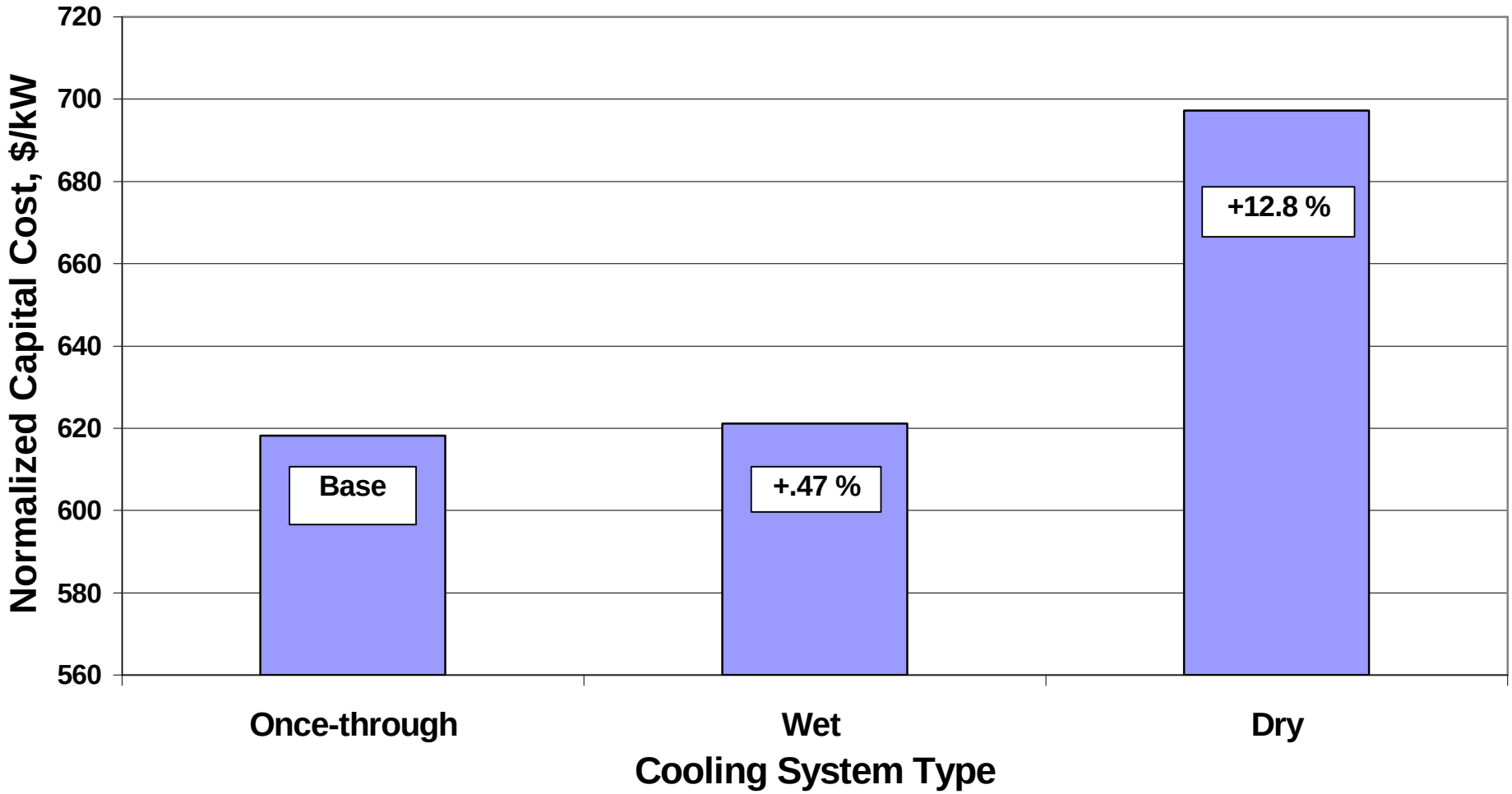

Cooling Water Taken In---500 MW Steam Plant
Cooling Water Taken In, gpm
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Once-through
Wet
Dry

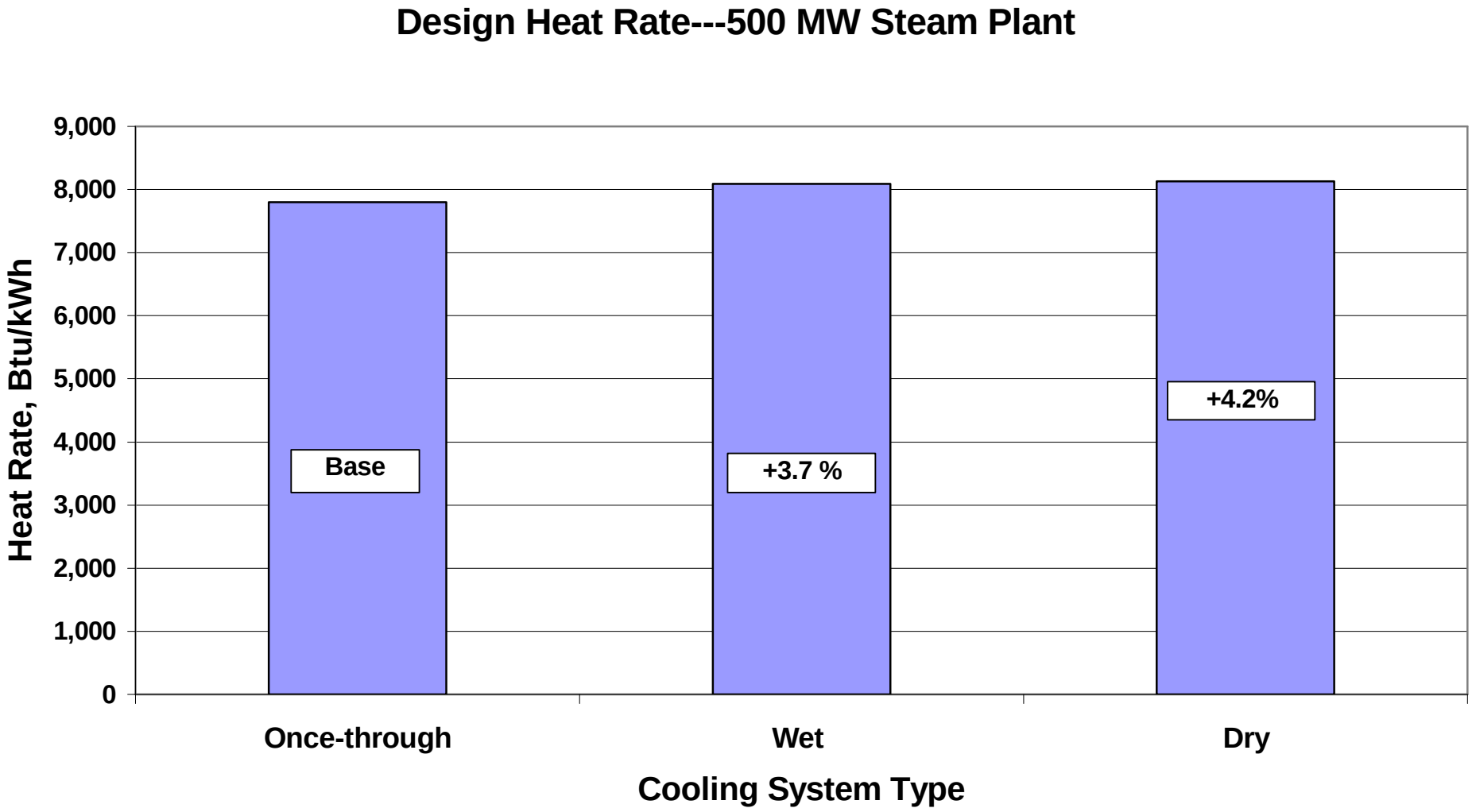

Cooling Water Consumed---500 MW Steam Plant
Water Consumed, gpm
3,500
3,000
2,500
2,000
1,500
1,000
500
0
?
Once-through
Wet
Dry

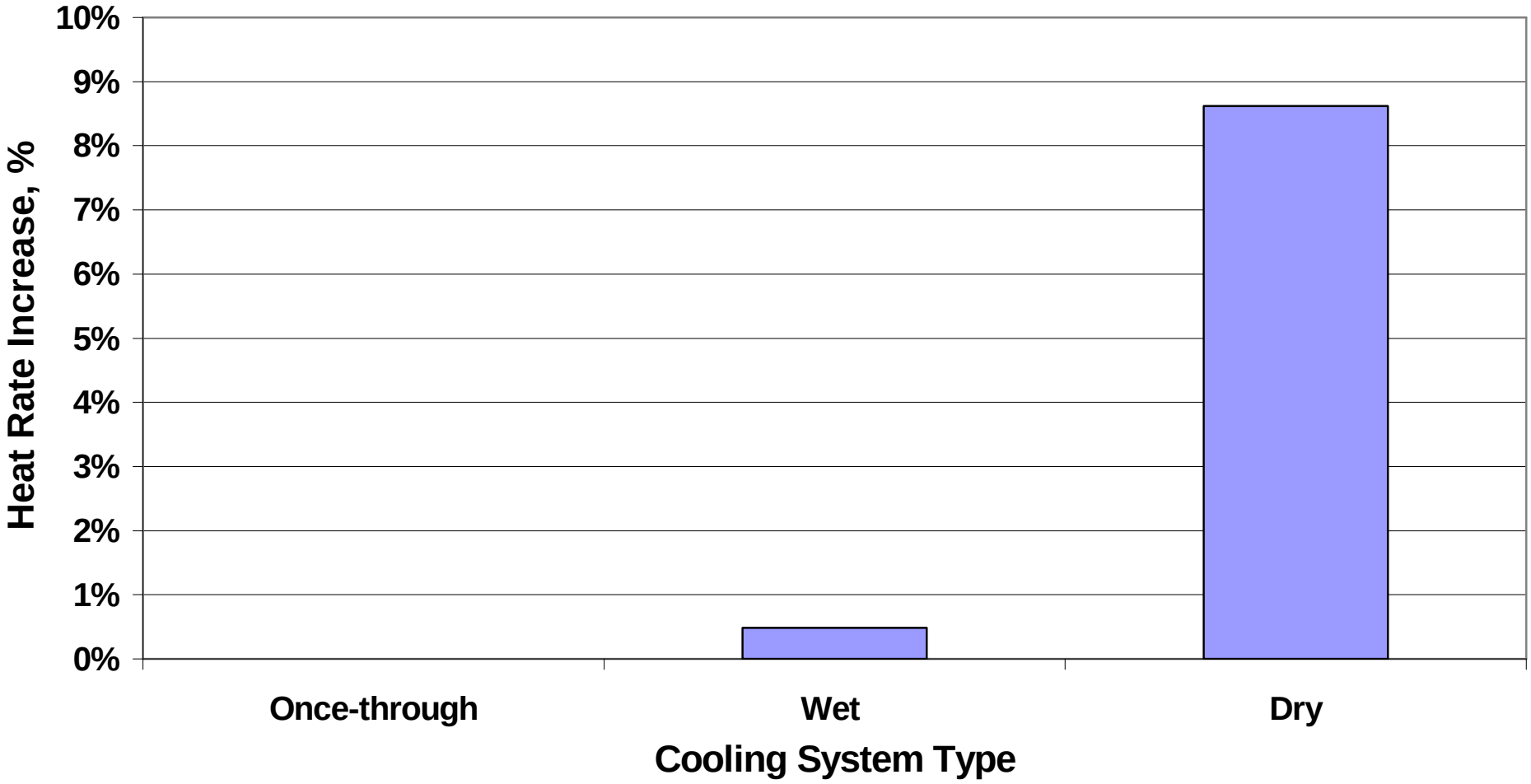
# Capital Cost---500 MW Steam Plant

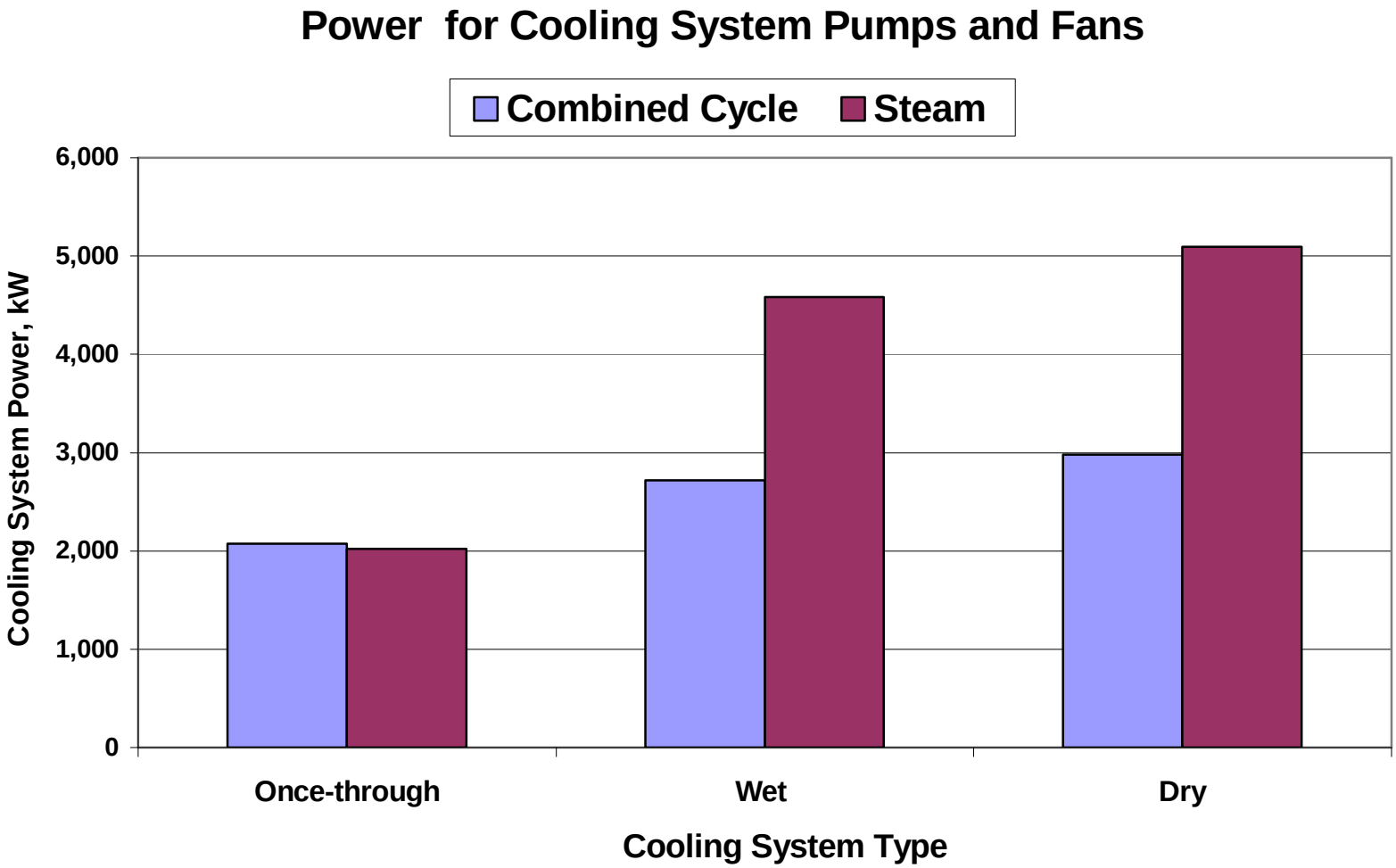


# Normalized Capital Cost---500 MW Steam Plant




Design Heat Rate---500 MW Steam Plant
Heat Rate, Btu/kWh
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Base
+3.7 %
+4.2%
Once-through
Wet
Dry
Cooling System Type

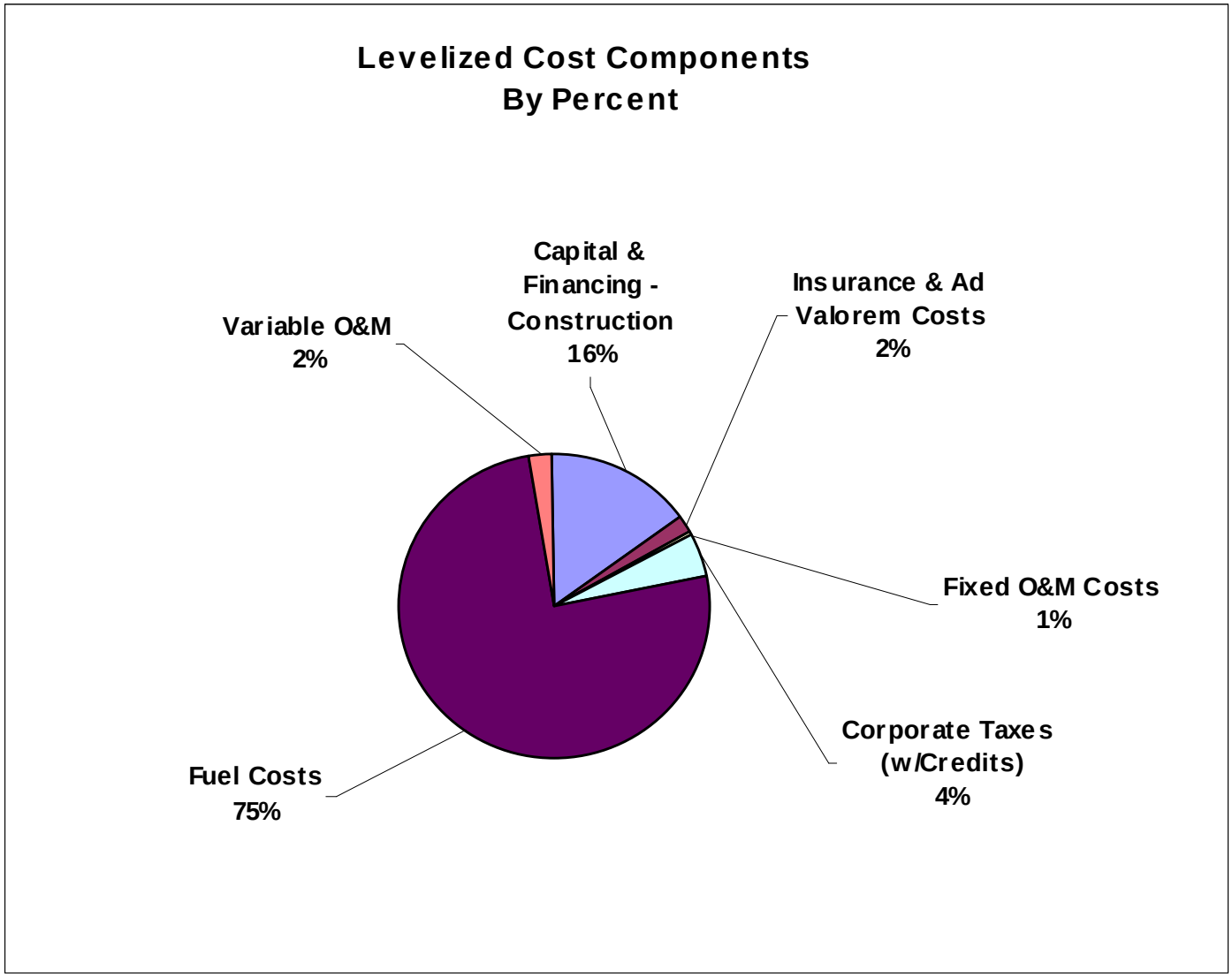

Hot Day Heat Rate Increase---500 MW Steam Plants
Heat Rate Increase, %
10%
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
Once-through
Wet
Dry
Cooling System Type


Power for Cooling System Pumps and Fans
Combined Cycle
Steam
6,000
5,000
4,000
3,000
2,000
1,000
0
Cooling System Power, kW
Once-through
Wet
Dry
Cooling System Type

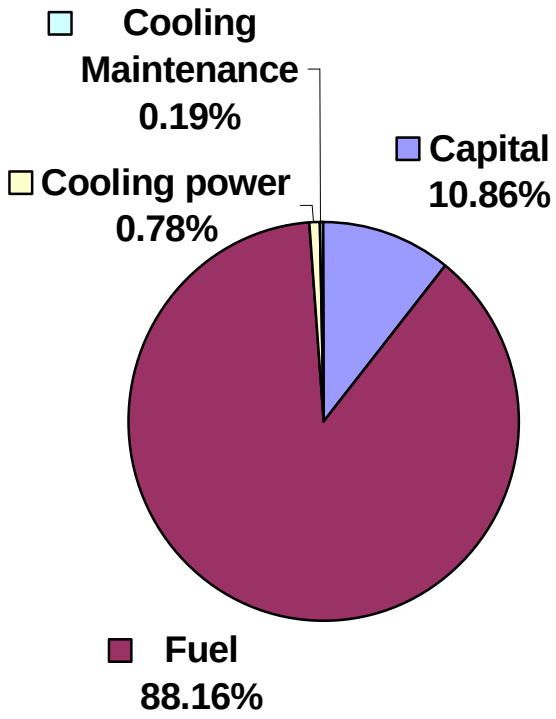
# Maintenance Costs

- ✓ 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

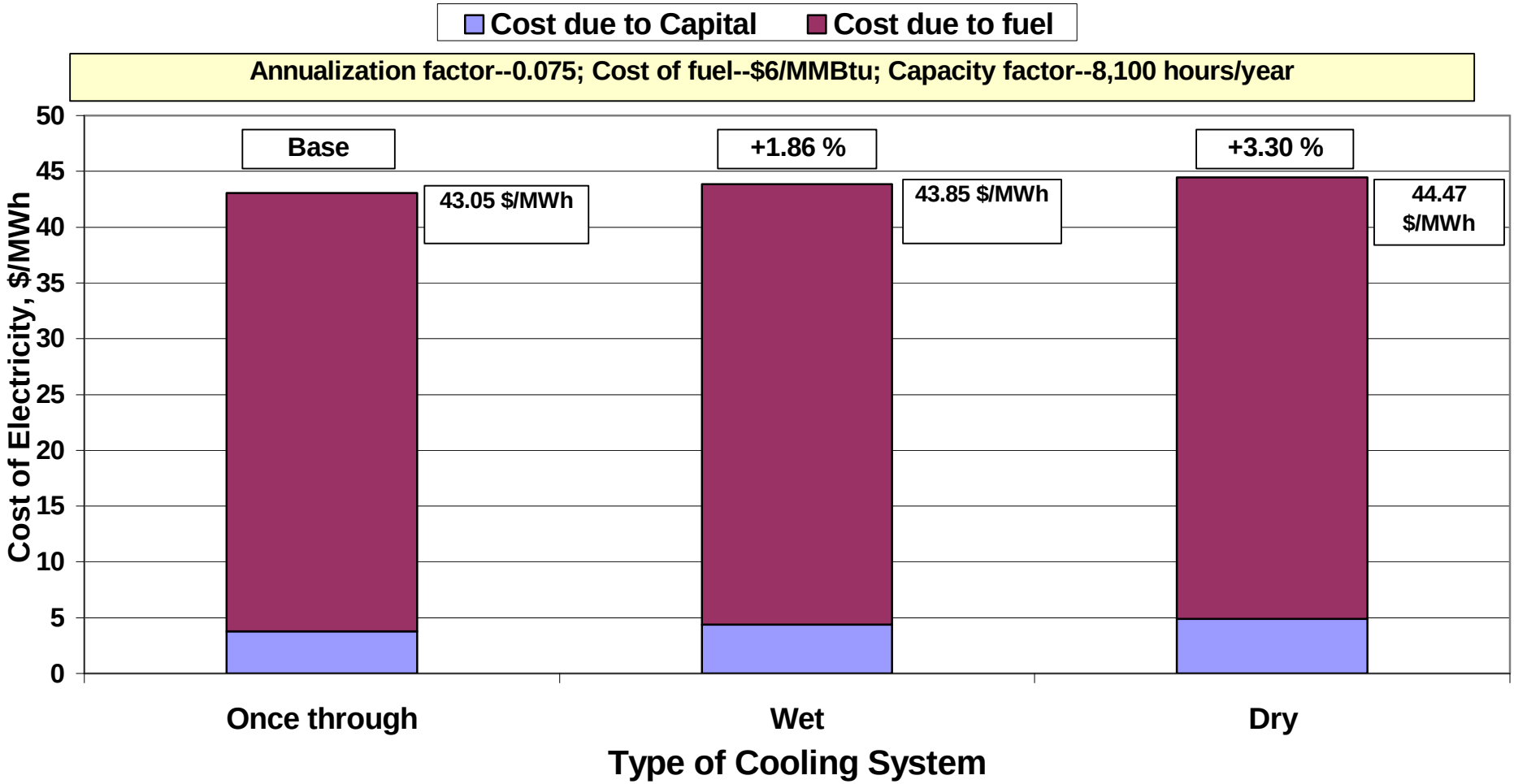
# Levelized Cost Components for Sample Combined-Cycle Natural Gas Power Plant

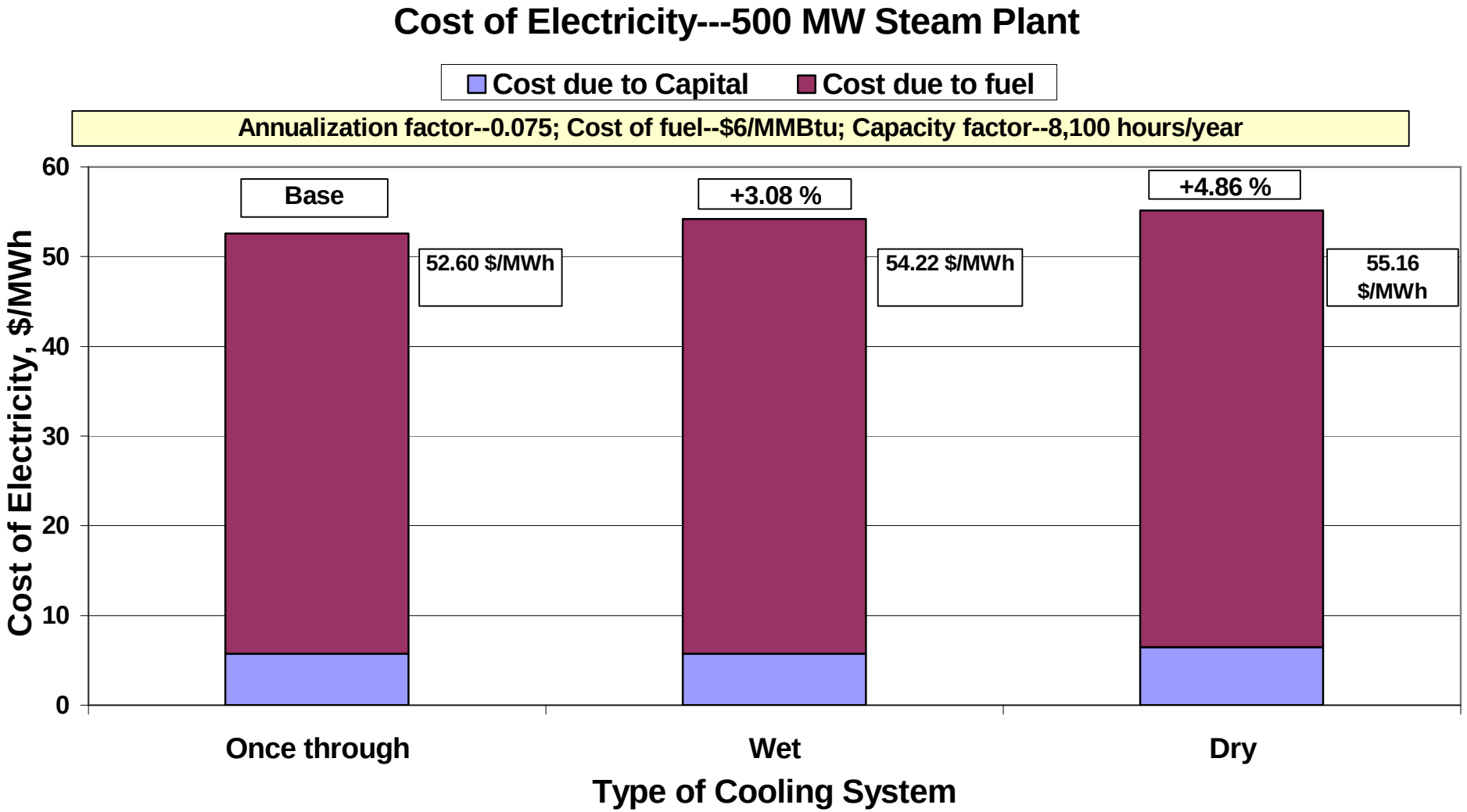


## Production Cost Breakdown---Dry Cooling
## 500 MW Combined-Cycle Plant



# Cost of Electricity---500 MW Combined-Cycle Plant

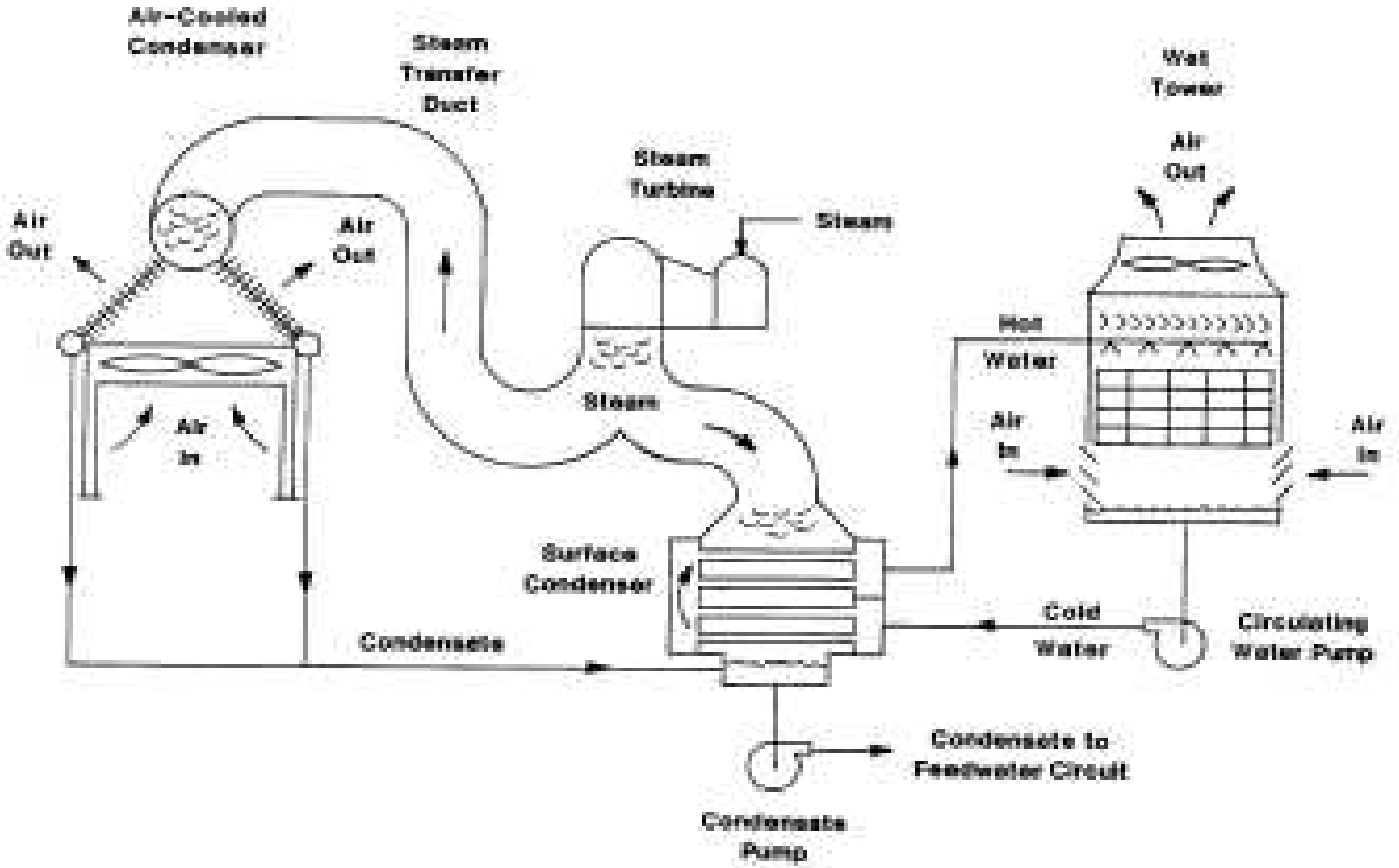



Cost of Electricity---500 MW Steam Plant
Cost due to Capital
Cost due to fuel
Annualization factor--0.075; Cost of fuel--$6/MMBtu; Capacity factor--8,100 hours/year
Cost of Electricity, $/MWh
60
50
40
30
20
10
0
Base
52.60 $/MWh
+3.08 %
54.22 $/MWh
+4.86 %
55.16 $/MWh
Once through
Wet
Dry
Type of Cooling System

# Additional considerations

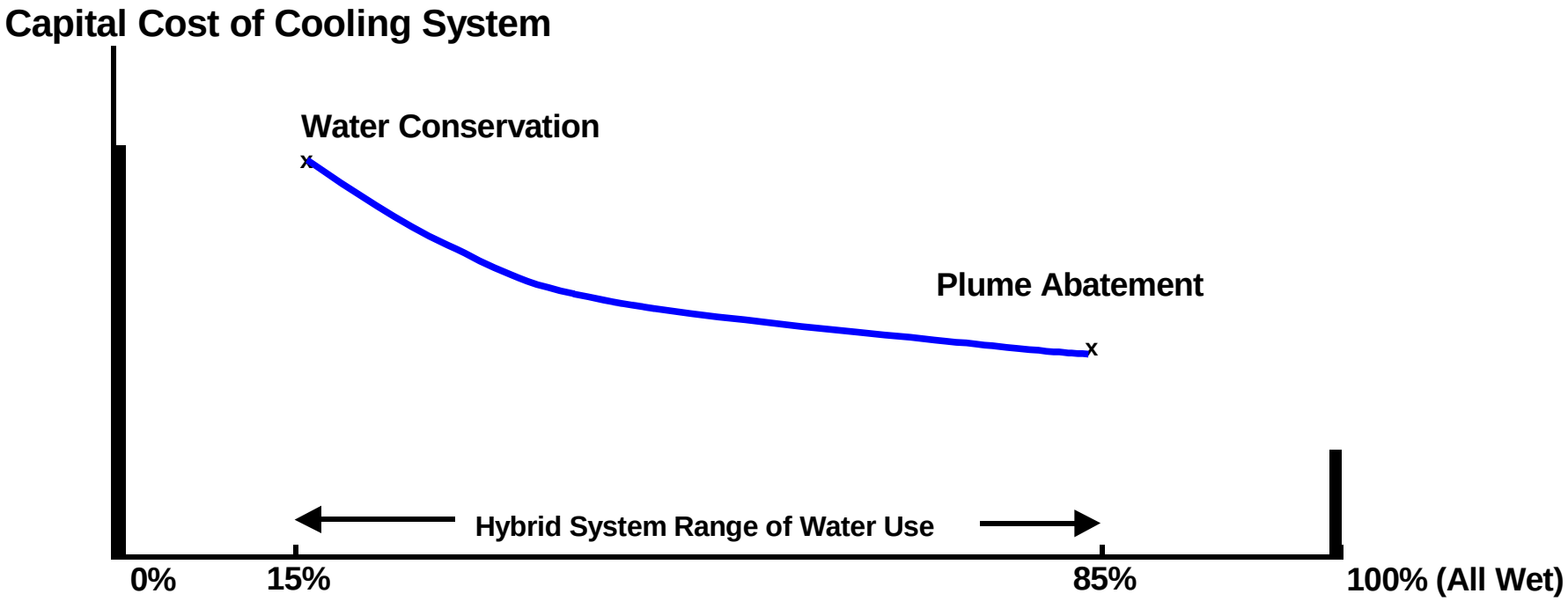
- ✓ Benefit of “a little bit” of water
  - Hybrid (wet/dry) systems
  - Spray enhancement

# Hybrid (wet/dry) system



# Tucuman 450 MW Combined Cycle (Argentina)
# PAC SYSTEM®
# (Air Cooled Condenser & Wet Cooling System)

# Hybrid System Cost Estimate



# 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 | | | | |
|---|---|---|---|---|
| Items for comparison | Cooling System | | | |
| | Once-through | Wet tower | Dry cooling | Hybrid |
| **Plant Cost** | | | | |
| Capital, $ | 198,800,000 | 201,200,000 | 223,700,000 | Variable |
| Normalized Capital Cost, $/kW | 405.7 | 410.6 | 456.5 | Variable |
| | | | | |
| **Performance** | | | | |
| Cooling Sysem Power, kW | 2,075 | 2,720 | 2,980 | Variable |
| Design Heat Rate, Btu/kWh | 6,549 | 6,573 | 2,980 | Close to dry |
| Hot day Capacity Loss, MW | Base | 2.7 | 26.1 | Close to wet |
| | | | | |
| **Water** | | | | |
| Water taken in, gpm | 132,410 | 2,290 | 0 (for cooling) | 20 - 30% of wet |
| Water consumed, gpm | *De minimis ??* | 2,048 | 0 (for cooling) | " |

# Summary—Steam Plants

| 500 MW Steam Plant | | | | |
|---|---|---|---|---|
| Items for comparison | Cooling System | | | |
| | Once-through | Wet tower | Dry cooling | Hybrid |
| **Plant Cost** | | | | |
| Capital, $ | 302,900,000 | 304,200,000 | 341,300,000 | Variable |
| Normalized Capital Cost, $/kW | 405.7 | 410.6 | 456.5 | Variable |
| | | | | |
| **Performance** | | | | |
| Cooling Sysem Power, kW | 2,021 | 4,580 | 5,095 | Variable |
| Design Heat Rate, Btu/kWh | 7,800 | 8,088 | 8,129 | Close to dry |
| Hot day Heat Rate, Btu/kWh | Base | 0.48% | 8.62% | Close to wet |
| | | | | |
| **Water** | | | | |
| Water taken in, gpm | 180,500 | 3,680 | 0 (for cooling) | 20 - 30% of wet |
| Water consumed, gpm | *De minimis ??* | 2,940 | 0 (for cooling) | " |