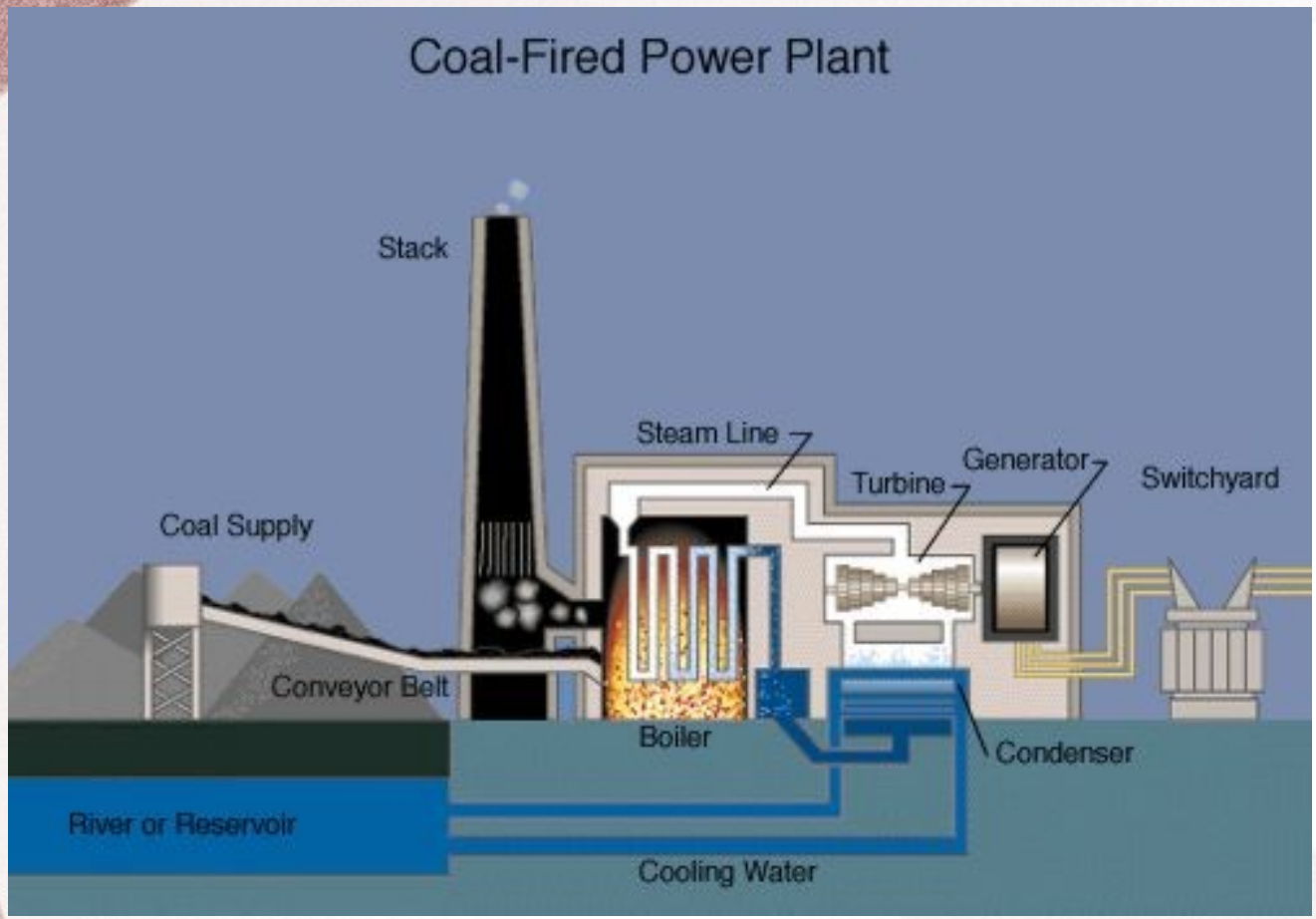
Electricity

Part 4: Power Plants, Distribution and Cooling,

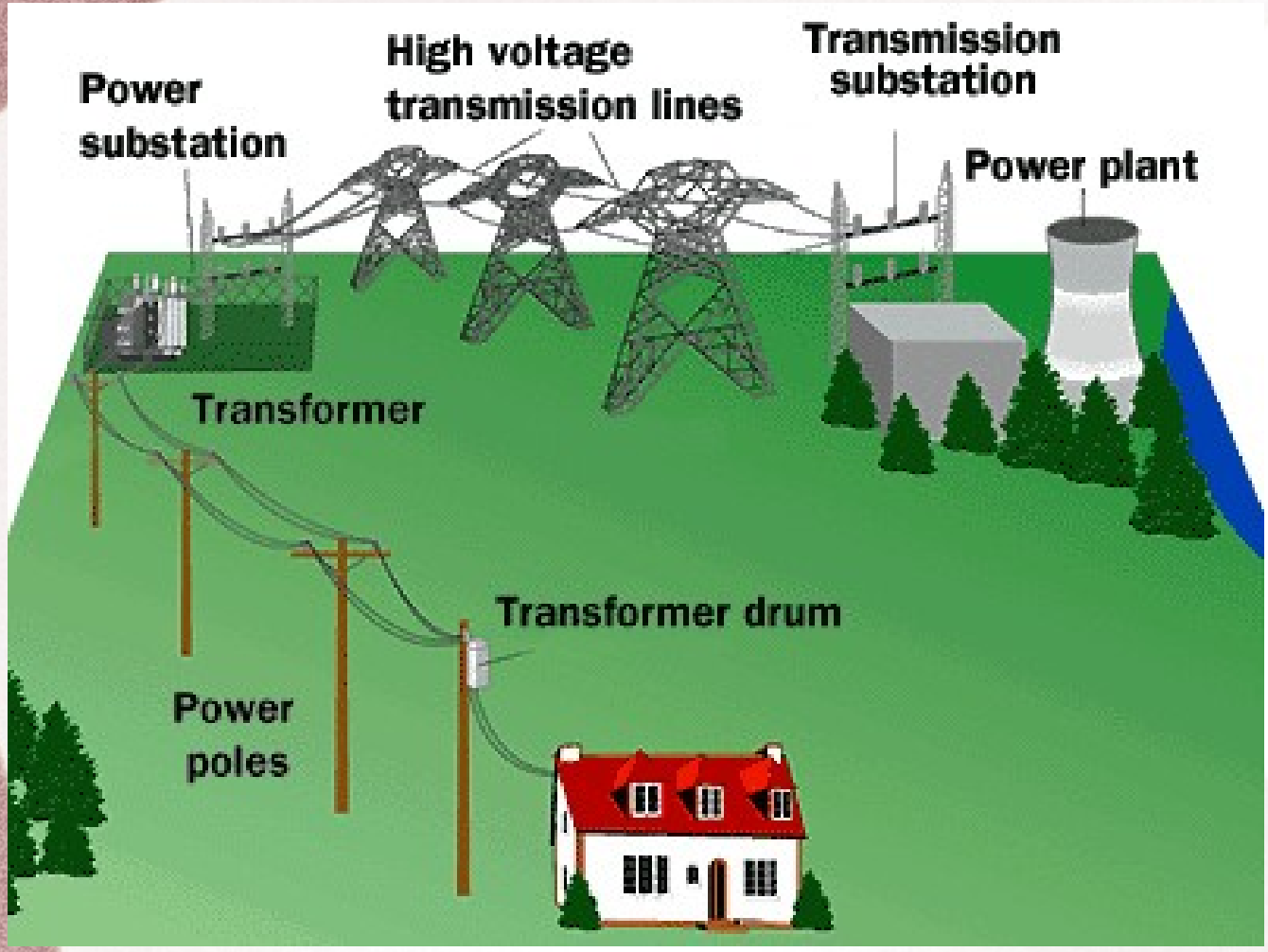
Original slides provided by Dr. Daniel Holland

Typical Coal Fired Power Plant



Audio Link

Power Distribution



- For Long Distances, use very high voltage: up to 750,000 Volts.
- For shorter distances use ~50,000 Volts
- Locally step down to wall voltage
- Use TRANSFORMERS to change voltages either up or down.

Advantage to High Voltage Transmission

- Minimizes losses in power lines
- Transmitted power is $P=IV$. If V is high, then I can be low.
- Losses in line are $P_{loss}=I^2R$

Example: Assume $R_{line}=3\Omega$, and P=1GW

- Case 1 V=50,000 V

$$I = \frac{P}{V} = \frac{10^9 W}{5 \times 10^4 V} = 20{,}000 A$$

Thus

$$P_{loss} = I^2 R_{line} = (2 \times 10^4 A)^2 (3\Omega)$$

$$= 1.2 \times 10^9 W$$

- This is more than we have, i.e. all our power is lost in transmission.

- Case 2 V=500,000 V

$$I = \frac{P}{V} = \frac{10^9 W}{5 \times 10^5 V} = 2{,}000 A$$

Thus

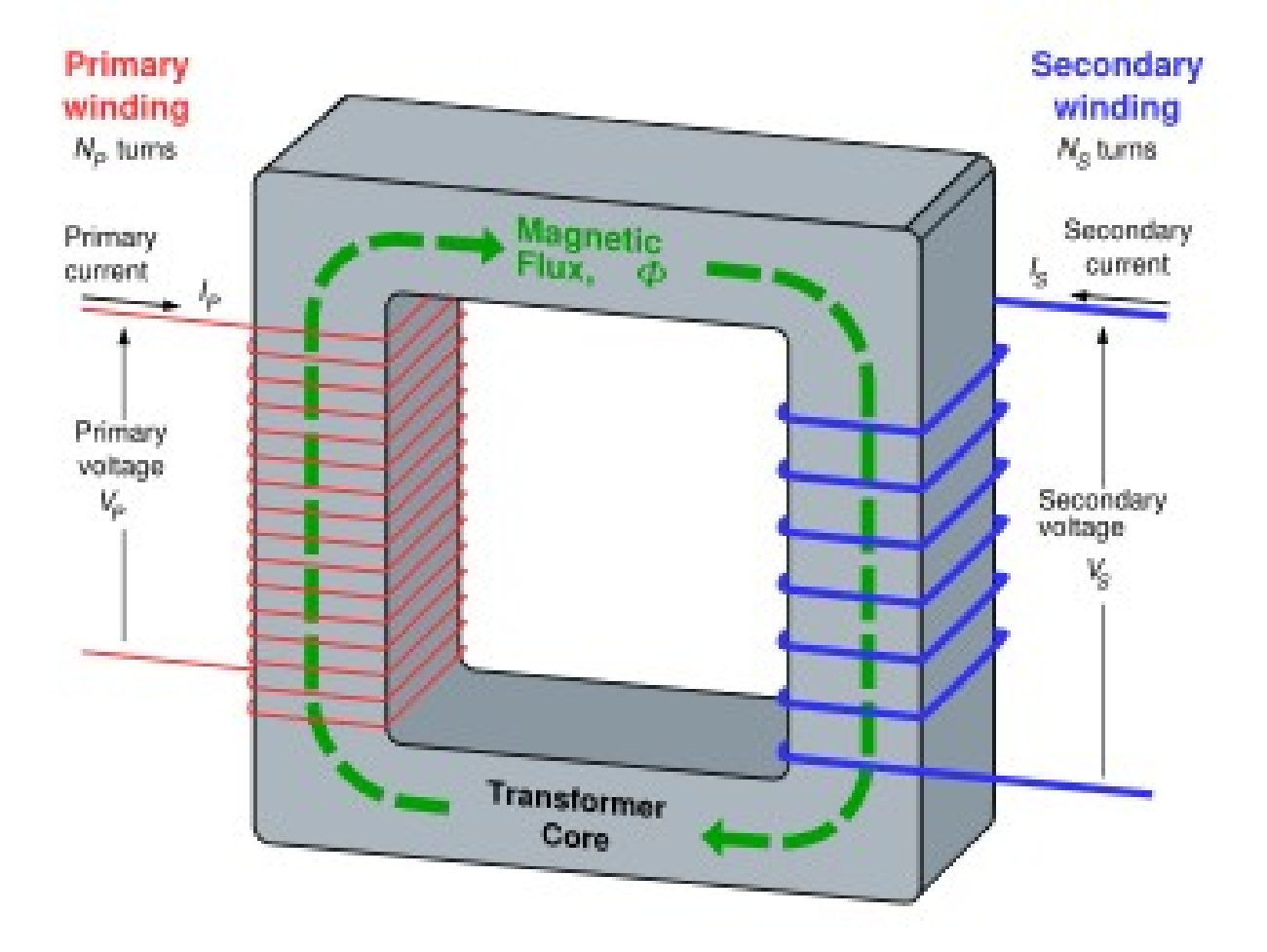
$$P_{loss} = I^2 R_{line} = (2 \times 10^3 A)^2 (3\Omega)$$

$$= 1.2 \times 10^7 W$$

- Here we only lose 1.2% of total power in transmission

- We only want to go short distance without much power at low voltages.
- Transformers make it possible to raise and lower voltages with essentially no power loss.
- This is the main reason we use AC power.

Transformer



Cooling the plant.

- We have to dispose of at least as much energy as we generate. (Power plants do not operate above 50% efficiency due to 2nd law.)
- Usually remove the waste heat with a continuous supply of water.
- Question: How much water do we need?

Estimate the amount of water per megawatt

- Assume we only want the water to raise 14°F (7°C).

$$P = \frac{Q}{t} = \frac{m}{t} C \Delta T$$

Thus

$$\frac{m}{t} = \frac{P}{C \Delta T} = \frac{10^6 W}{\left(4186 \, J/kg\,^{o}C\right)\left(7\,^{o}C\right)}$$

$$= 34.1 \, kg/s$$

$$= 34.1 \, liter/s$$

$$= 9 \, gal/s$$

- For 1 MW this is easy, but a typical power plant is 1000 MW.
- To keep the temperature of the water from rising more than 14°F on a 1000 MW = 1GW plant we would need approximately 9000 gallons per second. (Almost 800 million gallons per day.) (Approximately 6000 swimming pools per day.)
- To keep the temperature for rising only ~5°F we would need ~3 time as much water.

- Total freshwater runoff in the US is approximately 1200 billion gallons per day (this includes floods)
- Electrical plants need approximately 400 billions of gallons per day.

US Water Usage

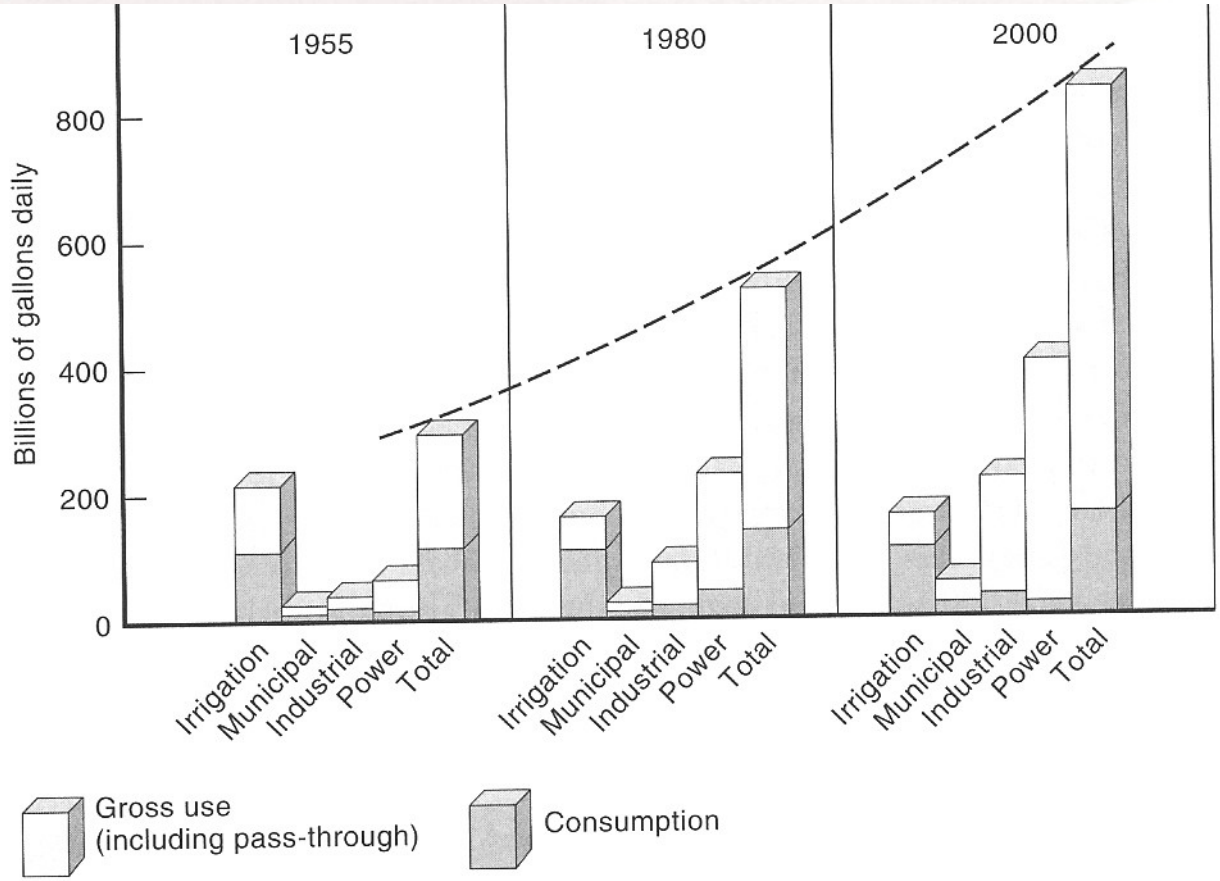
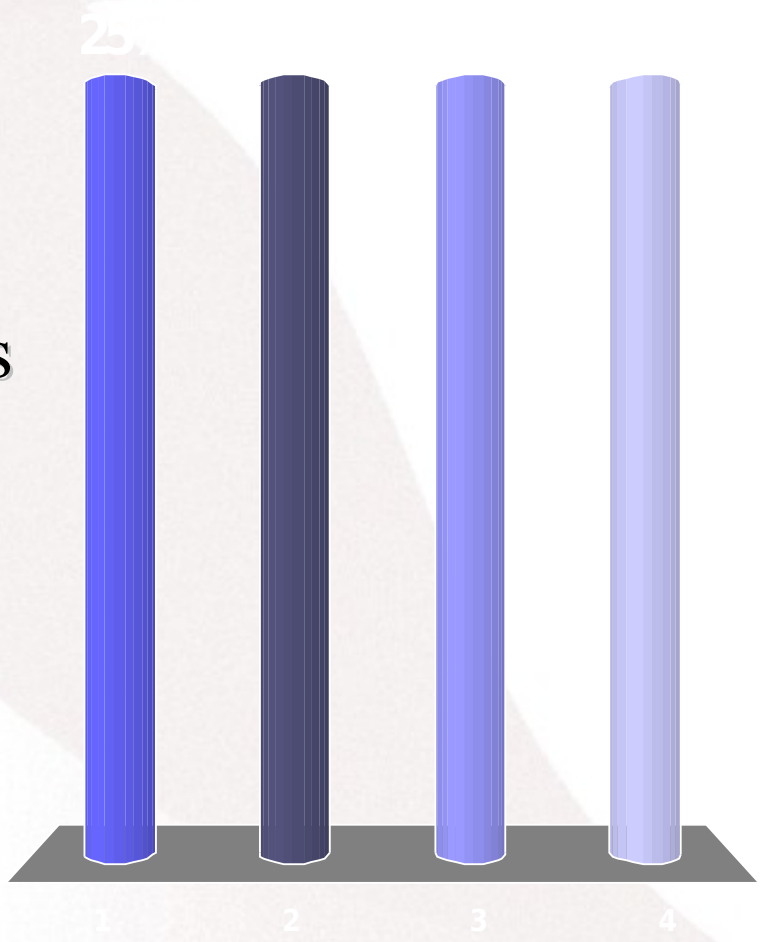


Figure 9.8

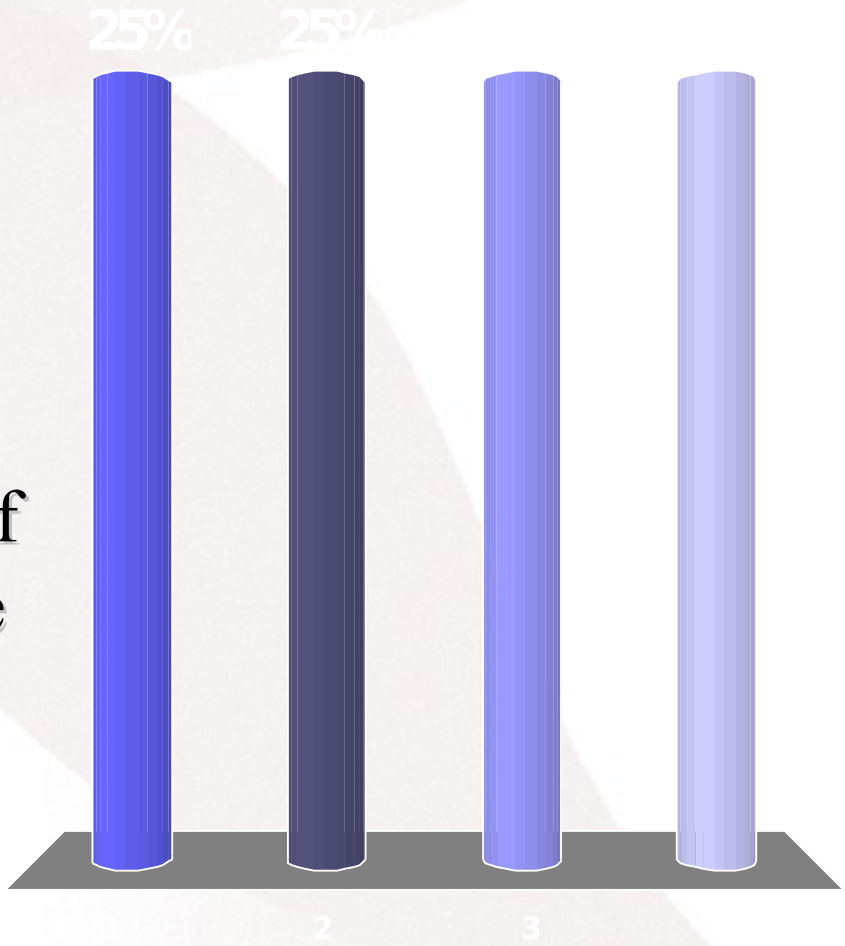
Why do power companies use high voltages to transmit electric power over long distances?

1. To increase the current in the power line.
2. To decrease the resistance of the power line.
3. To reduce transmission losses
4. To keep squirrels and small children away from power lines.



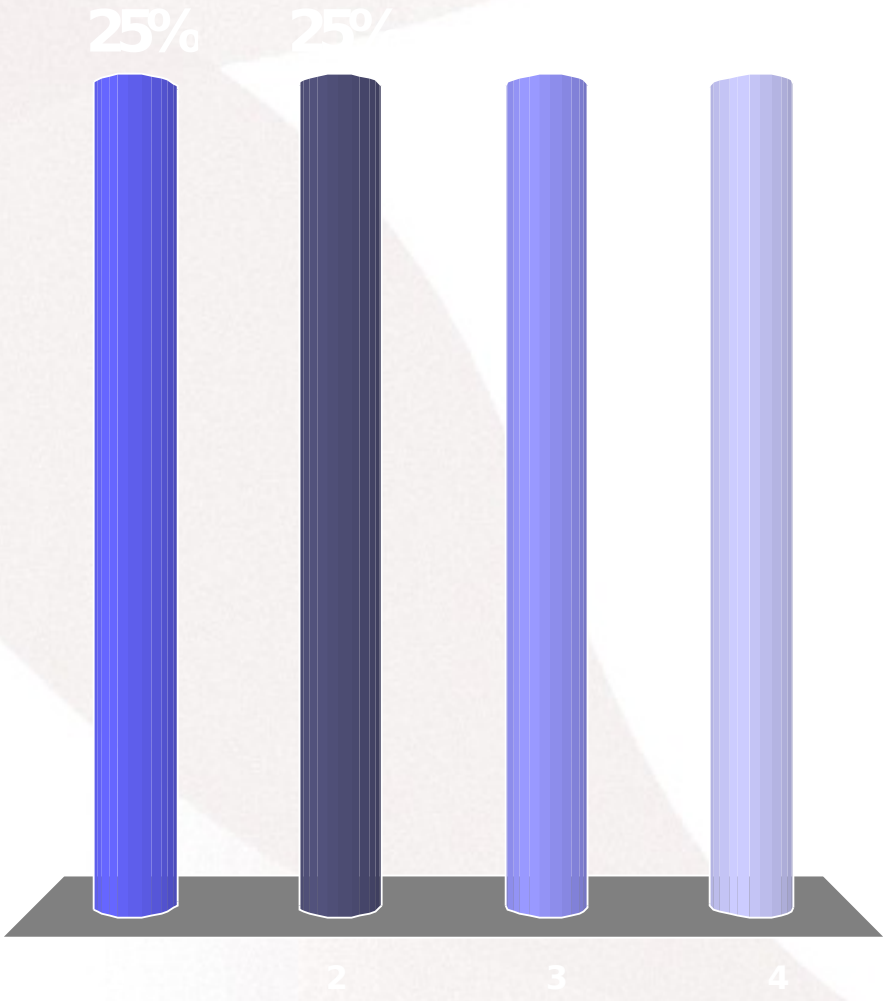
According to Faraday's Law, we may induce a voltage in a loop of wire immersed in a magnetic field by

1. Changing the area of the loop
2. Changing the strength of the magnetic field passing through the loop
3. Changing the orientation of the loop with respect to the magnetic field
4. All of the above



What is the primary advantage of AC power over DC power?

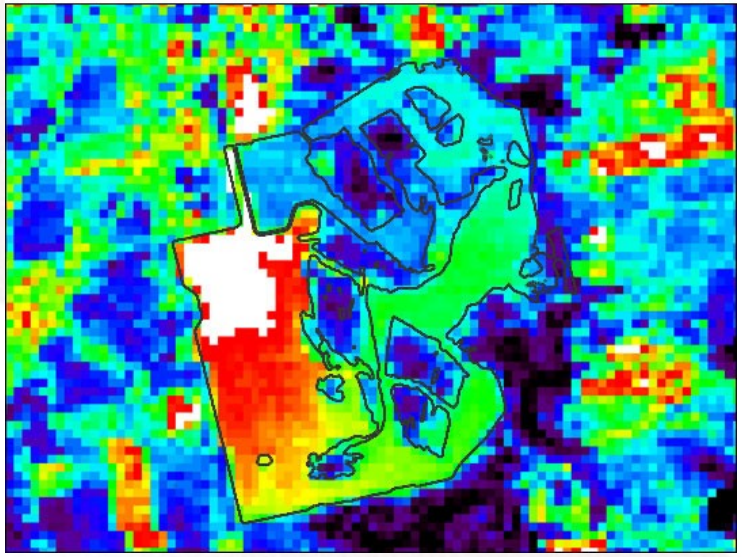
1. It is safer.
2. It is more reliable.
3. We can easily change the voltage.
4. It has more groovitute.



Methods of Cooling

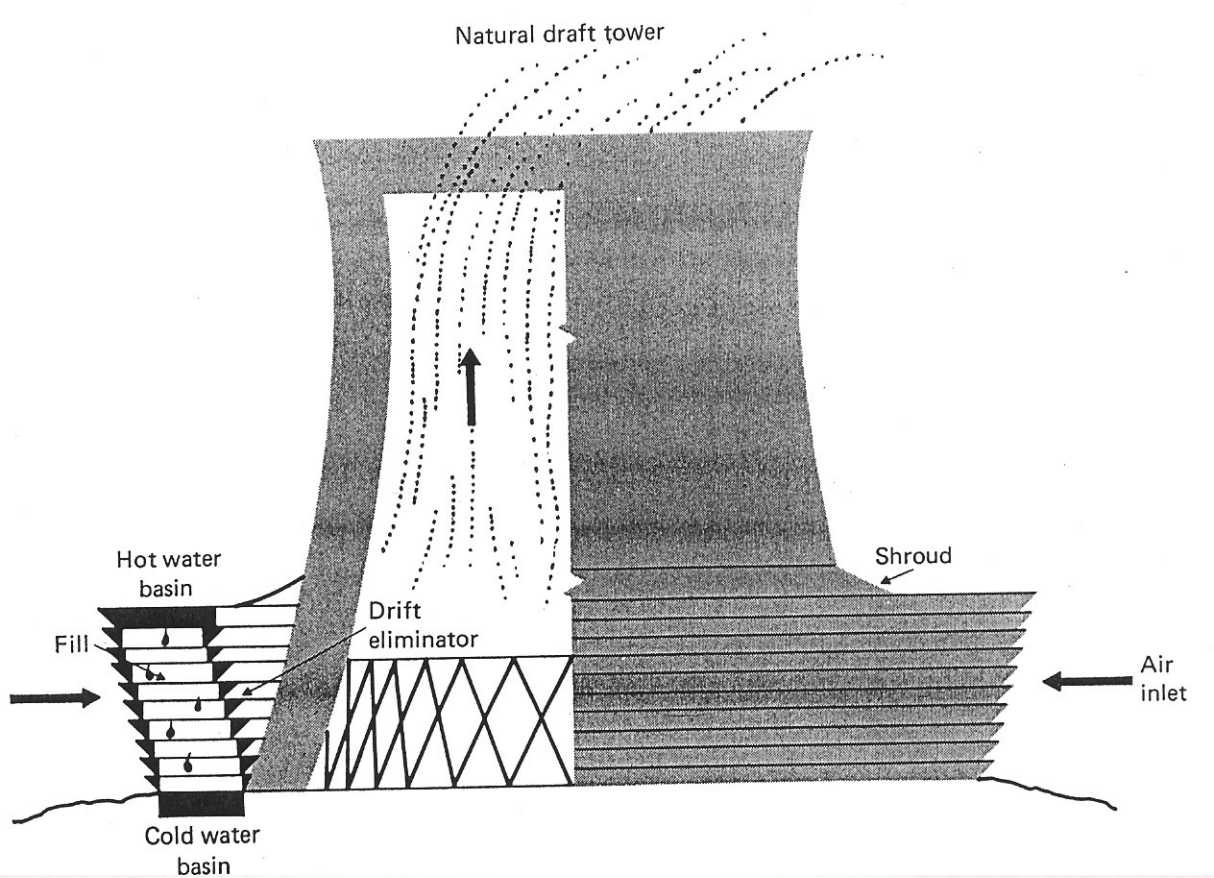
- Once through cooling: Requires a good size river OR a good size reservoir.
- Least Expensive Method

- Infrared imaging of the power plant near Joliet

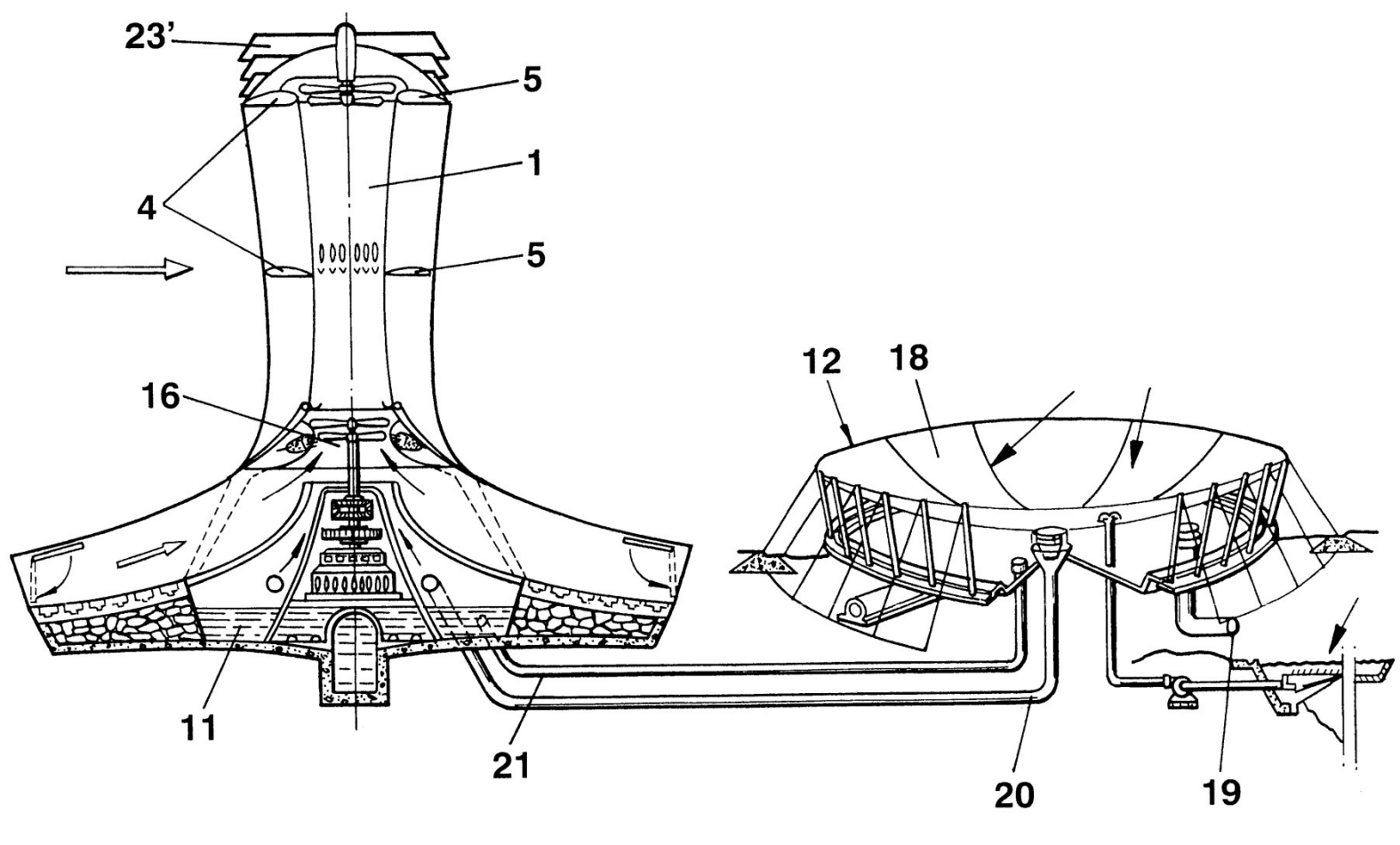


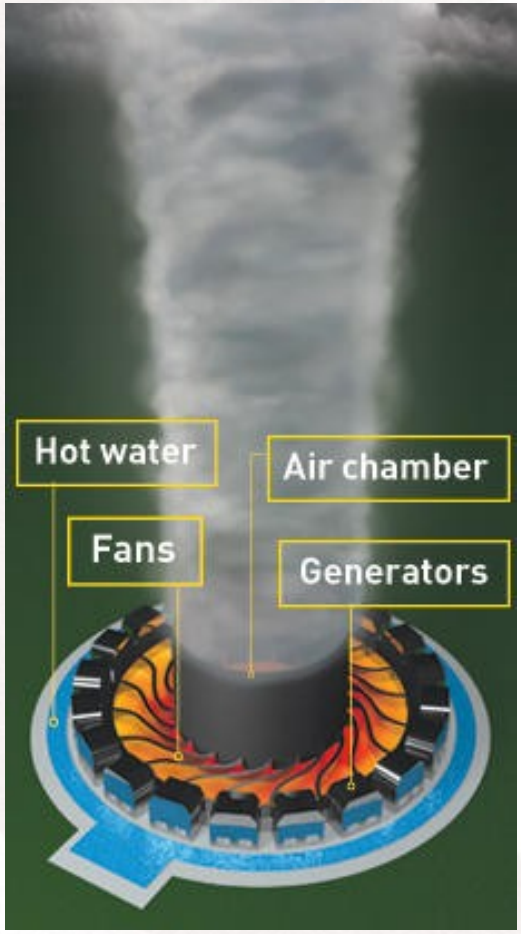
- Wet Cooling Tower
- Extremely large towers 400 ft high and 400 ft across.
- ~2% of water passing through evaporates, approximately 225 gallons per second.
- Enough water to cover 1mi^2, 1 in deep in water every day.

Shape enhances natural air flow

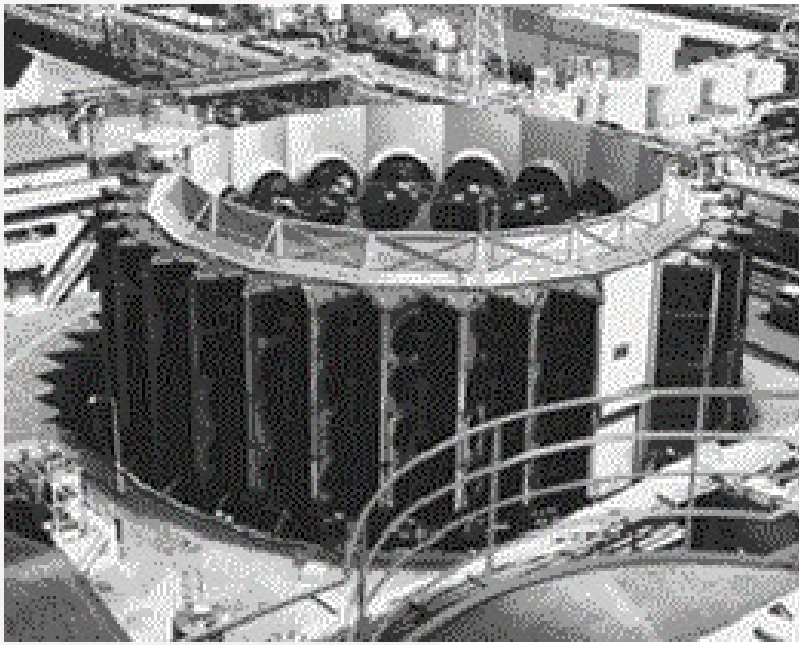


Vortex engine powered by excess heat




Hot water
Air chamber
Fans
Generators

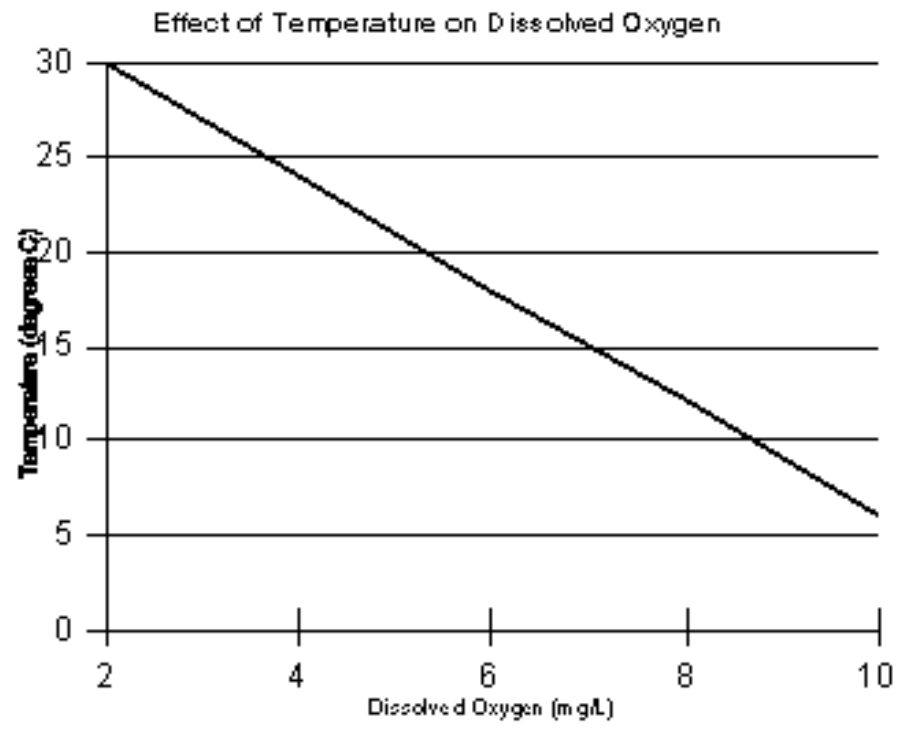
- Dry Cooling
- Used in places without access to large supplies of water.
- Much More costly than once through or wet cooling.
- Looses efficiency if ambient temperature much above 90°F.
- Sort of like a big car radiator.



- Since 1977 power plants have been required to dispose of wet heat without directly dumping it into the aquatic environment.
- Must construct cooling ponds or towers.

Effects of Increased Water Temperature

- Amount of oxygen dissolved in water decreases with temperature
- Most fish simply can't stand warm water and/or low levels of dissolved oxygen.



- Increased rate of chemical reactions
- Changes in reproduction, behavior, and growth patterns throughout the food chain.
- Long term damage to natural bodies of water.

Preferred Temperature Ranges for Fish

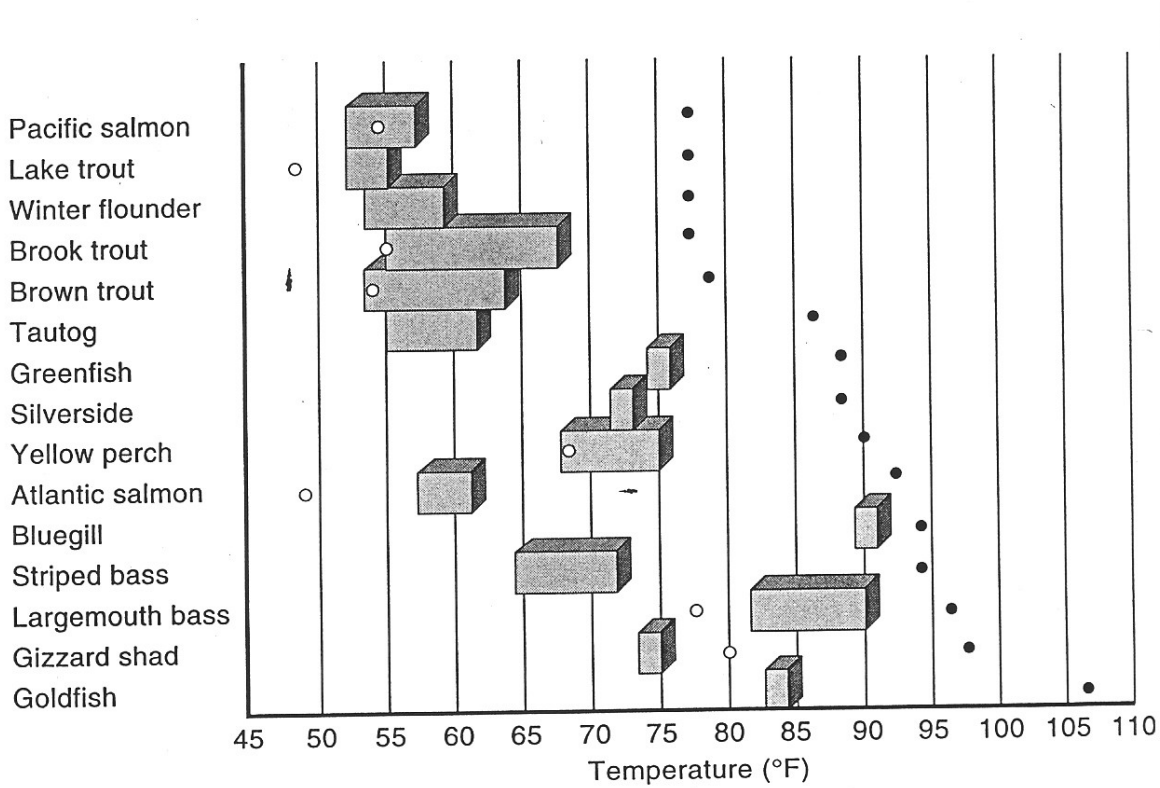


FIGURE 9–11

Sensitivity of fish to temperature. Preferred temperature ranges for some species, as determined in the field and laboratory, are shown as blocks ■. The solid dot ● indicates the upper lethal limit. The open dot ○ is the temperature found to be best for spawning.

(J. CLARK, "THERMAL POLLUTION AND AQUATIC LIFE," *SCIENTIFIC AMERICAN*, MARCH, 1969)

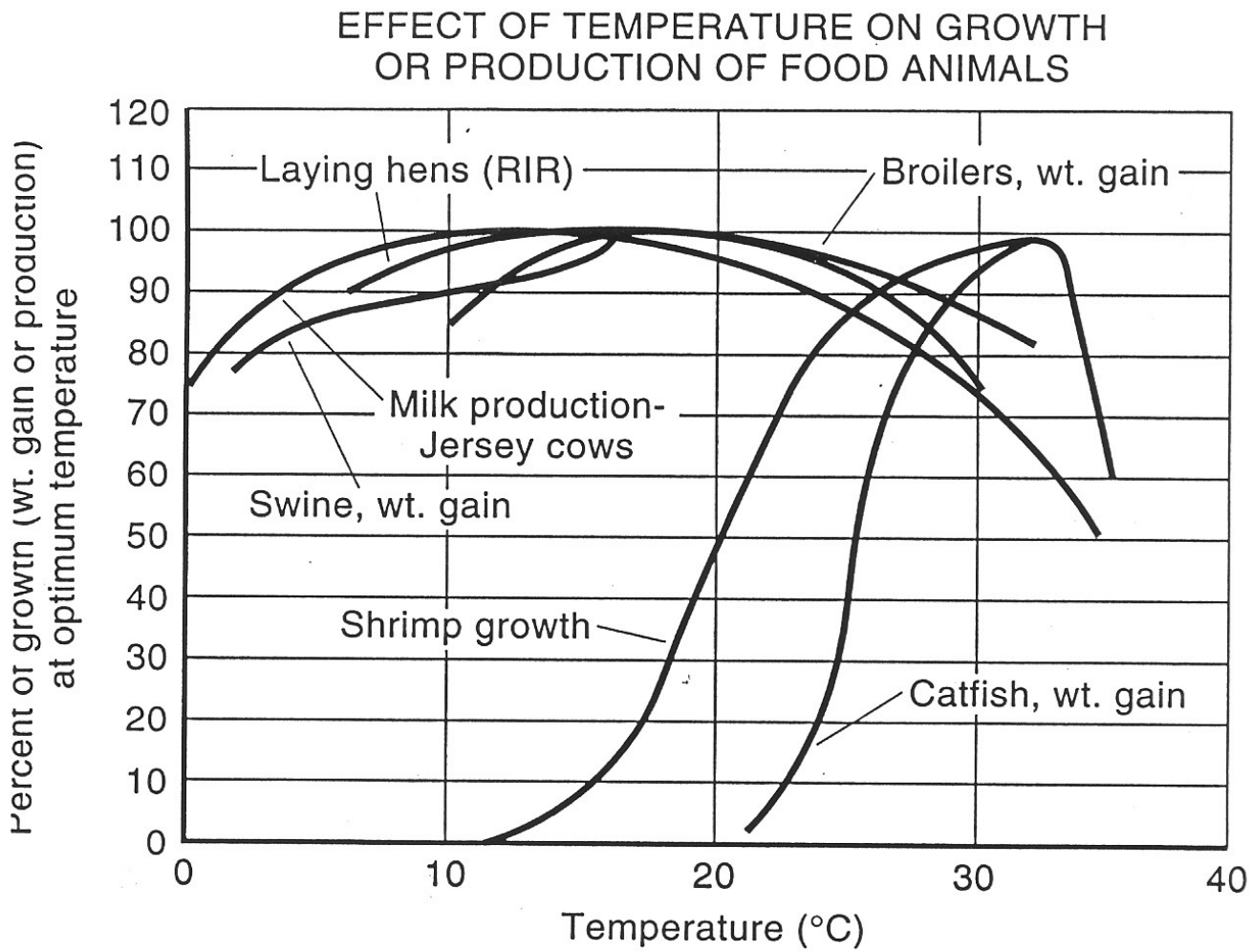


FIGURE 9–12

Effect of temperature on growth and production of food animals. (Oak Ridge National Laboratory, July 1972, ORNL-4797)

Stratification of lake in the summer

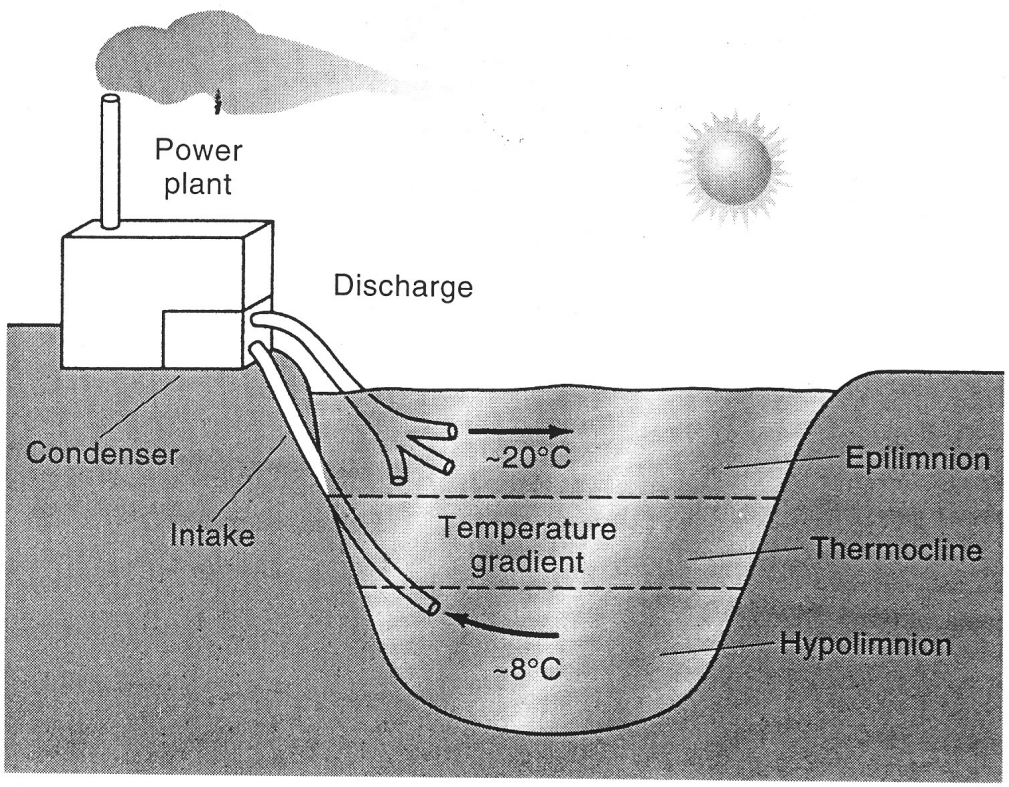


FIGURE 9–13

- In the winter the top layer becomes colder and sinks to the bottom
- This take Oxygen rich water down and brings up nutrient rich water.
- A power plant doesn’t allow this mixing to happen for as long.
- Bottom dwelling animals have less oxygen
- Discharge water from the bottom is rich in nutrients (Nitrogen and phosphorus) that stimulate algae and plant growth

- This can cause a mat of green scum on the surface that is toxic to many species.
- Dead algae sinks to bottom and is decomposed using up even more of the oxygen at the bottom.
- This can eventually lead to the “death” of the lake.

Eutrophication

- The process in which a body of water is enriched by the addition of extra nutrients, stimulating the growth of algae