4|Principles of Generation

- Generator Basics
- Energy Sources
- Energy Conversion
- Generating Plants
  - Hydro
  - Coal
  - Combustion Turbine and Combined Cycle
  - Wind
  - Solar
  - Nuclear
  - Other

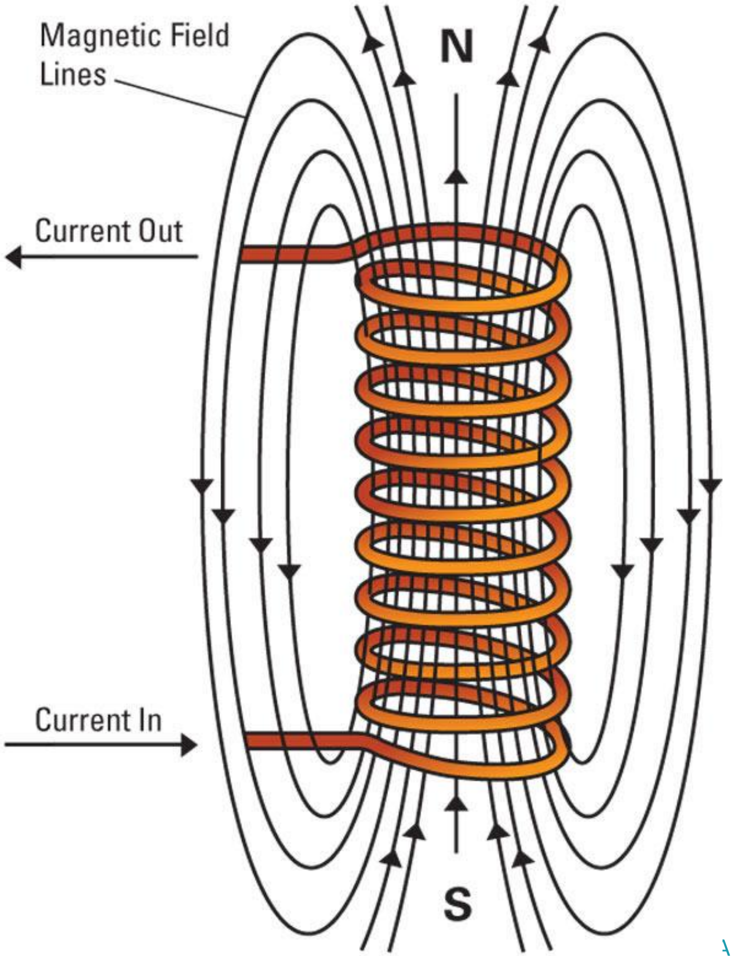
Course Outline

1. Introduction to WECC
2. Fundamentals of Electricity
3. Power System Overview
4. Principles of Generation
5. Substation Overview
6. Transformers
7. Power Transmission
8. System Protection
9. Principles of System Operation

Generator Basics

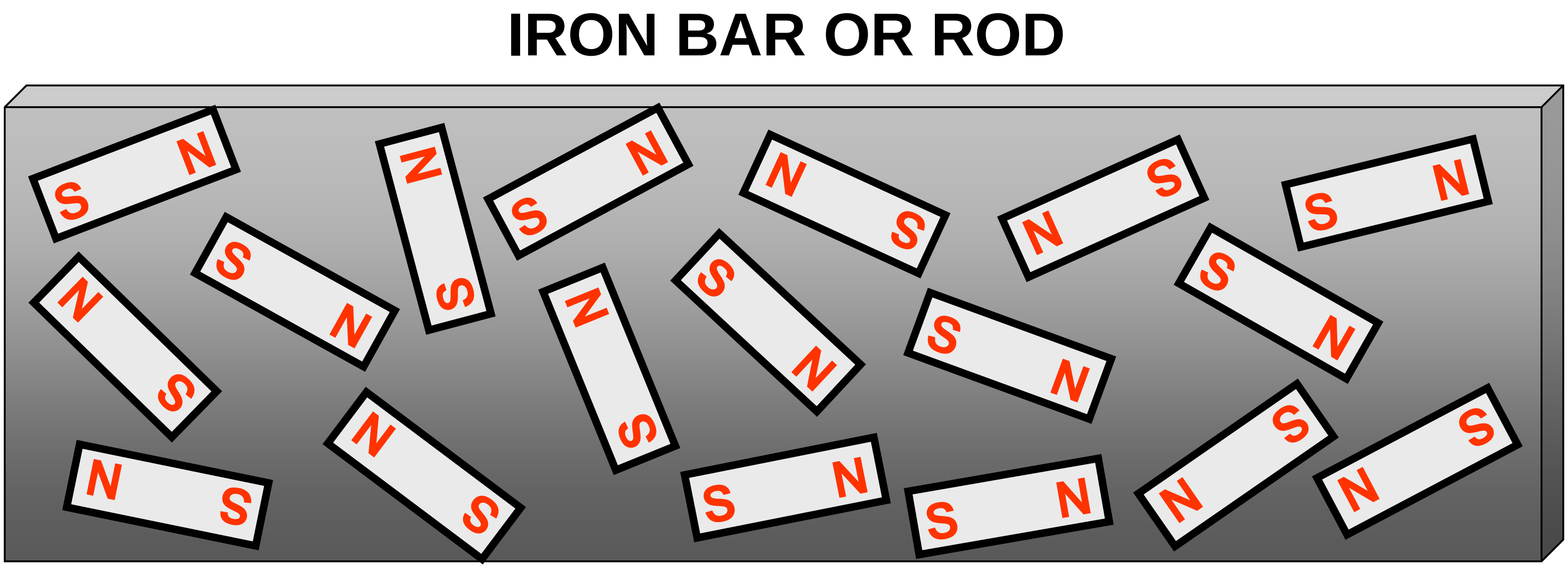
Generator Basics
Magnetism and Induction

Magnetism



Generator Basics
Magnetism and Induction

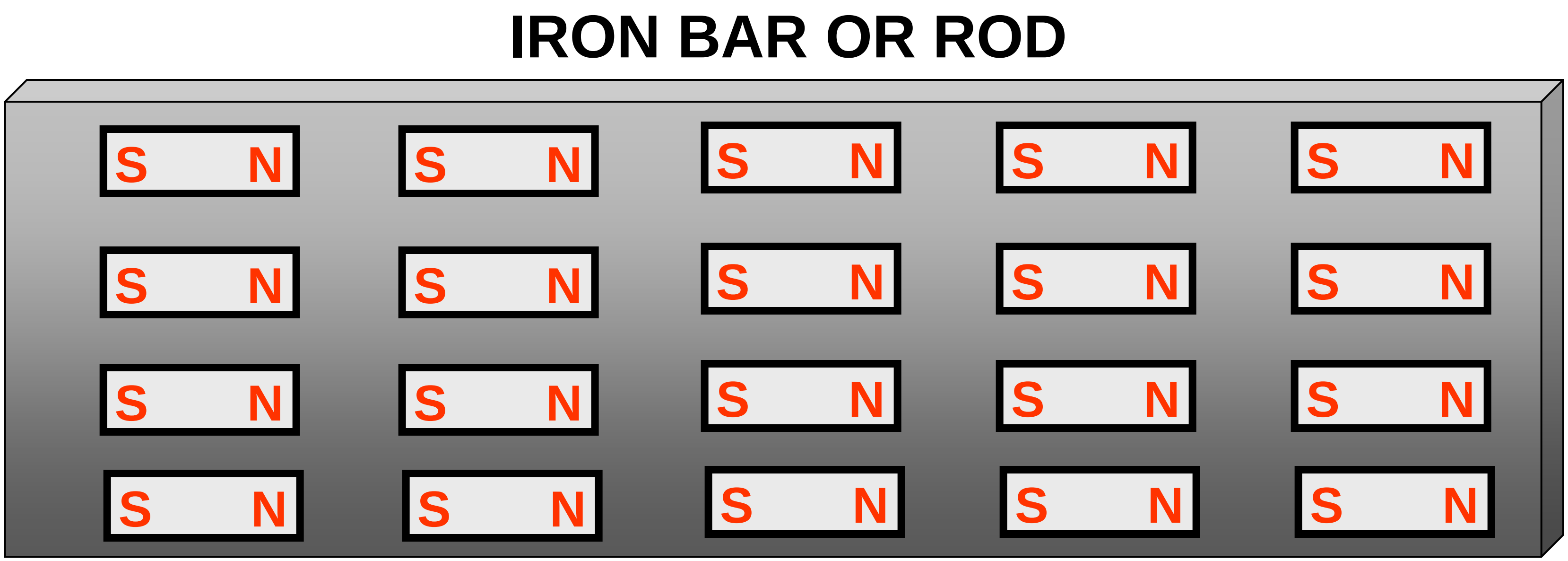
Random Magnetic Domains



Iron Not Magnetized

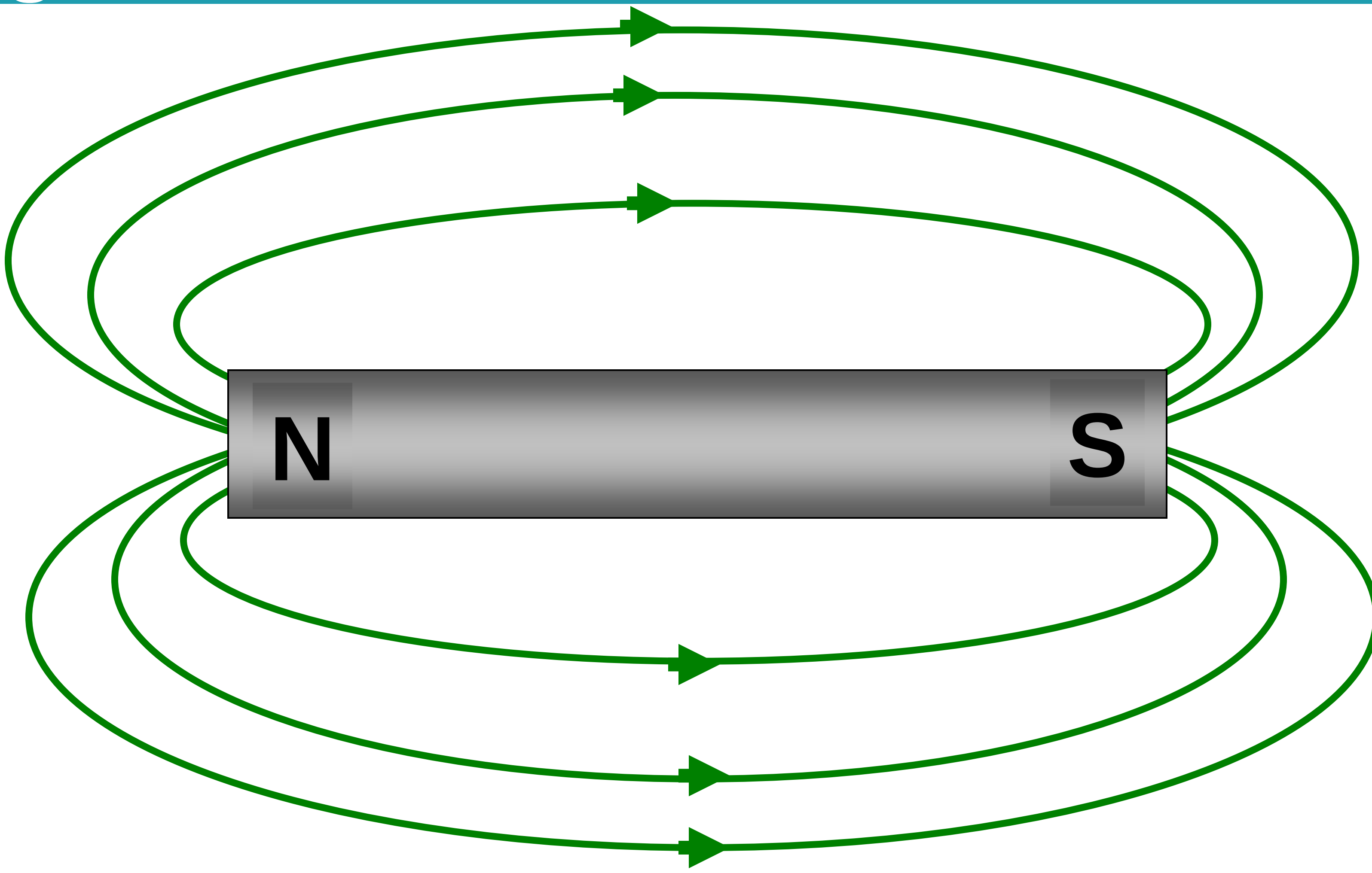
Generator Basics
Magnetism and Induction

Aligned Magnetic Domains



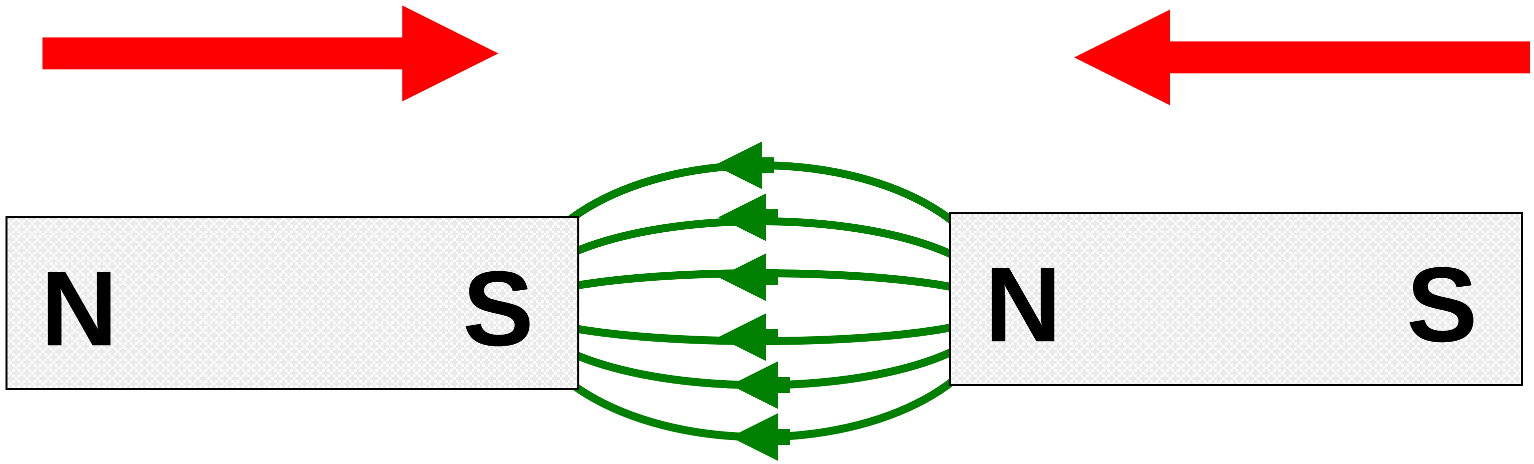
Iron Magnetized

Generator Basics
Magnetism and Induction



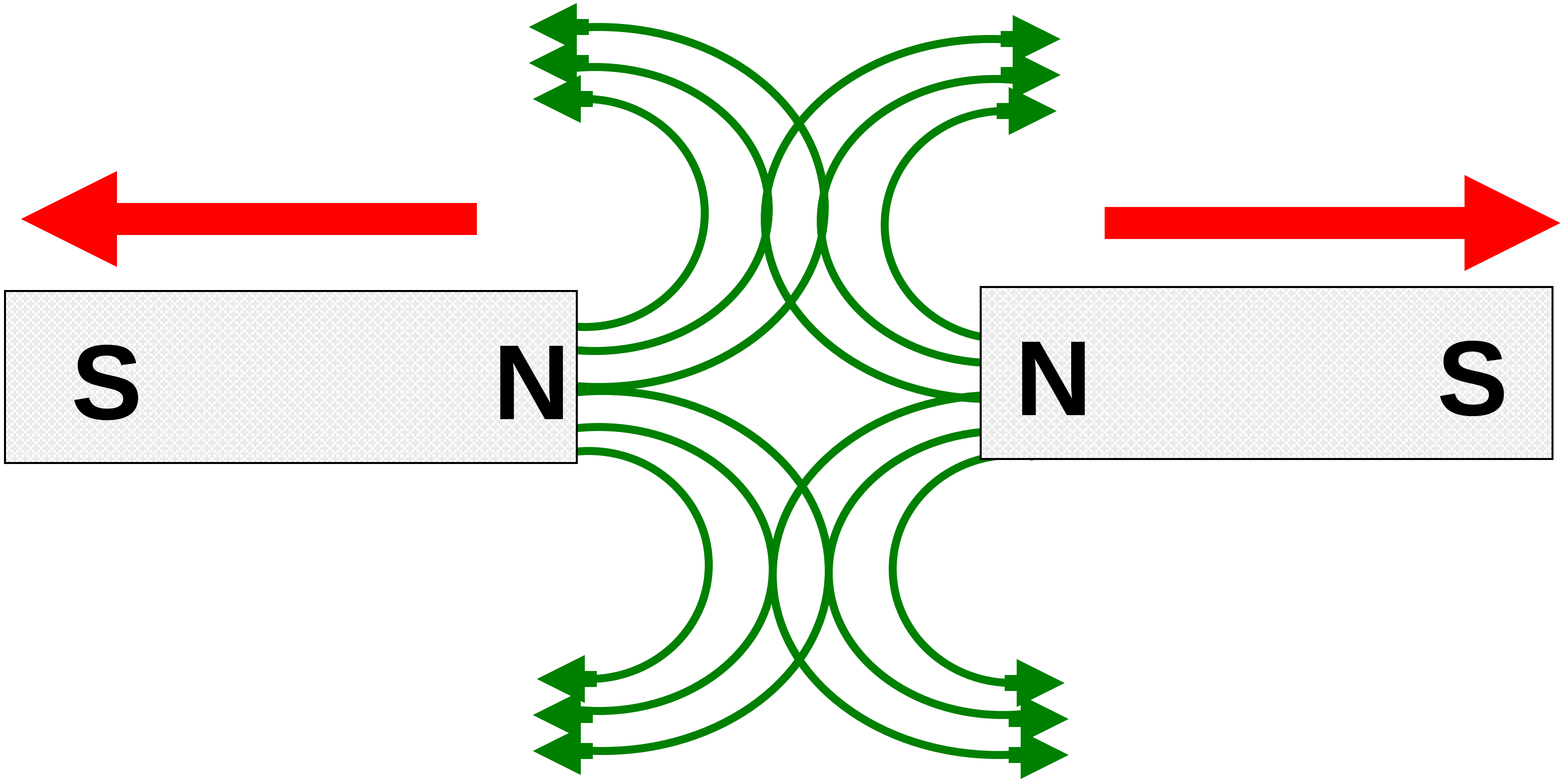
Lines Of Magnetic Force (Flux) - From North Pole to South Pole

Generator Basics
Magnetism and Induction



Lines of Magnetic Force (Flux)
Unlike Poles are Attracted Toward Each Other

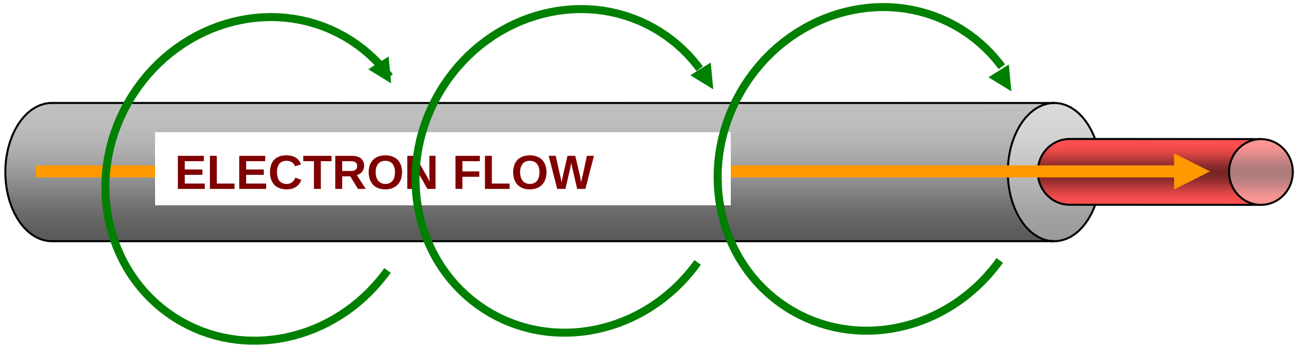
Generator Basics
Magnetism and Induction



Lines Of Magnetic Force (Flux)

Like Poles are Repelled From Each Other

Generator Basics
Magnetism and Induction



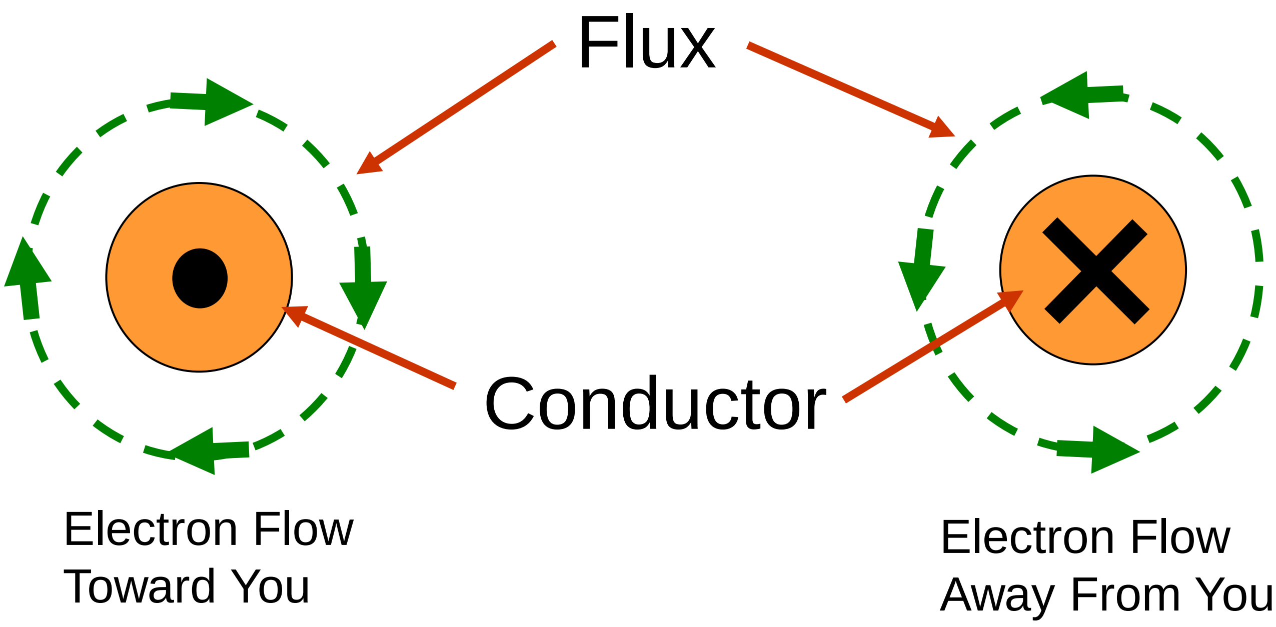
Induced Magnetic Fields

Whenever current flows through a conductor a magnetic field is created around the conductor

Generator Basics
Magnetism and Induction

Lines of Force (Flux)

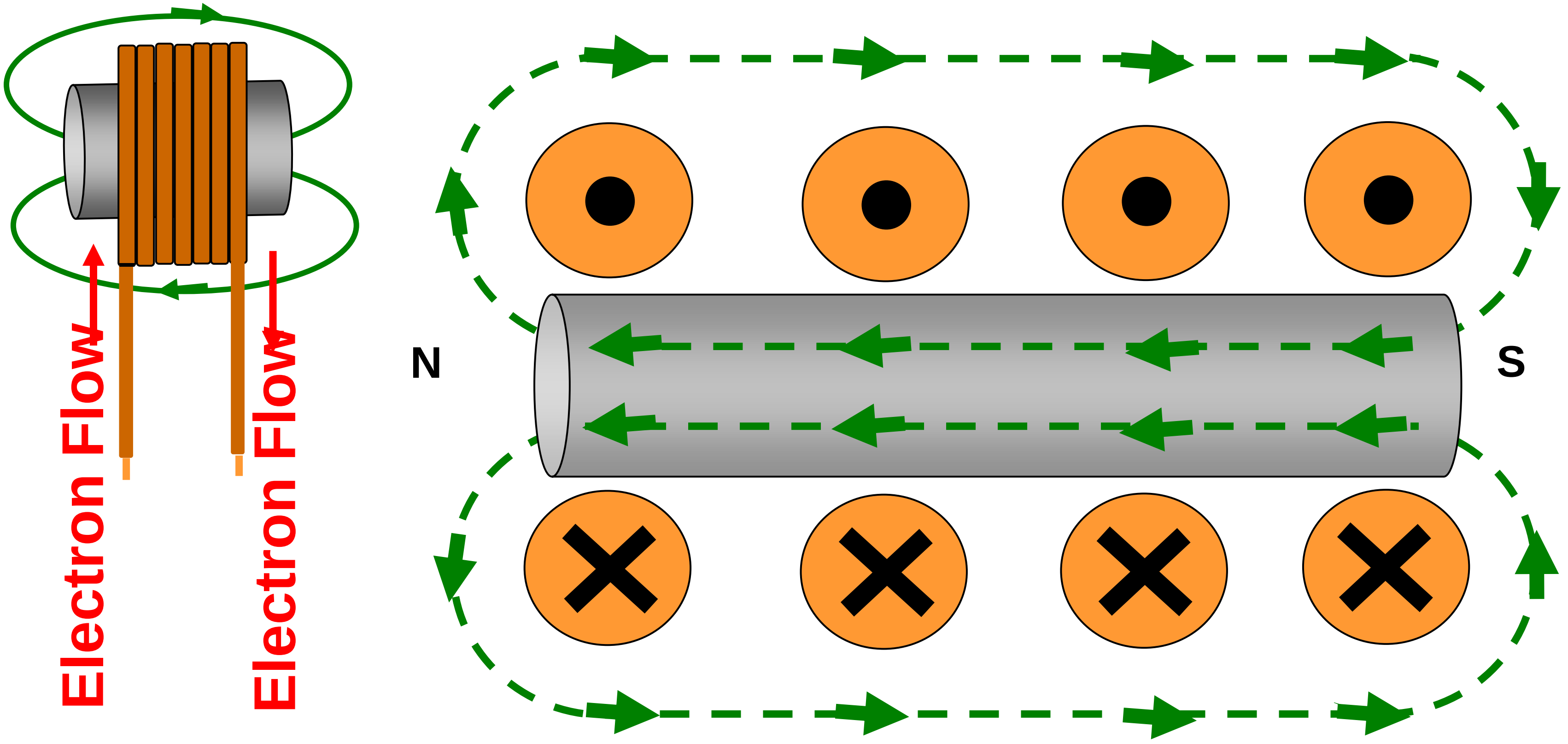
The Direction of the current flowing through a conductor determines the direction of the magnetic lines of force developed around it.



Flux the **Same** direction - **Adds** Flux the **Opposite** direction - **Cancels**

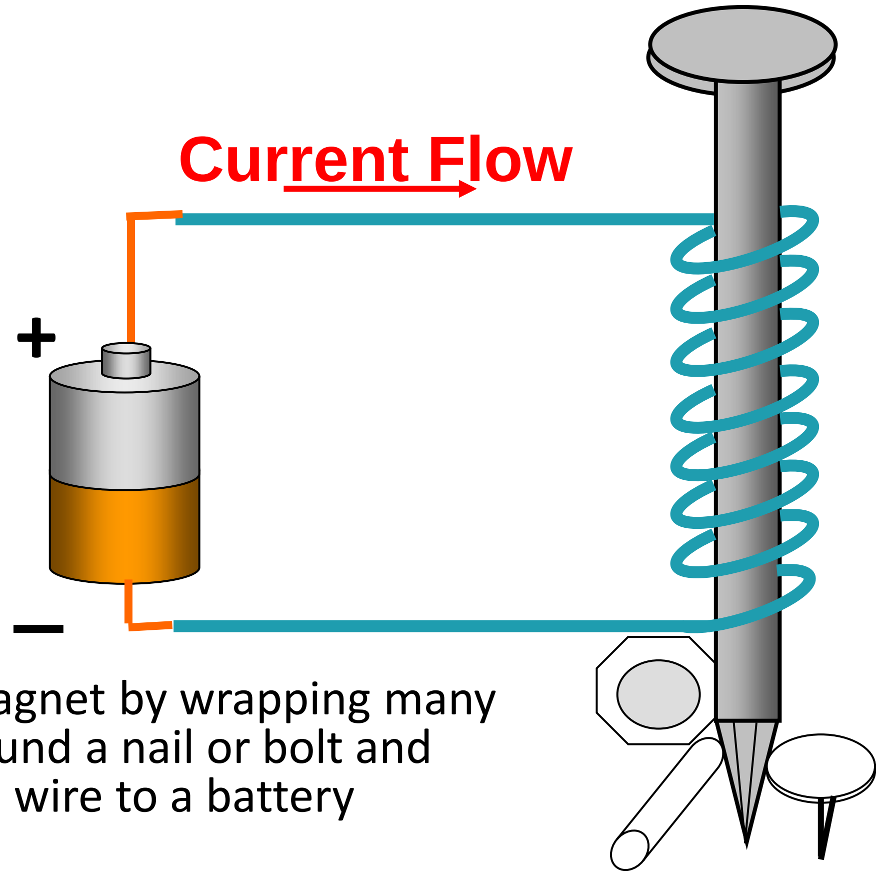
Generator Basics
Magnetism and Induction

Effects Of Magnetic Flux When Current Carrying Conductor Is Wrapped Into A Coil



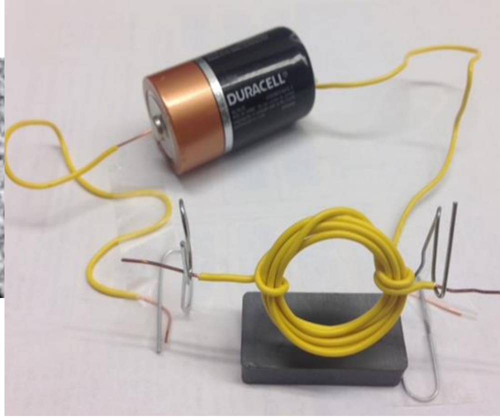
Generator Basics
Magnetism and Induction

Electromagnet



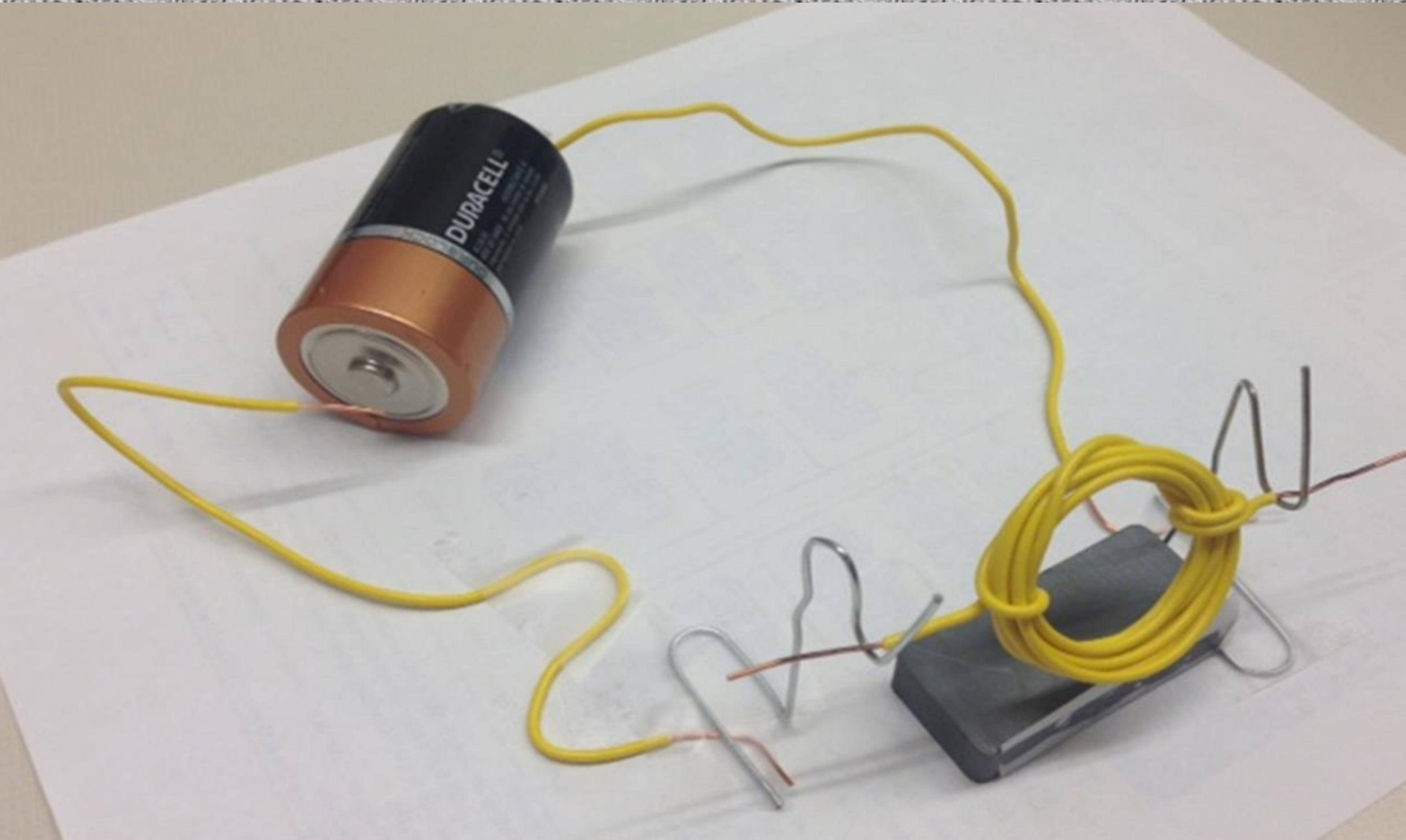
You can make an electromagnet by wrapping many turns of insulated wire around a nail or bolt and connecting the ends of the wire to a battery

Let's Make a Motor



1. Wrap Wire around battery six times to form a rotor loop.
2. Secure Wire ends around either side of the rotor.
3. Trim wires on either side of the rotor to about ½ inch. Strip these ends.
4. Bend Paper Clips to make yokes for the rotor.
5. Strip ends of two wires to lead from the yokes to the battery.
6. Place the magnet on the base.
7. Place the yokes on either side of the magnet. Connect them to the lead wires and tape them down.
8. Tape one end of a lead wire to one terminal of the battery.
9. Test spin the rotor on the yokes…make sure it clears the magnet, and that the copper of the axles touches the yokes.
10. Adjust the rotor lead wires to balance the rotor. It should spin freely.
11. Using a marker, draw on the top side of the wire axels extending from the rotor. This insulates the rotor for ½ of the cycle.
12. Connect the remaining lead to the battery to power the motor. You may need to give it a flip to get it going.

Let's Make a Motor



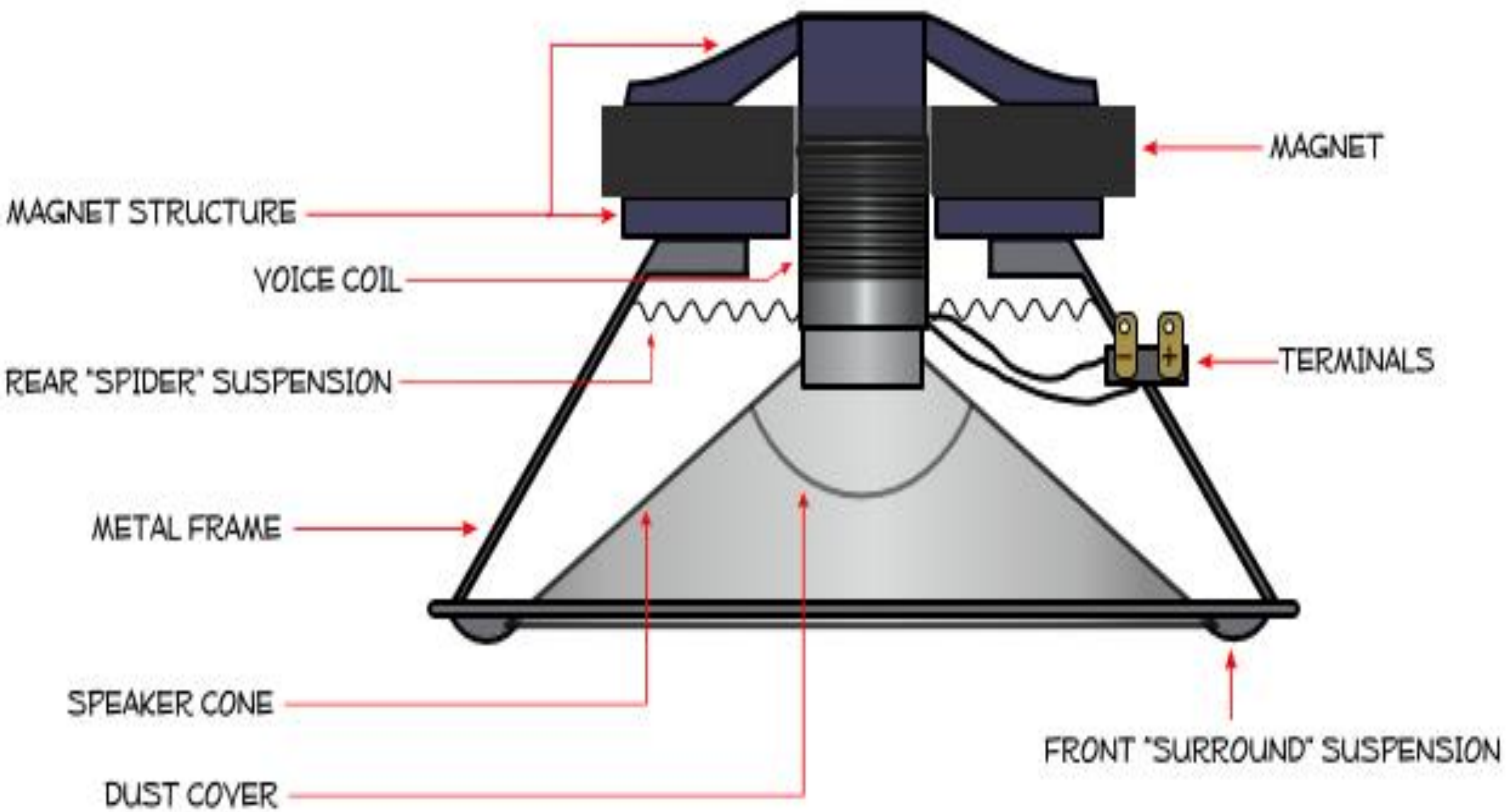
Generator Basics
Magnetism and Induction

Electromagnets are used for many applications

- Relays
- Solenoids
- Magnets
- Speakers
- Rotors in Generators and Motors

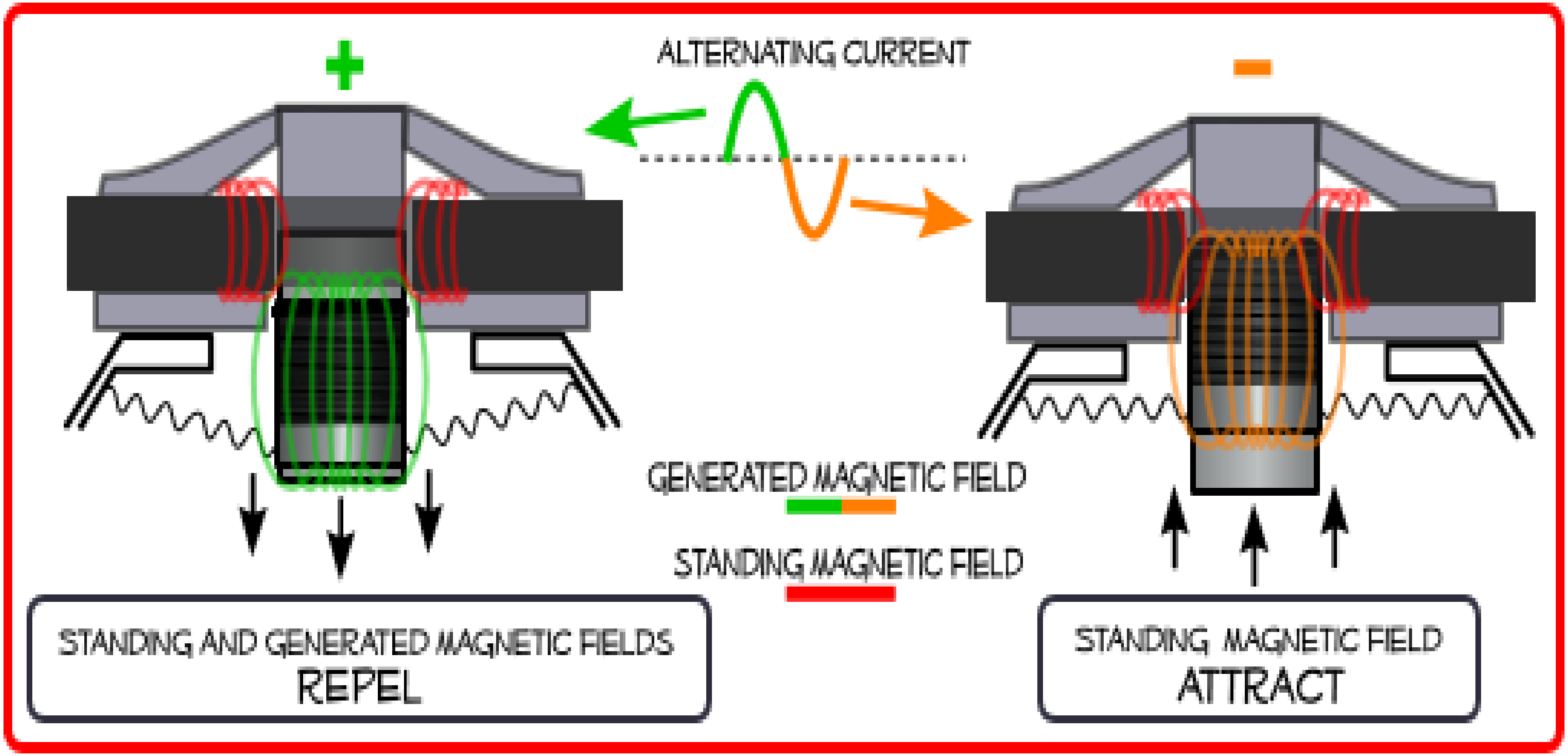
Generator Basics
Magnetism and Induction

How A Stereo Speaker Works



Generator Basics
Magnetism and Induction

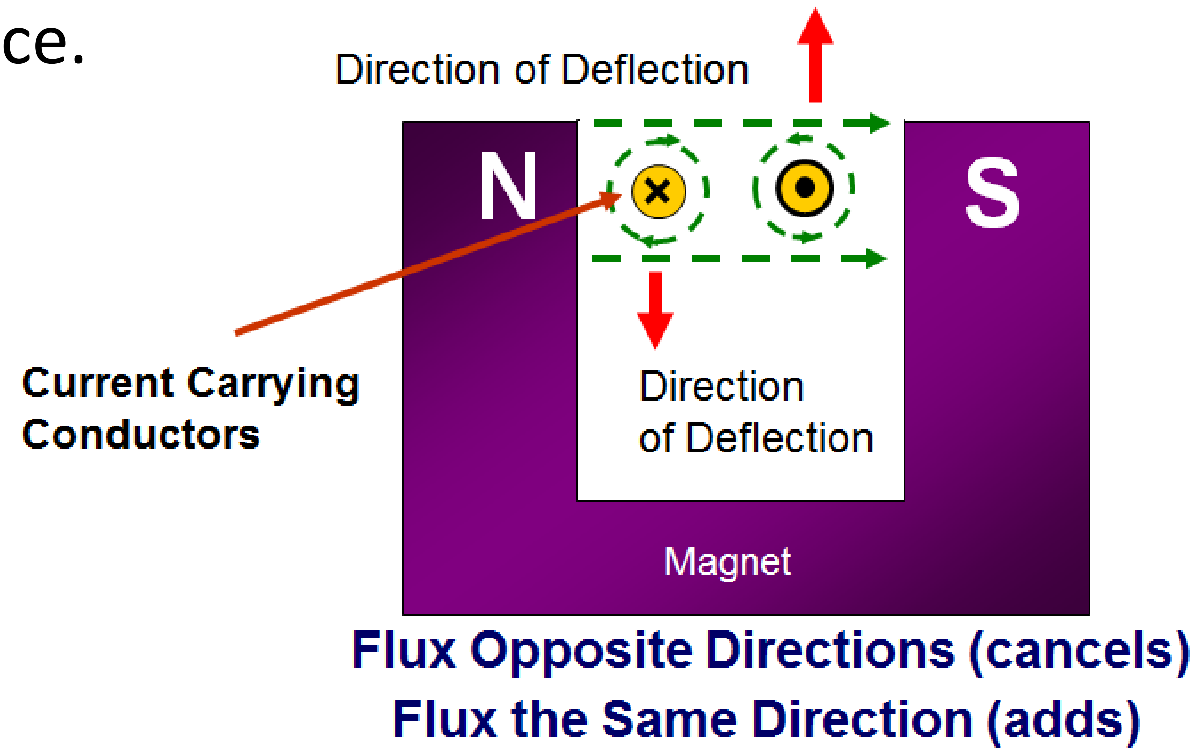
How a Stereo Speaker Works



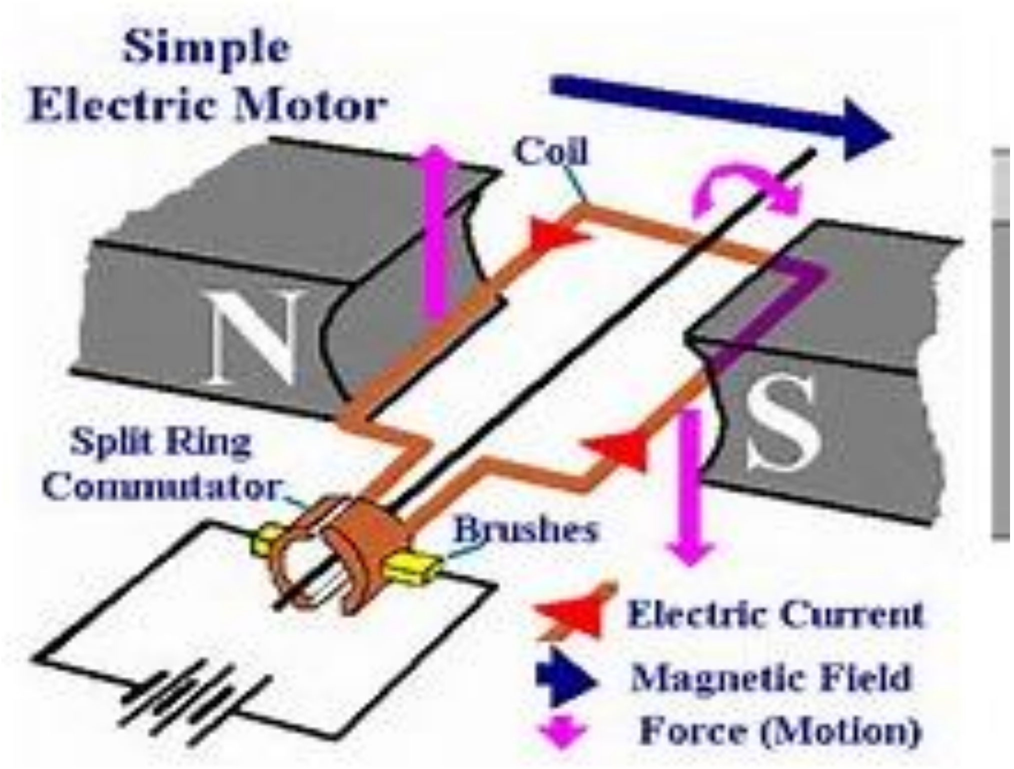
Generator Basics
Magnetism and Induction

Conductor in a Magnetic Field

A conductor with current flowing in a Magnetic Field experiences Force.



Generator Basics
A Simple Motor



Generator Basics
Magnetism and Induction

Electromagnetic Induction

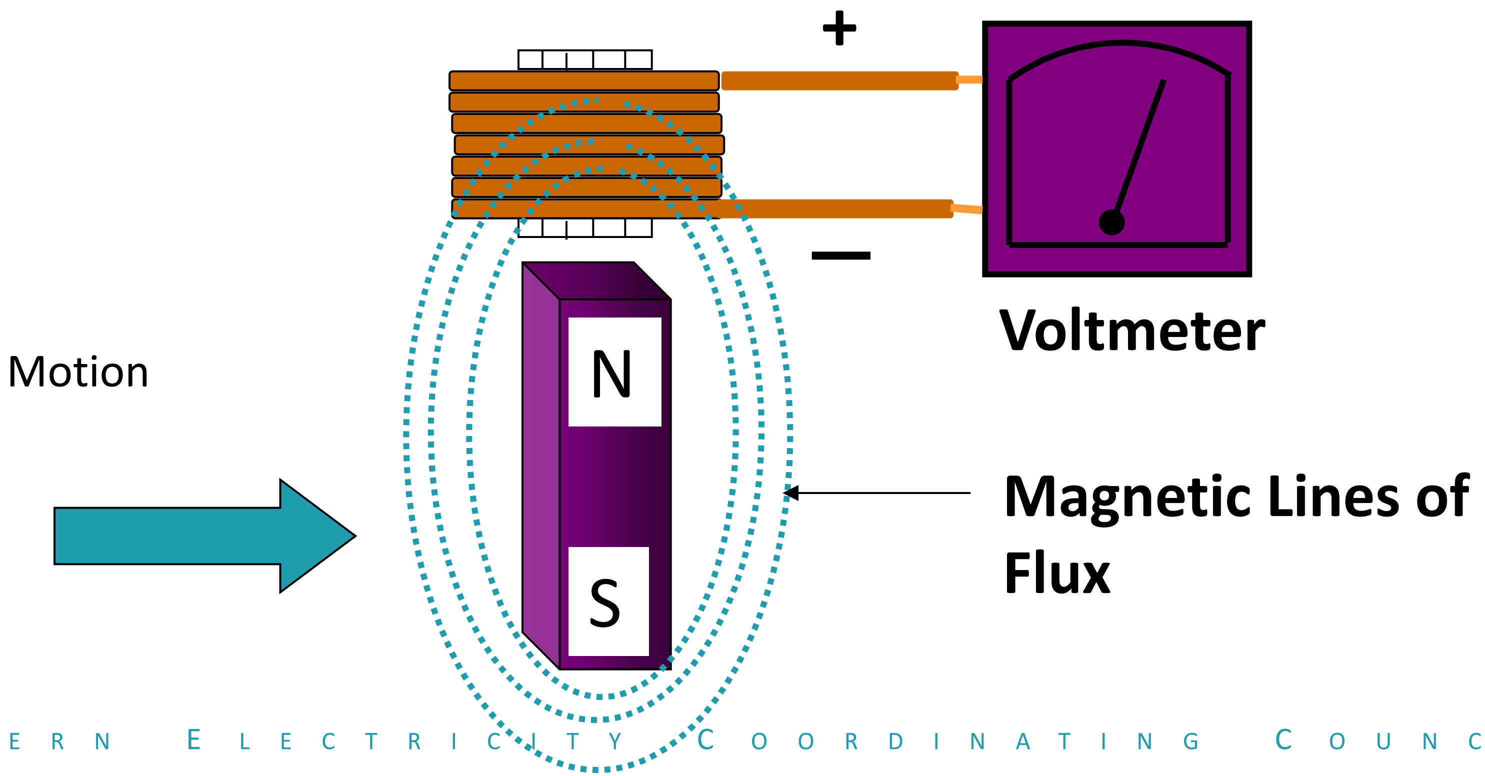
In order to induce a voltage you need 3-things:

1. Conductor
2. Magnetic field
3. Relative motion between the conductor and the magnetic field

Generator Basics
Magnetism and Induction

Electromagnetic Induction

Whenever a magnetic field is moved past a conductor a voltage is induced in the conductor

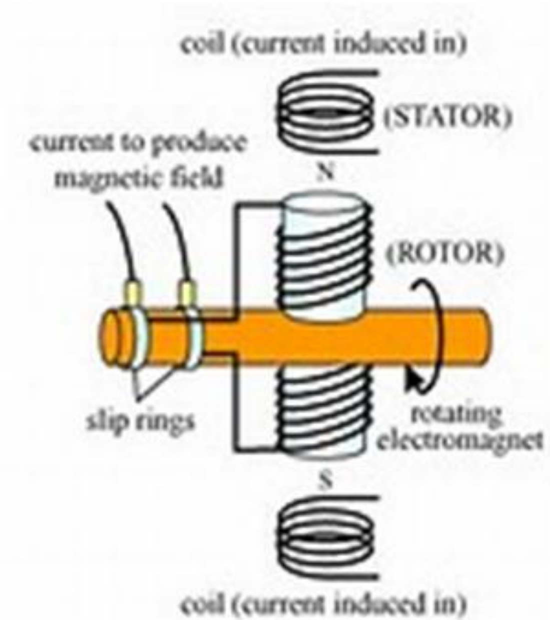


Generator Basics
Magnetism and Induction

Electromagnetic Induction

A generator is created by spinning a magnetic Rotor…

Past a stationary winding (Stator)



Generator Basics
Magnetism and Induction

Lenz's Law (Opposite and Equal Reaction)

The current induced in the Stator Windings creates a reverse magnetic field that Opposes the rotation of the magnet. So…

the power going out (in the form of Electricity) equals…
the power going in (Mechanical Energy).

Any imbalance speeds up or slows down the generator

Generator Basics
Magnetism and Induction

Transformer – Requires Changing Current

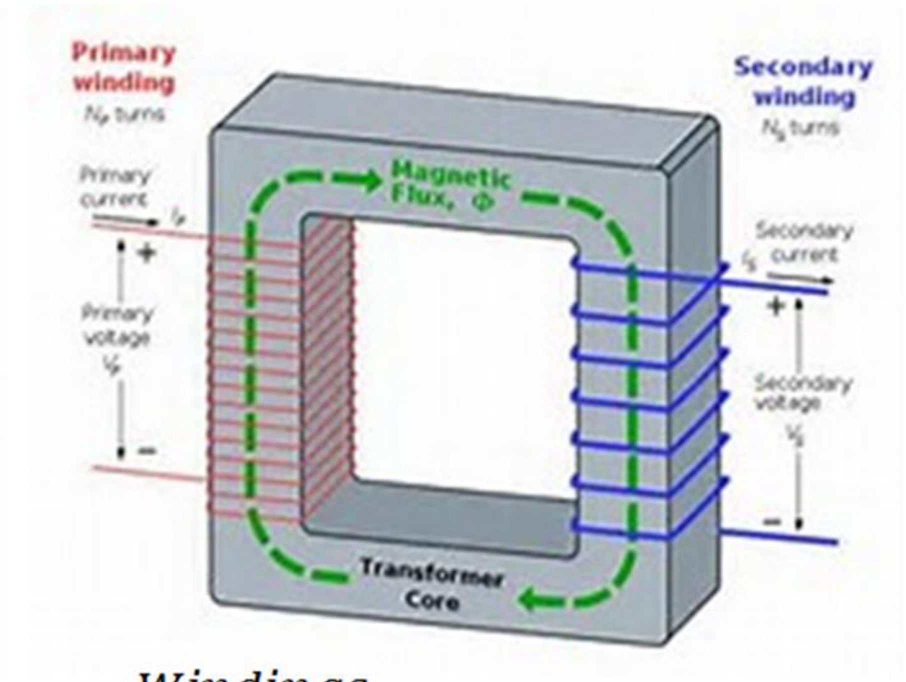
A transformer uses changing current in one winding…

To create a changing magnetic flux in the core…
Which induces a changing voltage in the second winding.

Power In equals Power Out…however…
Voltages and currents may change according to turns ratio of the two windings.

Generator Basics
Magnetism and Induction

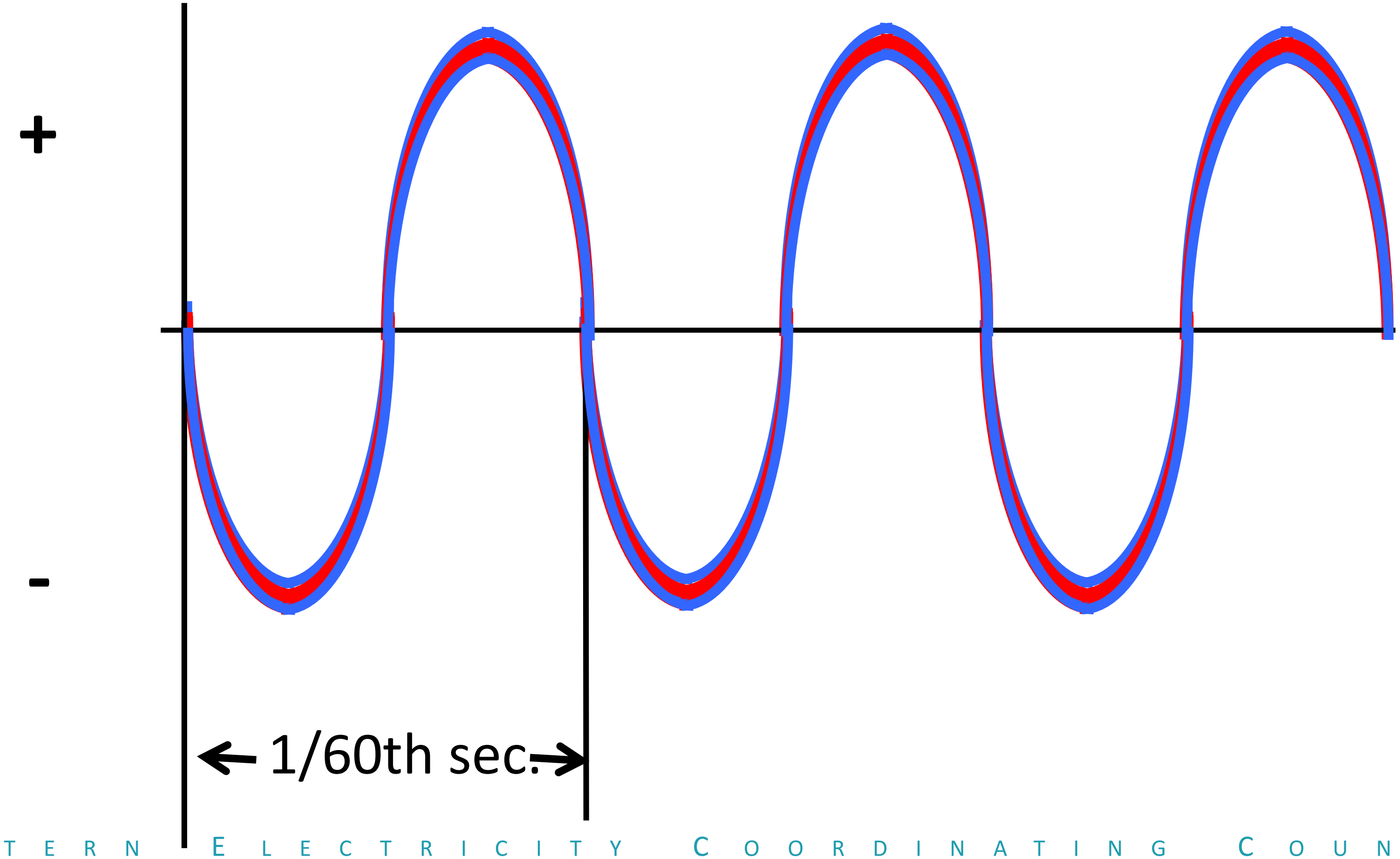
Transformer - Requires Changing Current



$$V_{Primary} = \frac{Windings_{Primary}}{Windings_{Secondary}} V_{Secondary}$$

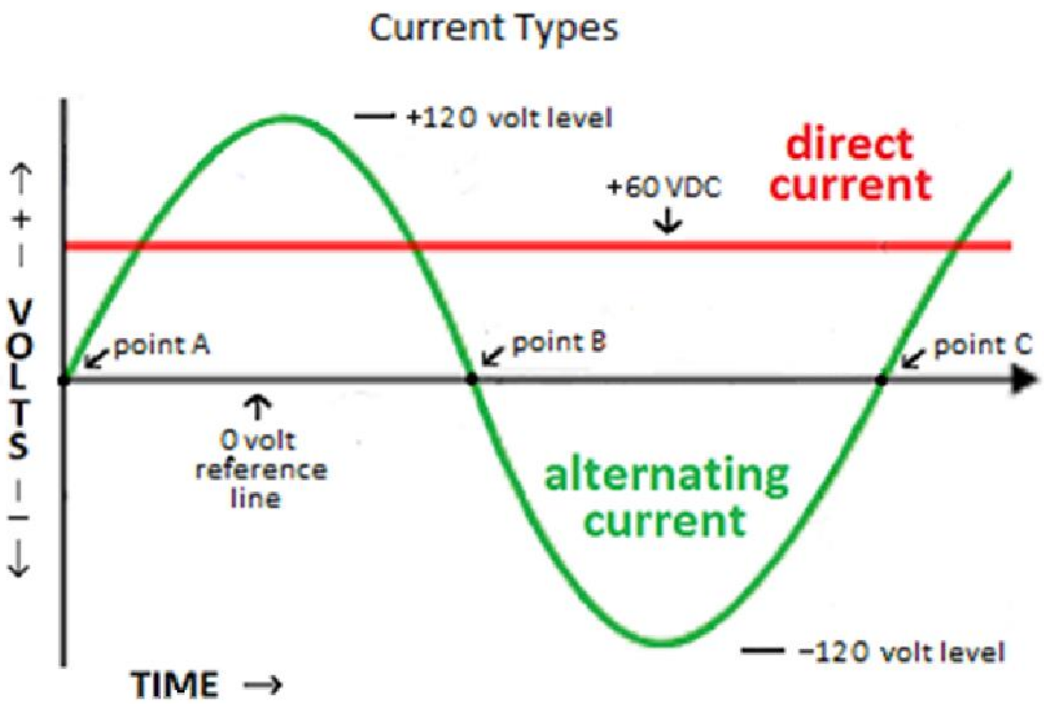
Generator Basics
Alternating vs. Direct Current

Single Phase Power



Generator Basics
Alternating vs. Direct Current

AC or DC Electricity?



Generator Basics
Alternating vs. Direct Current

Direct Current

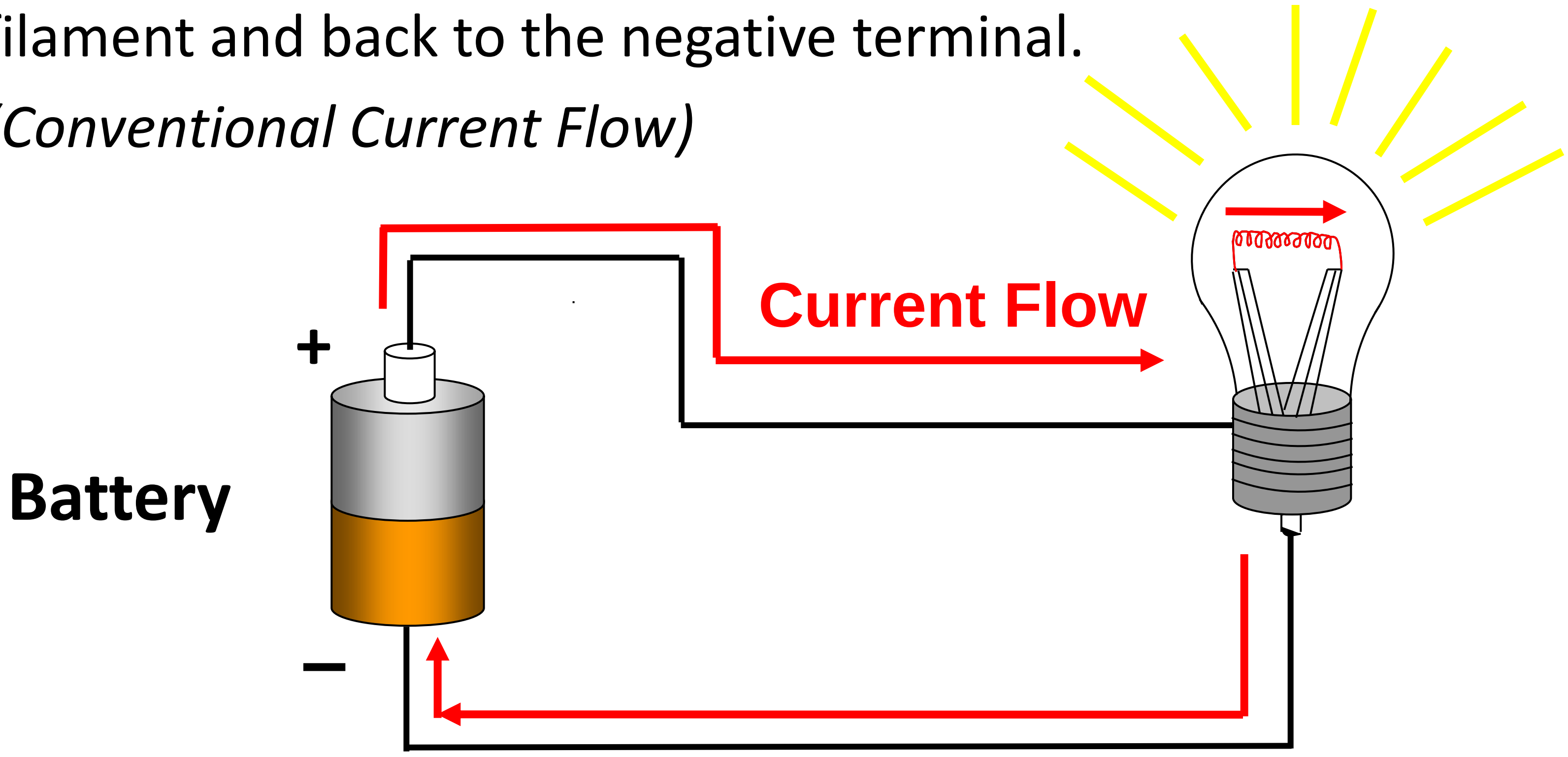
Direct Current (DC) is a constant value current that flows through a circuit in only one direction.

The electrical system in your car is an example of a direct current system.

Generator Basics
Alternating vs. Direct Current

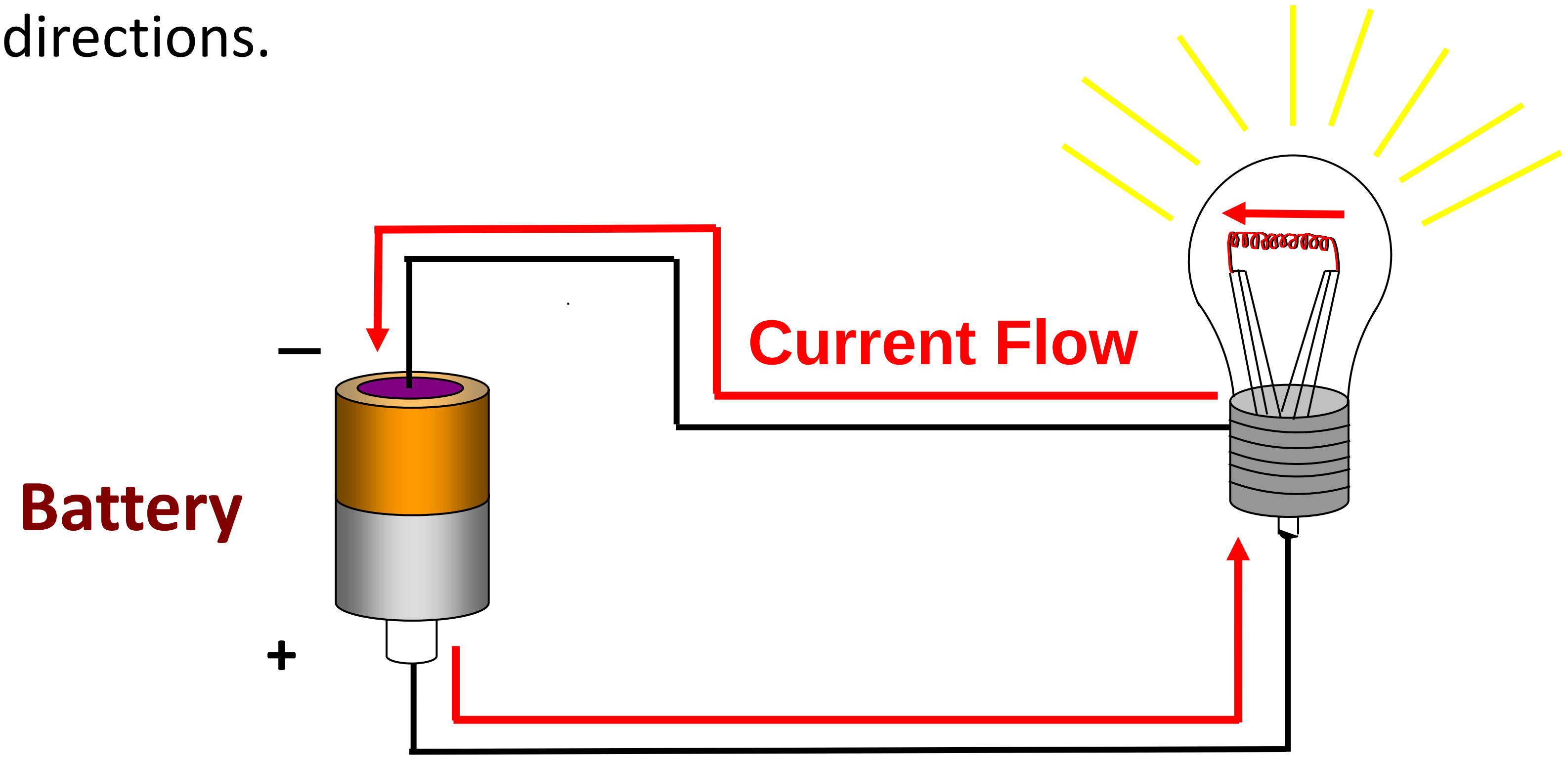
Direct Current: In this circuit there is a steady current flow from the positive terminal of the battery through the light bulb filament and back to the negative terminal.

(Conventional Current Flow)



Generator Basics
Alternating vs. Direct Current

Direct Current: If the battery connections are reversed, the current flowing through the light bulb filament will change directions.



THE CURRENT WAR

THE TALE OF AN EARLY TECH RIVALRY

DC

DIRECT CURRENT

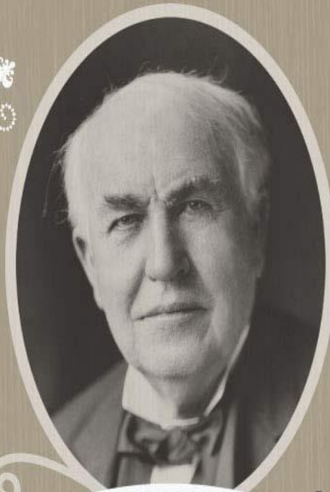
The flow of electricity is in one direction only. The system operates at the same voltage level throughout and is not as efficient for high-voltage, long distance transmission.

Direct current runs through:

- Battery-Powered Devices
- Fuel and Solar Cells
- Light Emitting Diodes

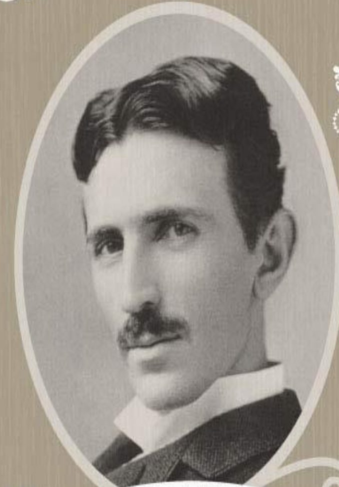
"[TESLA'S] IDEAS ARE SPLENDID, BUT THEY ARE UTTERLY IMPRACTICAL."

- THOMAS EDISON



THOMAS EDISON

VS.



NIKOLA TESLA

AC

ALTERNATING CURRENT

Electric charge periodically reverses direction and is transmitted to customers by a transformer that could handle much higher voltages.

Alternating current runs through:

- Car Motors
- Radio Signals
- Appliances

"IF EDISON HAD A NEEDLE TO FIND IN A HAYSTACK, HE WOULD PROCEED AT ONCE... UNTIL HE FOUND THE OBJECT OF HIS SEARCH. I WAS A SORRY WITNESS OF SUCH DOINGS, KNOWING THAT A LITTLE THEORY AND CALCULATION WOULD HAVE SAVED HIM 90 PERCENT OF HIS LABOR."

- NIKOLA TESLA

You would have never found two geniuses so spiteful of each other beyond turn-of-the-century inventors Nikola Tesla and Thomas Edison. They worked together—and hated each other. Let's compare their life, achievements, and embittered battles.

LATE BLOOMER

Thomas Edison, the youngest in his family, didn't learn to talk until he was almost 4 years old.

FALLING OUT

Edison promised Tesla a generous reward if he could smooth out his direct current system. The young engineer took on the assignment and ended up saving Edison more than $100,000 (millions of dollars by today's standards). When Tesla asked for his rightful compensation, Edison declined to pay him. Tesla resigned shortly after, and the elder inventor spent the rest of his life campaigning to discredit his counterpart.

"Genius is one percent inspiration and ninety nine percent perspiration."

-Thomas Edison

Thomas Edison		Nikola Tesla
1847	BORN	1858
Milan, Ohio	BIRTHPLACE	Smiljan, Croatia
Wizard of Menlo Park	NICKNAME	Wizard of the West
Home-schooled and self-taught	EDUCATION	Studied math, physics, and mechanics at The Polytechnic Institute at Gratz
Mass communication and business	FORTE	Electromagnetism and electromechanical engineering
Trial and error	METHOD	Getting inspired and seeing the invention in his mind in detail before fully constructing it
DC (Direct Current)	WAR OF CURRENTS: ELECTRICAL TRANSMISSION IDEA	AC (Alternating Current)
Incandescent light bulb; phonograph; cement making technology; motion picture camera; DC motors and electric power	NOTABLE INVENTIONS	Tesla coil - resonant transformer circuit; radio transmitter; fluorescent light; AC motors and electric power generation system
1,093	NUMBER OF US PATENTS	112
0	NUMBER OF NOBEL PRIZES WON	0
1	NUMBER OF ELEPHANTS ELECTROCUTED	0
1931—Passed away peacefully in his New Jersey home, surrounded by friends and family	DEATH	1943—Died lonely and in debt in Room 3327 at the New Yorker Hotel

WAR OF CURRENTS OFFICIALLY SETTLED

In 2007, Con Edison ended 125 years of direct current electricity service that began when Thomas Edison opened his power station in 1882. It changed to only provide alternating current.

NOBEL PRIZE CONTROVERSY

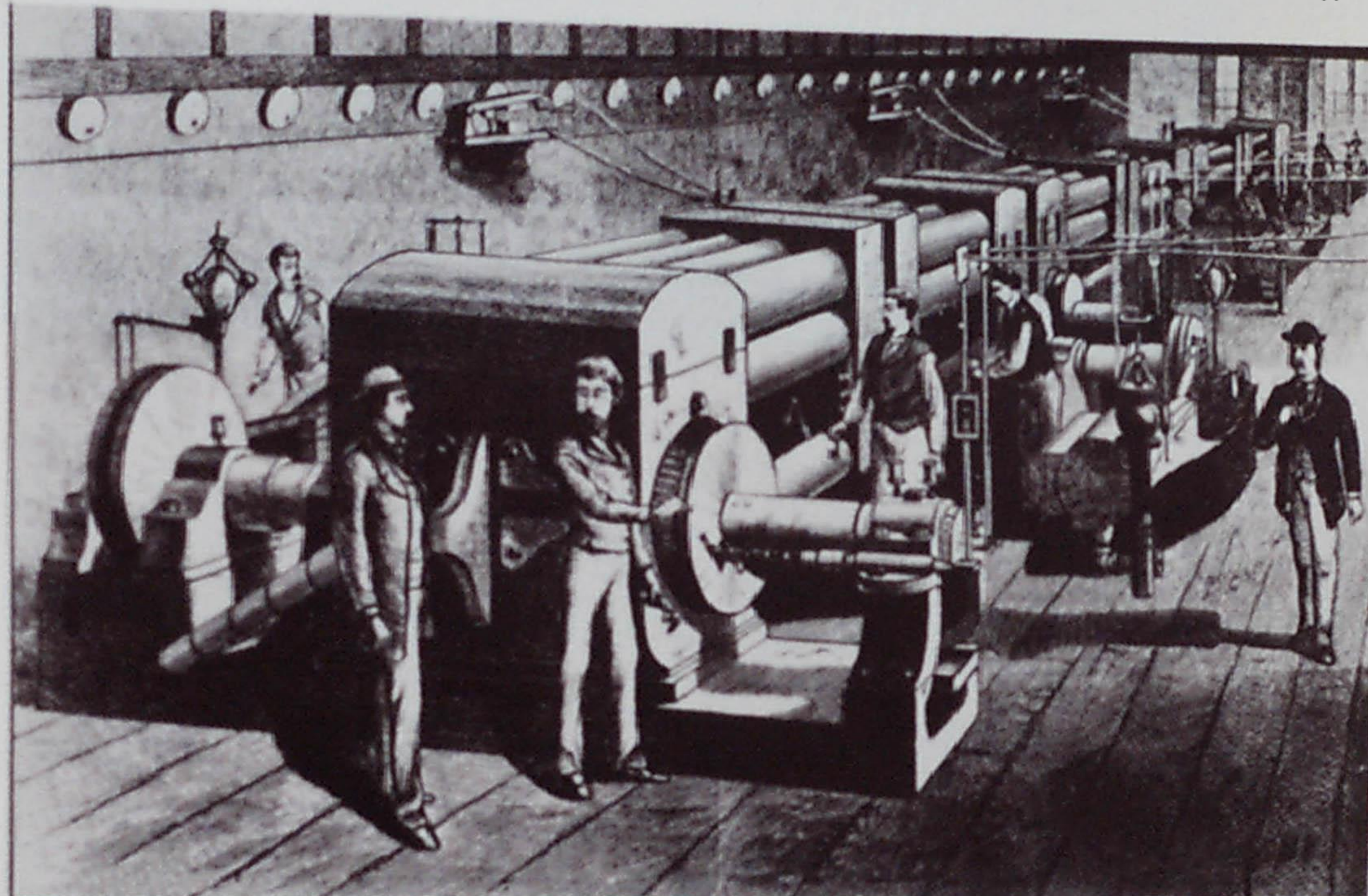
In 1915, both Edison and Tesla were to receive Nobel Prizes for their strides in physics, but ultimately, neither won. It is rumored to have been caused by their animosity towards each other and refusal to share the coveted award.

EDISON FRIES AN ELEPHANT

In order to prove the dangers of Tesla's alternating current, Thomas Edison staged a highly publicized electrocution of the three-ton elephant known as "Topsy." She died instantly after being shocked with a 6,600-volt AC charge.

SOURCES: CHENEY, MARGARET. "TESLA: MAN OUT OF TIME" | UTH, ROBERT. "TESLA: MASTER OF LIGHTNING." | THOMASEDISON.COM | PBS.ORG | WEB.MIT.EDU | WIRED.COM

A COLLABORATION BETWEEN GOOD AND COLUMN FIVE

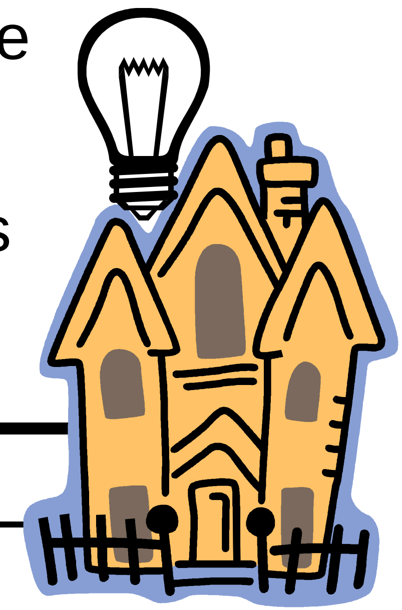


Pearl Street Station

Generator Basics
Alternating vs. Direct Current

Thomas Edison's DC System

- Electrical losses were high with DC
- Generation voltage and distribution voltage are the same
- Distance from generator to customer load was limited

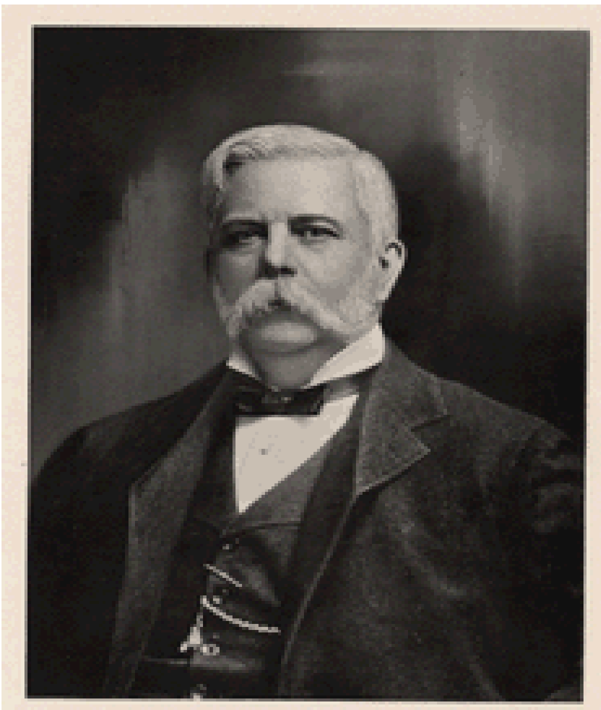


120V
100A
12kW

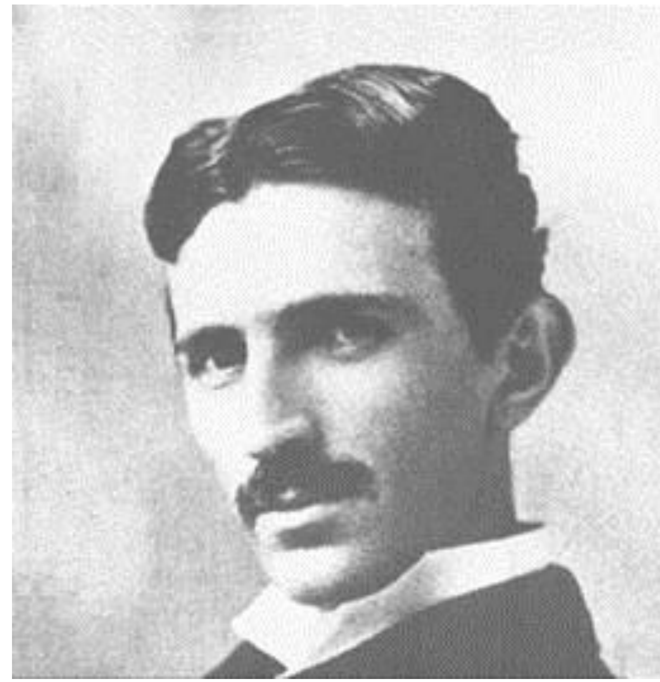
Loses = I^2R
are Very Large!

120V
100A
12kW

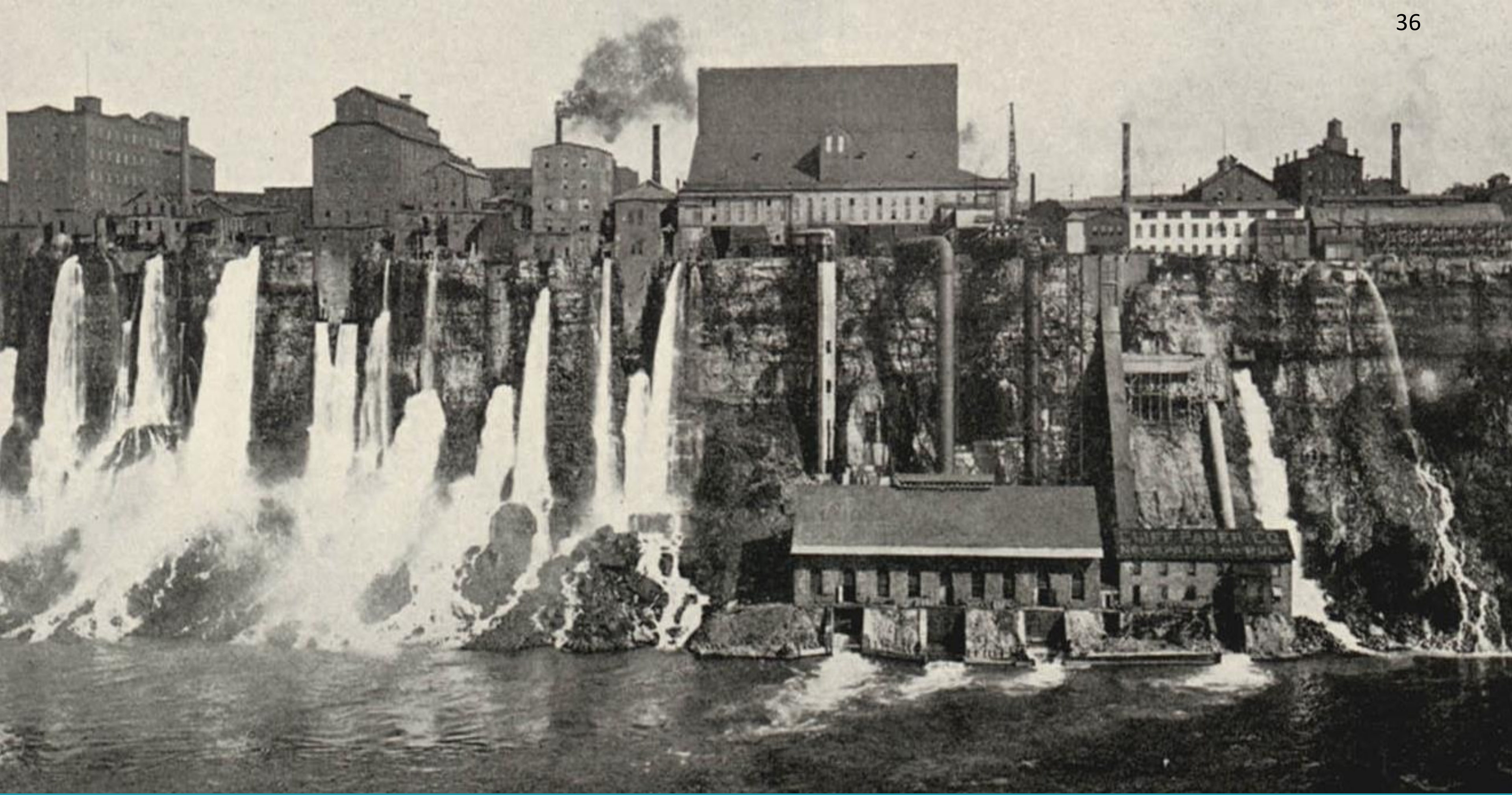
Generator Basics
Alternating vs. Direct Current



George Westinghouse
October 6, 1846 -
March 12, 1914
Milan, Ohio U.S.



Nikola Tesla
July 10, 1856 -
January 7, 1943
Austria-Hungary

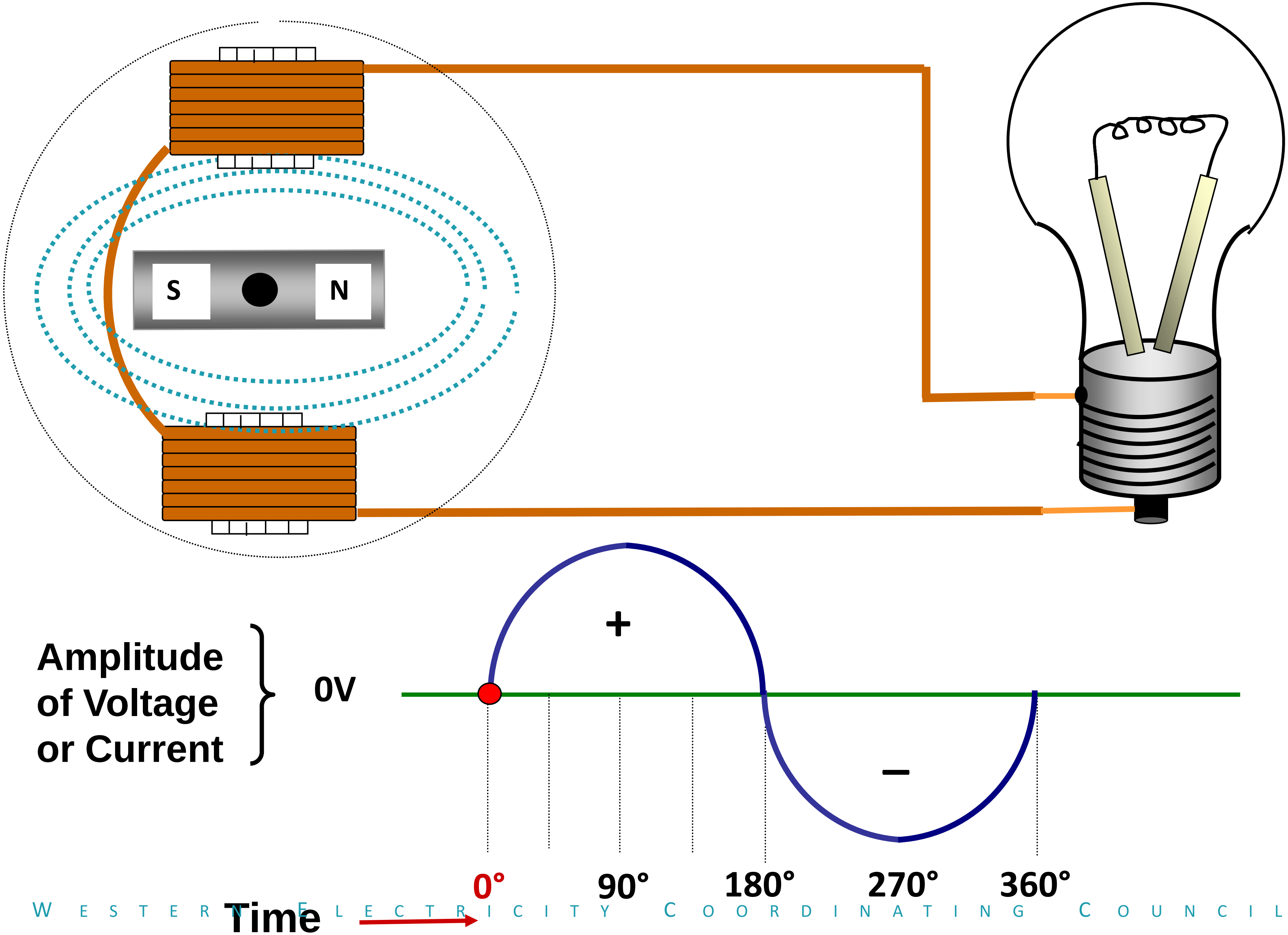


AC Generators Installed at Niagara Falls

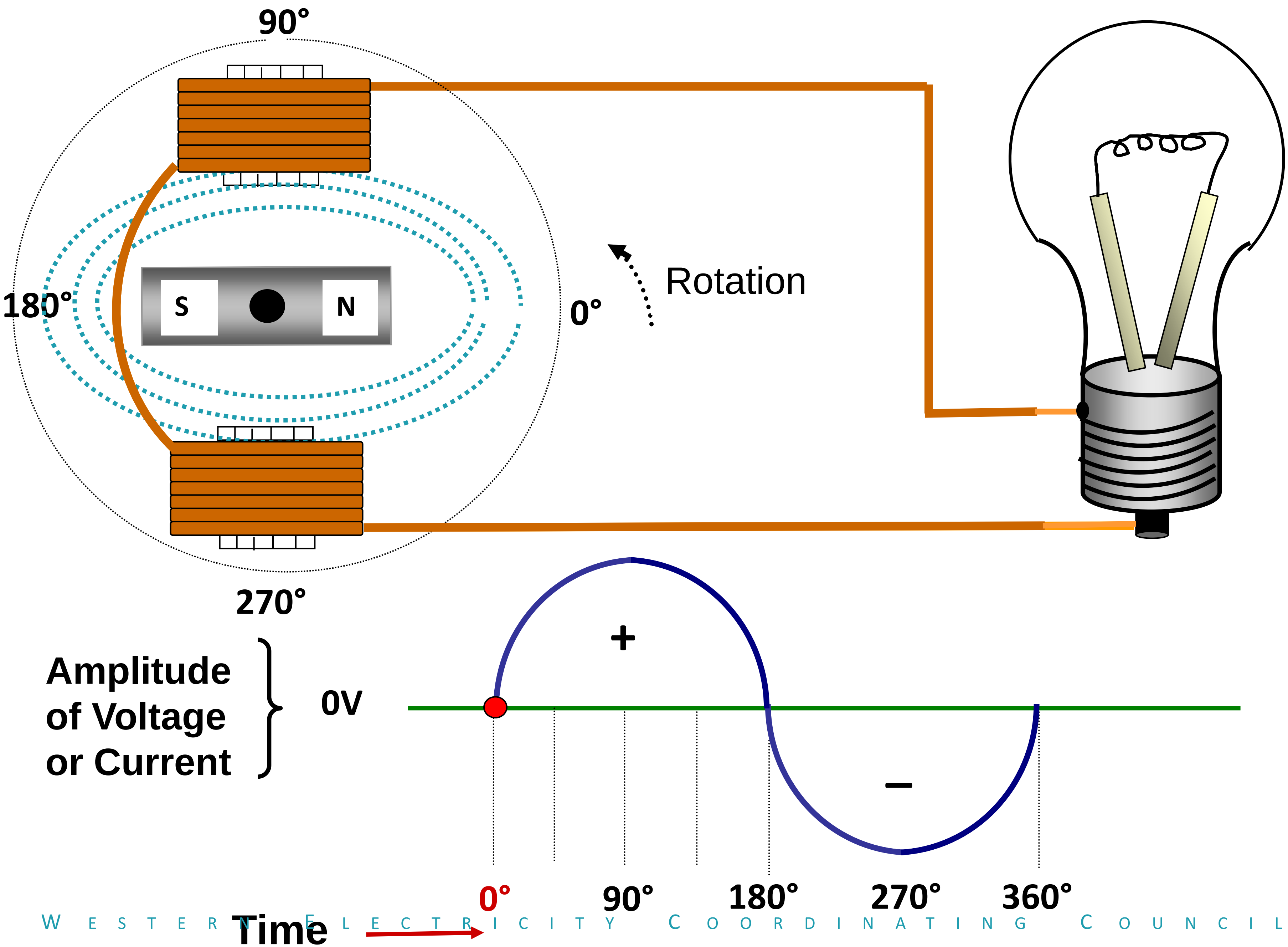
Generator Basics
Alternating Current vs Direct Current

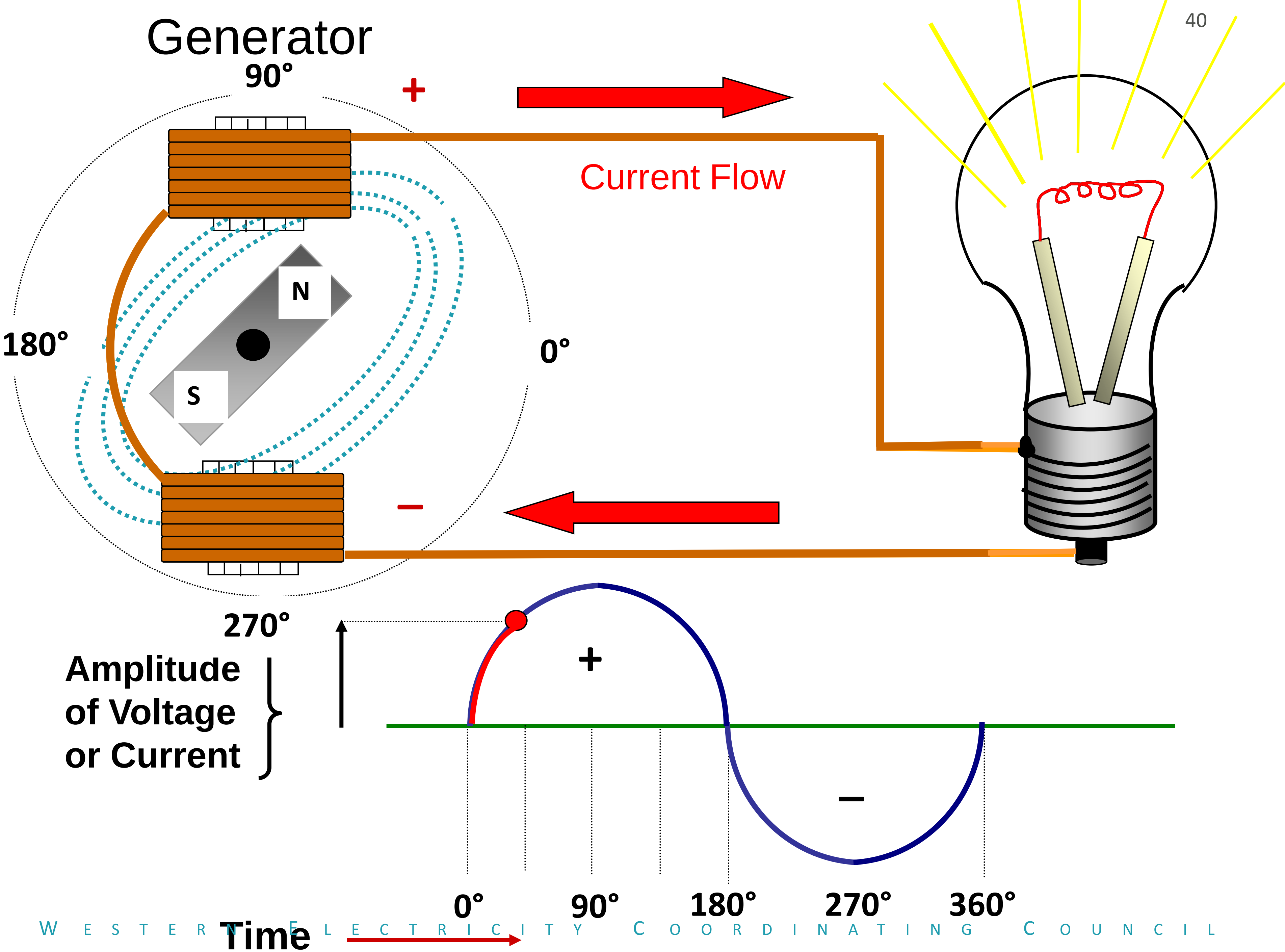
How to Generate Alternating Current

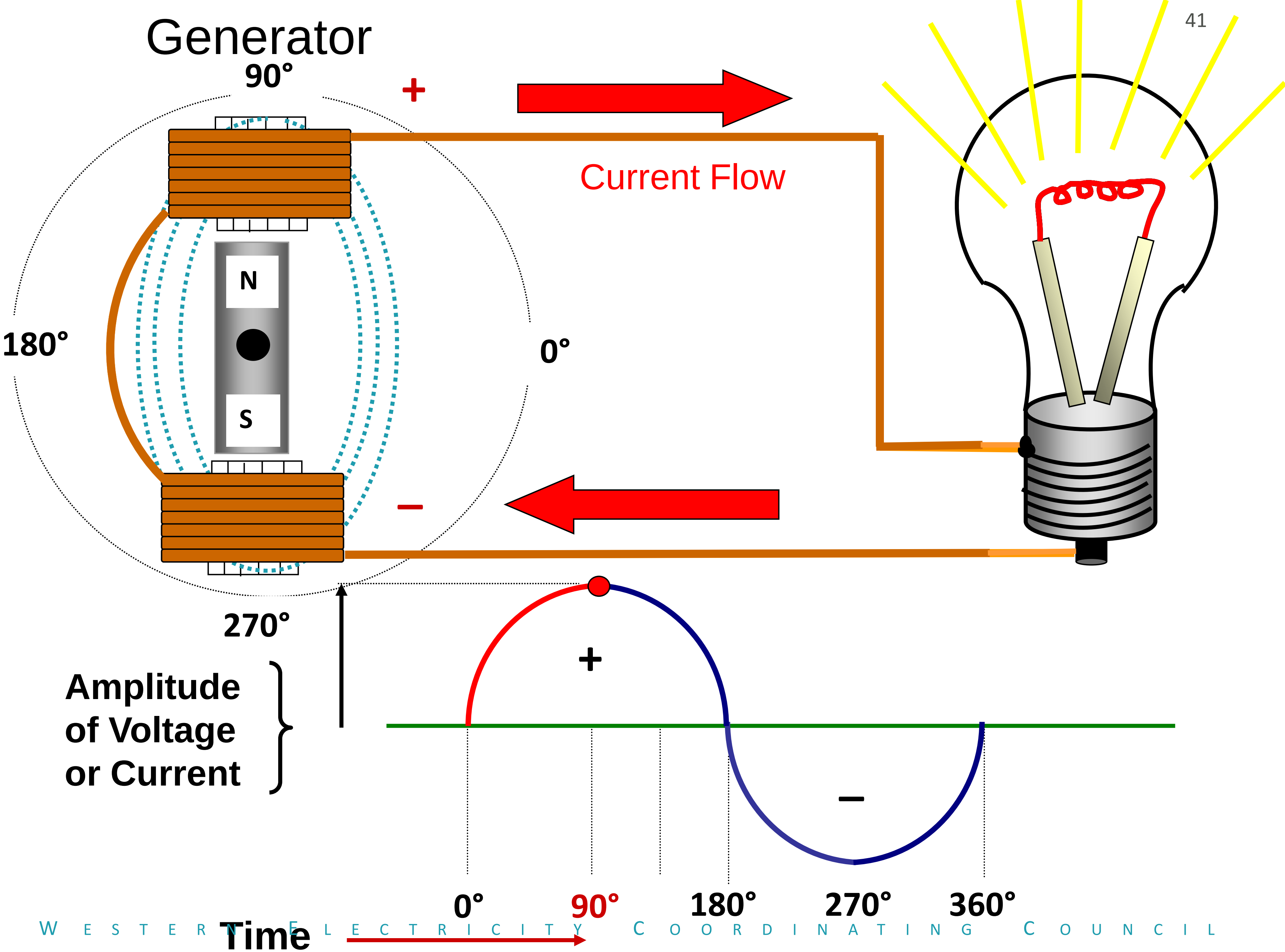
Generator

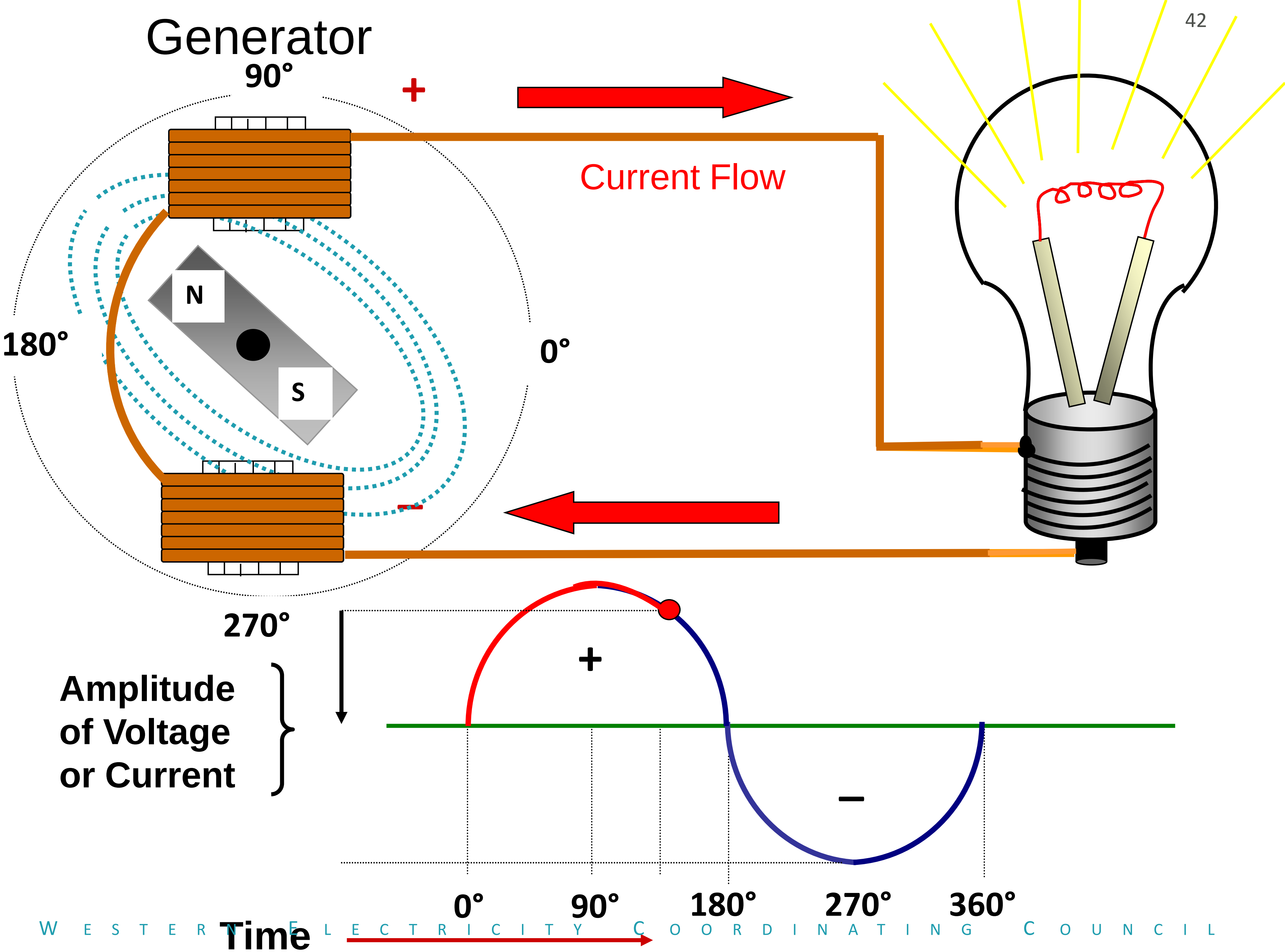


Generator


90°
180°
S
N
0°
Rotation
270°
Amplitude of Voltage or Current
0V
+
–
0°
90°
180°
270°
360°
Time


Generator
90°
180°
0°
270°
N
S
+
–
Current Flow
Amplitude
of Voltage
or Current
+
–
0°
90°
180°
270°
360°
Time


Generator
90°
+
Current Flow
180°
0°
N
S
–
270°
+
Amplitude
of Voltage
or Current
–
0°
90°
180°
270°
360°
Time


Generator
90°
+
Current Flow
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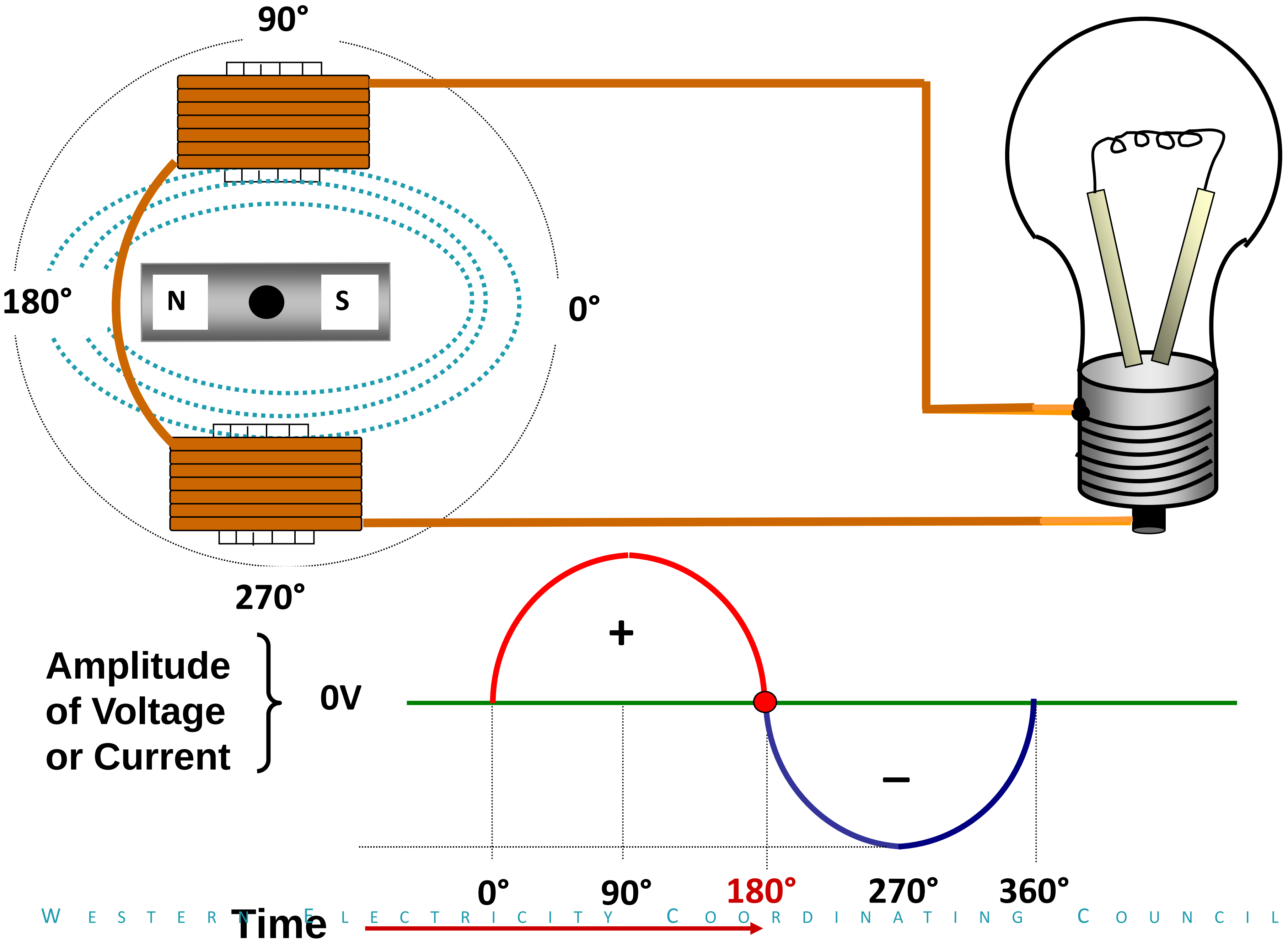
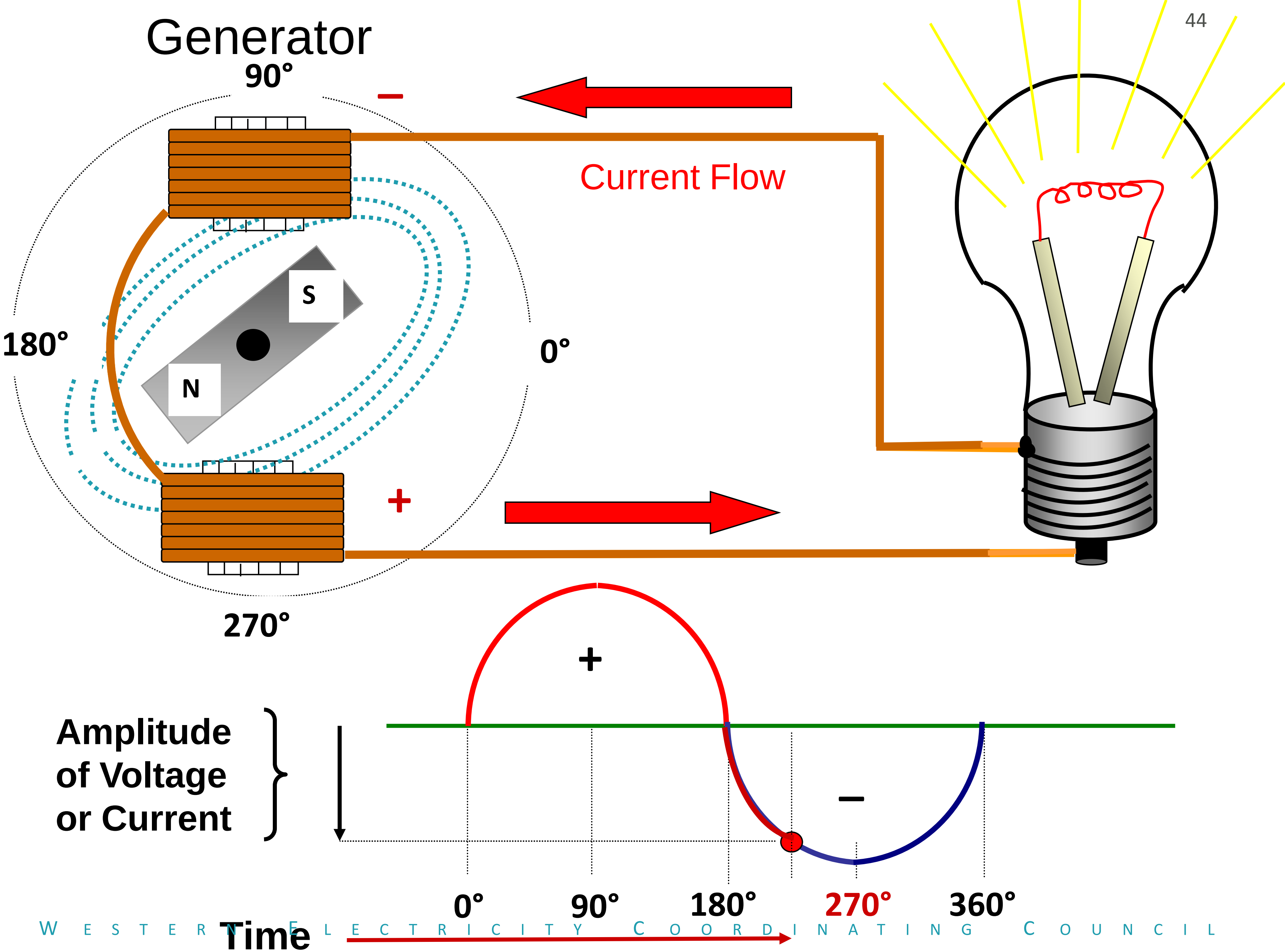
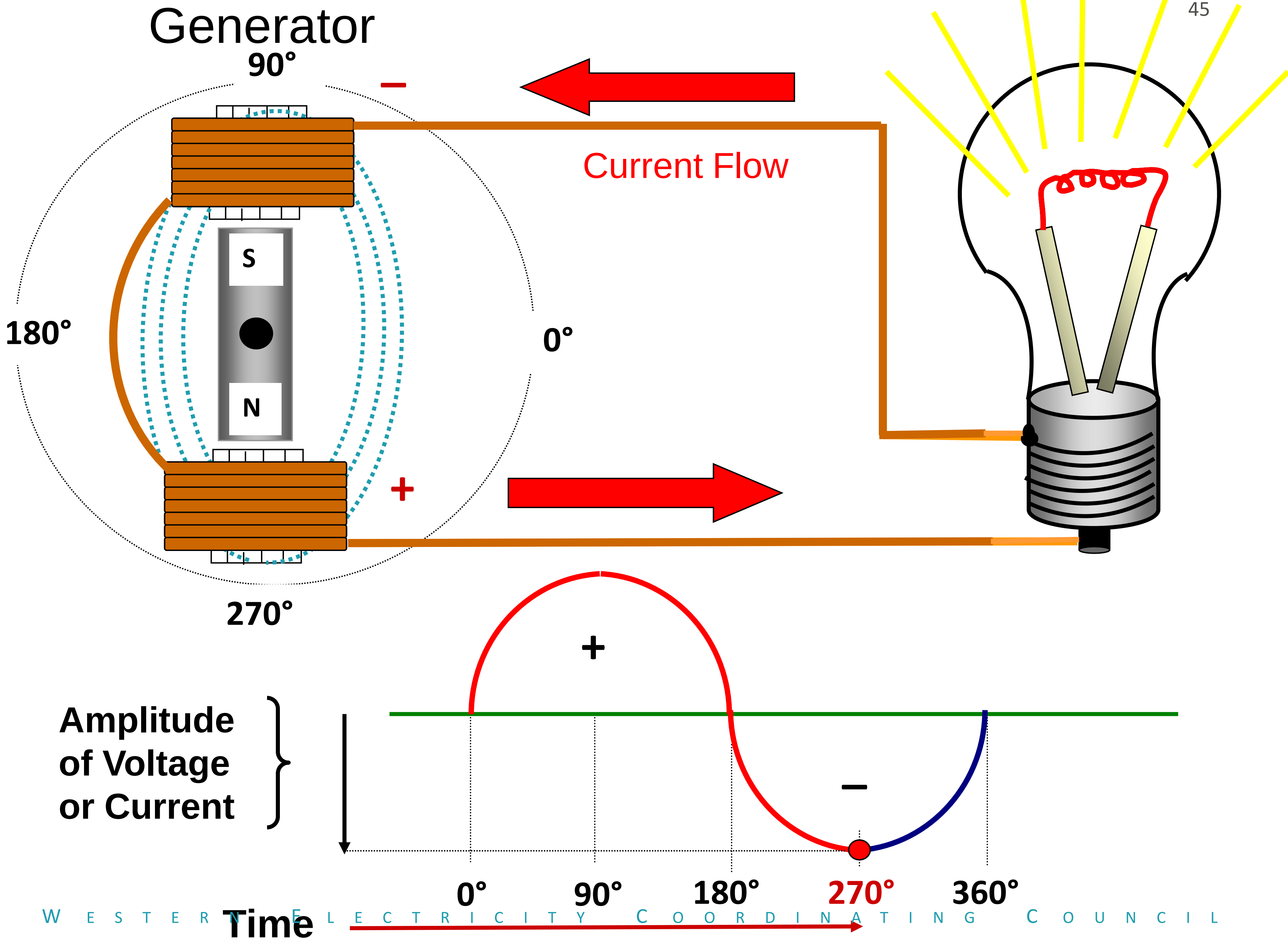
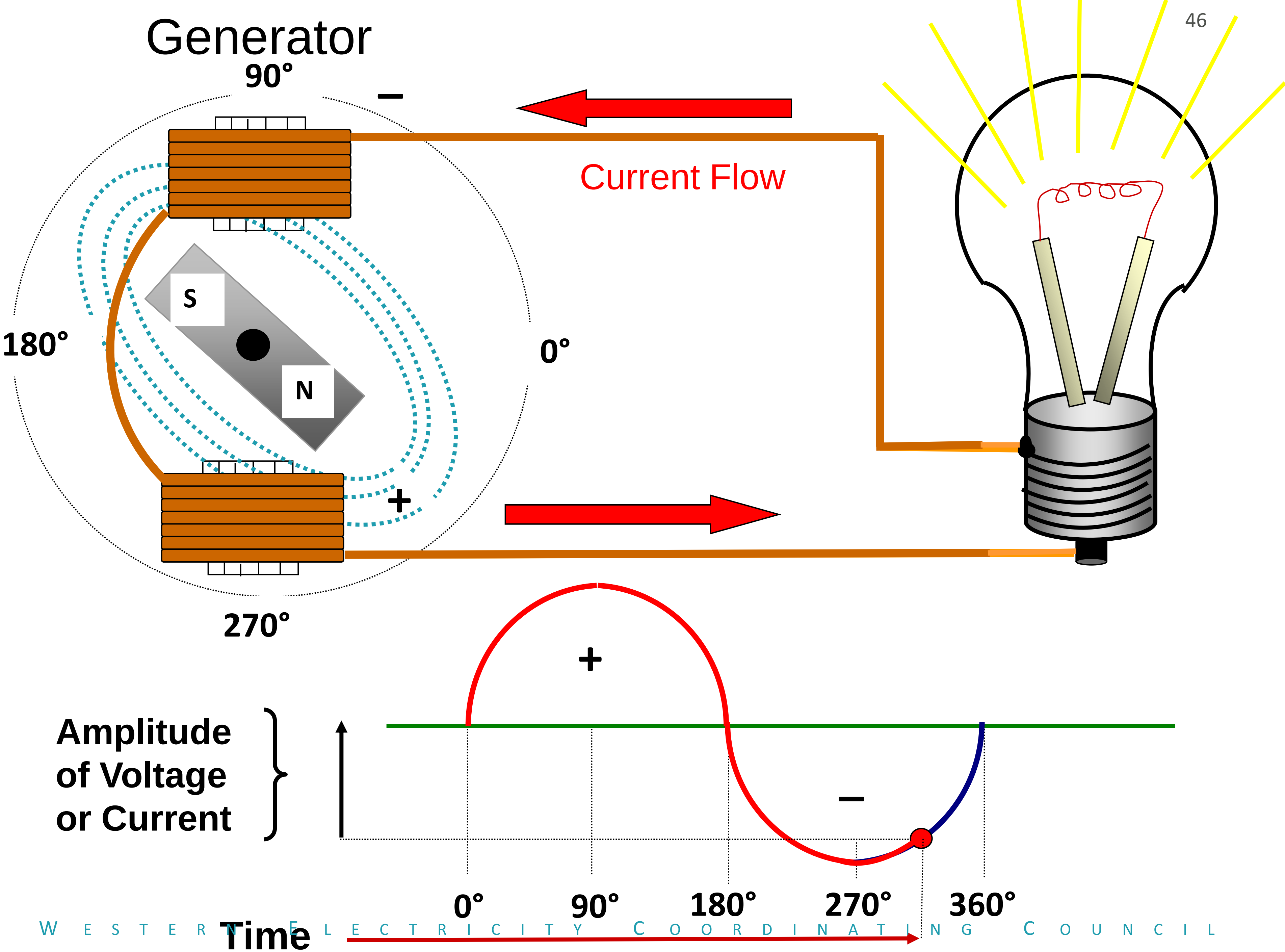
S
180°
0°
270°
–
Amplitude
of Voltage
or Current
+
–
0°
90°
180°
270°
360°
Time

Generator

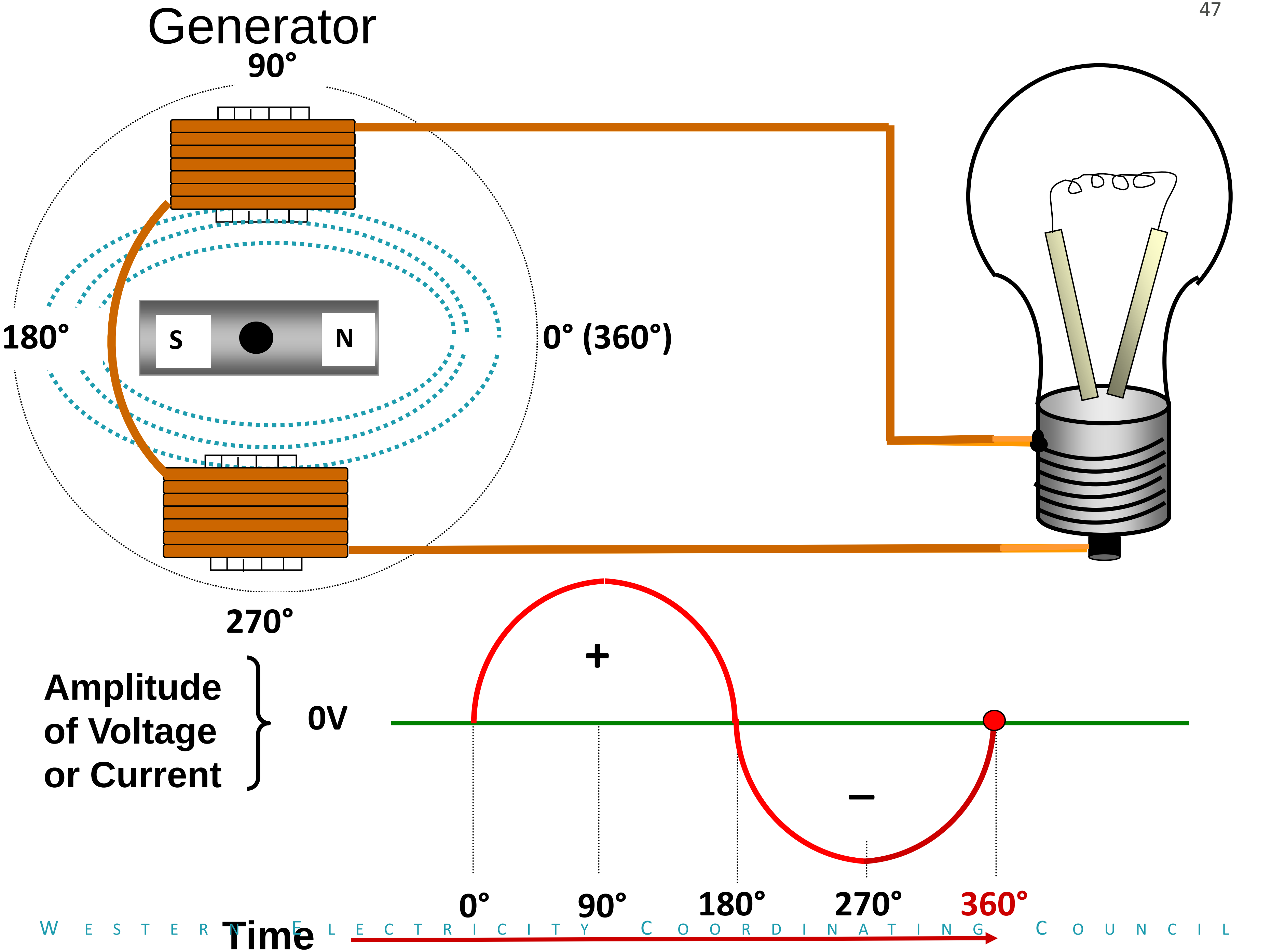

90°
180°
0°
270°
N
S
Amplitude of Voltage or Current
0V
+
–
0°
90°
180°
270°
360°
Time


Generator
90°
–
180°
0°
270°
S
N
+
Current Flow
+
–
Amplitude of Voltage or Current
0°
90°
180°
270°
360°
Time


Generator
90°
–
S
N
180°
0°
270°
+
Current Flow
+
–
Amplitude of Voltage or Current
0°
90°
180°
270°
360°
Time

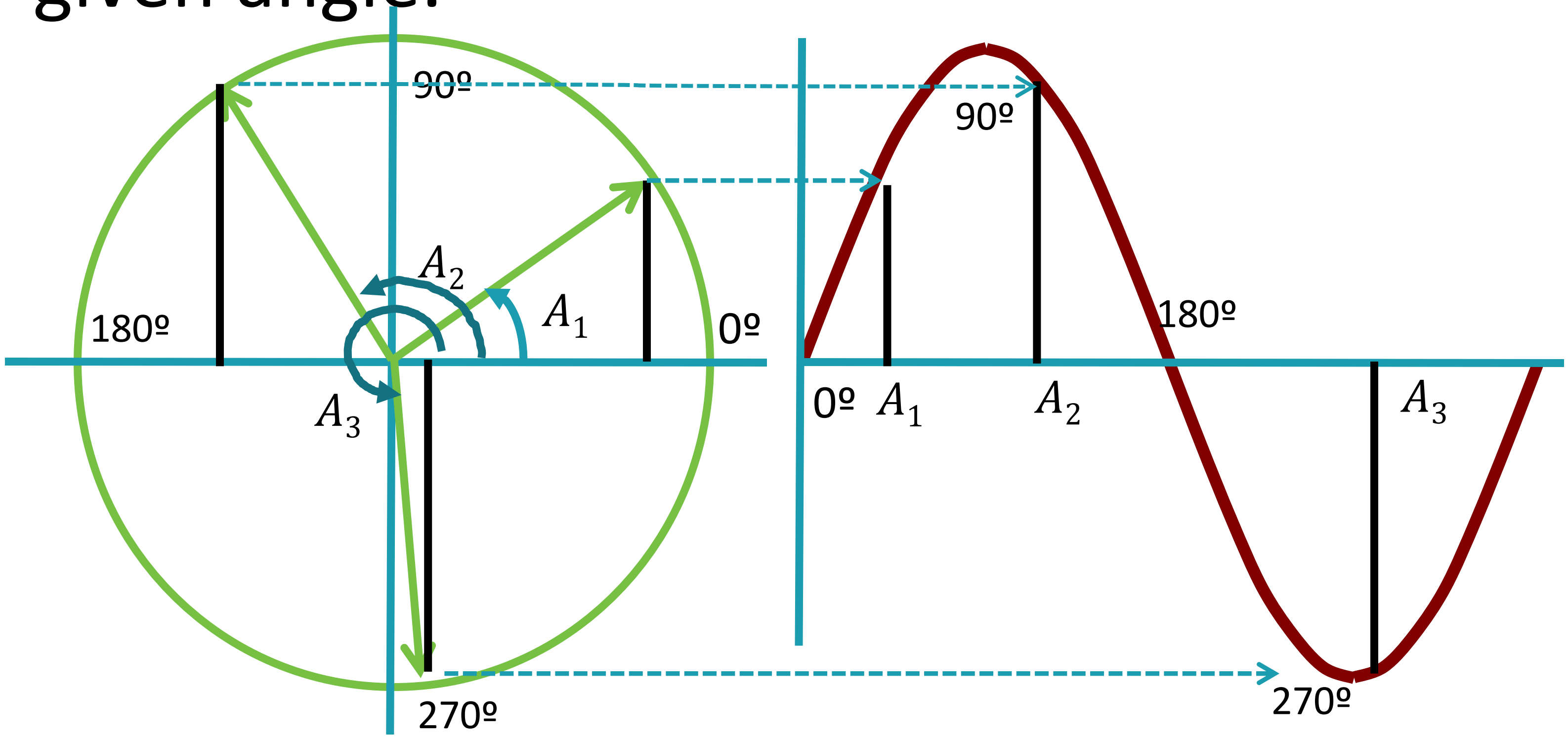


Generator
90°
–
180°
0°
270°
S
N
+
Current Flow
+
–
Amplitude of Voltage or Current
0°
90°
180°
270°
360°
Time


Generator
90°
180°
S
N
0° (360°)
270°
Amplitude of Voltage or Current
0V
+
–
0°
90°
180°
270°
360°
Time

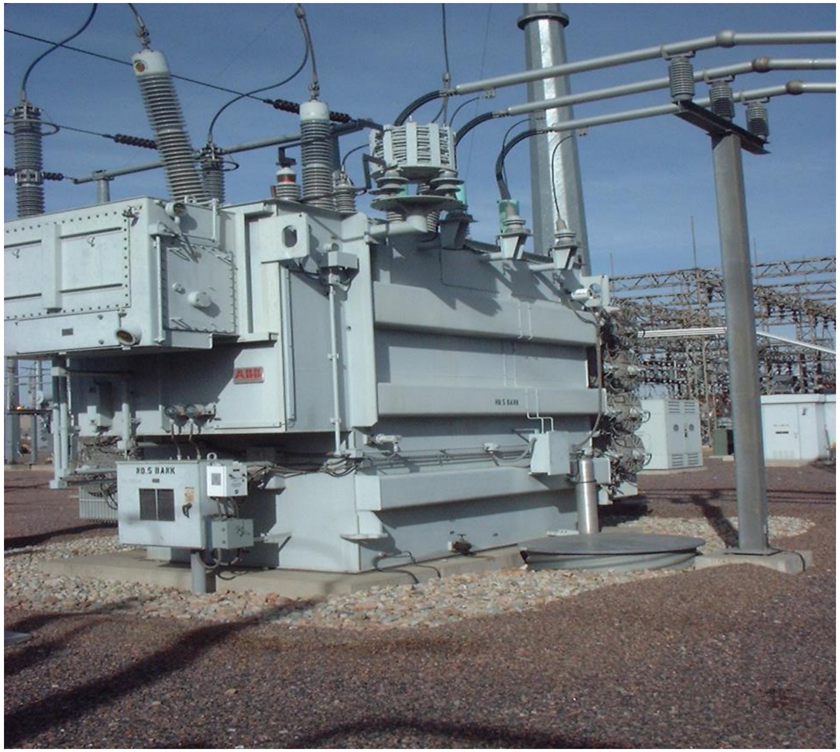
Generator Basics
Alternating Current vs Direct Current

A Sine Wave shows the height of the circle at a given angle.



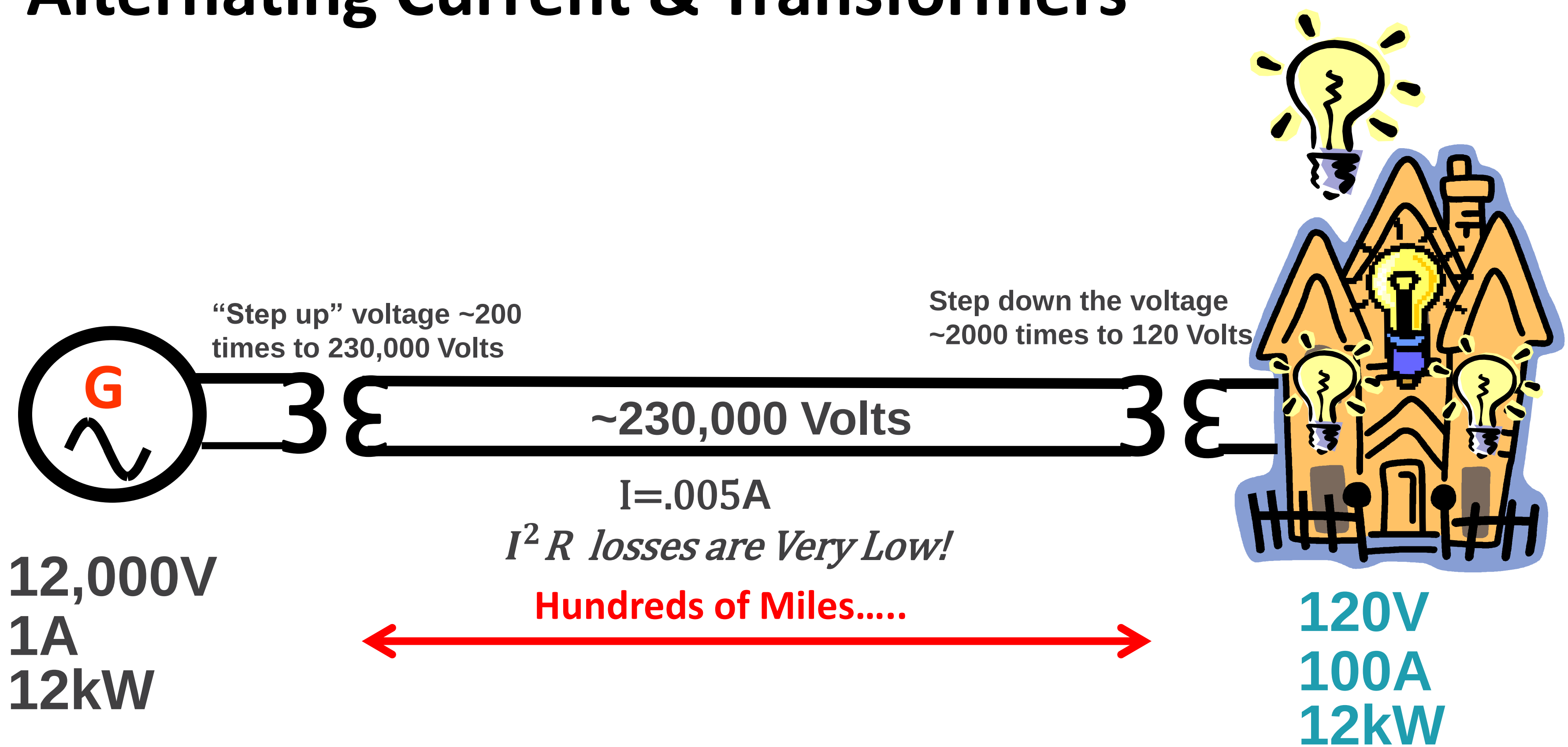
Generator Basics
Alternating Current vs Direct Current

With Alternating Current you can use a Transformer to step-up or step-down the voltage.



Generator Basics
Alternating vs. Direct Current

Alternating Current & Transformers



Generator Basics
Alternating Current vs Direct Current

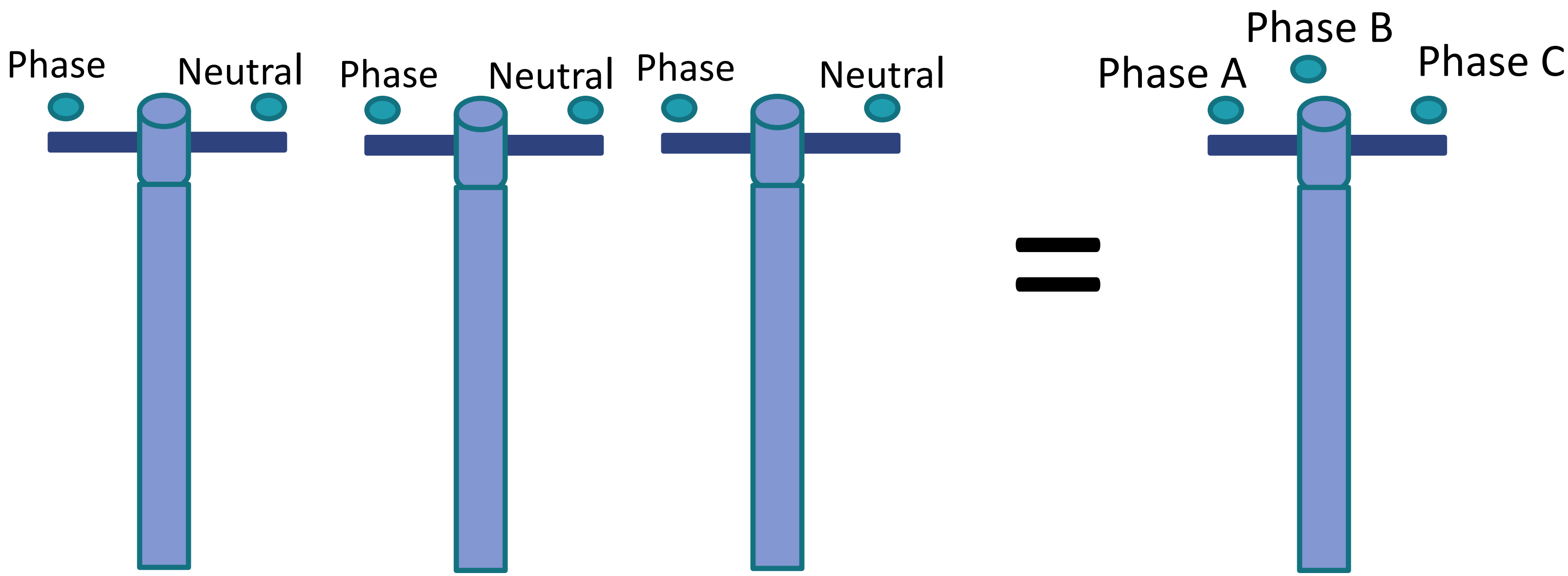
3-Phase Definition and Advantages

- Almost all electricity is generated and distributed as ***three-phase*** rather than single-phase.
- Cost of three-phase is less than single-phase
- Uses fewer conductors
- Reduces Losses

Generator Basics
Alternating Current vs Direct Current

3 – Single Phase Lines

1 – 3 Phase Line



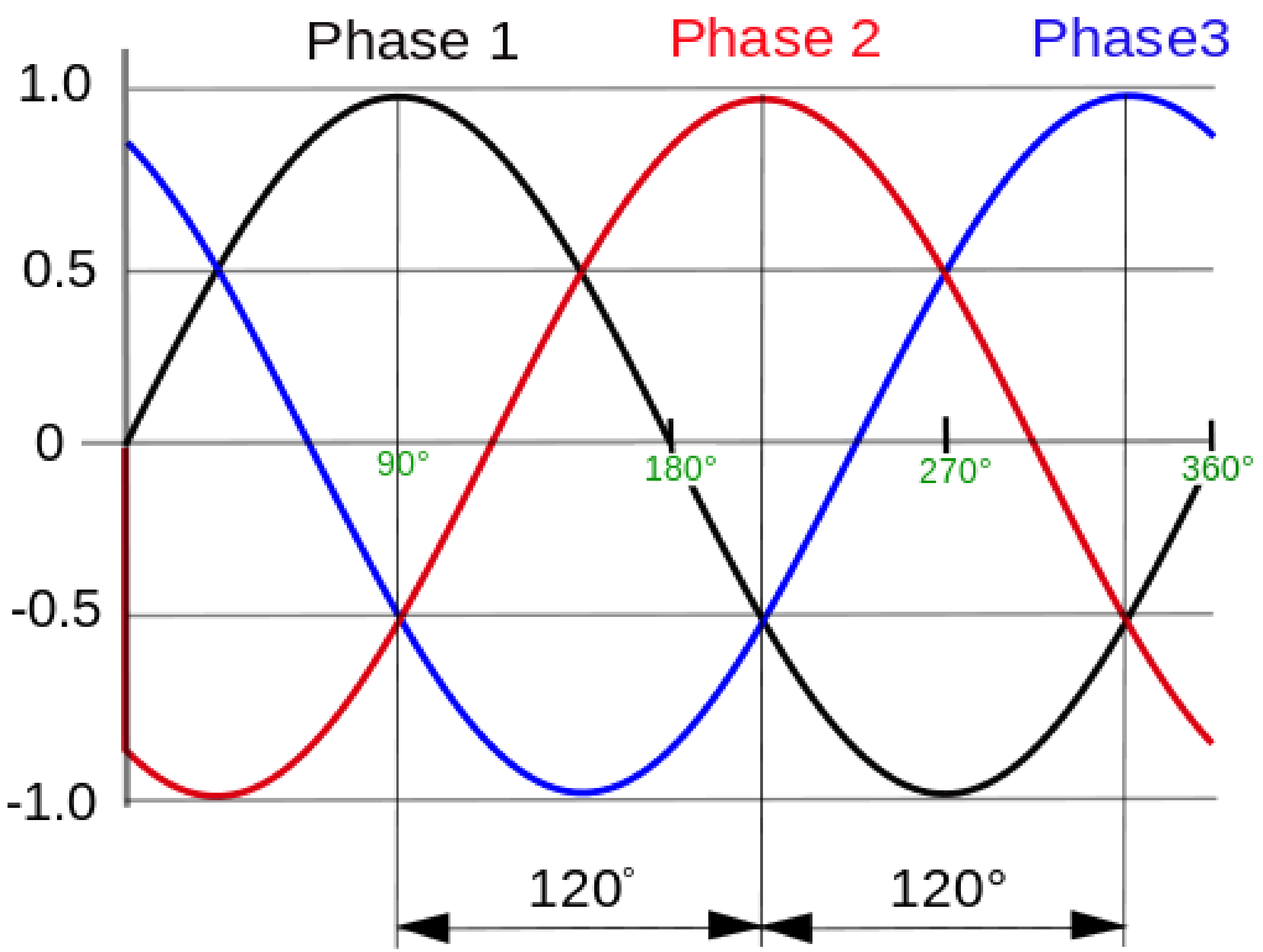
Six Conductors

Three Conductors

Neutral Current – returns on other two phases

3-Phase Definition and Advantages

Generator Basics
Alternating Current vs Direct Current

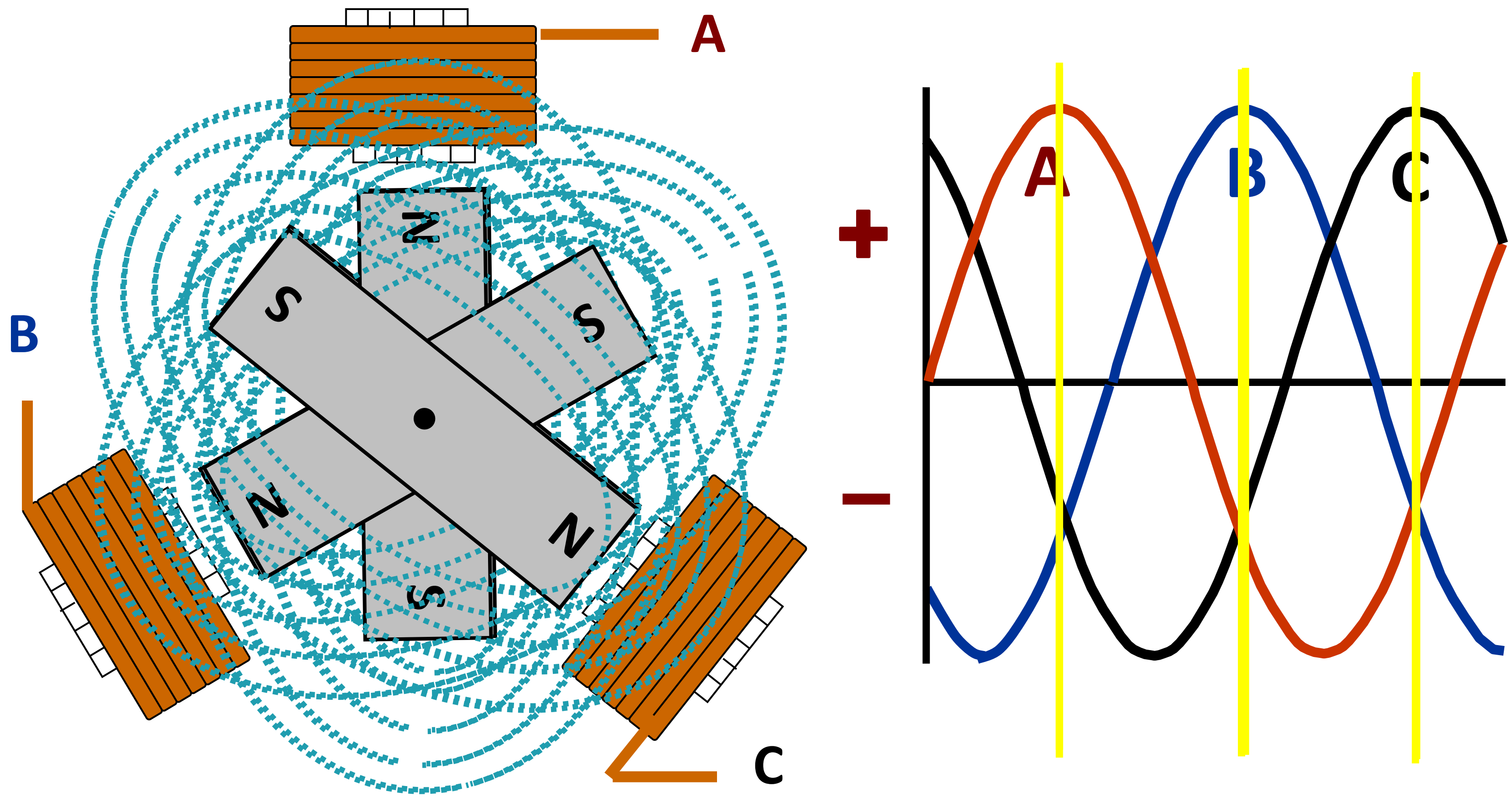


Alternating Current vs Direct Current

Three Phase Power

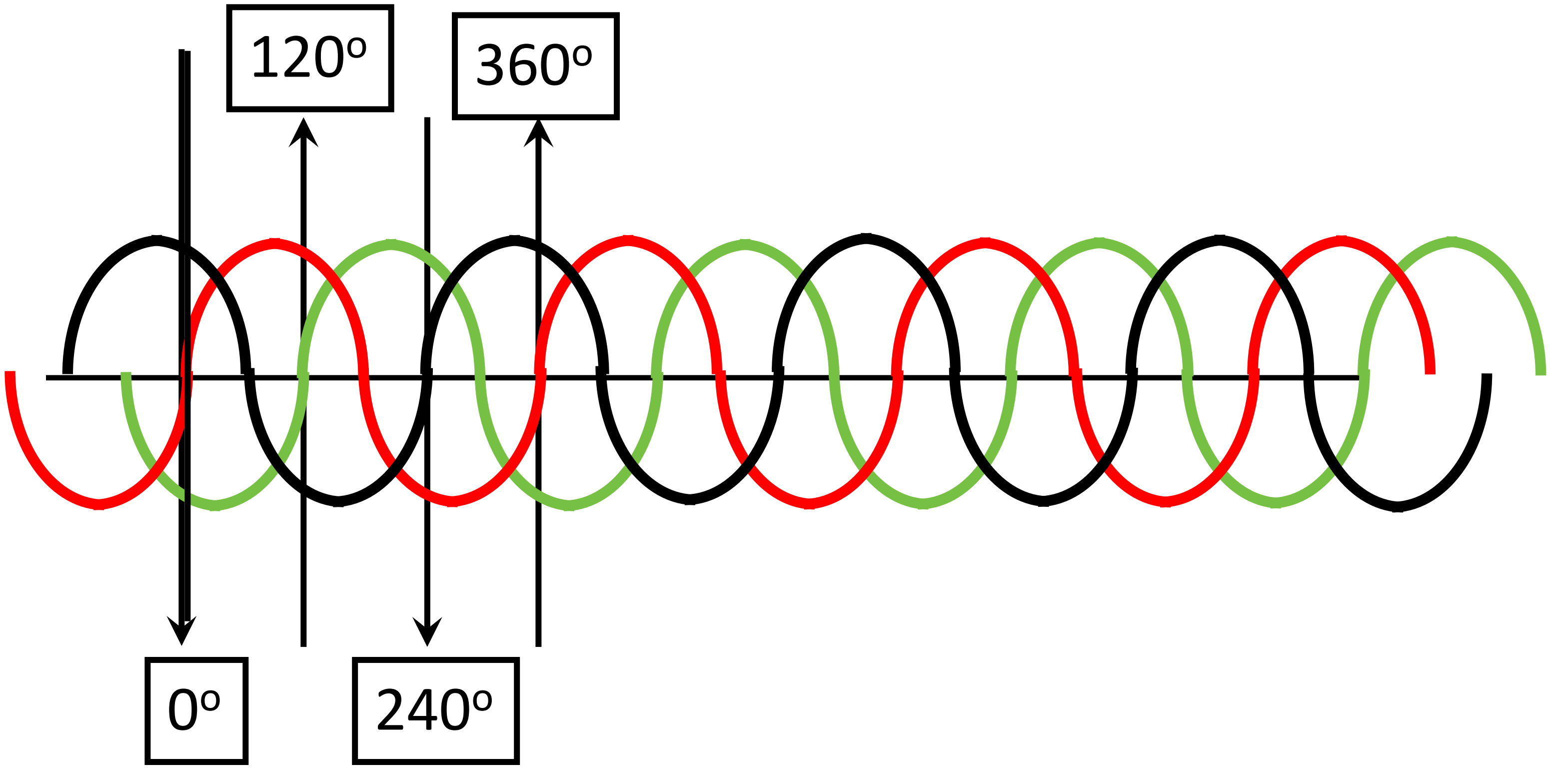
- Three-phase motors are generally much smaller than single phase motors of the same horse-power
- Conductors supplying a three-phase load can generally be smaller than those supplying a equivalent single-phase load
- The power delivered to the load is the same at any instance & never falls to zero

Generator Basics
Alternating Current vs Direct Current



Generating 3-Phase Power Waves

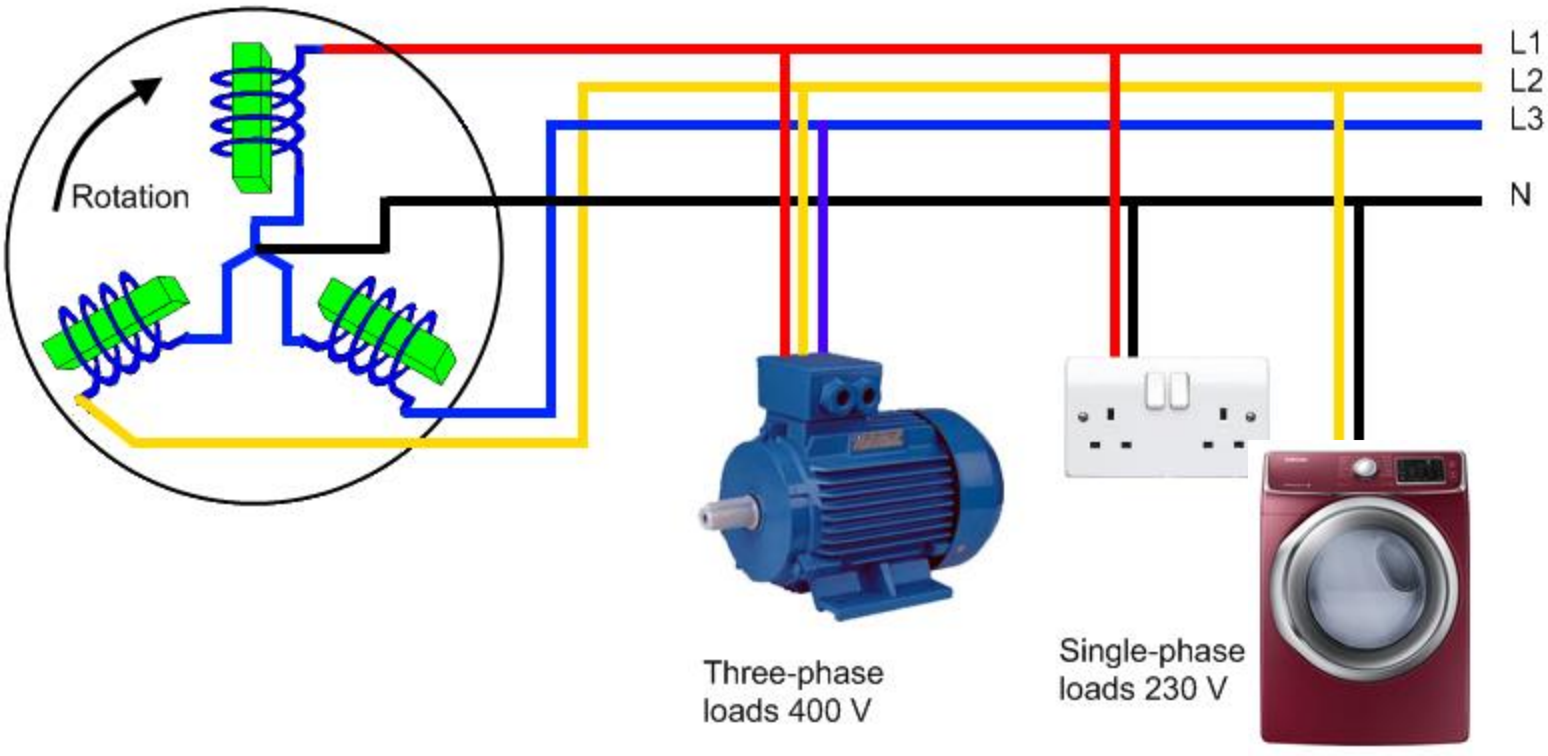
Generator Basics
Alternating Current vs Direct Current



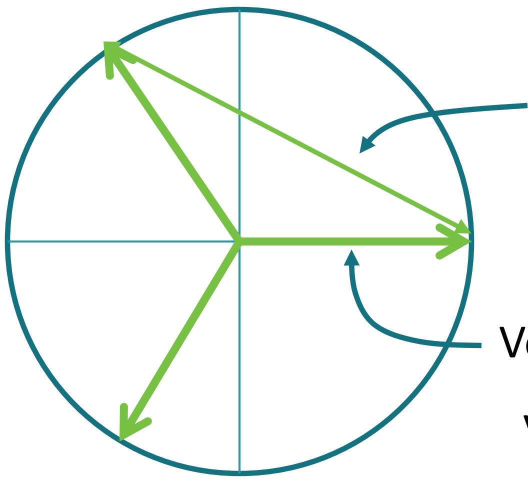
A Phase **B Phase** **C Phase**

Alternating Current vs Direct Current

Three Phase AC Generator



Generator Basics
Alternating Current vs Direct Current



Voltage Phase-to-Phase = $V_{P\text{-}P}$

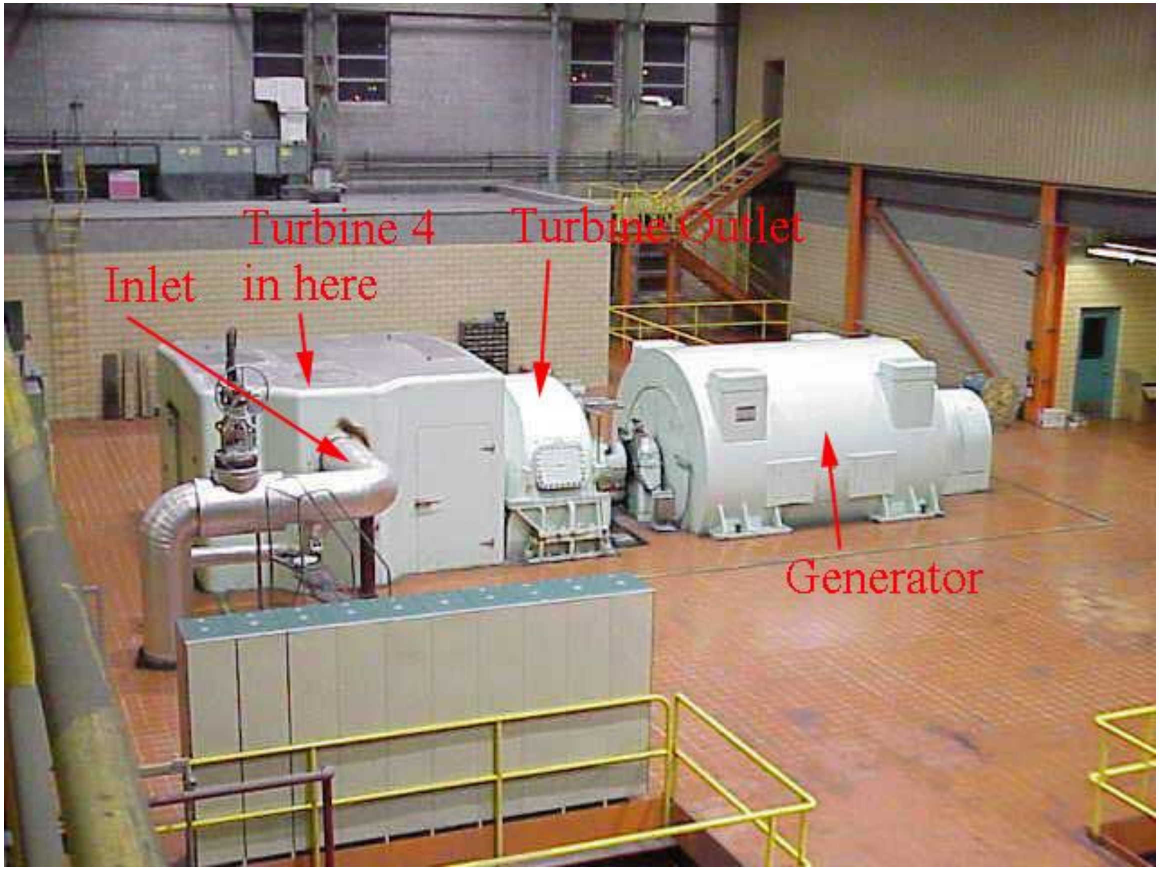
Voltage Phase-to-Neutral = $V_{P\text{-}N}$

Voltage Phase-to-Phase = $\sqrt{3}$ * Voltage Phase-to-Neutral

Power = 3* Current * $V_{P\text{-}N}$

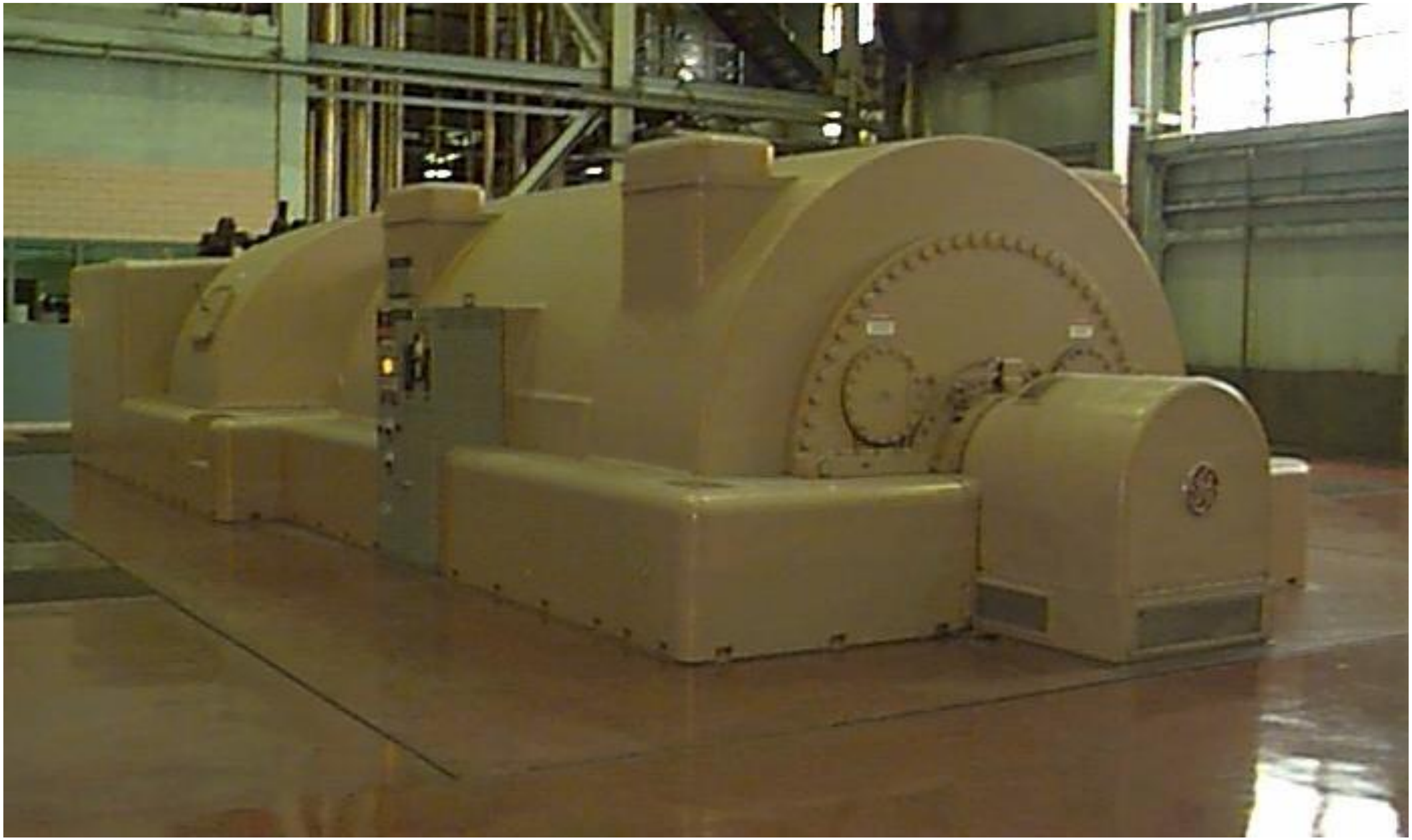
Power = $\sqrt{3}$* Current * $V_{P\text{-}P}$

Power System Elements are usually rated on their Phase-to-Phase Voltage, i.e. a 230kV line is rated at 230kV Phase-to-Phase



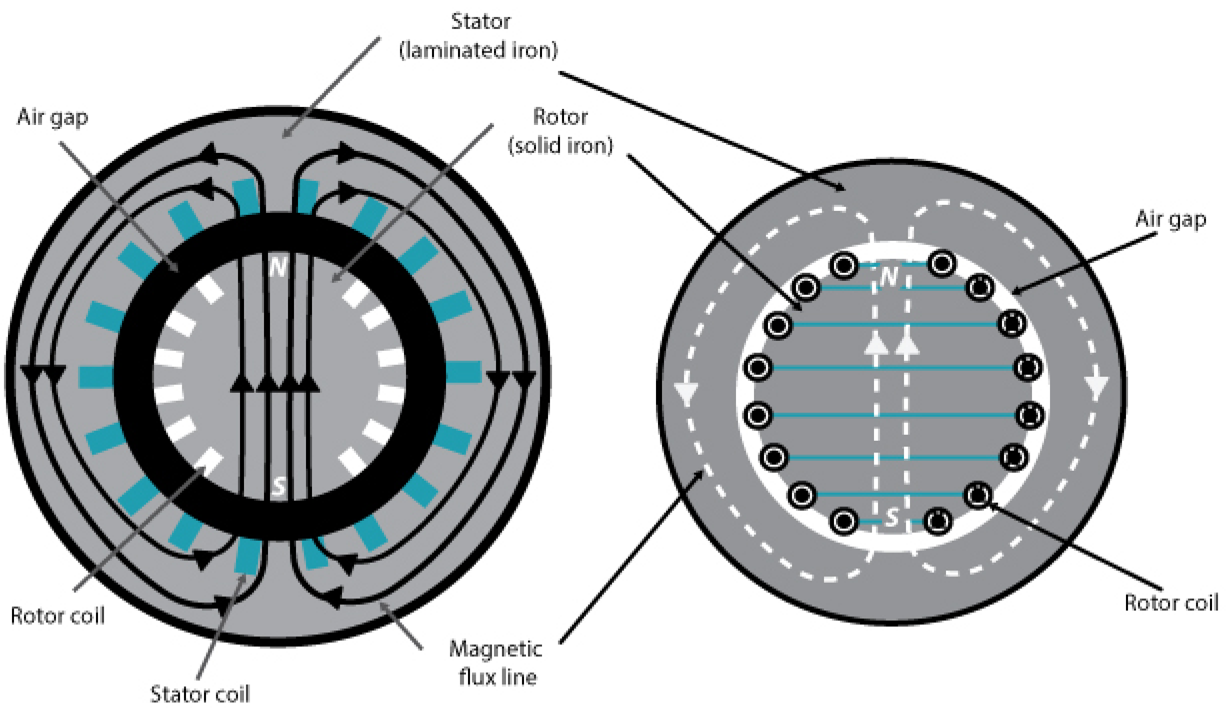
Generator Basics and Components

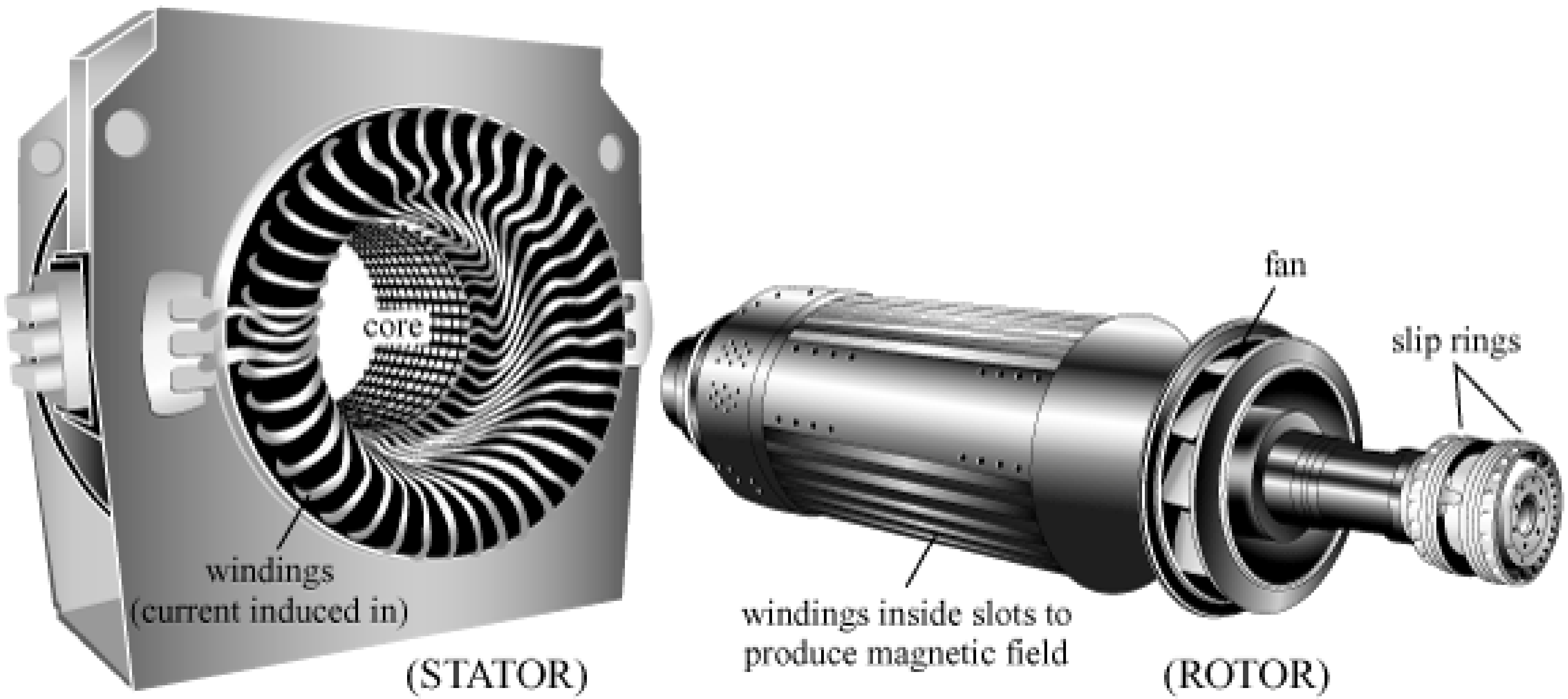
Turbine and Generator

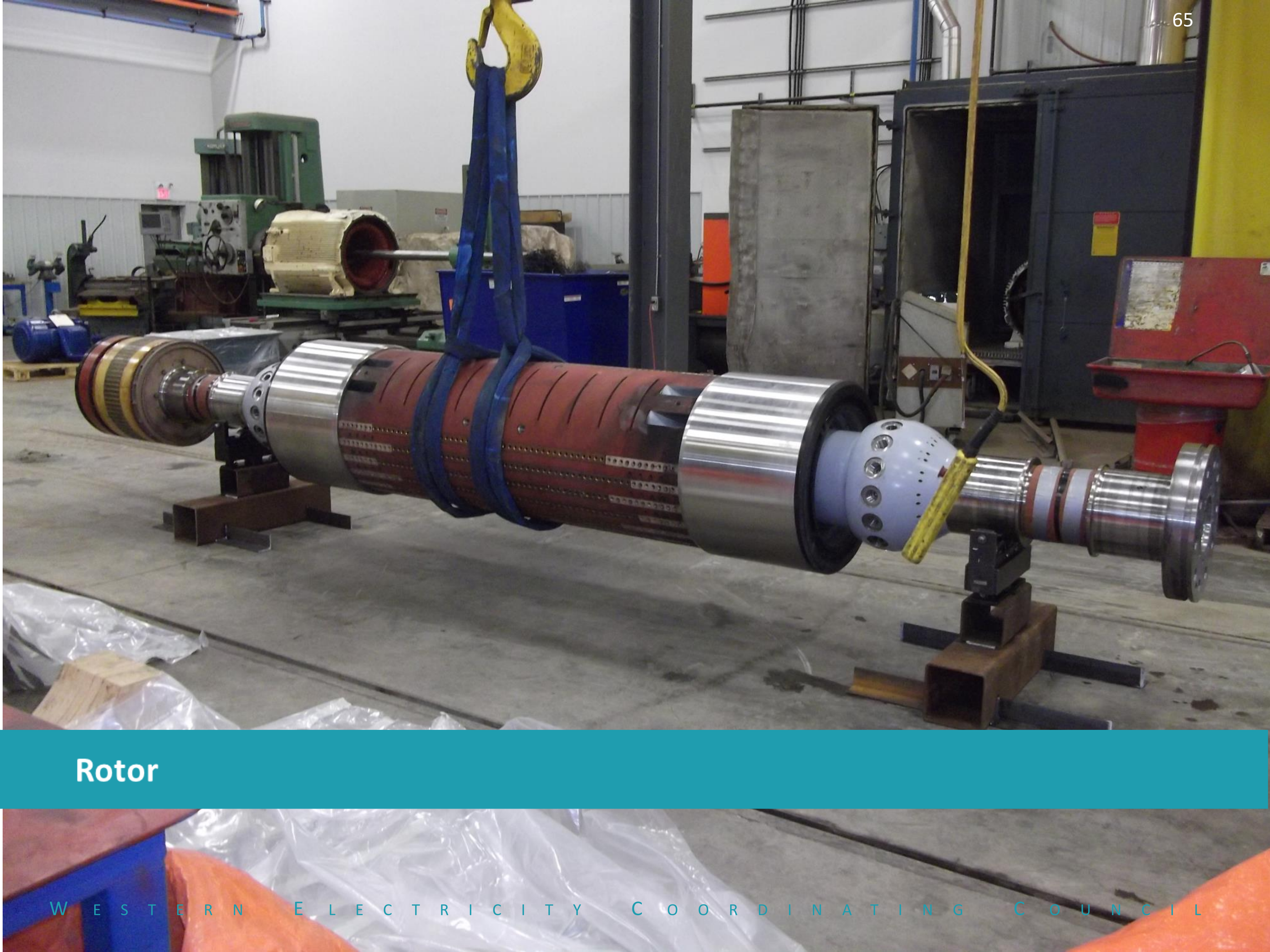


Generator Basics Components

Rotor and Stator End View showing Path of Magnetic Flux Lines

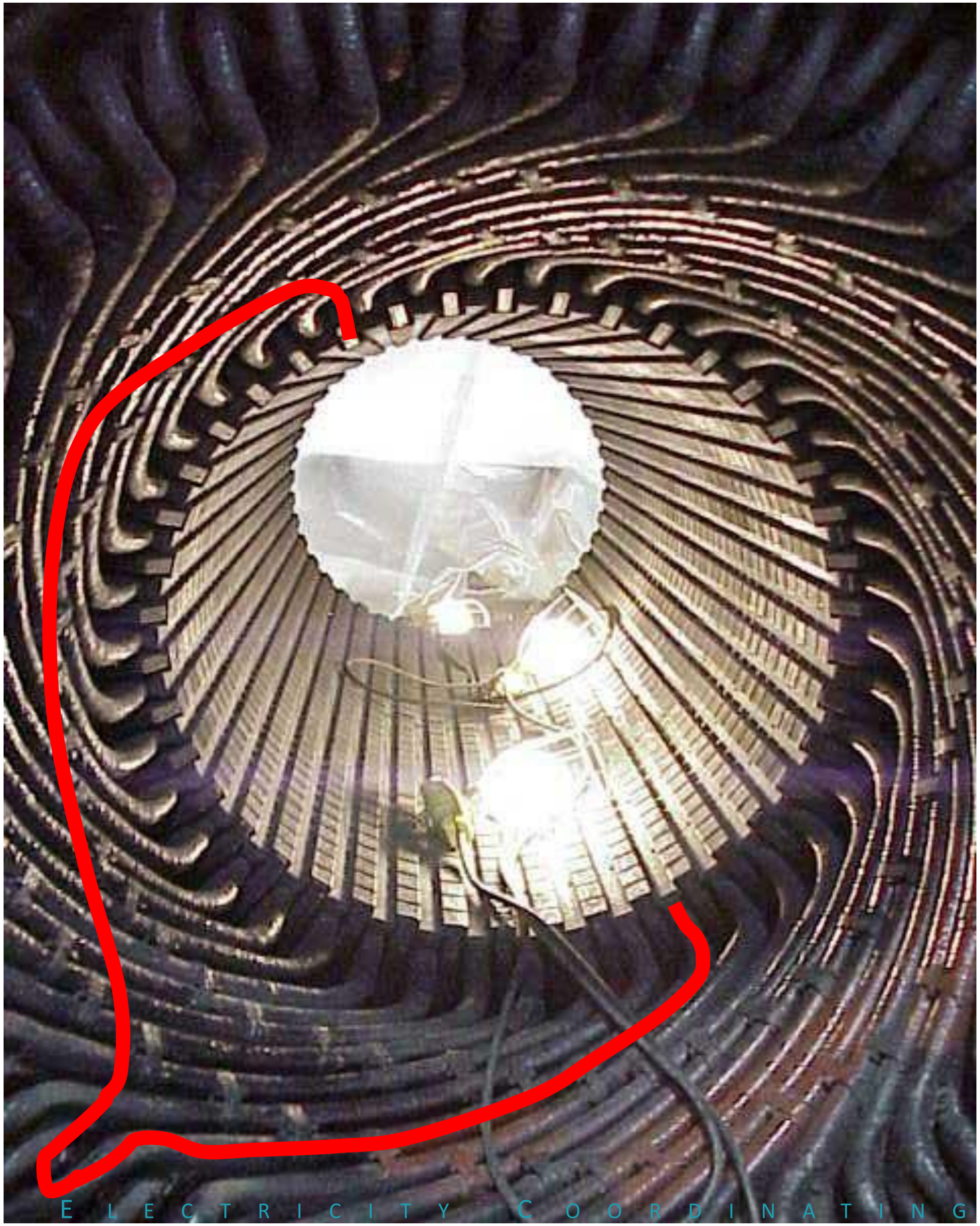


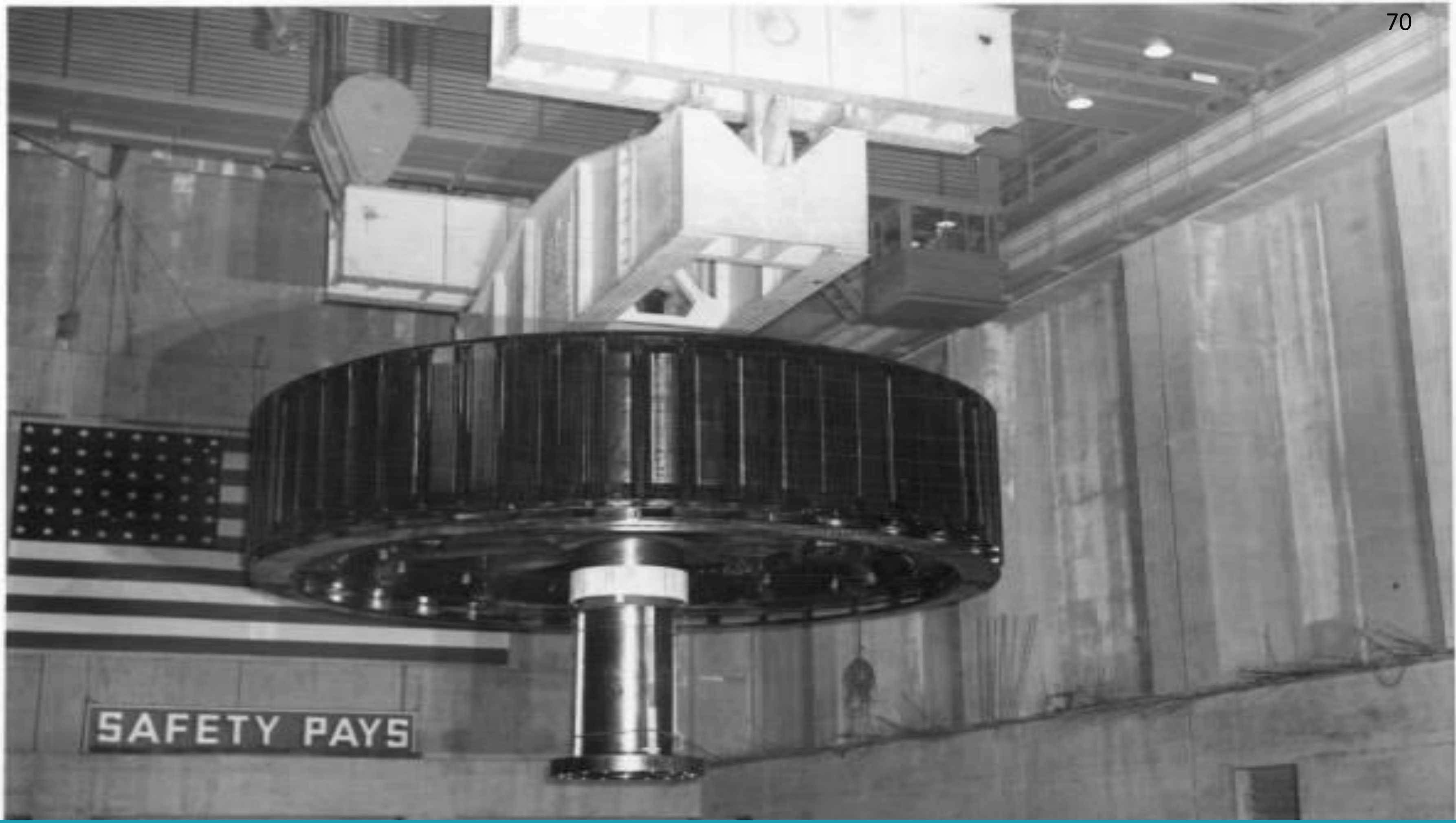

core
windings
(current induced in)
(STATOR)
windings inside slots to
produce magnetic field
fan
slip rings
(ROTOR)



Rotor

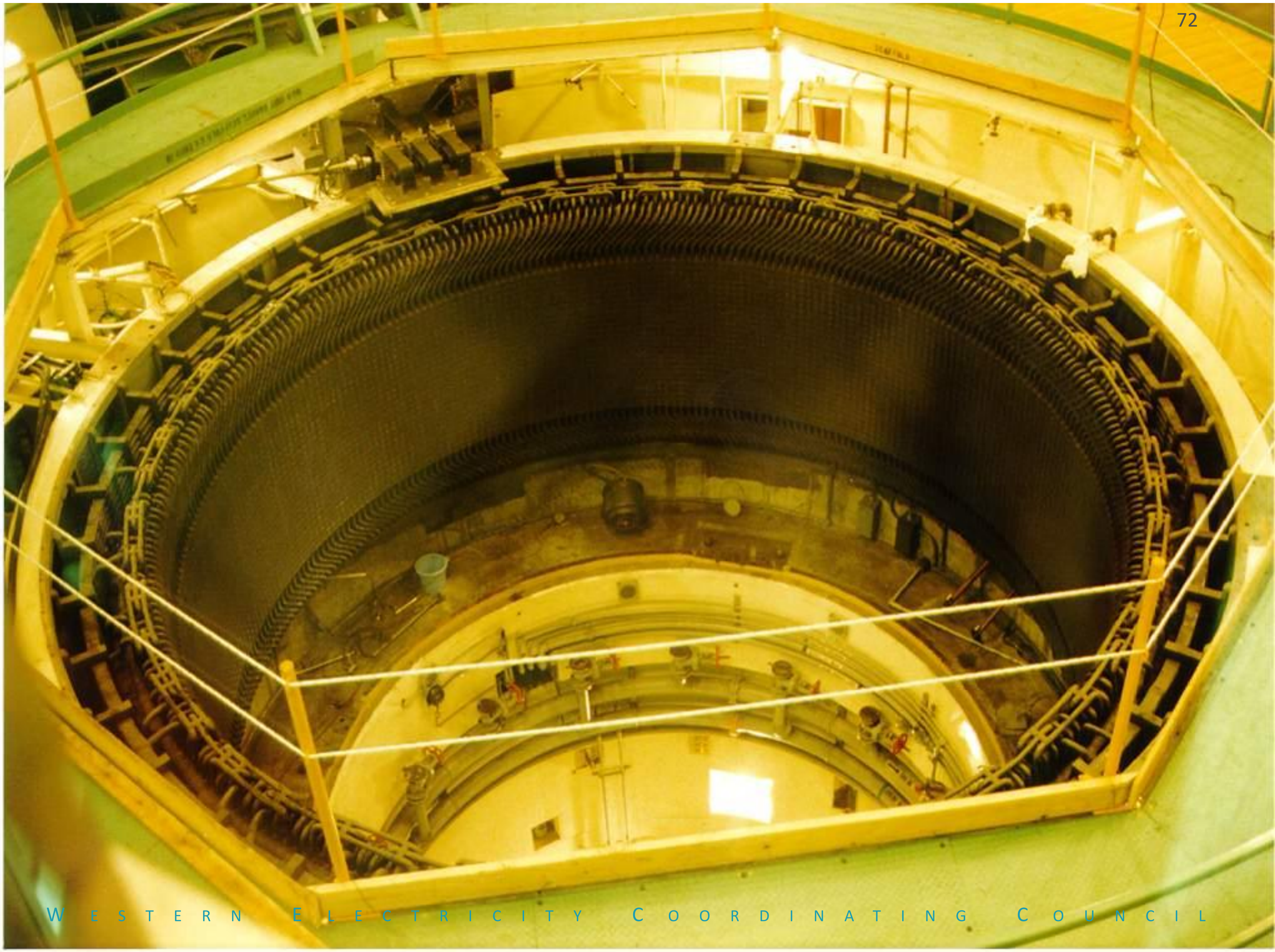
Rotor into Stator



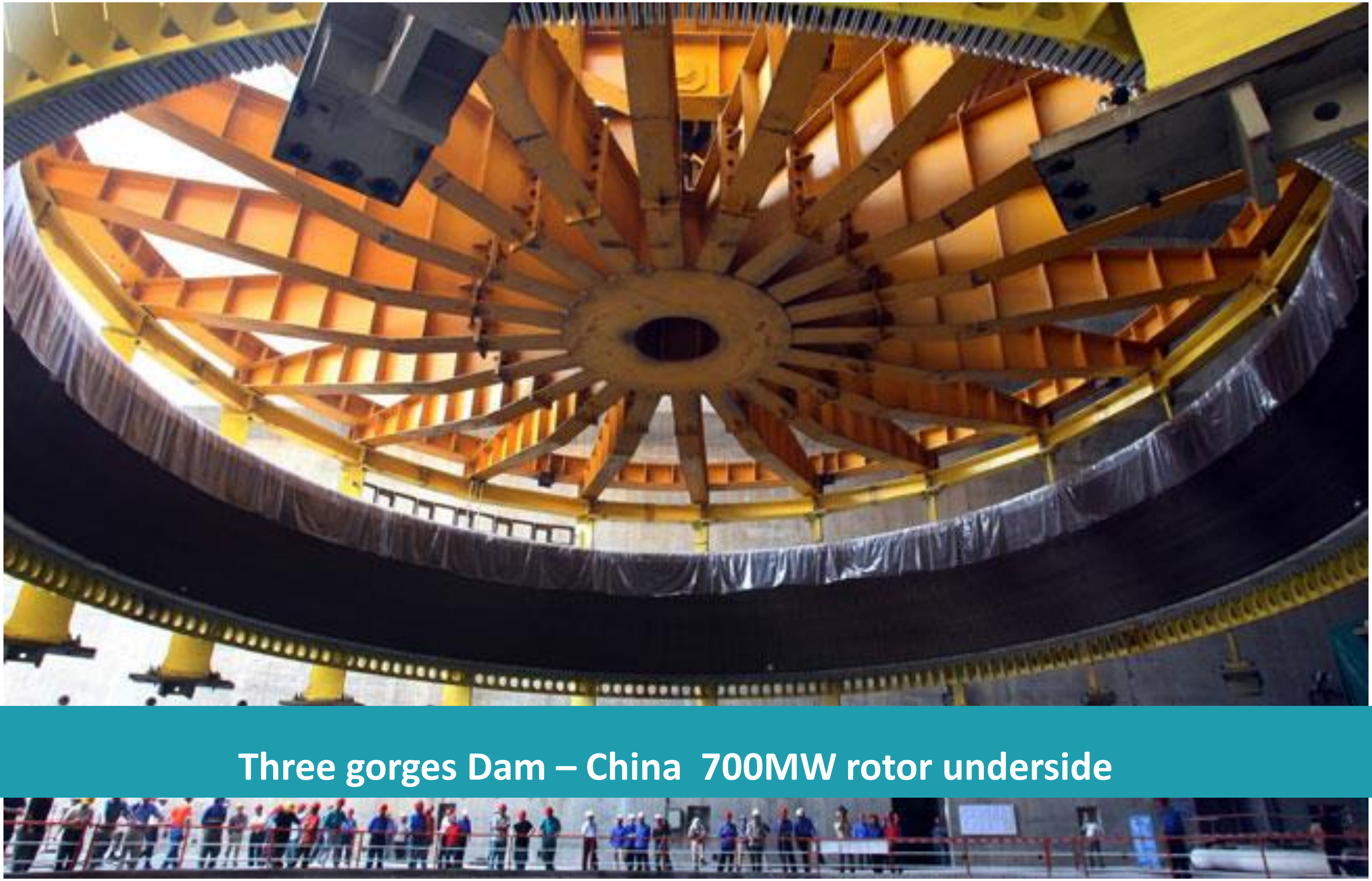


Grand Coulee 600 MW Rotor is 31 feet in diameter, weighing 535 tons, rotates at a speed of 120 revolutions per minute within the stator

Grand Coulee 600 MW Rotor is 31 feet in diameter, weighing 535 tons, rotates at a speed of 120 revolutions per minute within the stator



Three gorges Dam – China 700MW rotor top

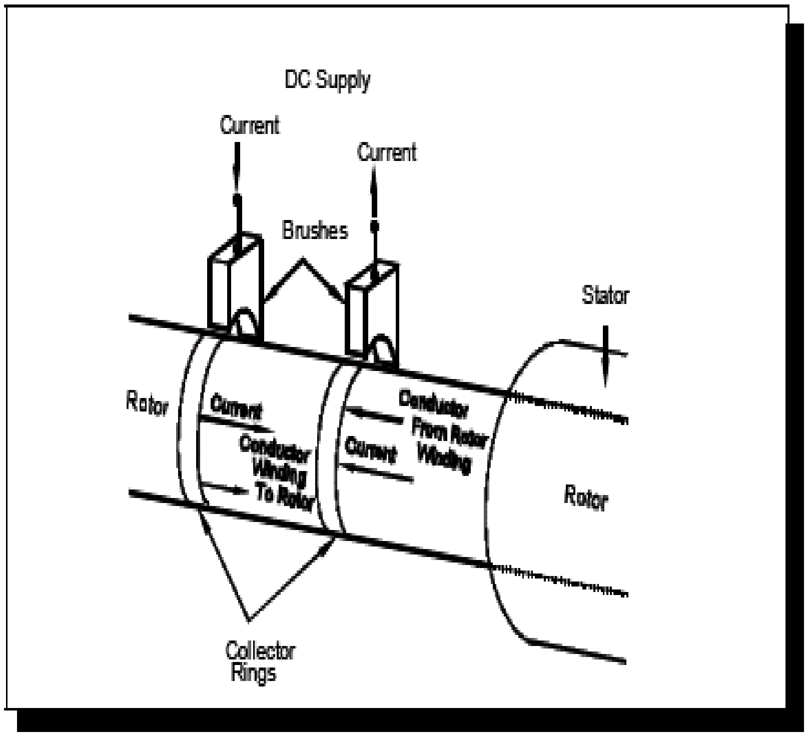


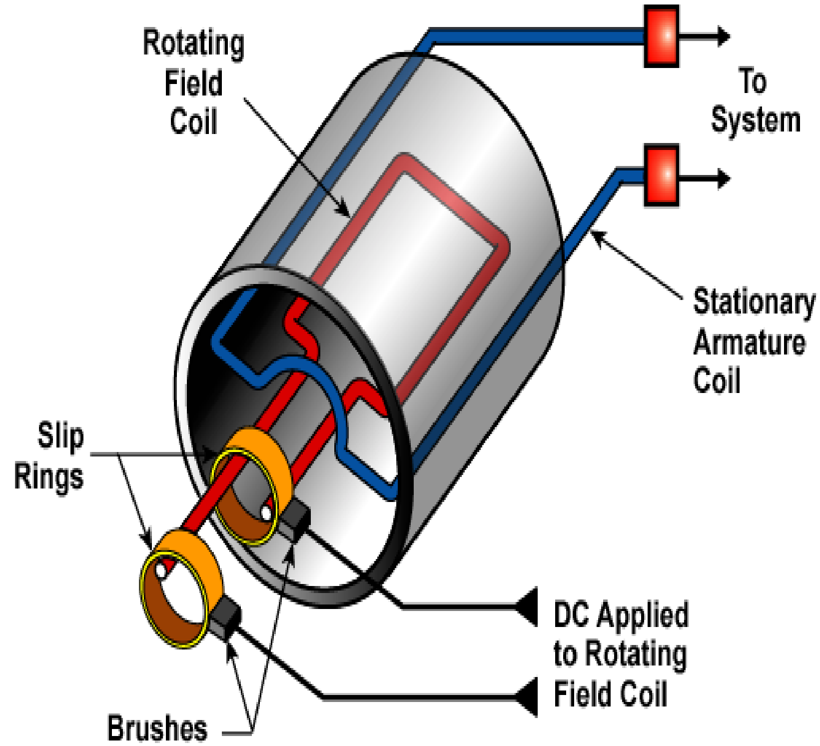
Three gorges Dam – China 700MW rotor underside

Three gorges Dam – China 700MW rotor inlets

Three gorges Dam – China 700MW Generator Hall (26)

Generator Basics
Excitation System

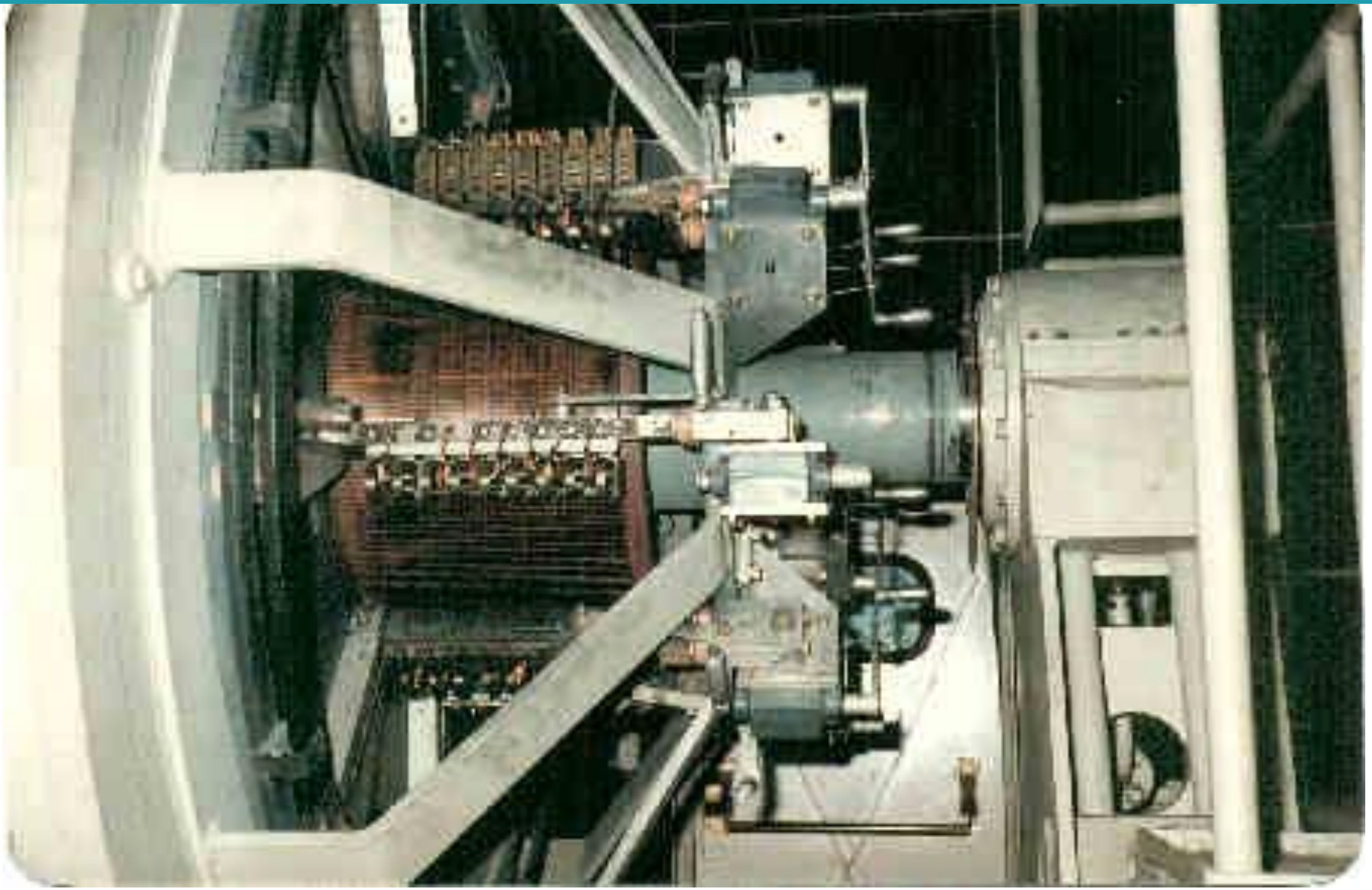




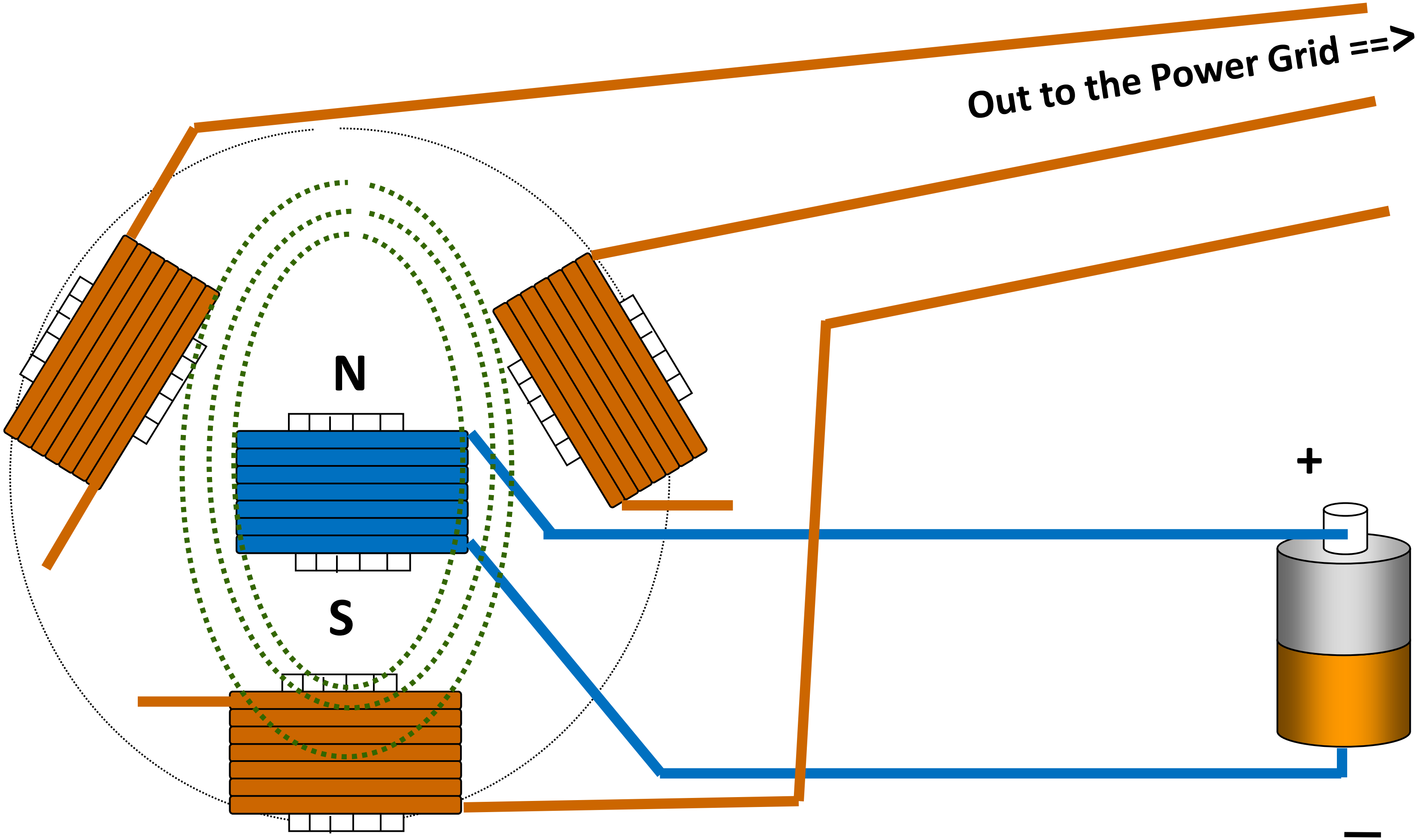
Generator Basics
Excitation System

- The Exciter supplies current to the Rotor
- This makes the rotor into a spinning magnet
- The Exciter can vary current to affect generator voltage and VAR output
- Exciter current flows from the brushes to the slip rings on the rotor

Exciter



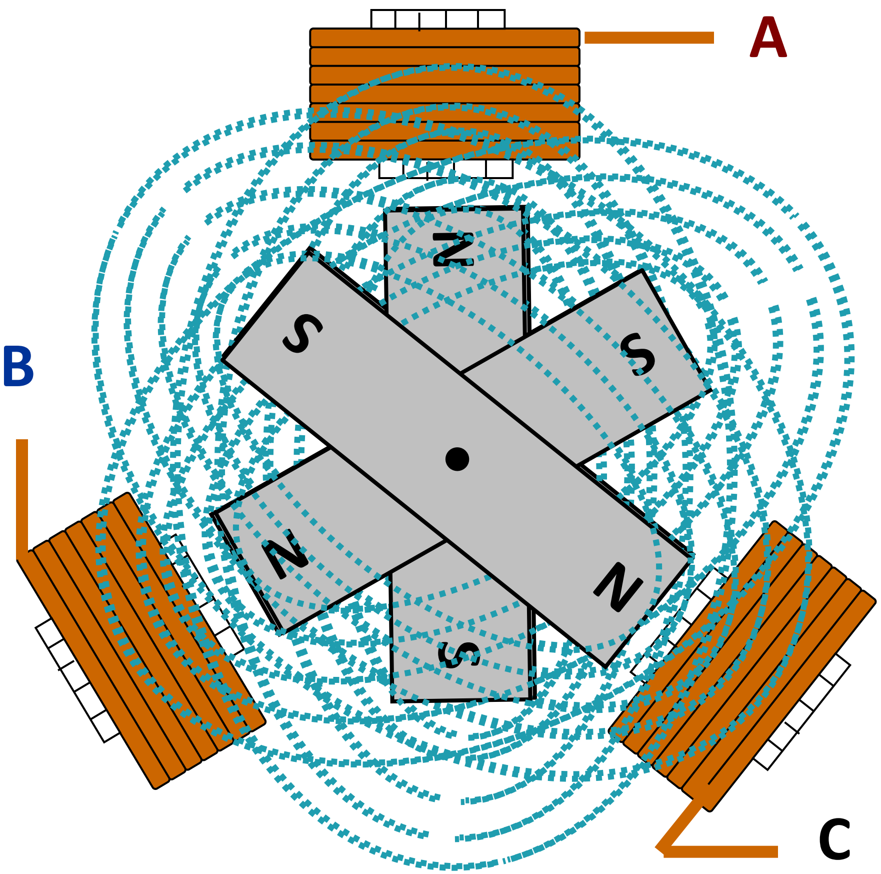
Creating a big magnet

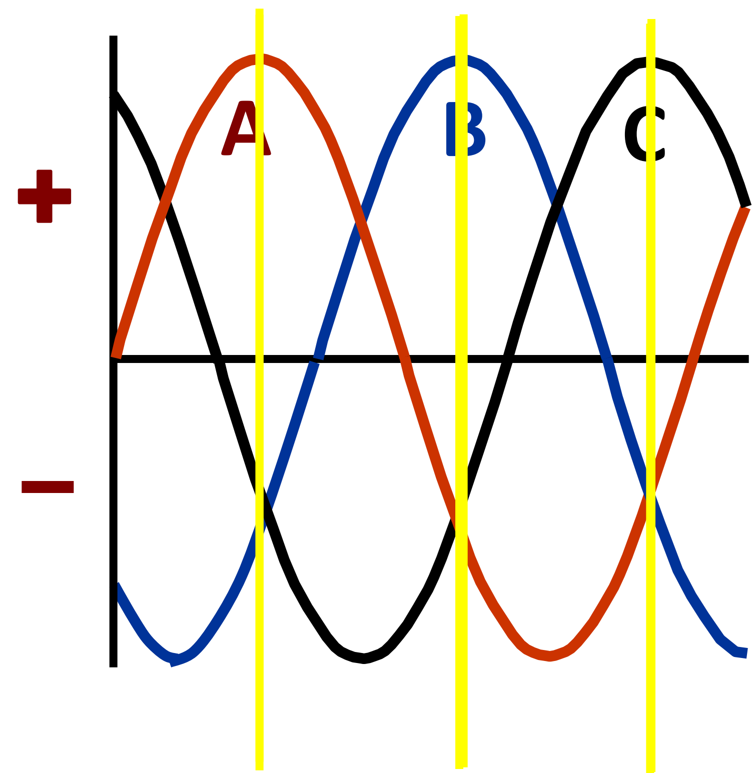


Excitation System

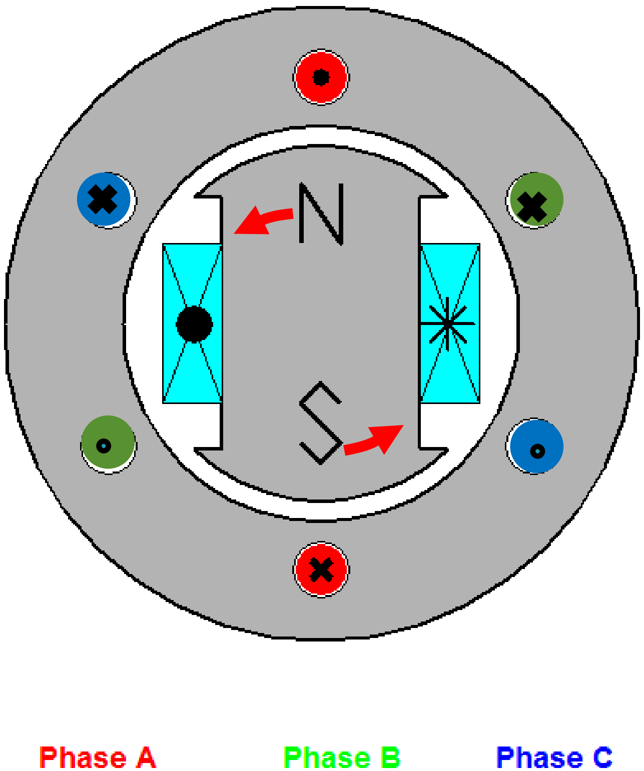
- What does the exciter do?
- Maintains Generator Voltage
  - Either automatically via the **Automatic Voltage Regulator (AVR)** or manually via the plant operator
- Controls reactive Power Flow
  - **Power System Stabilizers (PSS)** are applied at the generator to help dampen oscillations

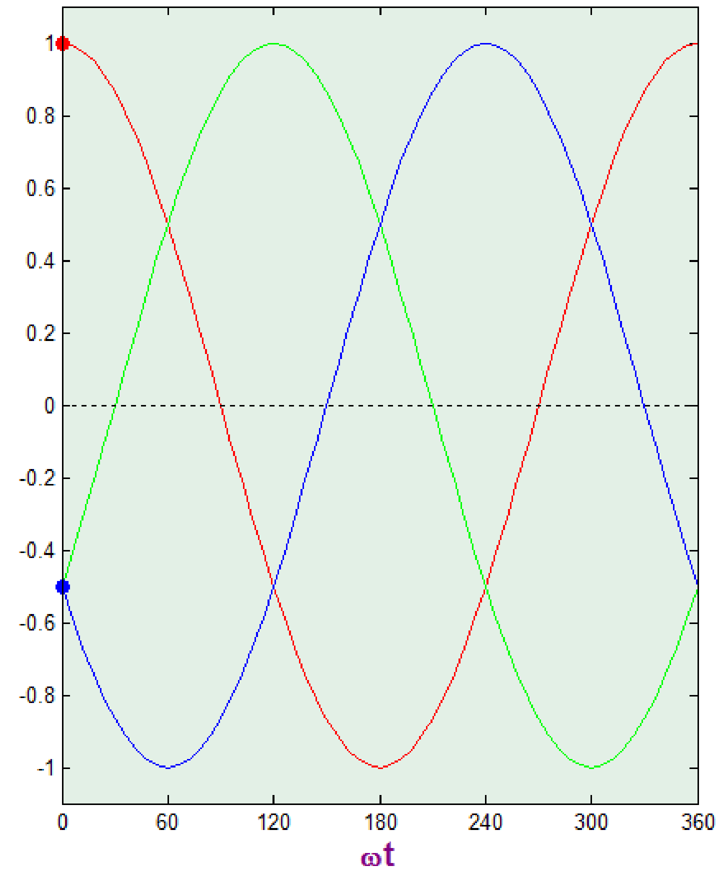
Fundamentals of Electricity
Generating 3-Phase Power Waves





Generator Basics
Three Phase AC Generator



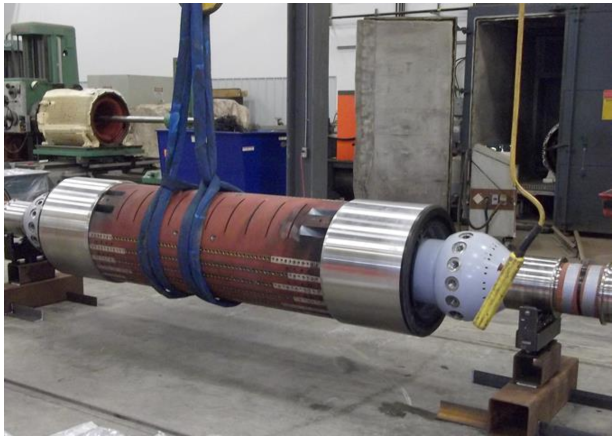


Generator Basics
Frequency and Synchronism

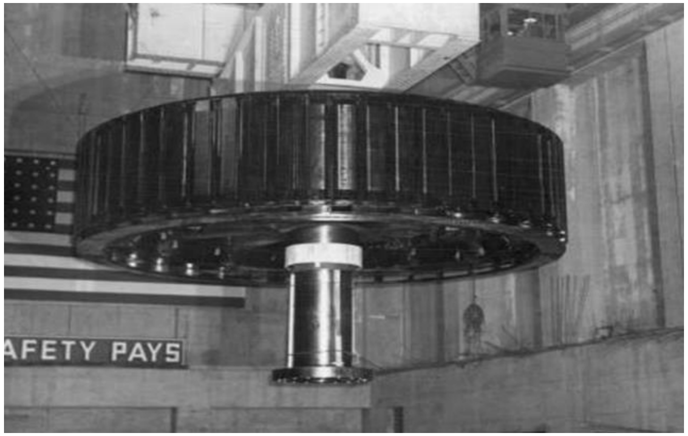
In an AC interconnection, all connected utilities see the same electrical frequency and all generators operate in synchronism with each other.

Generator Basics
Frequency and Synchronism

- In the US, power systems operate at 60 hz.
- The generator rotor must spin fast enough to produce 60 hz.
- RPM depends on how many poles on the rotor



3600 RPM



120 RPM

Generator Basics
Generator Frequency

The generator synchronous speed *N* is:

$$N = \frac{120\,f}{P}$$

Where N = Synchronous speed

f = Frequency

P = Number of poles

Generator Basics
Generator Frequency

The generator output frequency (f) is:

For the **two-pole generator**, each shaft revolution produces one cycle. If the generator rotates at 3,600 revolutions per minute, this is equal to 60 cycles per second. Recall from Module 2: Fundamentals of Electricity that ***one cycle per second is a hertz***. So, 60 revolutions per second equals 60 cycles per second (hertz) or 3,600 revolutions per minute.

What is the RPM of a 4 pole generator??

How many poles does a generator have that rotates at a speed of 120 revolutions per minute within the stator?

Generator Basics
Synchronism

Before closing the circuit breaker, the generator must be synchronized to the power system voltage.

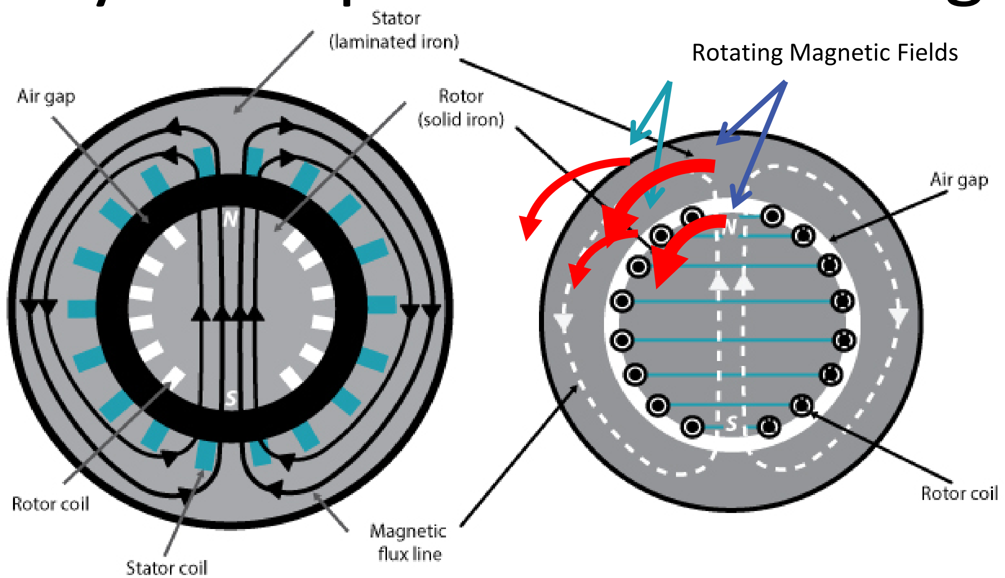
***Synchronism* -** AC systems, or machines, operate at the same frequency… and the angle displacement between them is constant, or in a stable position.

Generator Basics
Stator Field

- When not connected to the system, no current flows in the armature windings
- When connected to the system, current flows in the armature windings
- The current creates a rotating magnetic field called the ***stator field***
- The stator field is a result of the three-phase currents interacting to produce a rotating field

Generator Basics
Rotor DC Field

- There is a magnetic field in the rotor body called the DC field
- The DC field rotates along with the rotor
- The rotor must stay in-step with the rotating stator field



Generator Basics
Rotor Angle

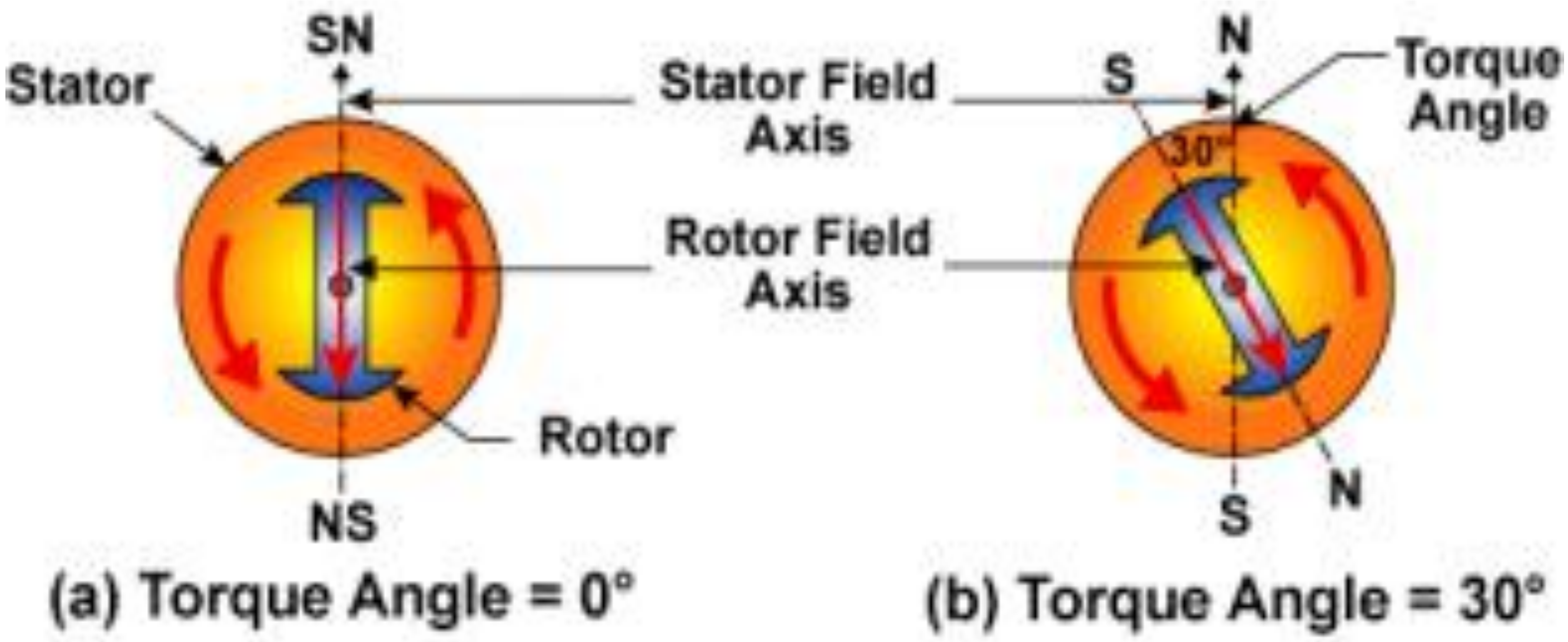
- The generator rotor (with its DC field) and the stator field move together
- To produce power the DC field must be slightly advanced from the stator field
- The ***rotor angle*** is the angular difference between these two fields
- The greater the mechanical input to a generator, the greater the rotor angle advancement, and the greater the electrical power output

Generator Basics
Rotor Angle

The interaction between these two fields is how power is transferred from the prime mover, the turbine, to the power system.

- Under normal conditions, the two fields rotate at the same speed
- When small load changes occur, the angular difference between the two fields increases slightly, but the generator adjusts to this new angle
- When a sudden or large load change occurs, the angular difference between the two fields increases suddenly and the generator may not be able to adjust to this new angle to meet the new power requirement

Generator Basics
Rotor Angle



Generator Basics
Rotor Angle

- When the rotor angle becomes too large, the magnetic force cannot hold the rotor in synchronism
- Under this condition, the generator is said to be out of step (OOS) with the power system
- When the generator loses synchronism with the power system it will most likely be tripped off-line by relays

Generator Basics
Generator Voltage to the System

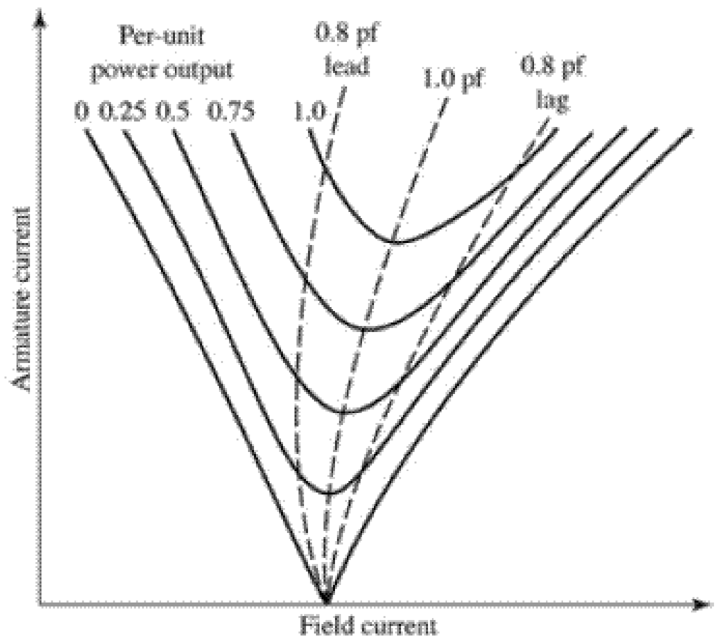
The generator's output voltage is dependent on:

- number of turns in the stator (armature) winding
- magnetic field strength (the number of lines of flux produced by the field)
- Generators generally have output voltages in the 12 kV to 18 kV range
- Design Engineers balance requirements of output voltage with insulation, copper costs, steel costs and mechanical requirements

Generator Basics
Generator Operating Characteristics

- ***Vee Curves*** show the relationship between Field Current and Armature Current for different power output levels

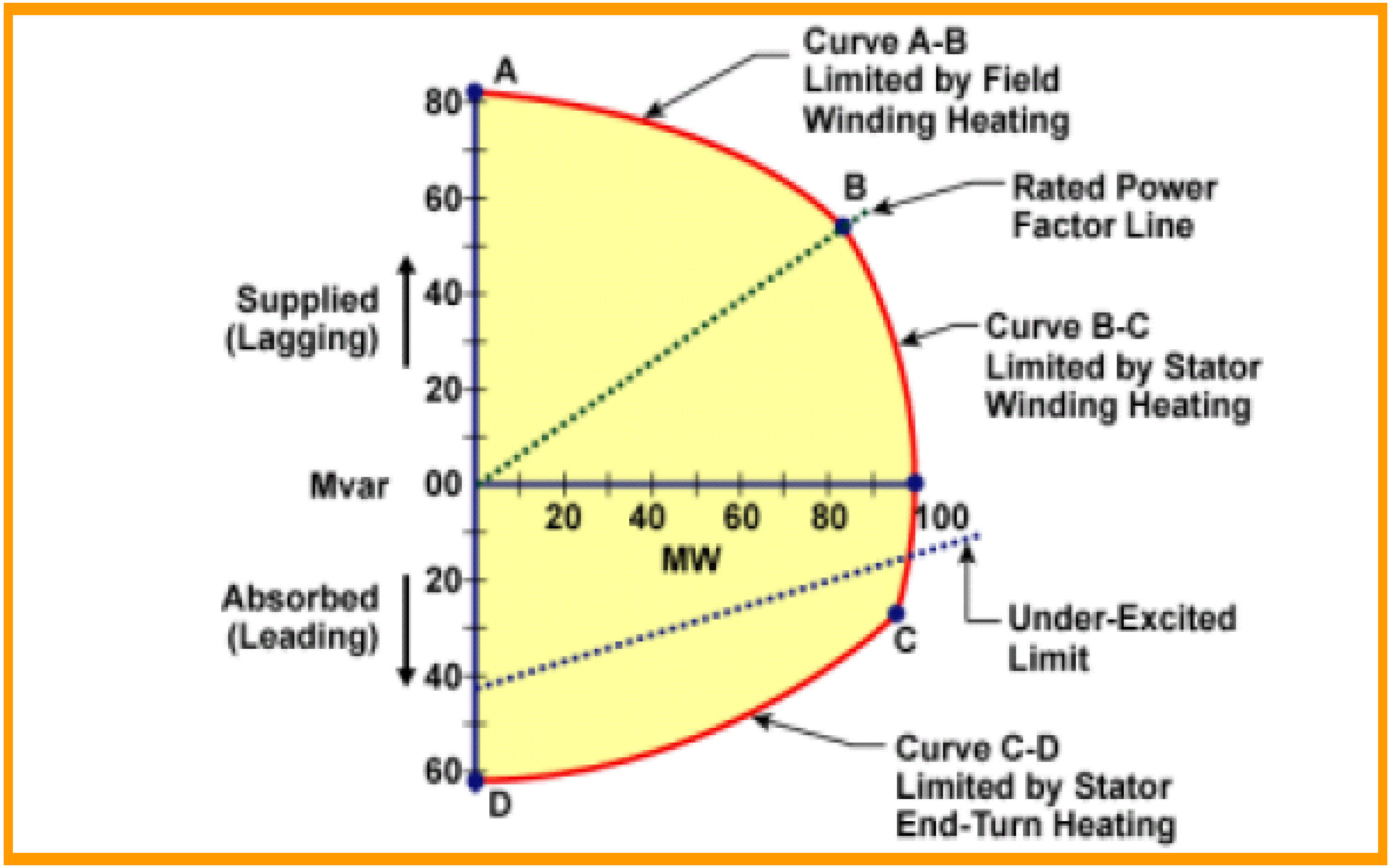
- Adjusting the Field Current (supplied by the Exciter) changes the VAR output (Power Factor) of the generator



Generator Basics
Generator Characteristic Curve (D Curve)

- The ***Generator Characteristic Curves*** show the maximum amount of real and reactive power a generator can provide
- The generator characteristic curves are also called ***D Curves*** …because of their shape
- Maximum power output is dependent on cooling. Frequently several curves are shown depending on cooling levels

Generator Basics
D Curve

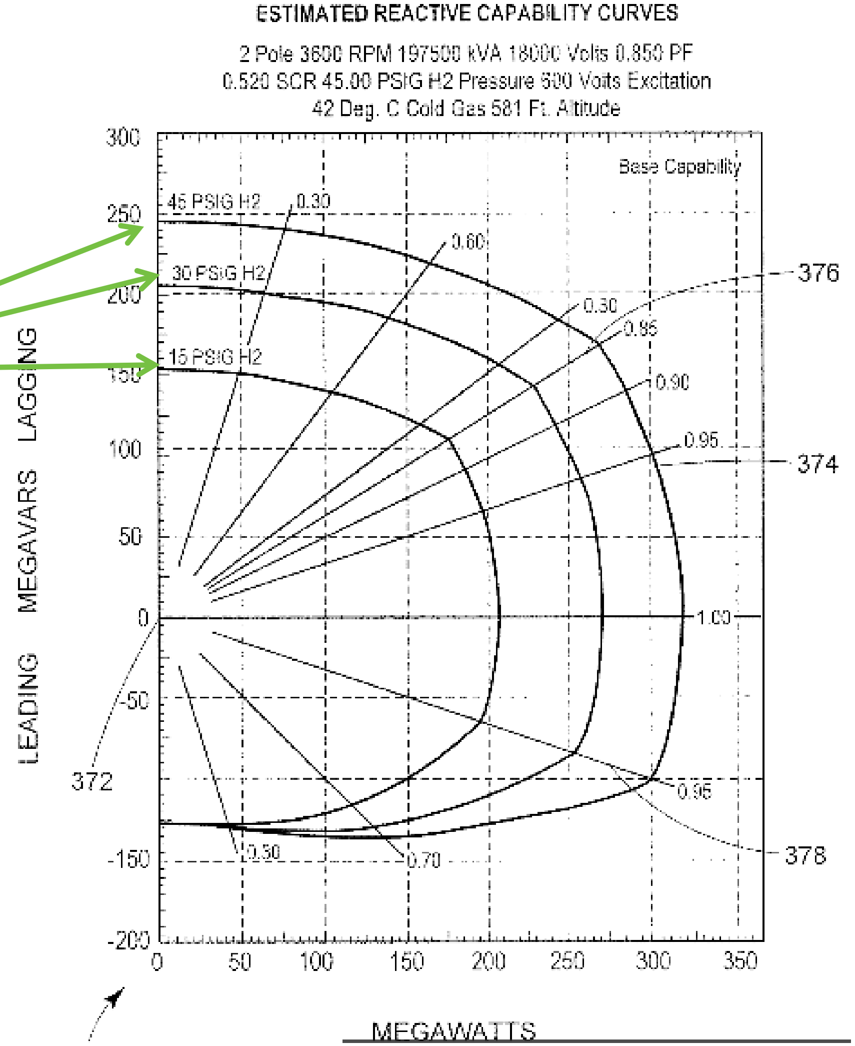


Generator Basics
Generator Operating Characteristics

Generator D Curves

Capability with different cooling levels

This Generator is cooled with Hydrogen gas.



Generator Basics
Generator Operating Characteristics

Generator Controls

- Automatic Voltage Regulator (AVR)
- Automatic Generator Control (AGC)
- Power System Stabilizer (PSS)
- Digital Control System (DCS)
- Human Machine Interface (HMI)
- Supervisory Control and Data Acquisition (SCADA)

Generator Basics
Generator Operating Characteristics

Automatic Voltage Regulator (AVR)

- Monitors voltage at the generator terminals
- Accepts input from the operator for a voltage or VAR set-point
- Automatically adjusts current that the Exciter feeds the rotor to meet the required voltage or VAR output

Generator Basics
Generator Operating Characteristics

Automatic Generator Control (AGC)

- A system for adjusting the power output of multiple generators at different power plants in response to changes in load
- May respond to changes in system frequency – if the frequency slows, it signals generators to supply more power
- May respond to economic dispatch goals to minimize overall generation costs

Generator Basics
Generator Operating Characteristics

Power System Stabilizer

– A control system that works with the AVR and Exciter

– Monitors output voltages for system oscillations that may affect stability

– Provides a signal to the Exciter to counteract the oscillations

Generator Basics
Generator Operating Characteristics

Distributed Control System (DCS)

- A control system that coordinates with control elements throughout the generating station
- Operators use the DCS to monitor and control various processes throughout the plant including fuel supply, boiler operation, turbine pressure, temperature, generator output and exhaust pollution controls

Generator Basics
Generator Operating Characteristics

Supervisory Control and Data Acquisition (SCADA)

- Inputs, outputs and controls throughout the plant are converted into analogue or digital signals
- Signals are wired into a central SCADA unit
- Data from the SCADA is conveyed over telephone, microwave, or fiber optic communications equipment to a Control or Operations center
- System Operators can monitor, analyze data, and send control signals to the plant or substation via the SCADA system

Generator Basics
Turbines and Energy Conversion

The Generator shaft is connected to- and turned by the ***Prime Mover –*** usually a ***Turbine***

- Main Types of Turbines used in Generation
  - Steam Turbine
  - Combustion Turbine
  - Water Turbine
  - Wind Turbine

Generator Basics
Turbines and Energy Conversion

- A turbine converts high-pressure driving force into mechanical energy that turns the generator rotor
- Efficiency of the turbine is a function of the difference between the ***high-pressure*** going in and the ***low-pressure*** coming out. (and a bunch of other factors)
- Turbine speed is controlled by balance between mechanical energy in and watts out

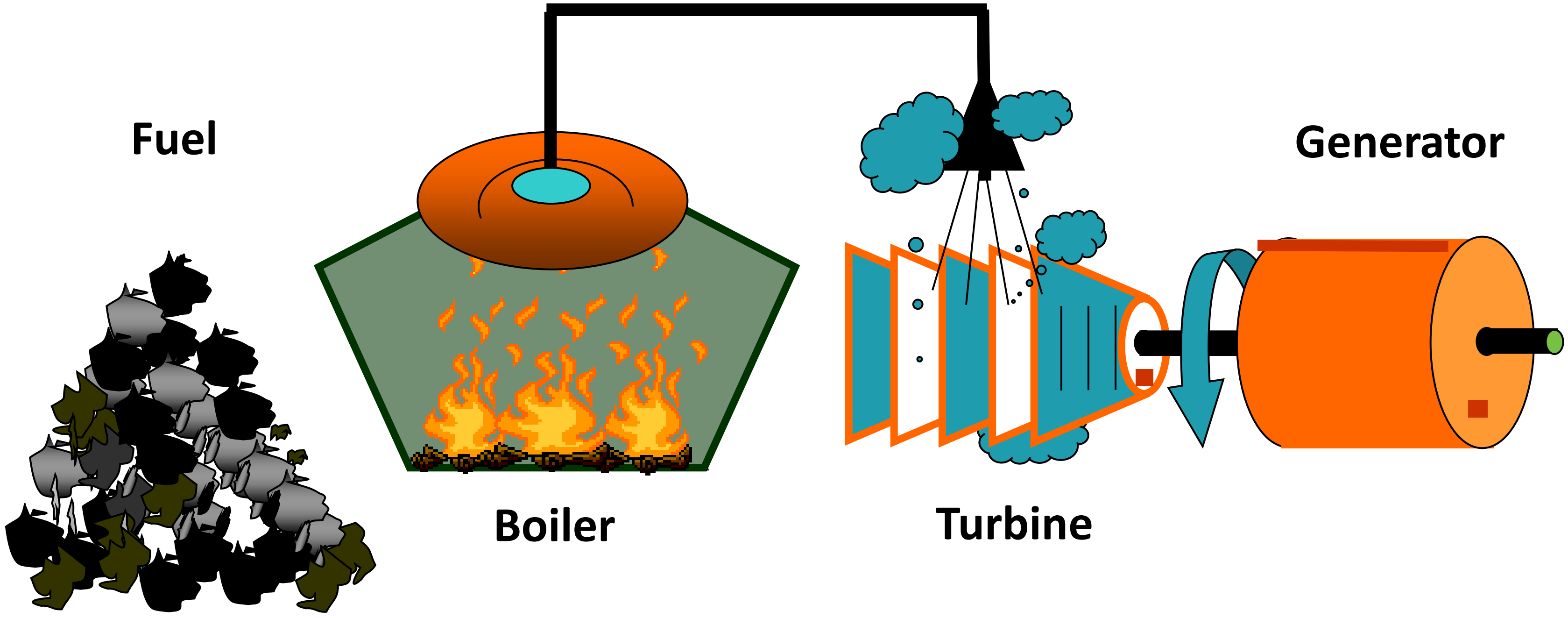
Generator Basics
Types of Turbines - Steam

- **Steam Turbines** — Steam, produced by combustion (coal, oil, gas, waste), nuclear, solar or geothermal energy drives the turbine
- Steam plants use **multiple turbines** with varying input and output pressure and temperatures to maximize energy use

Generator Basics
Thermal Generation

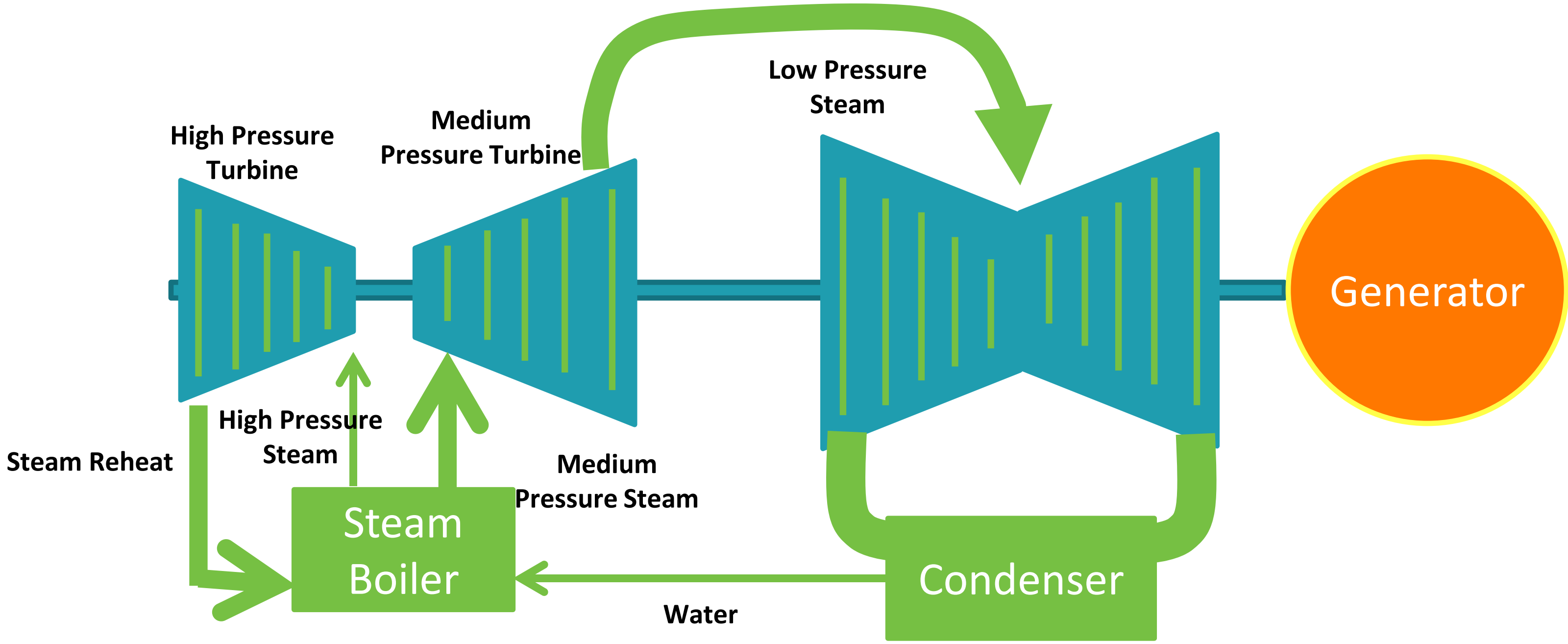
Steam boiler

Coal, Gas, Oil, Nuclear, Biomass, Biogas, Waste Heat, Geothermal



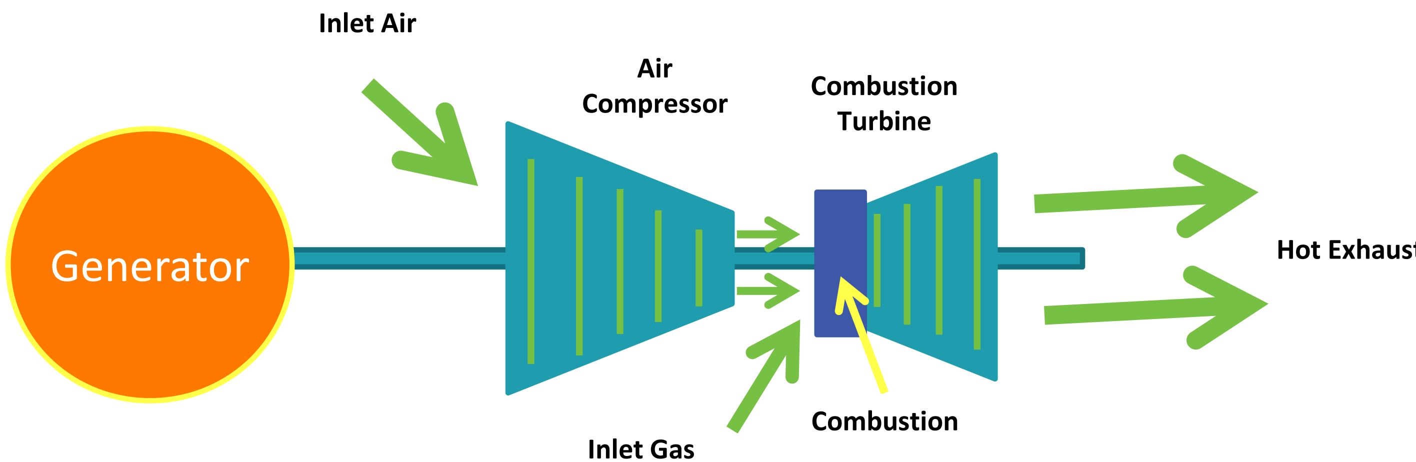
Generator Basics
Turbine Types – Steam

A combination of High, Medium, and Low pressure turbines may be used to capture as much energy as possible from the steam.



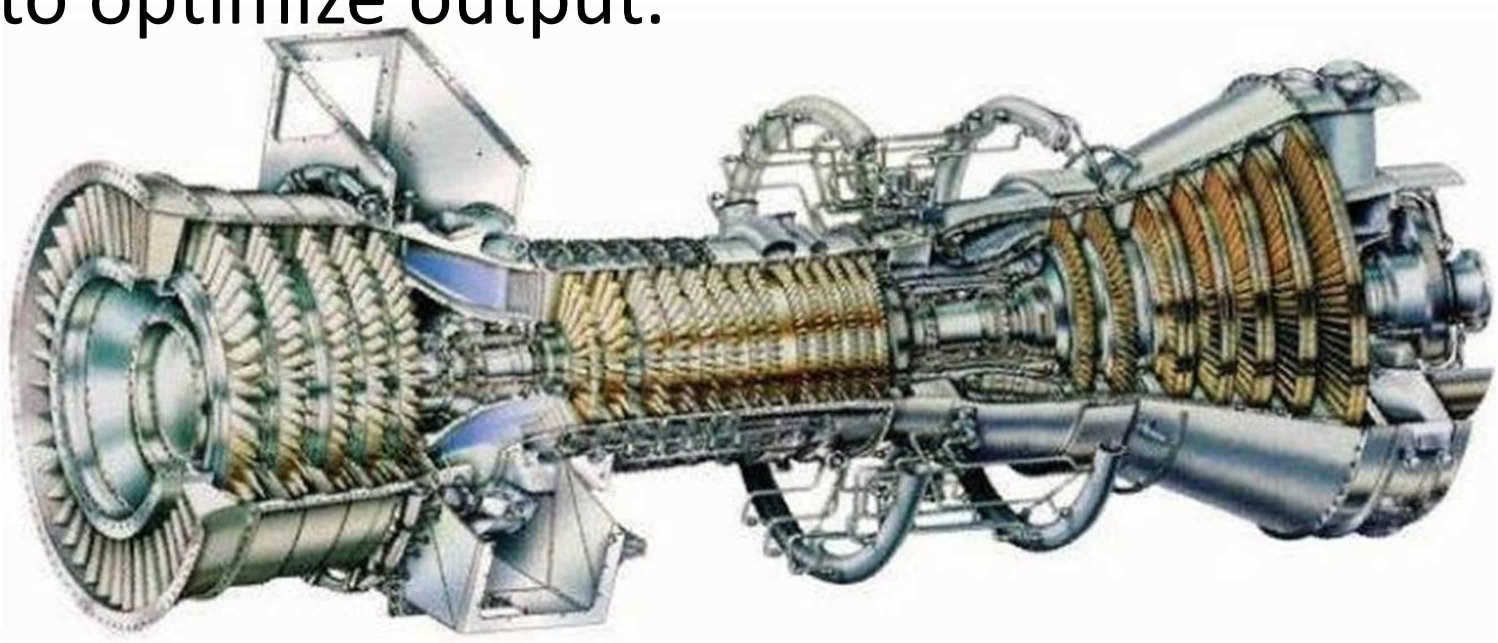
Generator Basics
Turbine Types - Combustion

Combustion Turbines - A mixture of compressed air and fuel is ignited and expands through the turbine.



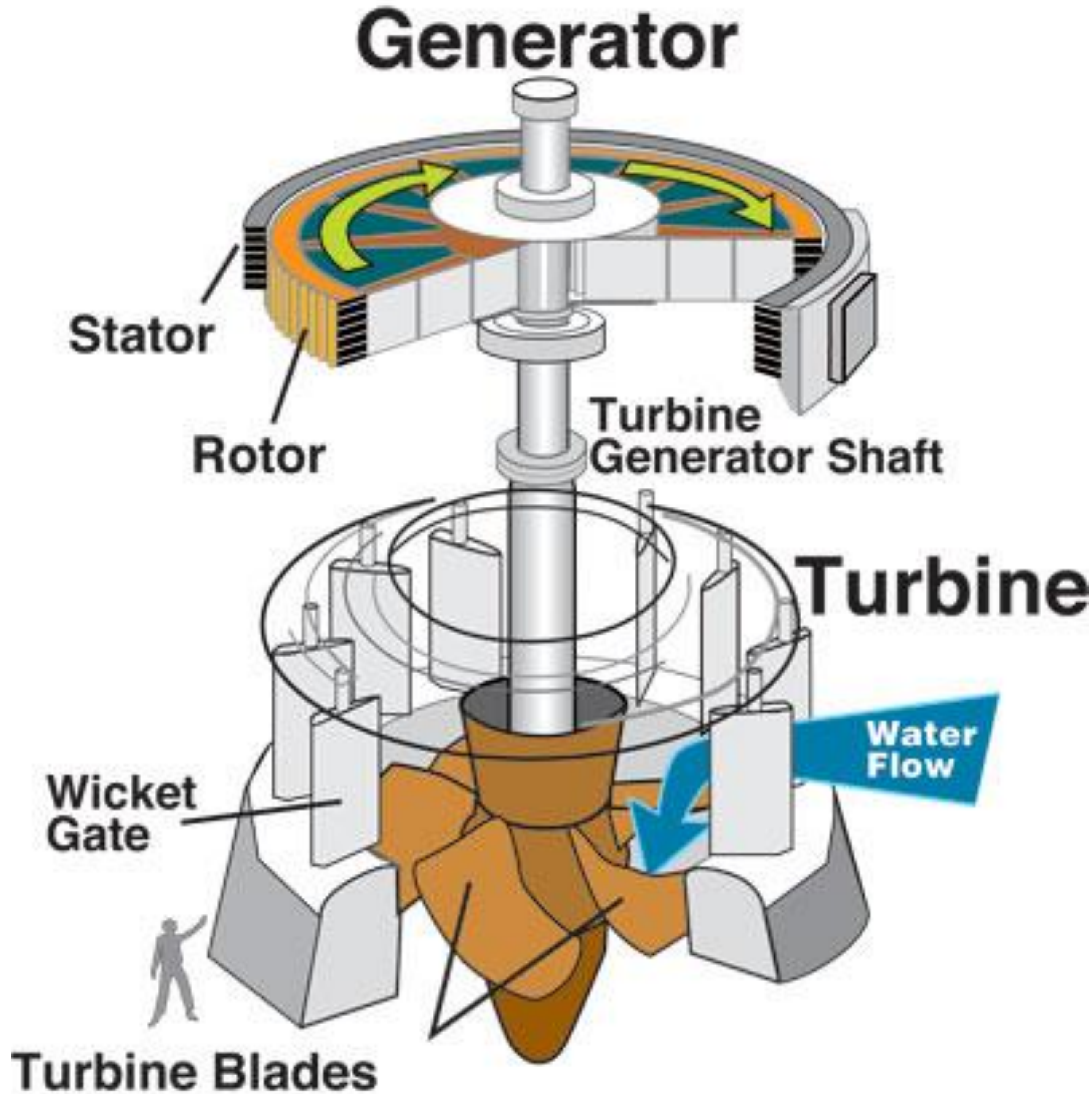
Generator Basics
Turbine Types - Combustion

Combustion Turbines – are affected by inlet air temperature and pressure. Mid-stage cooling of the compressed air, and Steam Injection may be used to optimize output.



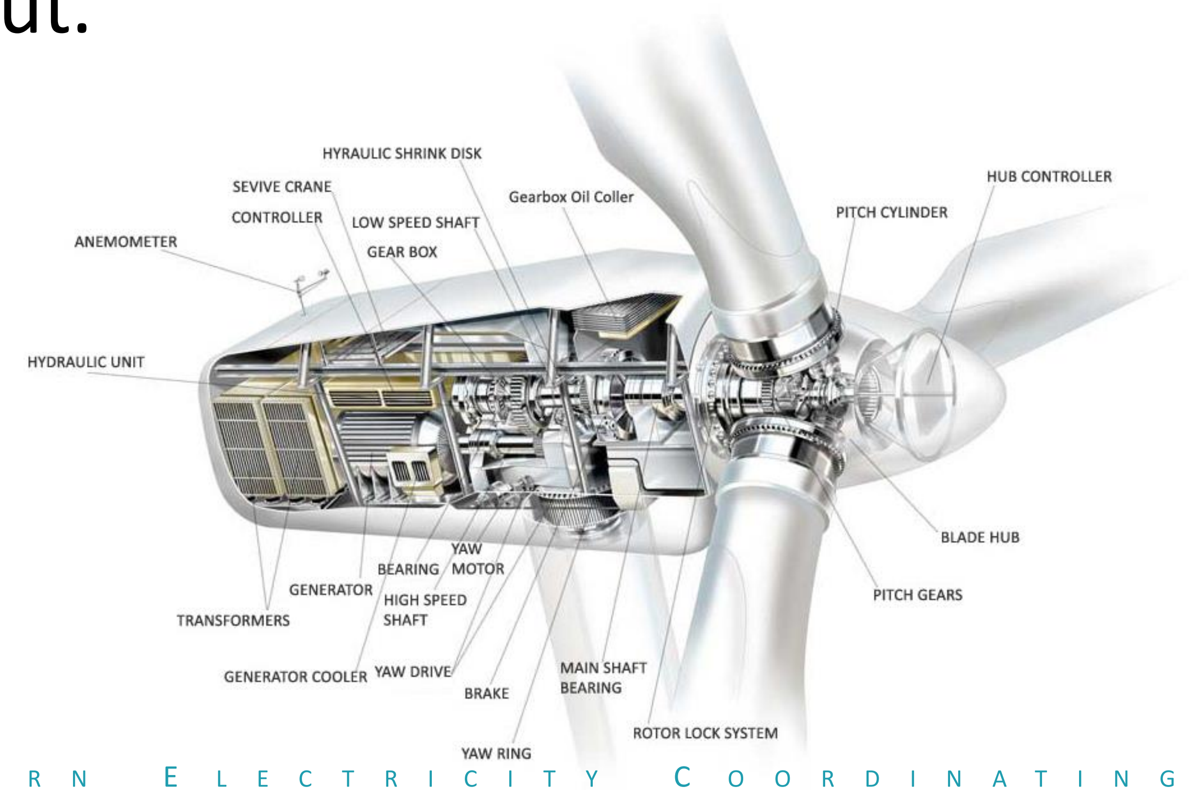
Generator Basics
Turbine Types - Hydroelectric

- **Hydroelectric Turbines**— Water flowing from higher to lower elevations drives the turbine
- Output depends on Pressure and Volume…and flow restrictions


Generator
Stator
Rotor
Turbine
Generator Shaft
Turbine
Water
Flow
Wicket
Gate
Turbine Blades

Generator Basics
Types of Turbines

Wind Turbines – Modern wind turbine generators are designed to maximize energy output.

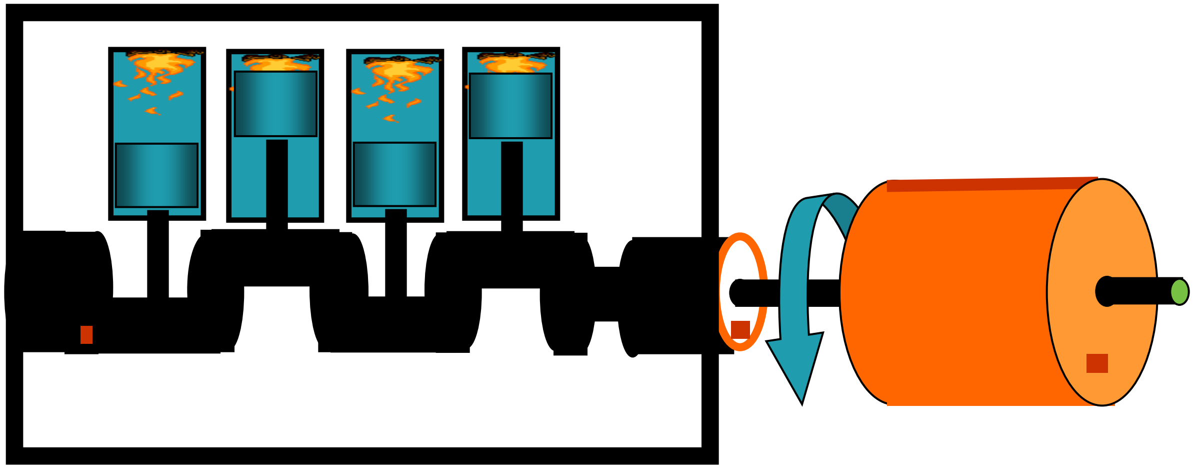


Generator Basics
Internal Combustion Engines

- **Piston-driven** or **Reciprocating Internal Combustion Engines** are also used to power generators
- Most Large Internal Combustion Engines used for Generation use Diesel fuel

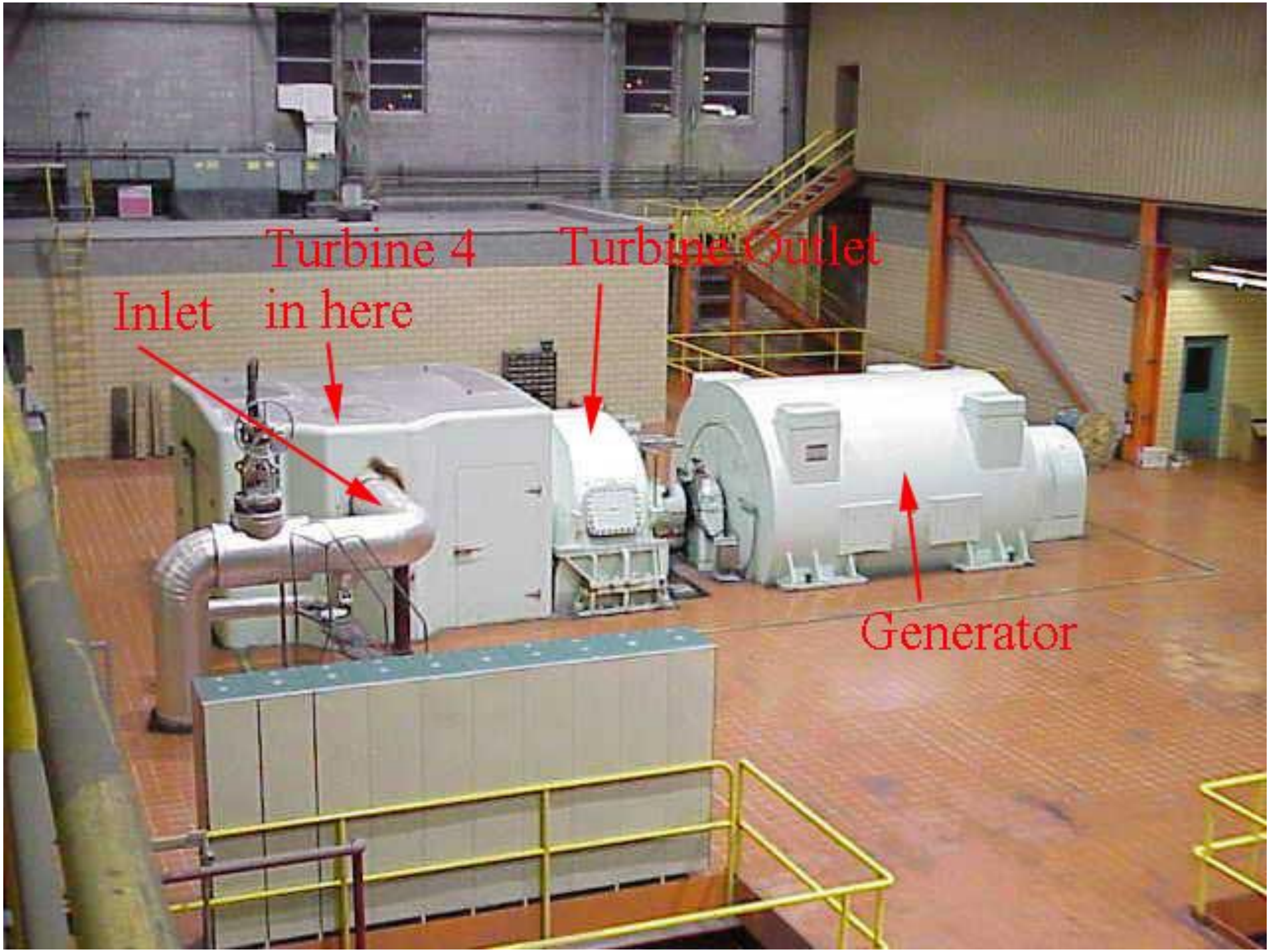
Generator Basics
Thermal Generation

Internal Combustion



Piston-Driven Diesel Engine

Generator


Turbine 4
in here
Turbine Outlet
Inlet
Generator

Energy Conversion

Energy Conversion
Turbines and Energy Conversion

Other non-rotation methods of energy conversion include:

- **Photovoltaic** – photons from the sun strike the solar panel and knock electrons loose from the atoms. The freed electrons flow in the circuit
- **Batteries** – chemical energy stored in the battery is converted to electricity as electrons flow from one terminal to the other…through the circuit and back again

Energy Conversion
Turbines and Energy Conversion

Continued…

- **Fuel Cell** – Natural Gas fuel reacts with oxygen on a membrane within the cell, electrons go one way creating a current
- **Thermionic**, **Thermocouple**, **Piezoelectric**, **Magneto-hydro-dynamic** – these don't tend to be commercially viable at a large scale

Energy Sources

Energy Sources

To produce electricity you need a source…

Energy Sources include

- Sun
- Earth
- Moon
- Stars

Energy Sources

Sun

- **Light -** is used by plants (photosynthesis) to turn CO_2 into Coal, Oil, natural gas, Wood, corn, etc. that can be used as **fuel**
- **Light** – can be converted directly to electric energy using photovoltaic panels – or using solar-thermal processes
- **Heat** - evaporates water and lifts it to higher rivers and lakes where it can be used in **Hydro** Generation
- **Heat** – causes wind to blow – which can be used in **Wind** generators and **Wave** powered generation

Energy Sources

Sun

- **Coal, Oil and Gas** – are called ***Fossil Fuels*** they were created long ago and trapped in the earth
- ***Biomass, wood, waste*** and other harvested fuels such as ***Ethanol*** – are sometimes called renewable because we can grow more

Energy Sources

Earth

- **Rotation -** causes uneven heating of the air and helps create the wind and waves
- **Heat –** from hot spots in the earths crust close to the surface can be used for geothermal energy
- **Radioactive Elements** - can be mined and refined and used for nuclear energy

Energy Sources

Moon

- **Tide action -** caused by the moon orbiting around the earth is the source of wave and tide-power generation

Stars

- The heavy elements of the earth and moon are the result of previous stars that have cooked down their nuclear fuel and then exploded
- *"We are star dust"*…Carl Sagan

Energy Sources

Things that are NOT sources of energy include…

– Batteries - Pump Storage

– Compressed Air - Hydrogen

– Transformers - Generators

– Others???

– These devices store or convert energy… they are not the source of the energy

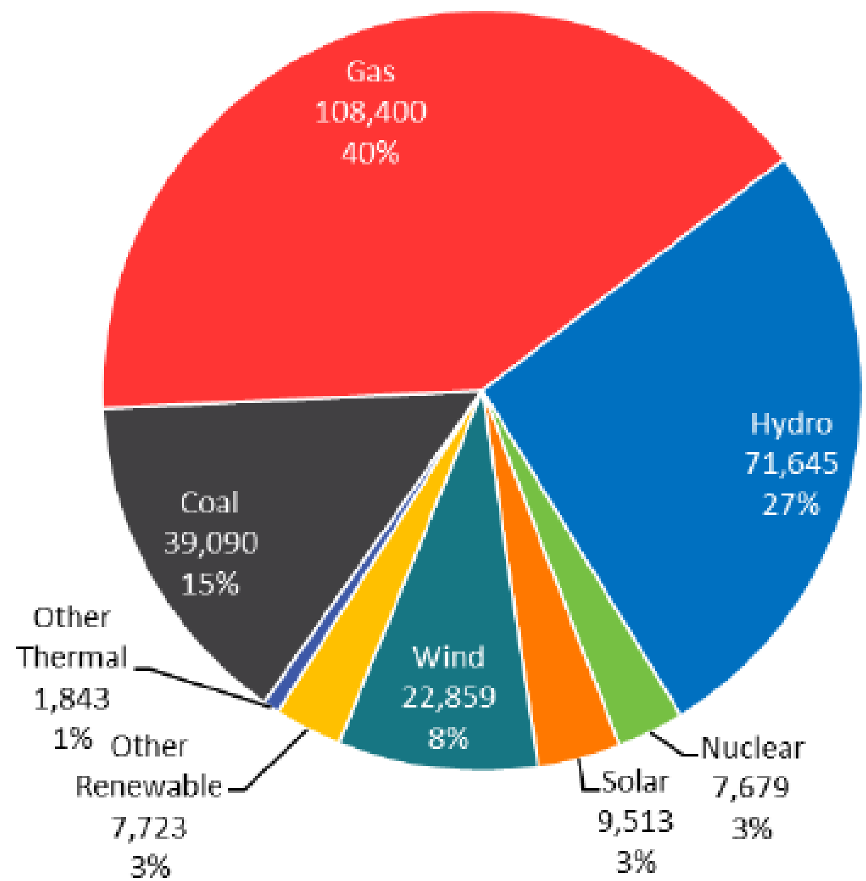
Course Outline

1. Introduction to WECC
2. Fundamentals of Electricity
3. Power System Overview
4. Principles of Generation
5. Substation Overview
6. Transformers
7. Power Transmission
8. System Protection
9. Principles of System Operation

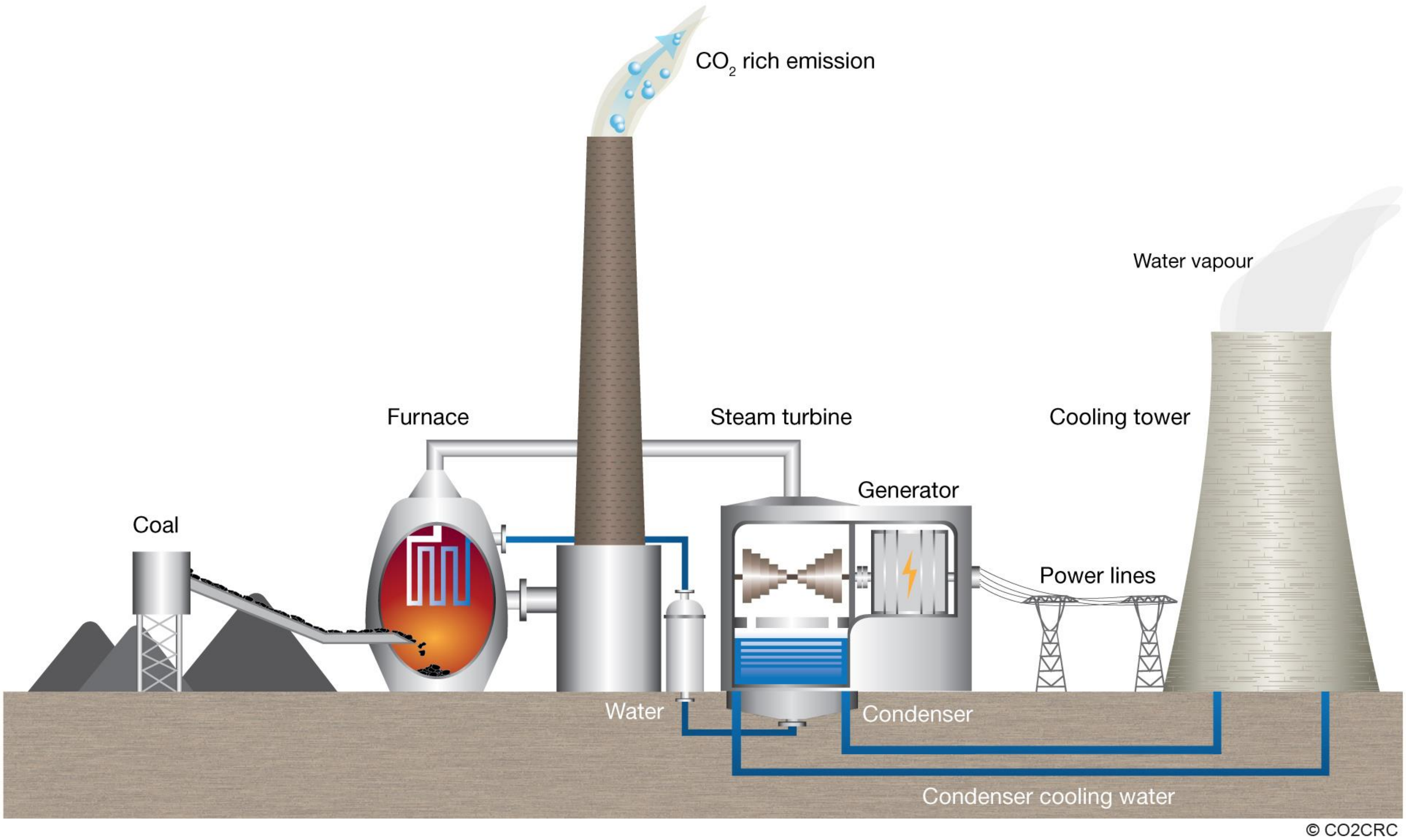
Generating Plants

Generation

Nameplate Capacity, 2015 (MW)[1]



Generating Plants
Coal Fired Generation Plants



Generating Plants
Coal Fired Generation Plants

- Coal – Underground or Strip-Mined
- Transportation – Train, Truck or Conveyor
- Storage – Large Pile near the Plant
- Processing – Pulverized and blown into Boiler

Generating Plants
Coal Fired Generation Plants

- Burning – Carbon in the Coal joins with two Oxygen atoms
- Each ton of Coal produces ~ 3 tons of CO_2

…And about 1/4 ton of Ash

…And about 2800 KWH of energy

Generating Plants
Coal Fired Generation Plants

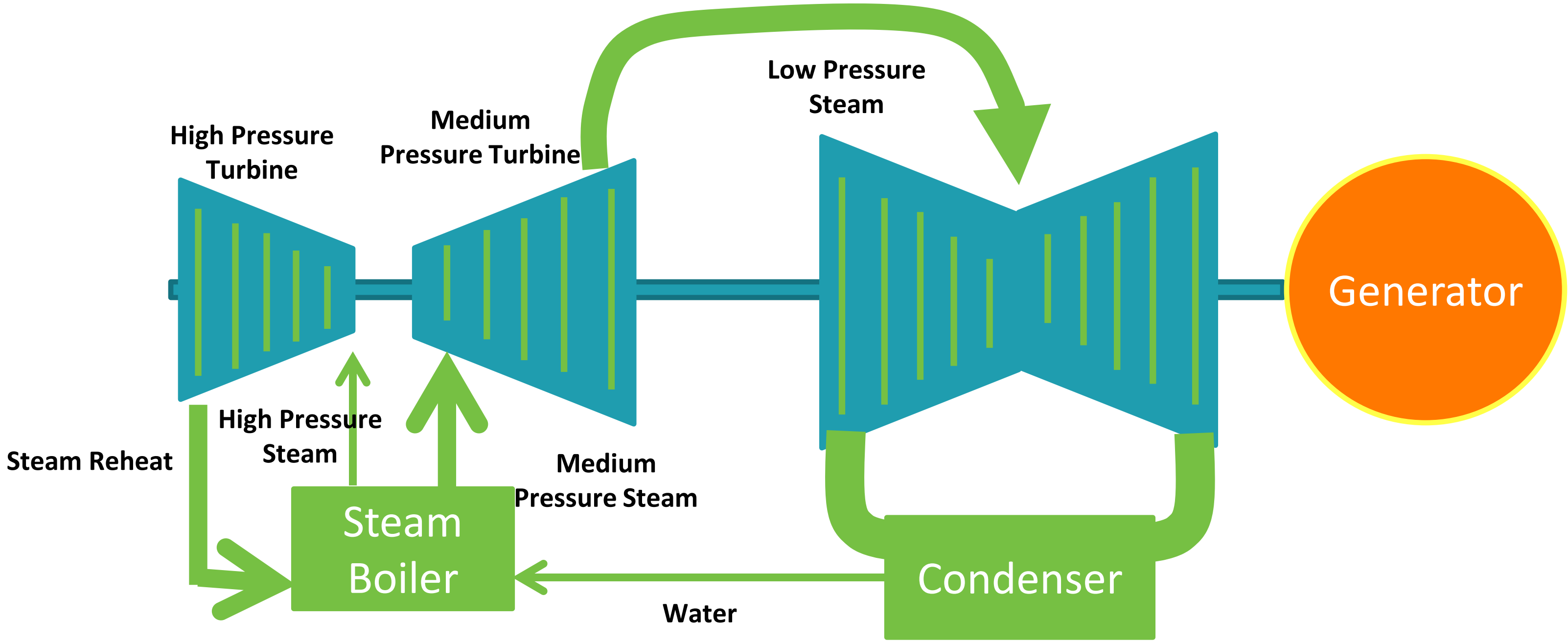
- One pound of coal contains about 14000 btu
- Typical Heat Rate ~ 10,000btu/kwh
- Giving 1.4 KWH of recoverable energy per pound
- Running a clothes dryer for about an hour uses a pound of coal…and creates 3 pounds of CO_2

Generating Plants
Coal Fired Generation Plants

- A 1000 MW power plant could produce…
  - 24hours * 1000MW = 24000MWH per day
- And consume…
  - 24000 MWH *1000 KWH/MWH* 1Ton/2800KWH = 8600 Tons
- That's 72 loaded Train Cars per day!

Generating Plants
Coal Fired Generation Plants

- Pulverized Coal is burned in the Boiler
- Goal is to Extract the maximum amount of heat from the combustion



Generating Plants
Coal Fired Generation Plants

Modern Boiler

- Burns Coal
- Heats water to create Steam critical-supercritical
- Super-heats the steam and sends to HP Turbine
- Re-heats returning steam and sends to MP and LP Turbines
- Heats water from the condenser in the Economizer sends it back to the boiler
- Heats incoming air for combustion

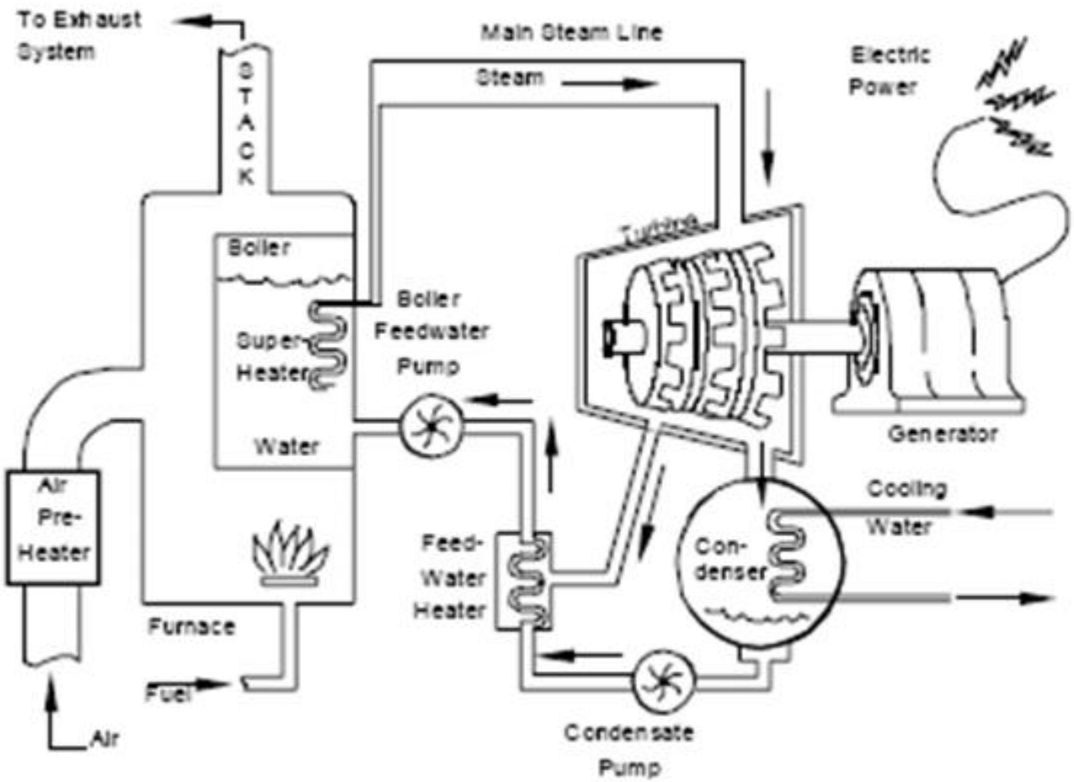
Generating Plants
Coal Fired Generation Plants

- Water in the steam system must be ultra-pure to keep from fowling or corroding the tubes and turbines
- To maximize efficiency, steam is injected into the turbines at the highest pressure…
- and extracted out the back of the LP turbine at the lowest possible pressure

Generating Plants
Coal Fired Generation Plants

- A separate cooling system is used to cool and condense the spent steam
- By far the most water used at a Steam Plant is in the Cooling water system
- The steam Plume from the cooling system is often visible for miles

Generating Plants
Thermal Steam Generation



Generating Plants
Coal Fired Generation Plants

Combustion Exhaust includes

- SOx (Sulfur and Oxygen – creates acid Rain)
- NOx (Nitrogen – creates PM10 and regional haze)
- Rocks (dust and ash)
- CO2 (Greenhouse gas)
- Mercury (Native to the coal and dirt – goes airborne in the smoke) fortunately in super-small concentrations

Generating Plants
Coal Fired Generation Plants

Pollution control includes:

- Electro-static precipitators – Static Electricity attracts pollution particles
- Bag-house – Giant Vacuum cleaner bags filter the air
- SCR (Selective Catalytic Converter) Spray Ammonia into the exhaust then send it through a Catalytic Converter
- Scrubber – Spray Wet Limestone dust into the exhaust –it reacts with the NOx and SOx

Cherokee Station – Denver Coal/Gas 700MW

Coal power plant in Boardman, Oregon

Cooling Tower

Generating Plants
Nuclear Units

- Fuel Handling
- Nuclear Reactor Basics
- Steam Generation

Generating Plants
Fuel Handling

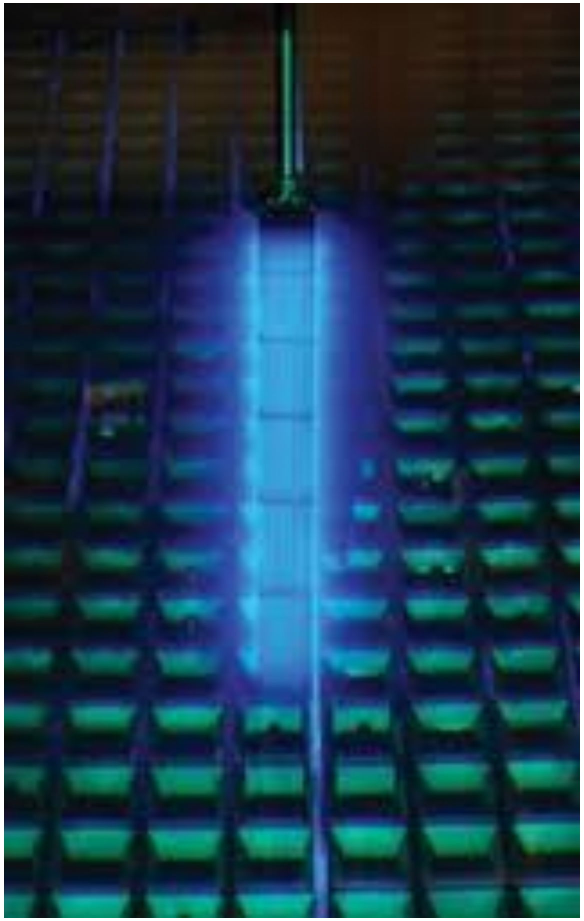
- All nuclear fuel is stored inside the nuclear reactor itself
- When the fuel is used up, the unit is shut down and fuel is reloaded
- This is called a ***refueling outage*** and it is usually combined with a maintenance outage
- Nuclear units require a refueling outage approximately every 18-36 months

Generating Plants
Nuclear (NewClear) Fuel

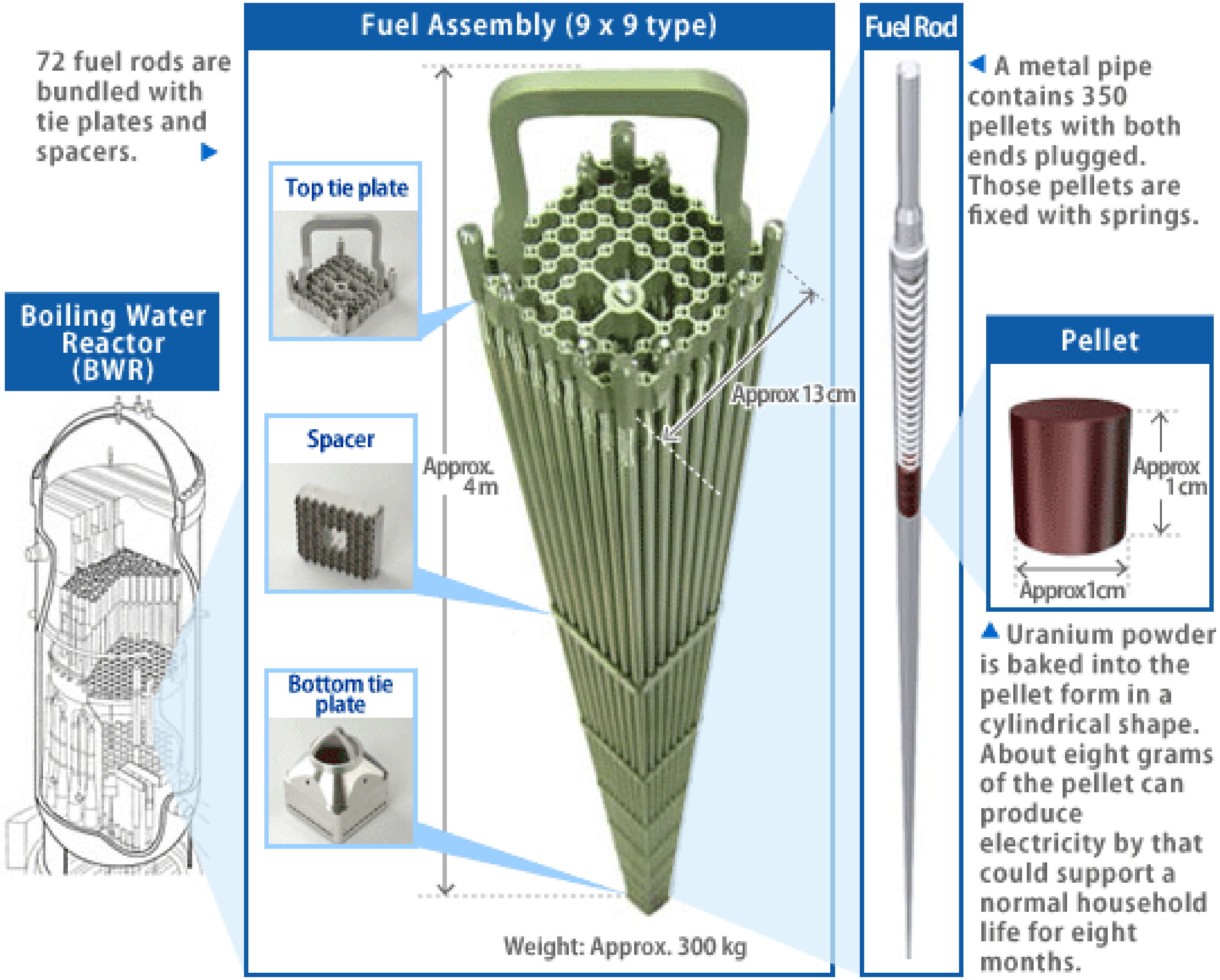
- Nuclear fuel is a uranium dioxide (UO2) compound consisting of natural uranium (U-238) and uranium isotopes, such as U-235
- The ceramic fuel comes in small, cylindrical pellets
- Fuel rods contain stacks of pellets. The fuel rods are about 12-14 feet long. Groups of fuel rods, called ***bundles,*** are mounted vertically inside the reactor

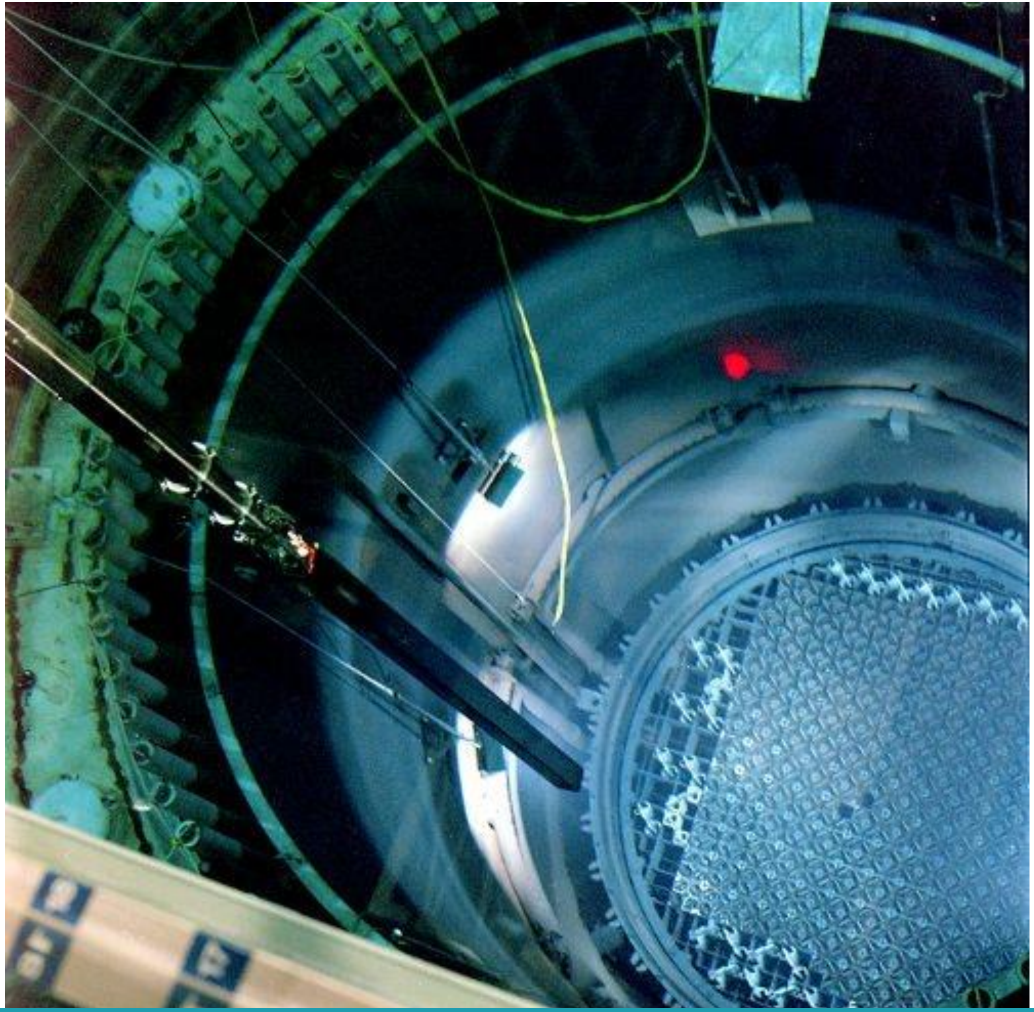
Generating Plants
Nuclear Fuel Pellets

Generating Plants
Nuclear Fuel Rods (Bundles)



Generating Plants
Nuclear Fuel Rods (Bundles)





Reactor Core

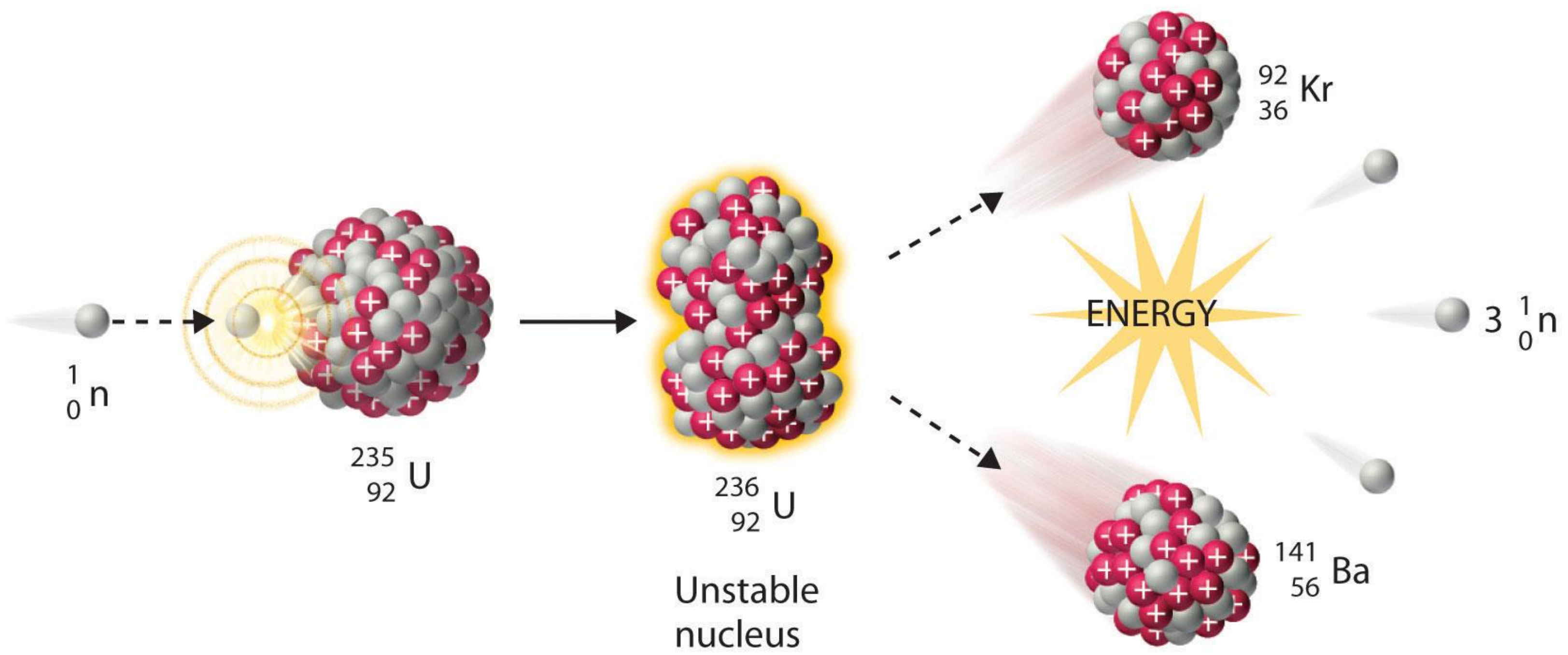
Fuel Storage Pool

Spent (used) Fuel Storage

Generating Plants Nuclear Fission

- Heat required to produce steam is generated in a nuclear reactor by a process called ***nuclear fission***
- When a neutron, collides with an atom of uranium, the nucleus splits into numerous fragments

Generating Plants
Nuclear Fission



Generating Plants
Nuclear Fission

- Each collision releases a small amount of energy in the form of heat (~177MeV)
- Some fragments collide with other atoms, causing these atoms to split and generate additional heat
- Within the nuclear reactor, millions of these reactions take place continuously, creating large amounts of heat used to boil water

Generating Plants
Nuclear Fission

So how long do these reactions take?

Within 1 second, one neutron can result in 10,000 to 10,000,000 other reactions.

Sub-critical, Critical, Supercritical

Generating Plants
Nuclear Control

- Fission must be controlled. Certain materials, such as boron, carbon, and gadolinium, can absorb neutrons and other particles
- Reactor control is accomplished with rods made of neutron absorbing materials
- Inserting a control rod reduces the amount of neutrons in the reactor, reducing the amount of heat generated

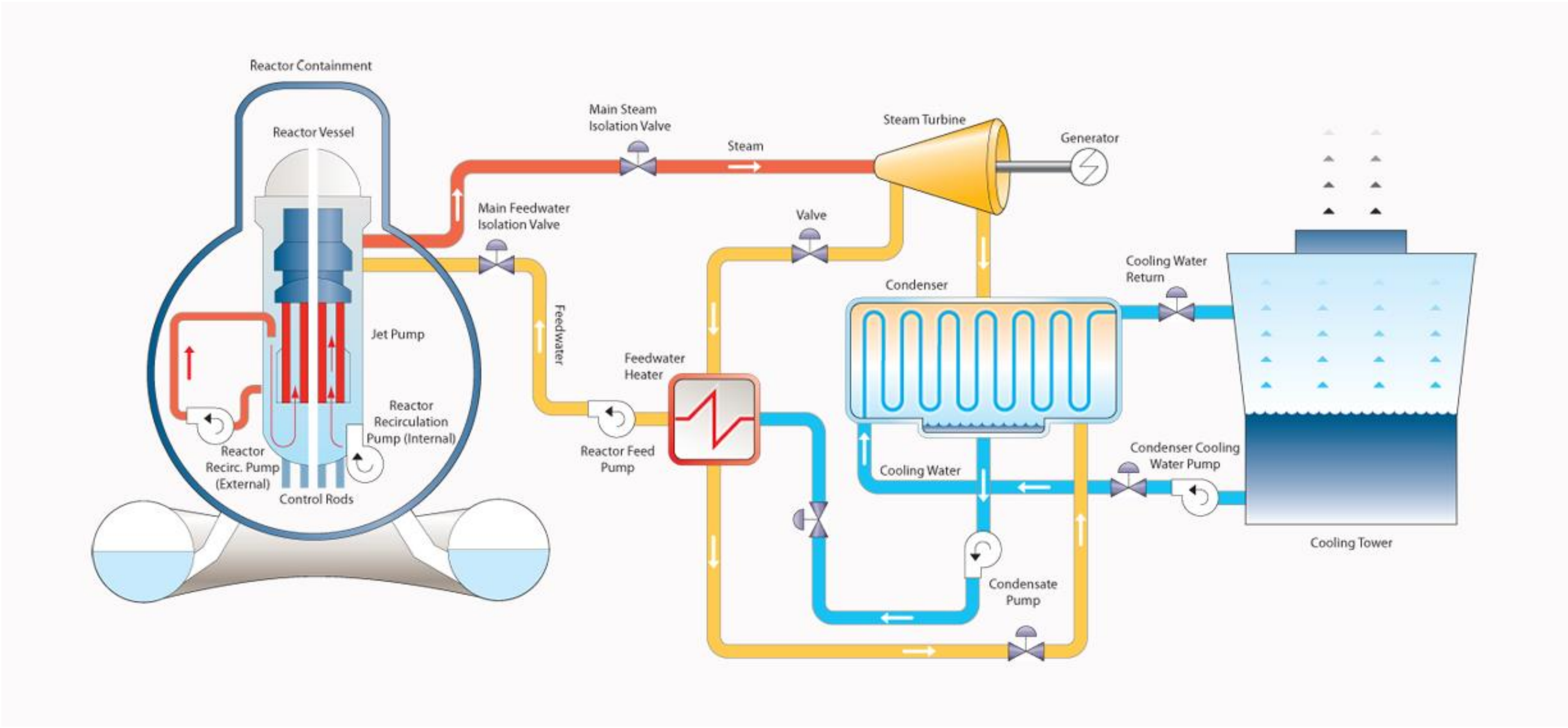
Generating Plants
Nuclear Control

- Withdrawing a control rod increases the number of neutrons available to react

- Nuclear reactors include hundreds of these control rods. Fully inserting all rods shuts down the unit. This is called a SCRAM

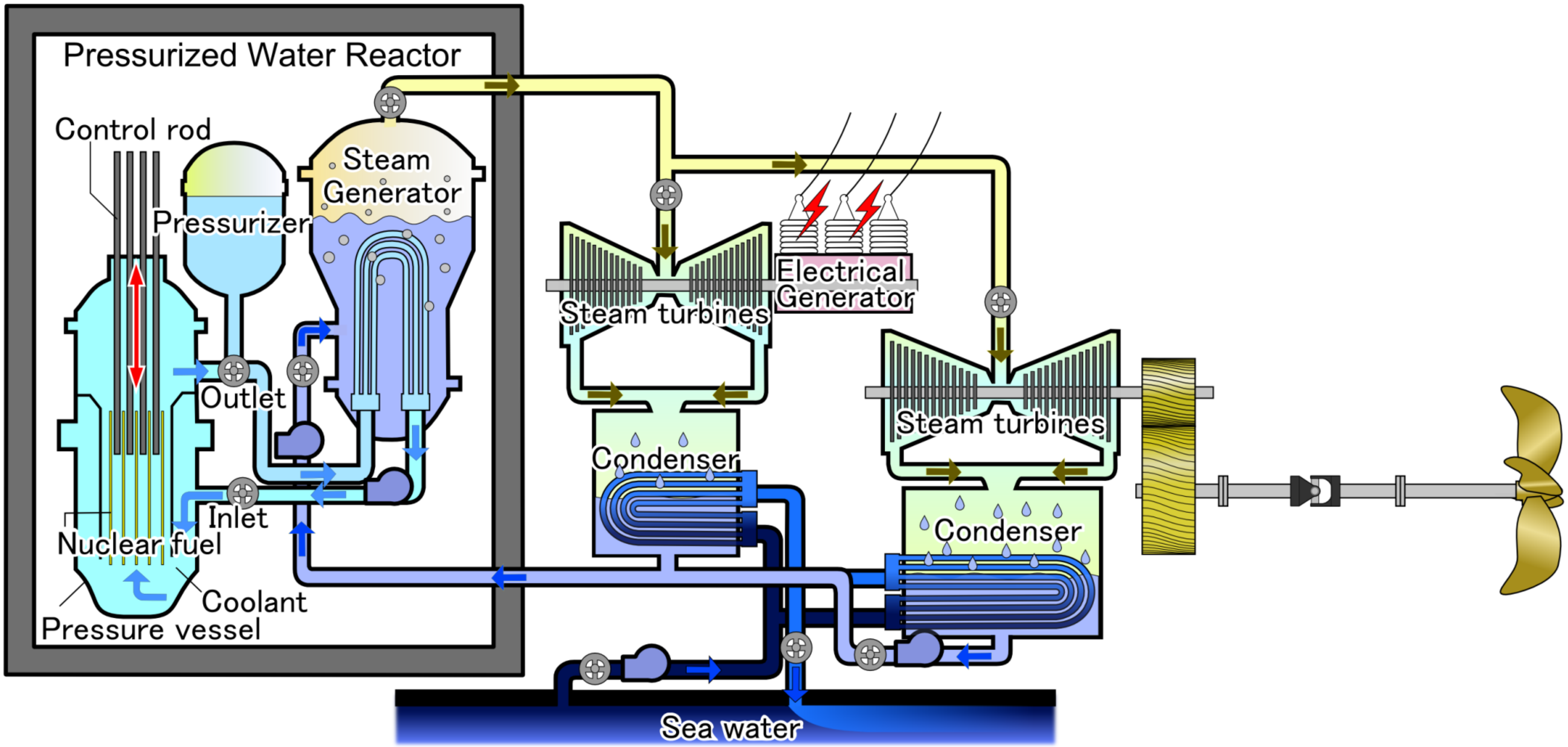
Generating Plants
Nuclear Steam Generation

- Heat generated by the fuel rods is absorbed by water that is pumped through the reactor
- Two basic nuclear reactor designs are in use:
  - Boiling Water Reactors (BWR)
  - Pressurized Water Reactors (PWR)

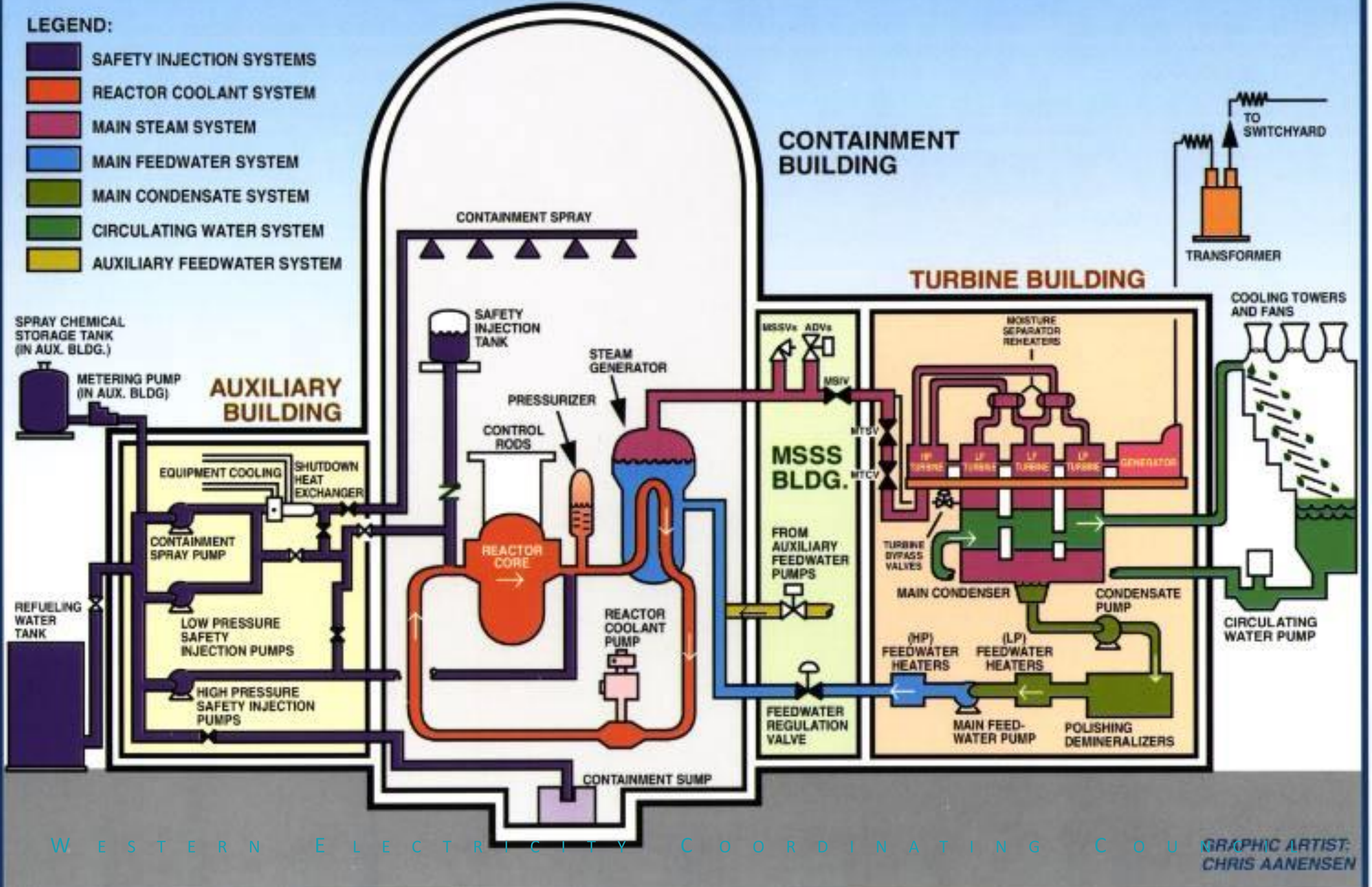


Nuclear Boiling Water Reactor (BWR) Process Diagram

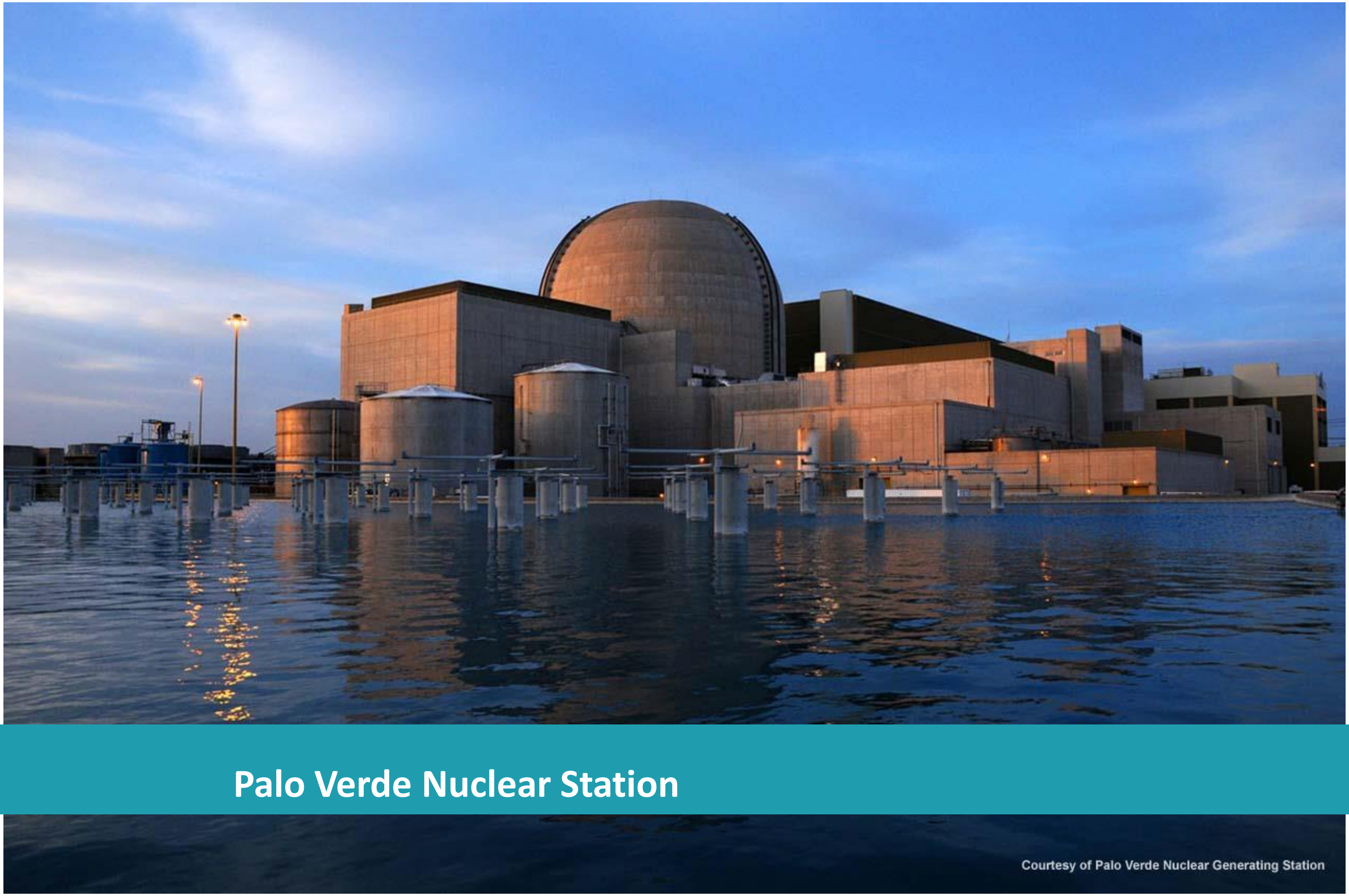
Generating Plants
Pressurized Water Reactor



GENERAL SYSTEM DIAGRAM OF PALO VERDE NUCLEAR GENERATING STATION



Palo Verde Nuclear Station



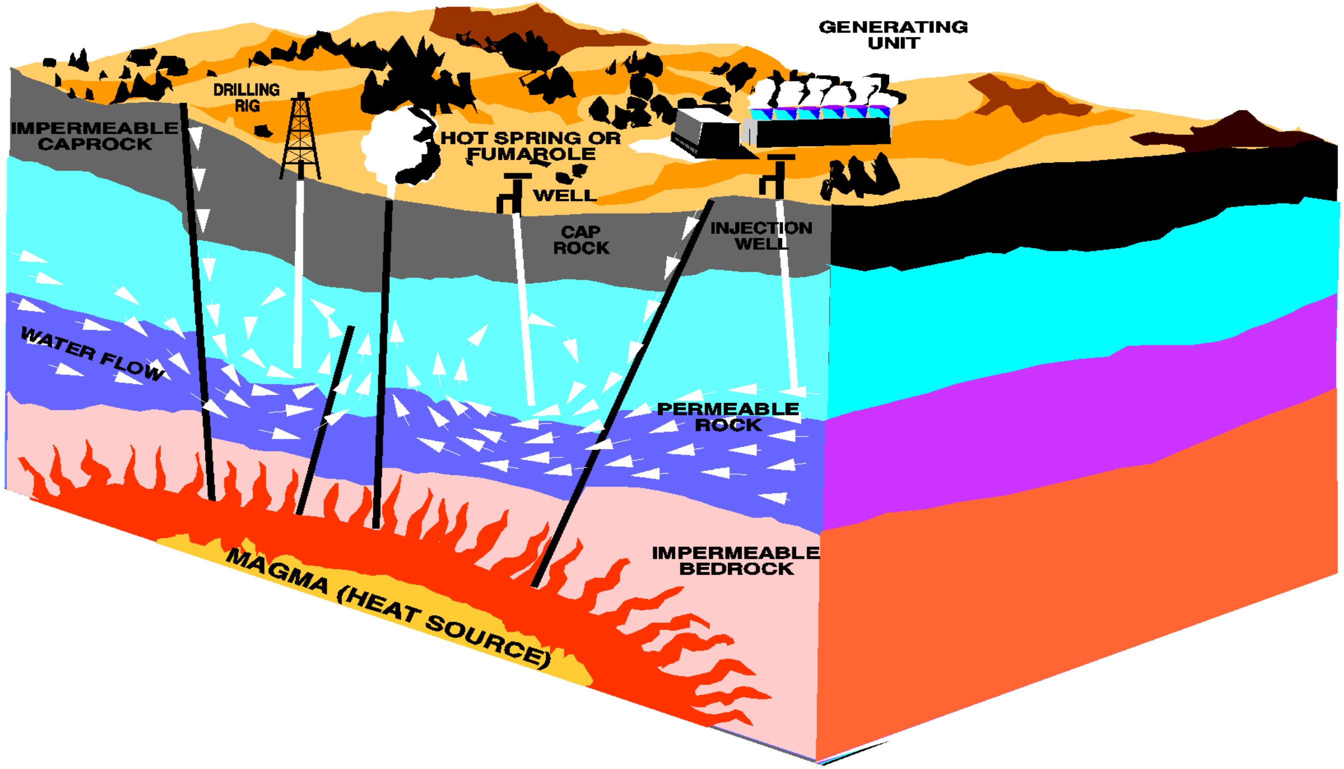
Palo Verde Nuclear Station

Courtesy of Palo Verde Nuclear Generating Station

Generating Plants
Geothermal Units

- Geothermal generation relies on thermal energy originating within the Earth's core and transferred through fissures to the surface by steam or hot brine
- ***Fissures*** are breaks or cracks of considerable length and depth in the Earth's surface
- ***Brine*** is water saturated with salt and other minerals Heat extracted from the geothermal energy source generates steam that drives the turbine

Generating Plants
Geothermal Units

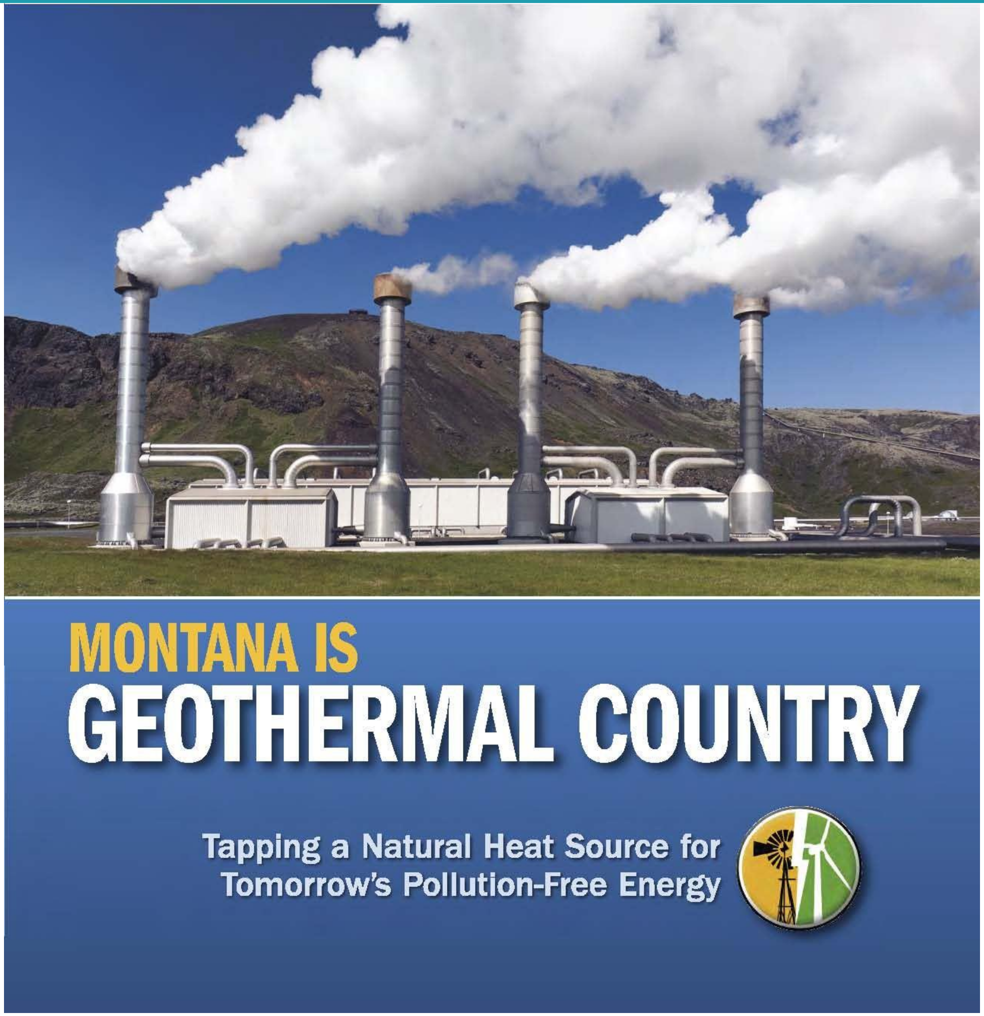


Generating Plants
Geothermal Units

There are two basic kinds of geothermal units:

- **Dry steam** —Superheated geothermal steam directly drives turbine-generators and then is condensed, cooled, and reinjected into the earth
- **Wet steam** — two approaches are available:
  - Hot brine flows naturally into wells where the pressure release causes boiling. It is commonly stated that the water is "flashed" into steam. The steam drives the low-pressure steam turbine
  - The brine heats a secondary (working) fluid with a lower boiling temperature than water. Then vapor from the boiling secondary fluid drives the turbine

Generating Plants
Geothermal Units



Generating Plants
Geothermal Units

Ability to Develop depends on…

- Closeness to the surface
- Availability of Water
- Access to the Grid
- Environmental Concerns
- In the United States, this type of energy source is limited to areas in the western third of the country where favorable steam conditions (80-90 percent moisture) make it feasible

Generating Plants
Hydroelectric Units

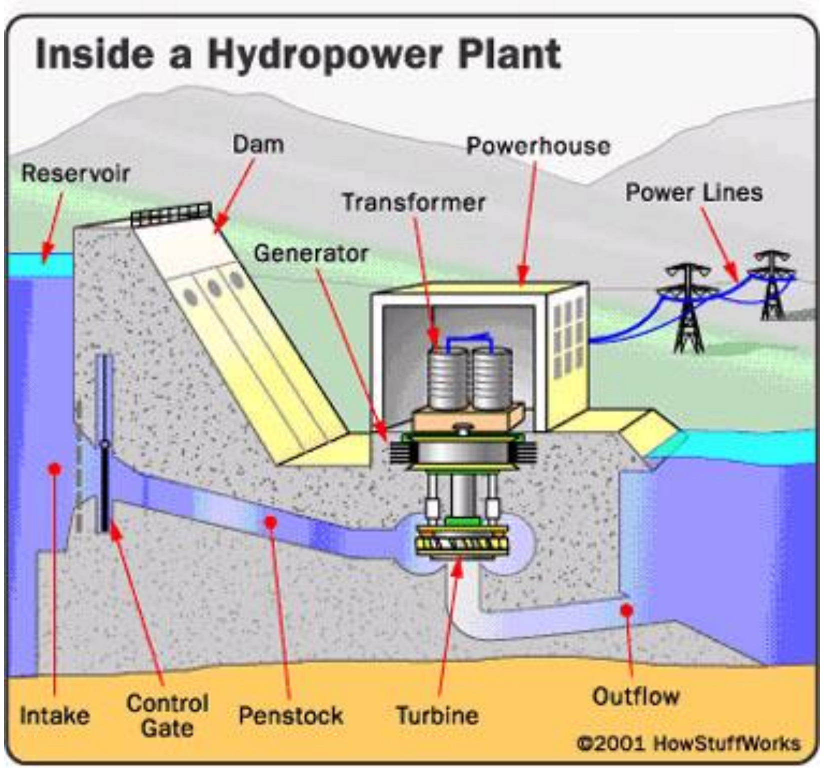
- Hydroelectric Generation is a large and important source of Electricity
- Plant output is proportional to **Head** (how far the water falls)
- And to **rate of flow** (how much water can flow past a point in a given amount of time)

Generating Plants
Hydroelectric Units

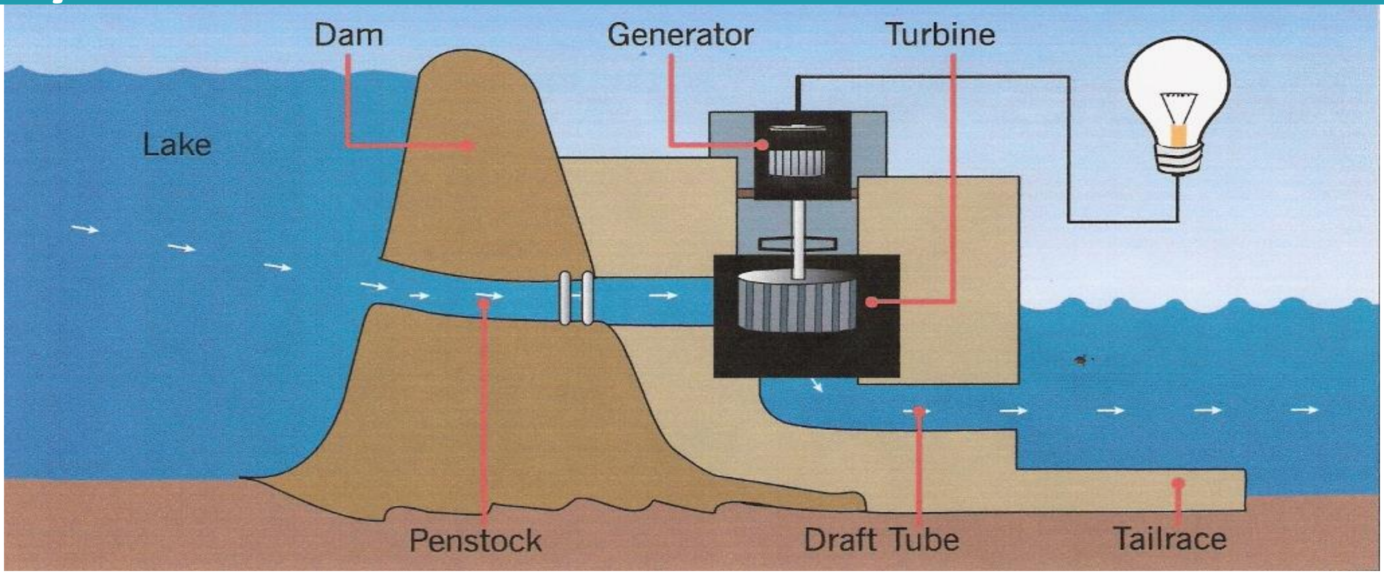
Plant operators have numerous restrictions to follow related to:

- Reservoir limits
- River flow
- Fish spawning requirements
- Down-stream requirements
- Irrigation needs

Generating Plants
Hydro Generation



Generating Plants
How Hydro Plants Work



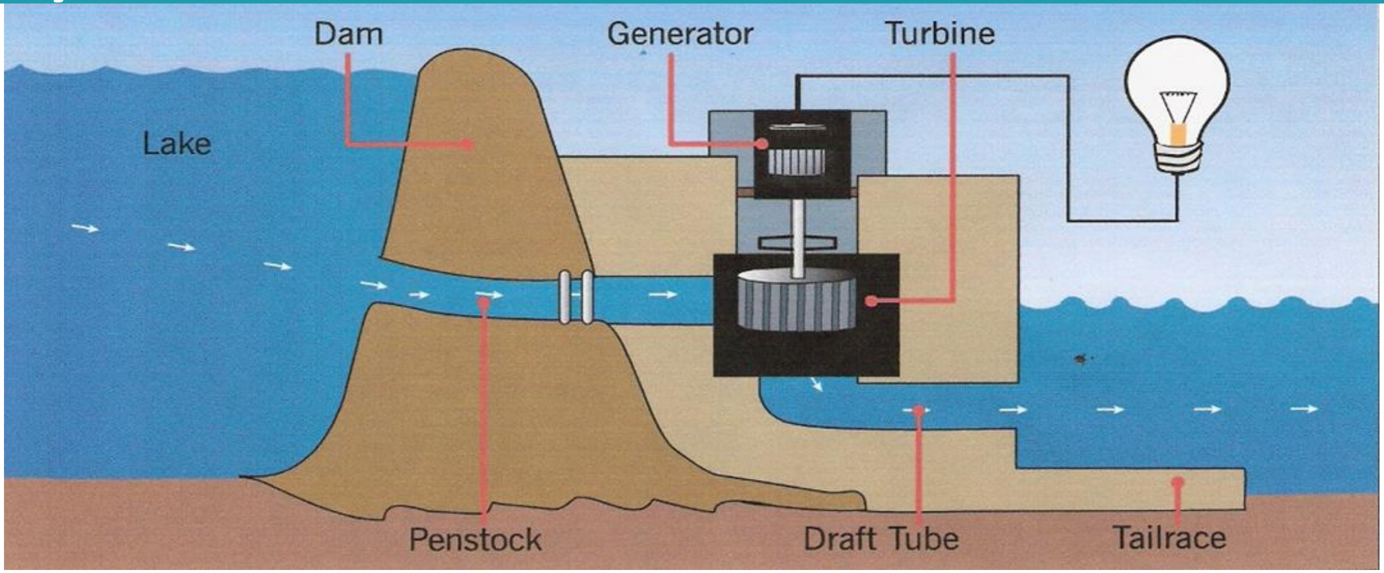
1. Reservoir

The water is held in a reservoir, or lake, behind the dam.

2. Penstock

Penstocks lead the water into a chamber housing the turbine. The water is held at a higher elevation than the turbine, so that it can fall with enough force to strike the turbine blades and cause it to spin.

Generating Plants
How Hydro Plants Work



3. Turbine

The turbine wheel is attached by a shaft to a generator.

4. Draft tube and Tailrace

The water returns to the river by passing through a draft tube under the turbine and into the tailrace.

Generating Plants
Hydro Characteristics

- Hydraulic turbines use **blades or buckets** shaped and positioned so that the water's force causes the turbine to rotate
- The **turbine runner** is the portion of the turbine on which the blades or buckets are mounted
- Moveable vanes, called ***wicket gates*****,** regulate the turbine power output by controlling the amount of water that enters the turbine runner

Generating Plants
Hydro Characteristics

Utilities use two basic types of turbines at hydroelectric generating stations:

- **Impulse** — Nozzles direct high velocity water onto cup-shaped buckets. This type of turbine is commonly used for plants having a high head (greater than 1000 feet)
- **Reaction** — Turbine output is obtained from a combination of the water pressure and velocity that completely fills the turbine water passages and runner

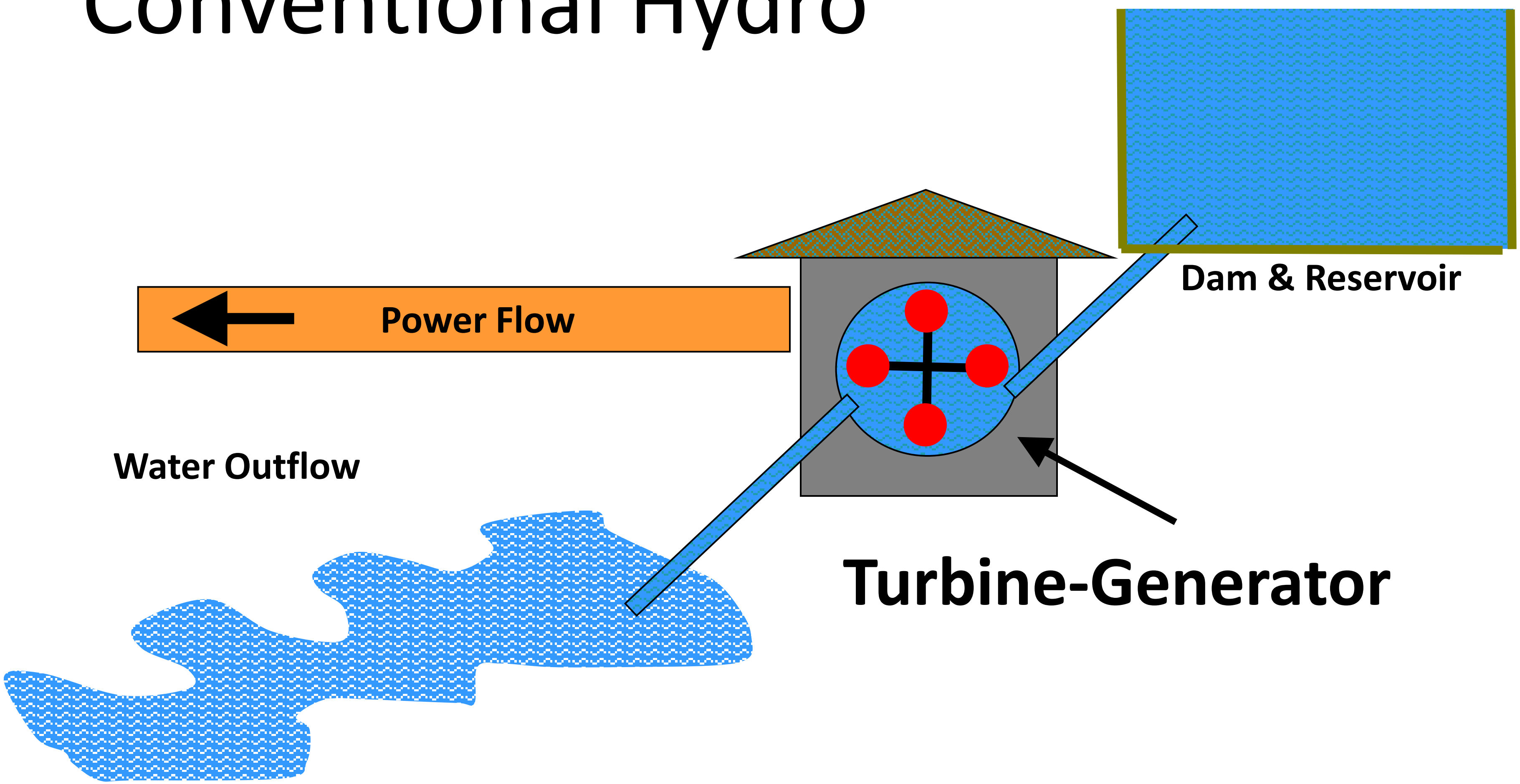
Generating Plants
Types of Hydro-Electric Plants

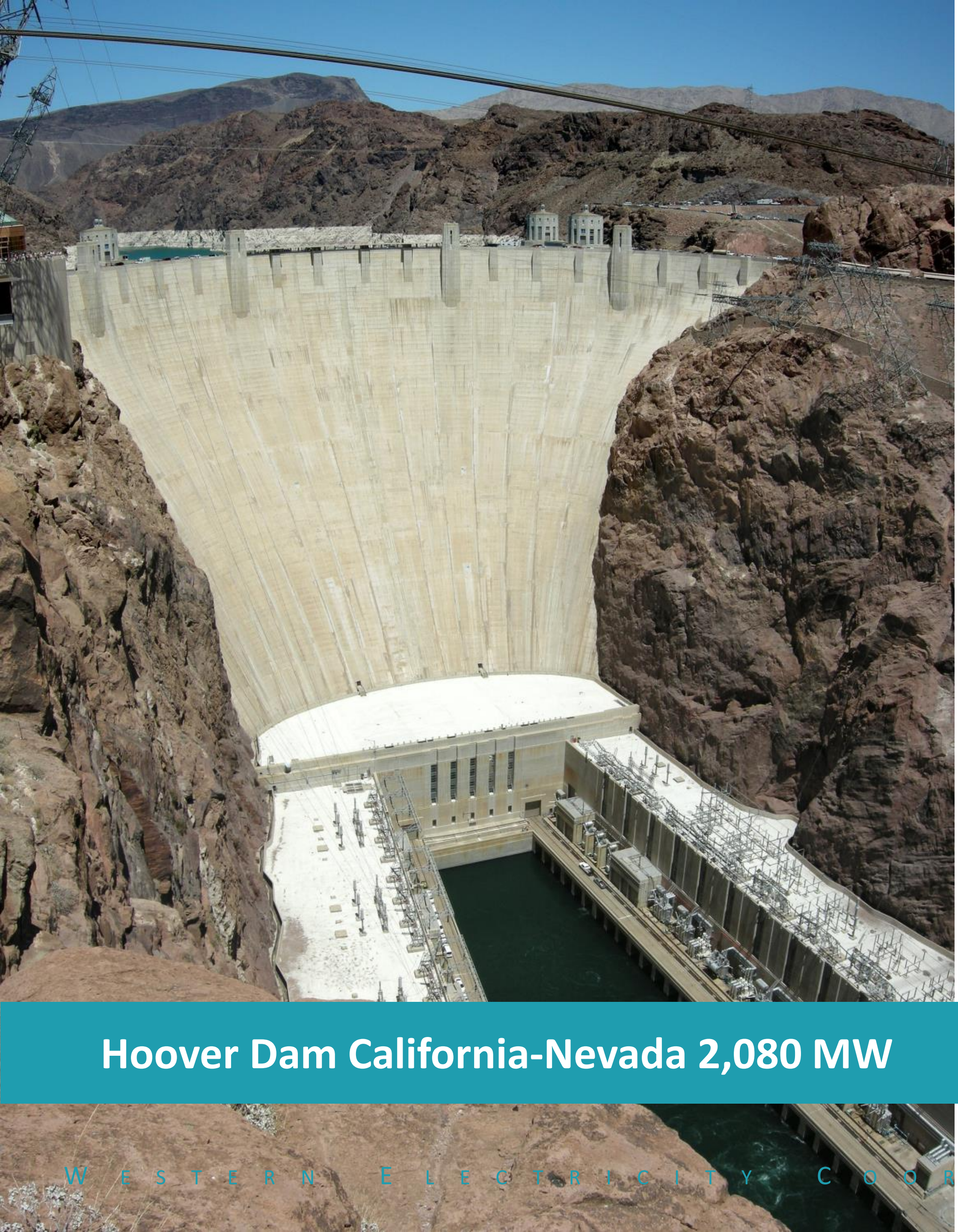
There are three types of hydro units that utilities use for generation:

- **Conventional**
- **Pumped Storage**
- **Run-of-the-river**

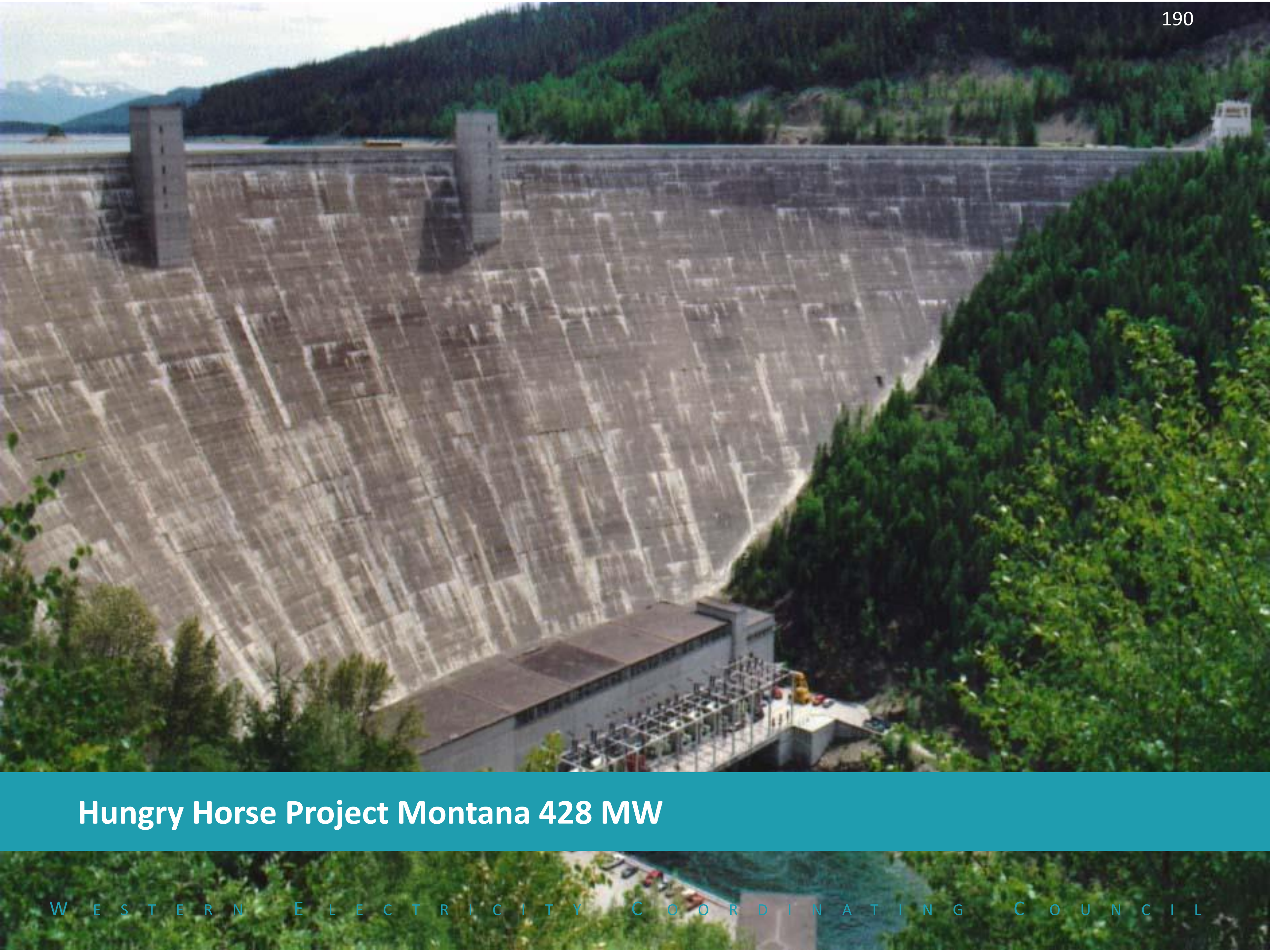
Generating Plants
Hydro Generation

Conventional Hydro





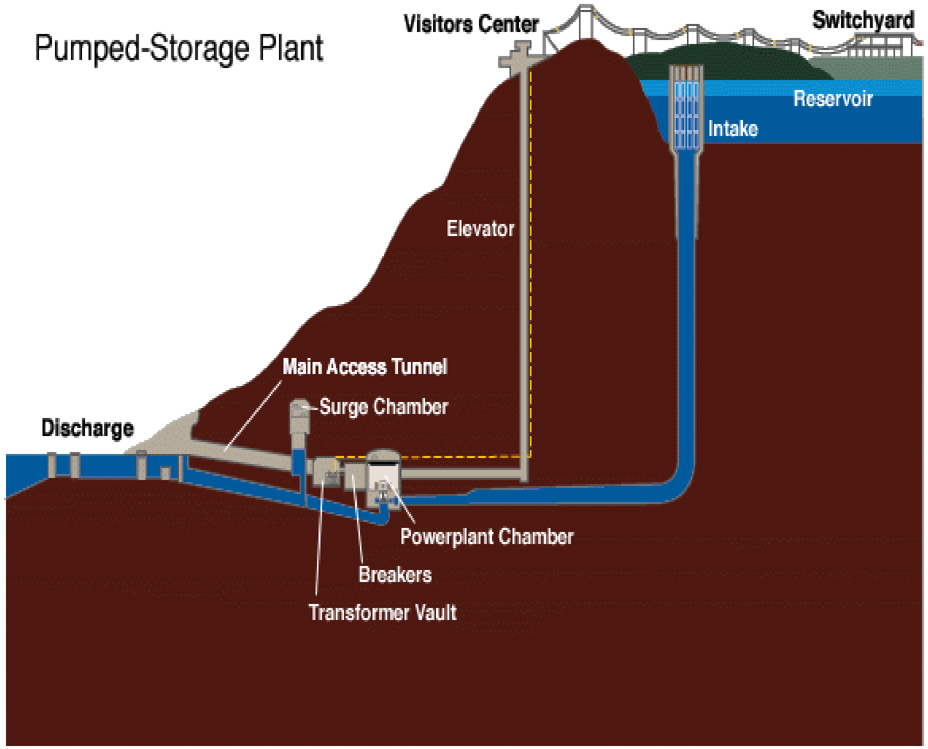
Hoover Dam California-Nevada 2,080 MW



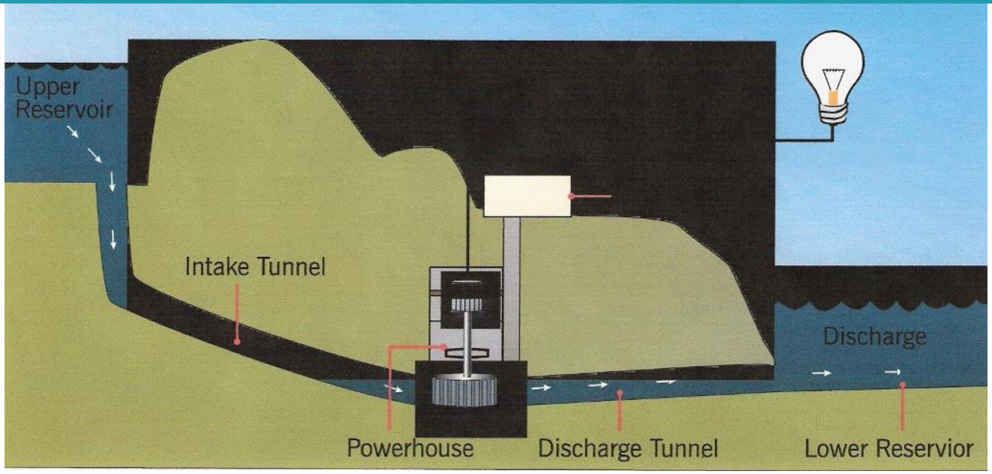
Hungry Horse Project Montana 428 MW

Chief Joseph Hydro Washington 2,600 MW

Generating Plants
Pumped Storage Hydro Plants



Generating Plants
How Pumped Storage Plants Work

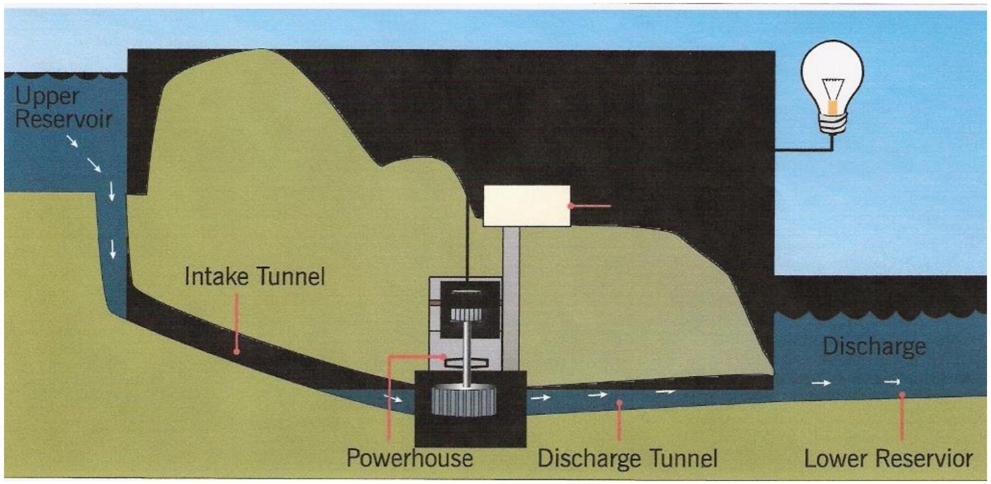


1. **Upper Reservoir**
   When power from the plant is needed, water stored in an upper reservoir is released into an underground tunnel.

2. **Intake Tunnel**
   The water rushes down the intake tunnel.

3. **Turbines**
   The force of the water drives huge turbines, which are underground at the base of a dam. The spinning turbines are connected to large generators, which produce the electricity.

Generating Plants
How Pumped Storage Plants Work



4. Discharge Tunnel

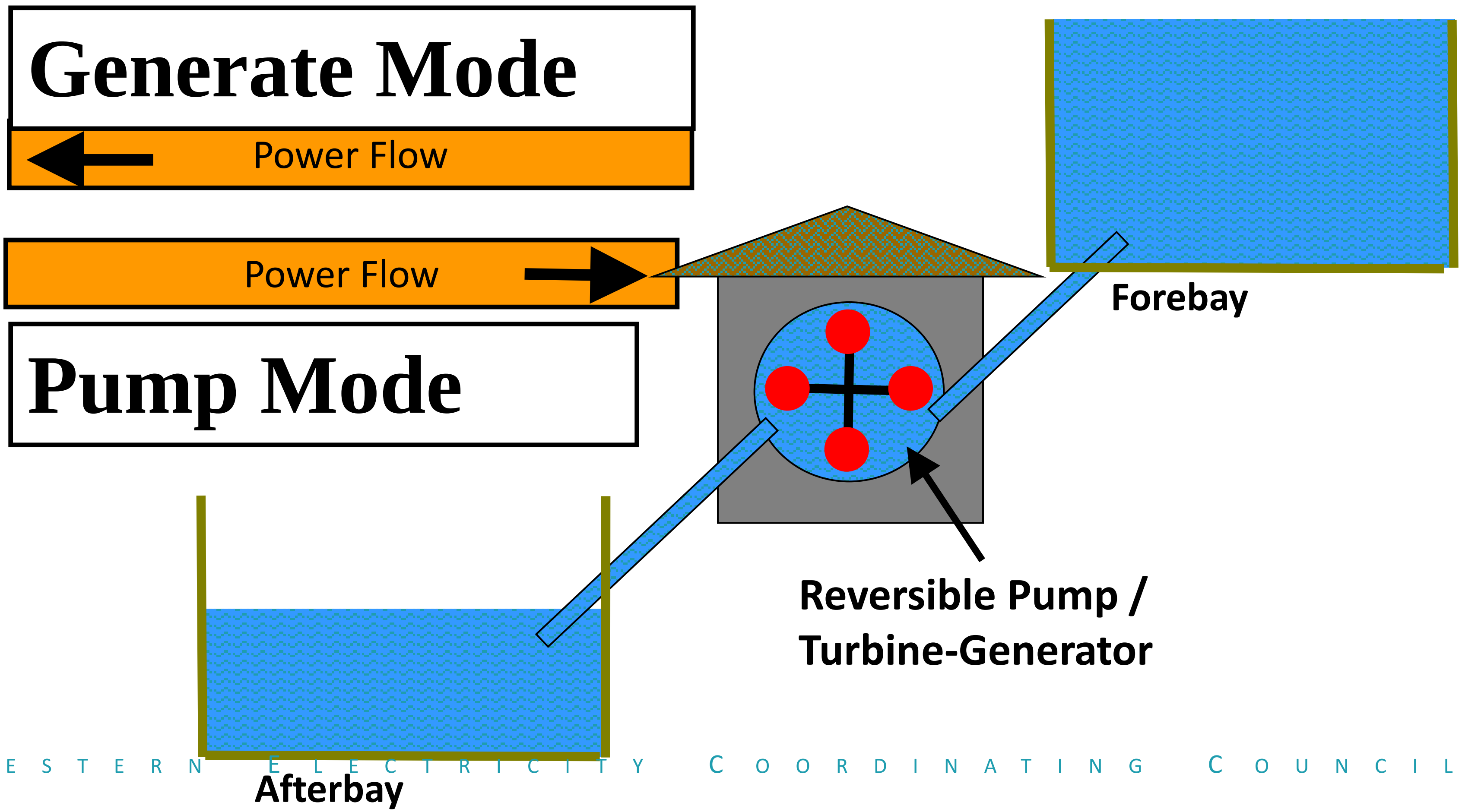
The water then flows through a discharge tunnel into a lower reservoir.

5. Recharging

When demand for electricity is slow, the turbines spin backward and pump the water back up into the upper reservoir to make it available to generate electricity when its needed.

Generating Plants
Hydro Generation

Pumped Storage Hydro

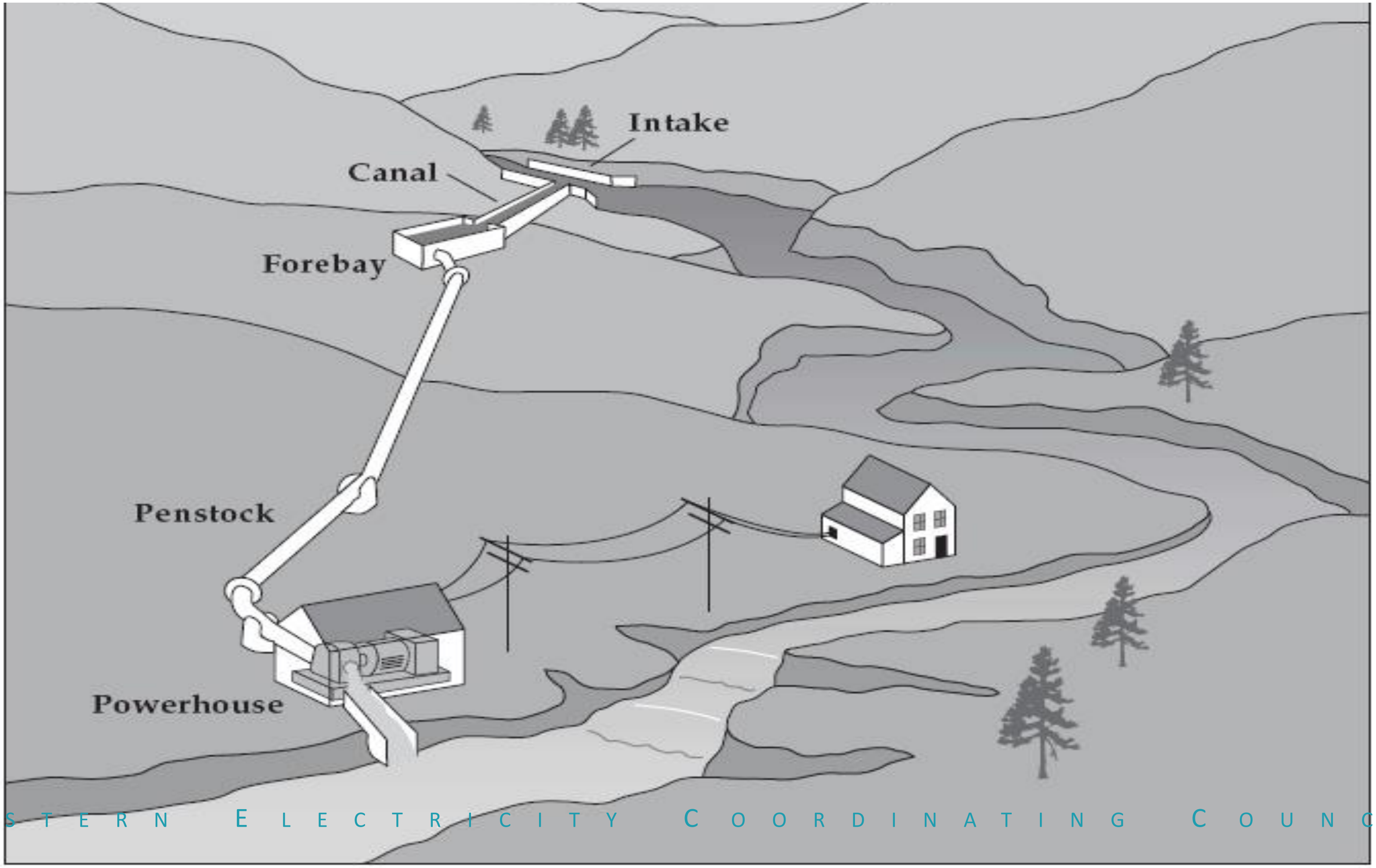


Cabin Creek Pump Storage

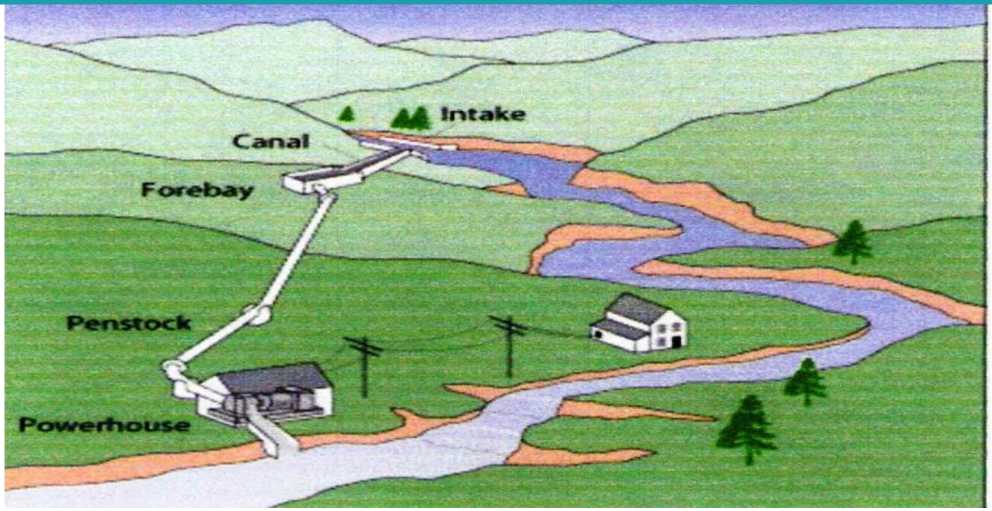
Castaic Pumped Storage 1,500 MW

Generating Plants
Hydro Generation

Run of the River Hydro

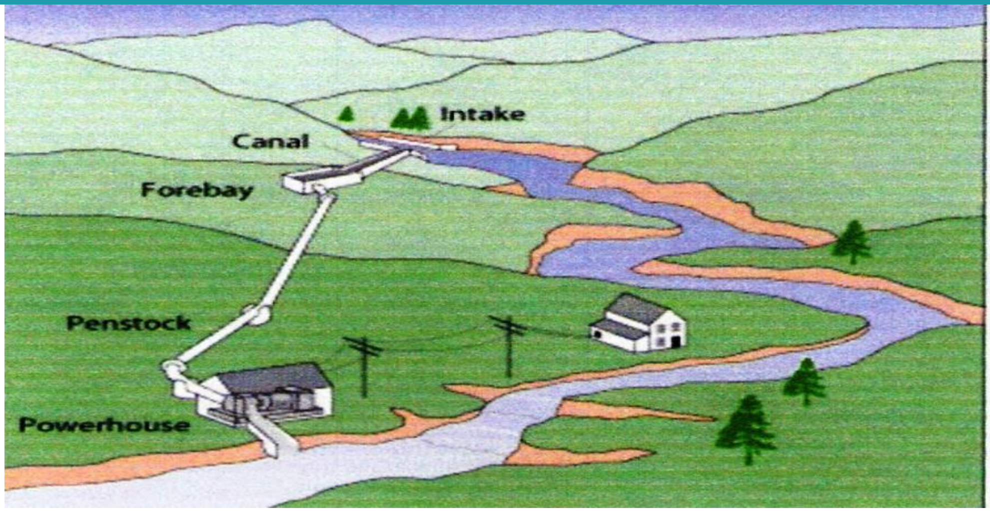


Generating Plants
How Run-of-the-River Hydro Plants Work



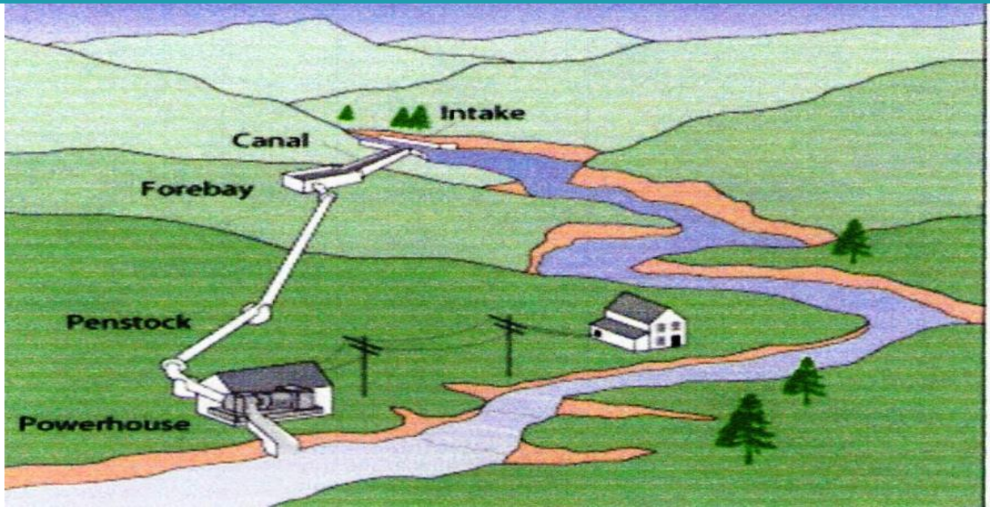
This type of hydro generation requires no water storage but instead diverts some of the water from the river which is channeled along the side of the valley before “dropped” into the turbine via a penstock, and then returns the water to the river through a discharge channel. The turbine drives a generator that provides electricity.

Generating Plants
How Run-of-the-River Hydro Plants Work



1. **Intake Channel**
   Diversion and intake channel collects the water and directs it to the forebay.
2. **Penstock**
   Penstock transports the water from the forebay to the turbine.

Generating Plants
How Run-of-the-River Hydro Plants Work



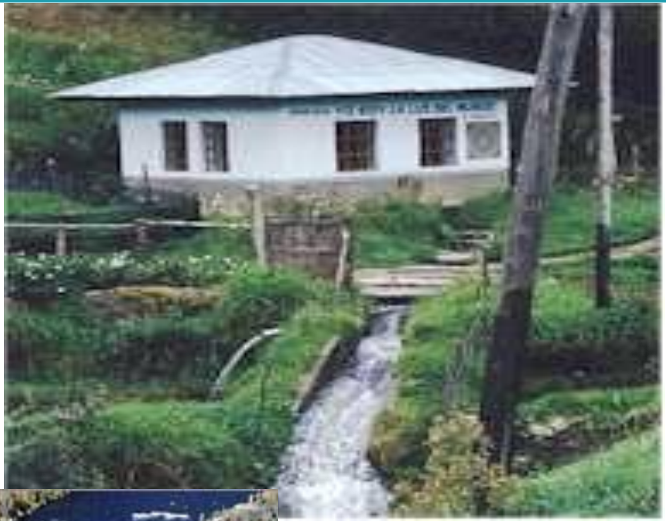
3. Turbine-Generator

Turbine and generator convert the kinetic energy and potential energy in the water to electrical energy.

4. Discharge Channel

Returns the water to the river after it has passed through the turbine.

Generating Plants
Run-of-the-River Hydro Plants



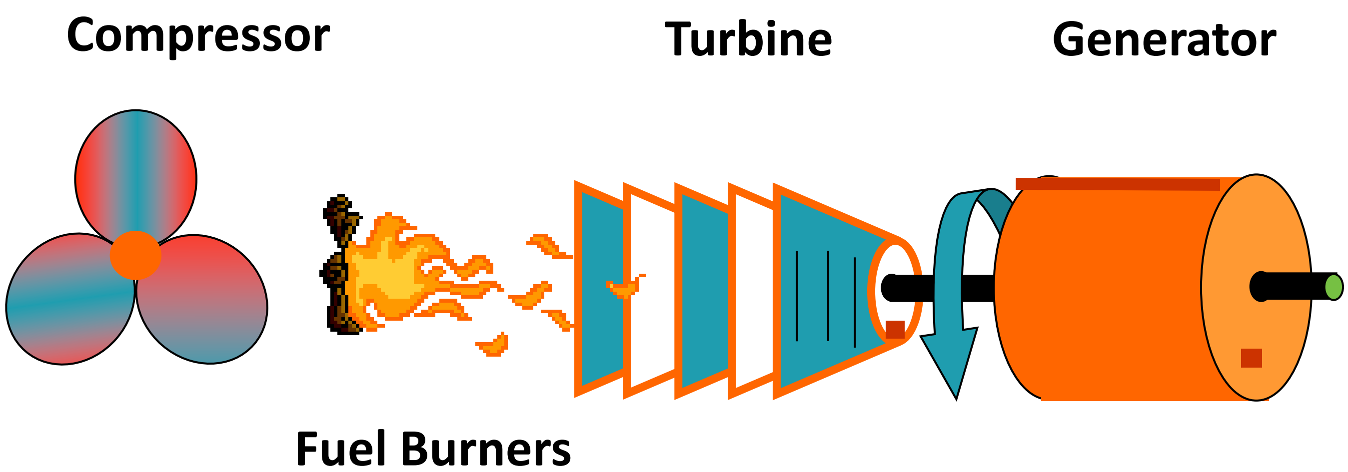
Generating Plants
Hydro problems….

Generating Plants
Combustion Turbines

- Operates similar to a jet engine
- Changes the chemical energy of fuel directly into mechanical energy that turns a Generator
- Combustion turbines eliminate using steam for thermal energy
- Hot Exhaust can be used to make steam for a steam turbine

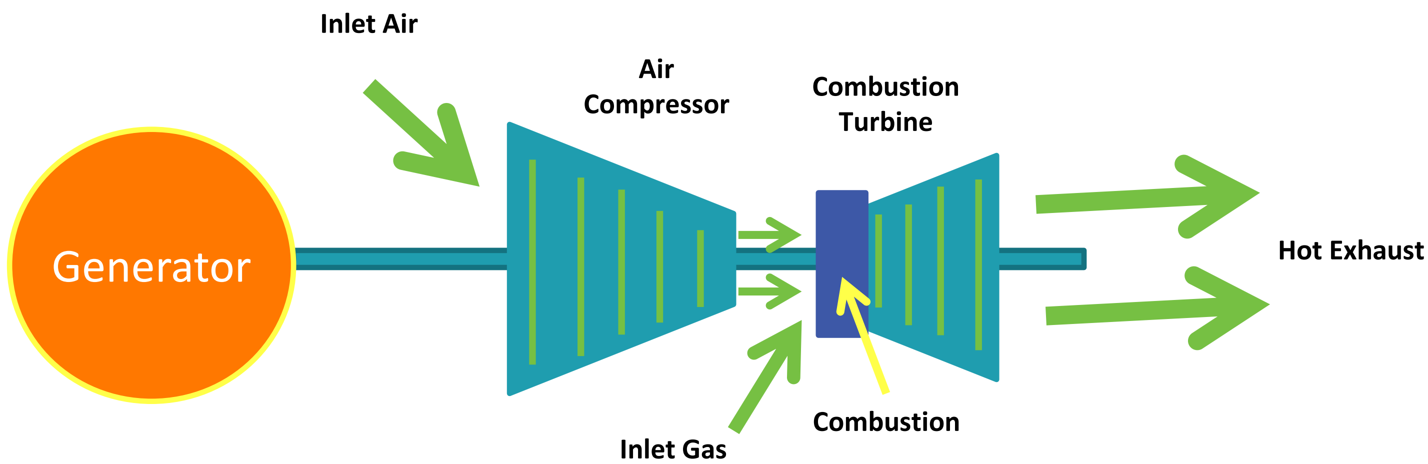
Generating Plants
Thermal Generation

Combustion turbine (also called CT or GT) Gas, Oil



Generating Plants
Combustion Turbines

- Compressed air and fuel is ignited and expands through the turbine
- The turbine turns the air compressor and the Generator



Generating Plants
Combustion Turbines

Most Combustion Turbines are Open Cycle - Expanded gas is exhausted into the atmosphere, as with an aircraft jet engine.

- Many Combustion Turbines are based on aircraft jet engine design – these are called **Aero-derivative Combustion Turbines**
- Larger units are built on a ground based frame. These are called Frame units

Generating Plants
Combustion Turbines

- Combustion gas turbine advantages
  - quick start-up (5-10 Minutes)
  - low investment cost
  - short construction time
  - well-suited for standby and peaking purposes
- However, thermal efficiency is low…and generation is expensive

Generating Plants
Combustion Turbines

- Advantages – Continued
  - Requires no cooling water
  - Emissions are relatively low
  - No Ash
  - Fuel is easy to handle (relatively)
- Size ranges from about 15 to 250 MW

Generating Plants
Combustion Turbine

- Fuel Supply – Natural Gas (Methane or CH_4)
- Combines with 4 Atoms of Oxygen to produce
- CO_2 and 2 – H_2O molecules (water)
- If there is sulfur in the fuel it also produces some SOx
- Some NOx is also produced

Generating Plants
Combustion Turbine

- Heat rates can be around 9000 btu/kwh
- Exhaust heat can be used in a combined cycle system.
- Output is affected by Inlet air temperature – sometimes evaporative cooling or chillers are used to cool the air
- Output is affected by air density – same machine at a lower elevation will produce more

Generating Plants
Combustion Turbine

Pollution can be reduced by

– Use Dry – Low NOx burners – controlled burn temperature

– Use Selective Catalytic Converters (SCR) – spray Ammonia into the exhaust stream, then run the exhaust through a labyrinth of ceramic catalytic material to react with the NOx and turn it into N_2 and H_2O

Combustion Turbine

Combustion Turbines

Generating Plants
Combined Cycle Units

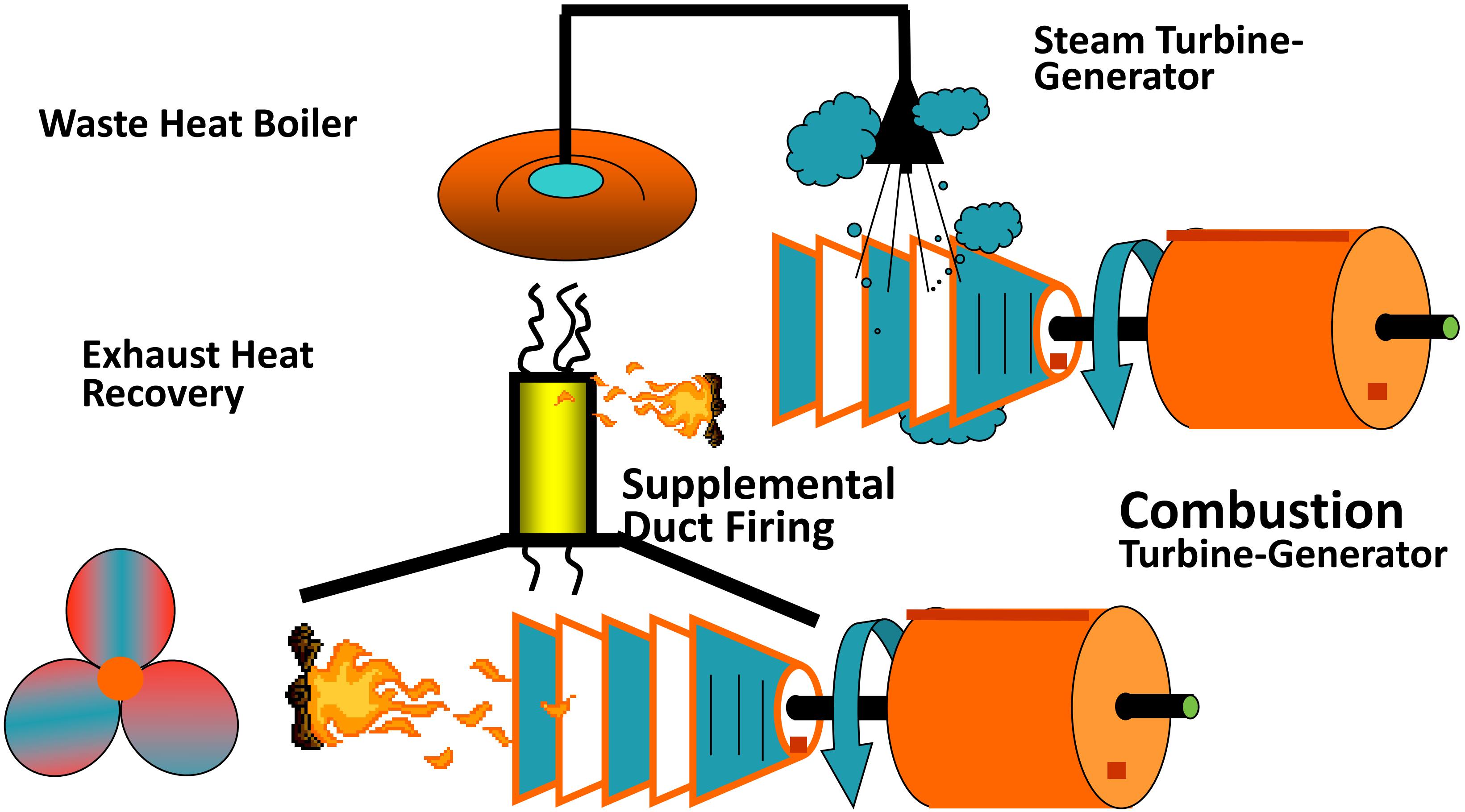
- A **Combined Cycle** plant includes one or more Combustion Turbines combined with a Steam Turbine
- Exhaust from the Combustion Turbine(CT) is used to heat the steam
- The turbine exhaust gases exit into a boiler, called a Heat Recovery Steam Generator (HRSG), where the heat is used to convert water to steam

Generating Plants
Combined Cycle Units

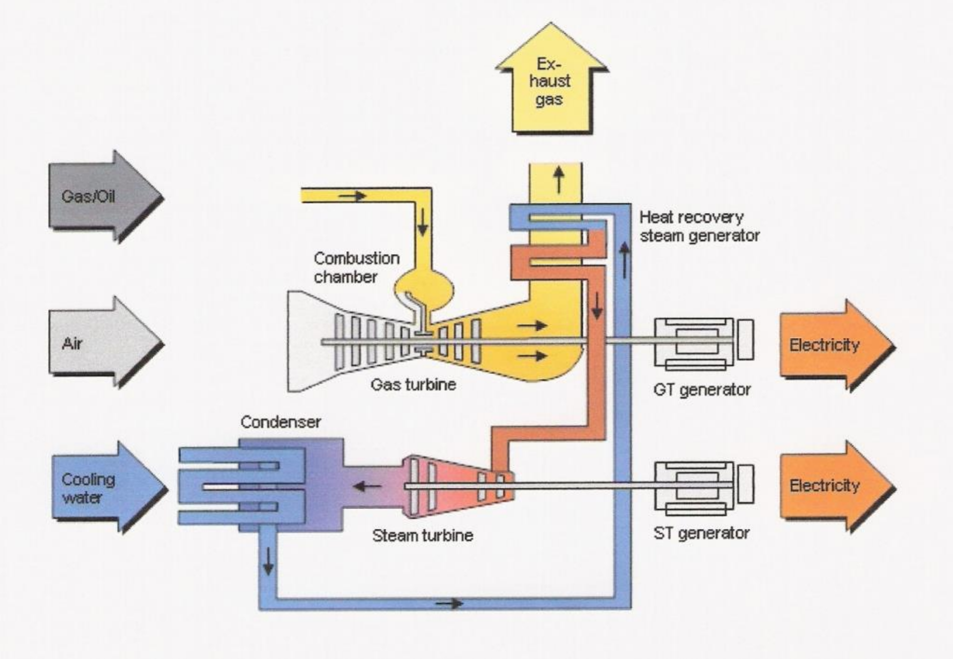
- The steam drives a separate steam turbine to generate additional electricity
- Efficiency is dramatically increased since this power is generated without consumption of additional fuel
- Each generator is connected to the power grid through independent circuit breakers

Generating Plants
Thermal Generation

Combined Cycle

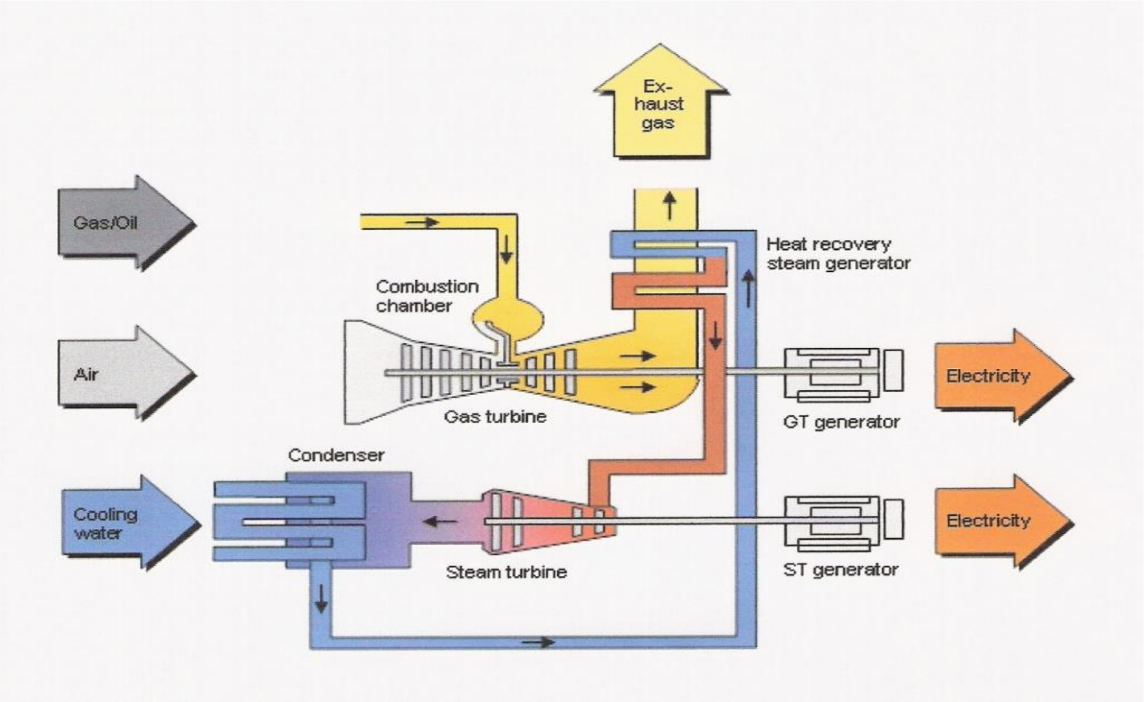


Generating Plants
How Combined Cycle Plants Work



Exhaust from the combustion turbine passes through a Heat Recovery Steam Generator (HRSG), where the exhaust heat is used to produce steam. The steam then flows through a non reheat steam turbine to drive a generator. Plant capacity ranges from 100 MW to more than a 1000 MW. All plants use a single steam turbine with from one to four combustion turbines. The combination of gas and steam turbines allows electric power generation with the highest efficiency.

Generating Plants
How Combined Cycle Plants Work



In a multi shaft arrangement (as shown in the picture) both the gas turbine and the steam turbine, each are connected to a generator. In a single shaft arrangement gas turbine and steam turbine drive the same generator to produce electricity.

Southwest Generation-Denver Combined Cycle 130 MW

Generating Plants
Combined Cycle Units

Generating Plants
Combined Cycle Units

Combined-cycle plants combine some of the best features of combustion gas turbines and steam units:

- Like gas turbines, the gas turbine portions of combined-cycle units start up quickly and respond rapidly to changes in power demand. The steam generator portions take longer to bring into use
- New technology combined-cycle plants run at 50 percent thermal efficiency and higher, which is almost the efficiency of simple-cycle steam generating plants. We discuss efficiency in more detail later in this module

Generating Plants
Combined Cycle Units

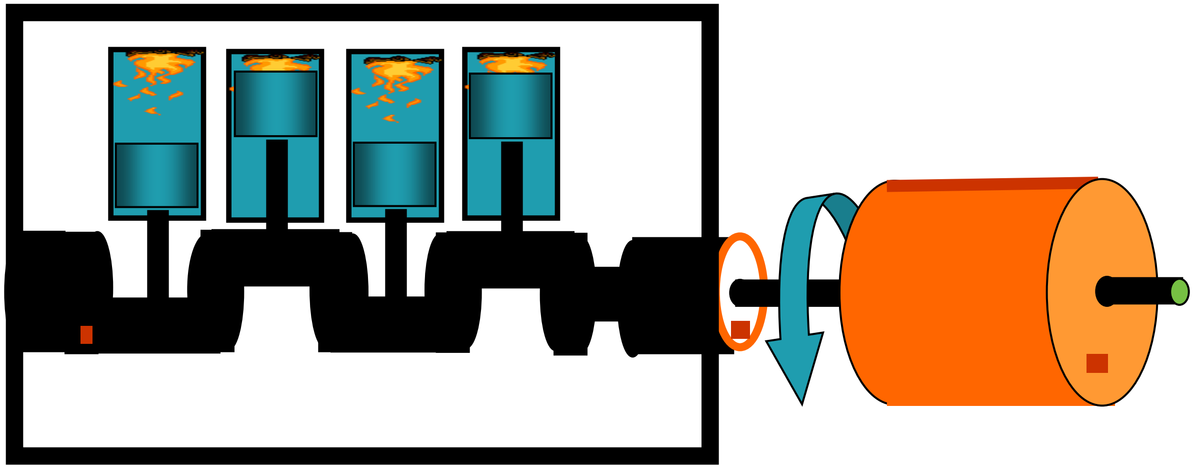
- Beginning in about 2000, combined cycle plants began proliferating across the WECC region
- Presently constitute 75-80 percent of all new generation capacity being installed
- Increased efficiency
- Lower capital costs
- Shorter construction time (two years compared to five years for a coal-fired plant)
- Use of environmentally acceptable natural gas to reduce emissions

Generating Plants
Combined Cycle Units

- **Duct-firing** can be used to increase output
- Natural gas is injected into the exhaust ducts and ignited in the HRSG to provide additional heat and steam
- Cooling can be provided with either a conventional water cooled condenser (cooling tower) or with an Air-cooled condenser

Generating Plants
Diesel Engine Generator

Internal Combustion

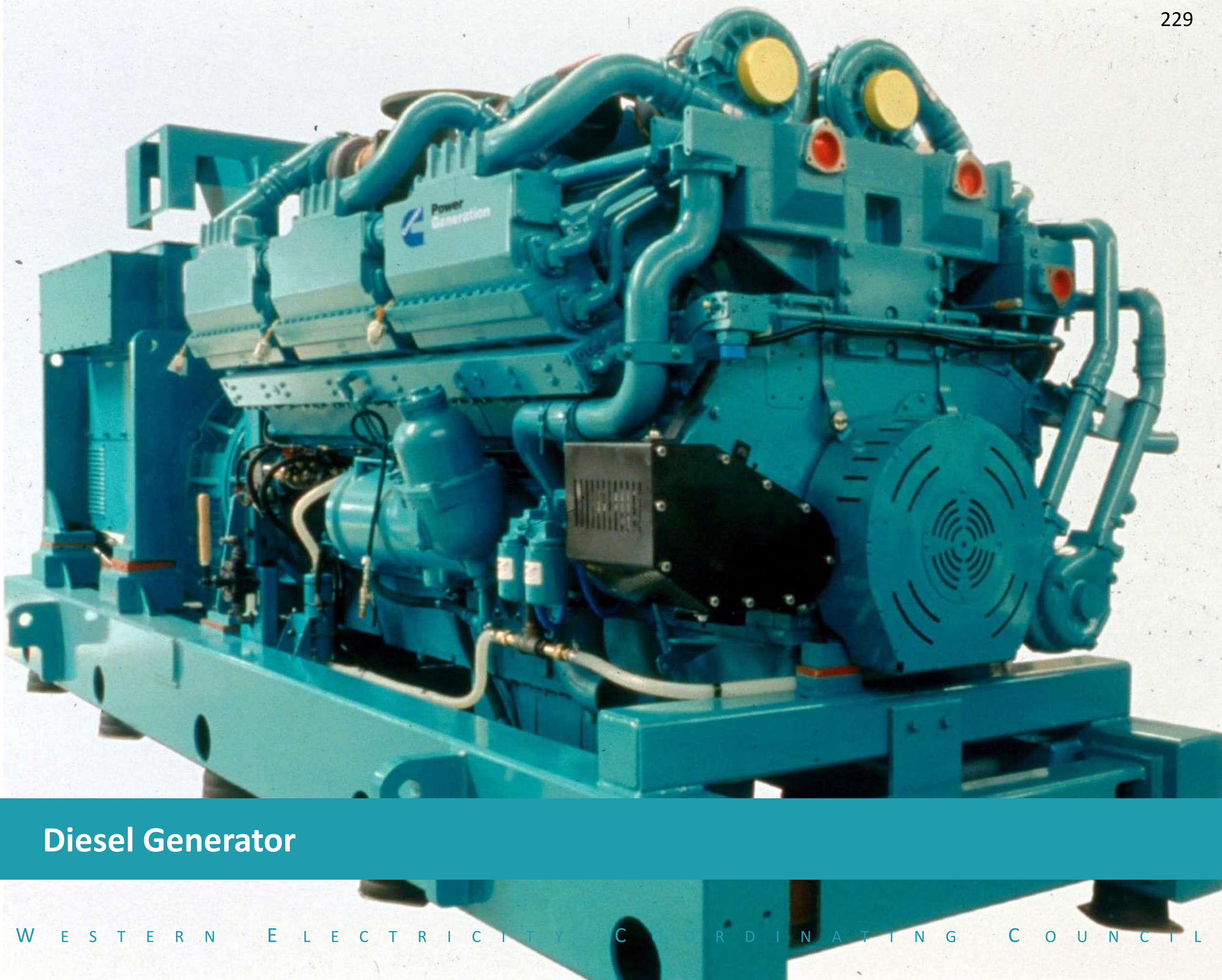


Piston-Driven Diesel Engine

Generator

Generating Plants
Diesel Engine Generator

- The high compression ratio and high operating temperature of Diesel Engines make them very efficient
- Cost of Fuel is high
- Come in many sizes – from a few KiloWatts to around 15 Megawatts
- Can be portable to move around for special events or system support



Diesel Generator


EMD-B
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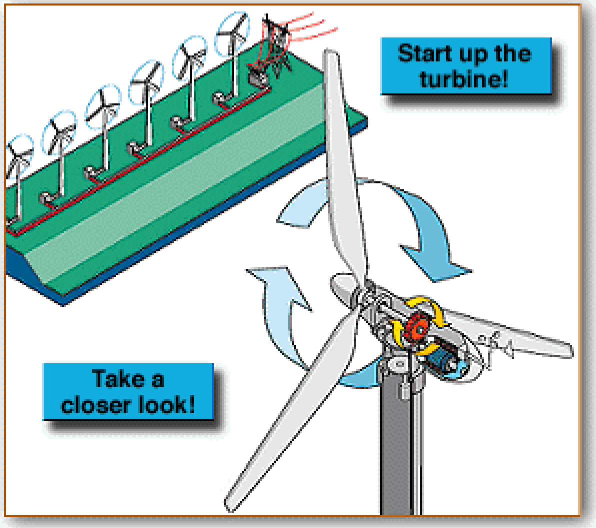
Energy Sources
Wind Generation

Generating Plants
Wind Turbines



Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and the rotation of the earth.

Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetation.

The terms wind energy or wind power describes the process by which wind is used to generate mechanical power or electricity.

Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks or a generator can convert this mechanical energy into electricity.

Generating Plants
Wind Turbines

How do Wind Turbines Make Electricity?

Simply stated: a wind turbine works the opposite of a fan

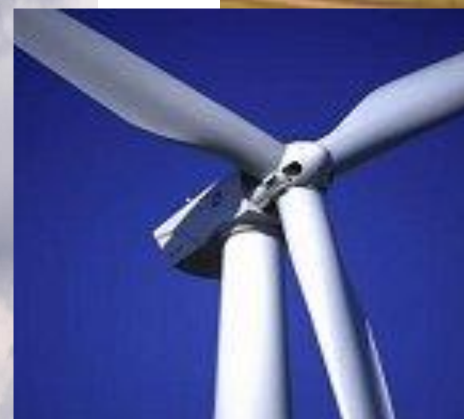
- Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity
- The wind turns the blades, which spin a shaft, which connects to a generator

Generating Plants
Types of Wind Turbines

Modern wind turbines fall into two basic groups:

1. Horizontal-axis design
   - Horizontal-axis turbines have either two or three blades
   - They are operated "upwind" with the blades facing into the wind

Horizontal Axis Wind Turbine



Generating Plants
Types of Wind Turbines

2. The second type of wind turbine is the Vertical-axis design (like an egg-beater) called the Darrieus model.

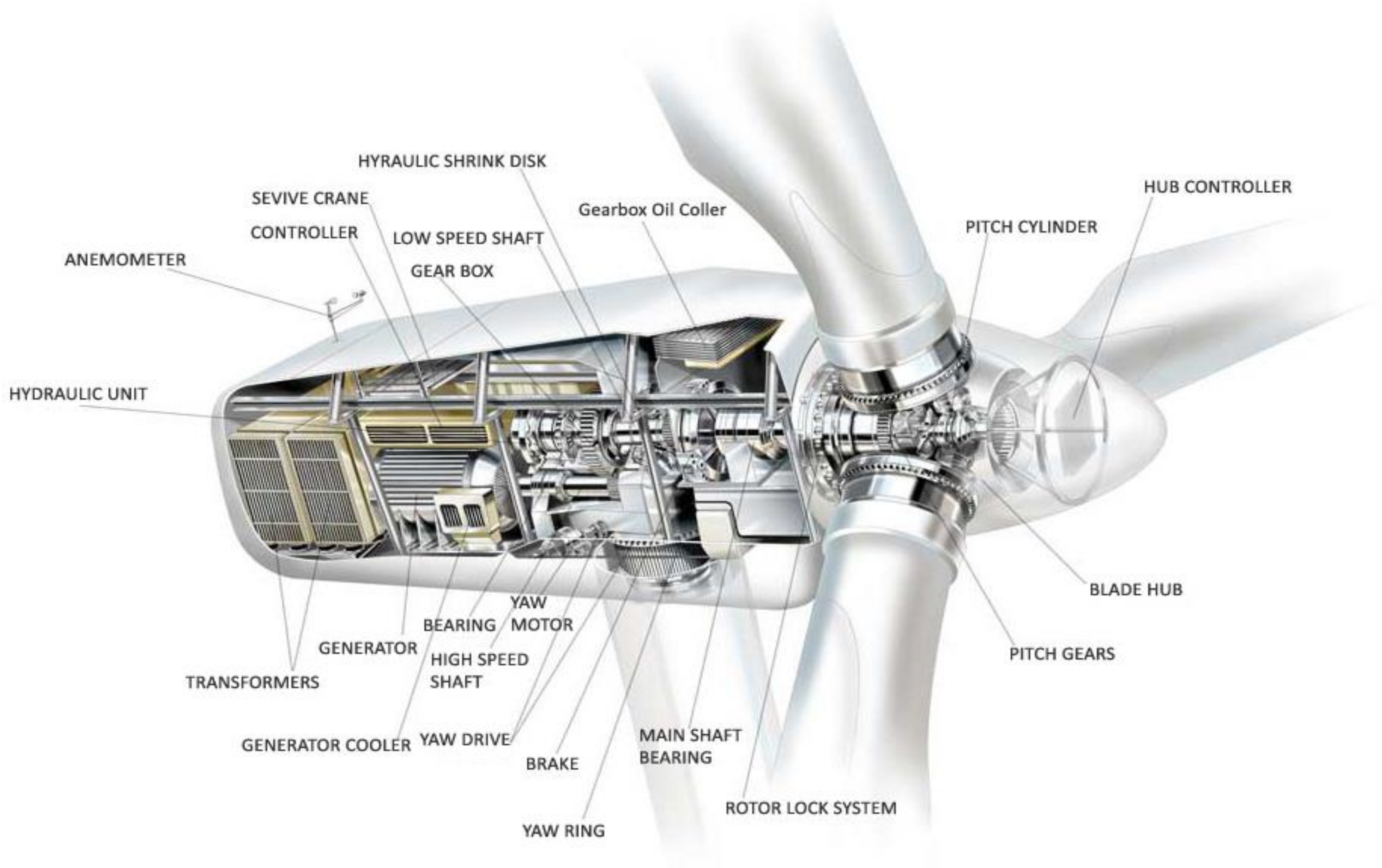
These are not as common, and are difficult to scale up.

Vertical Axis Wind Turbine

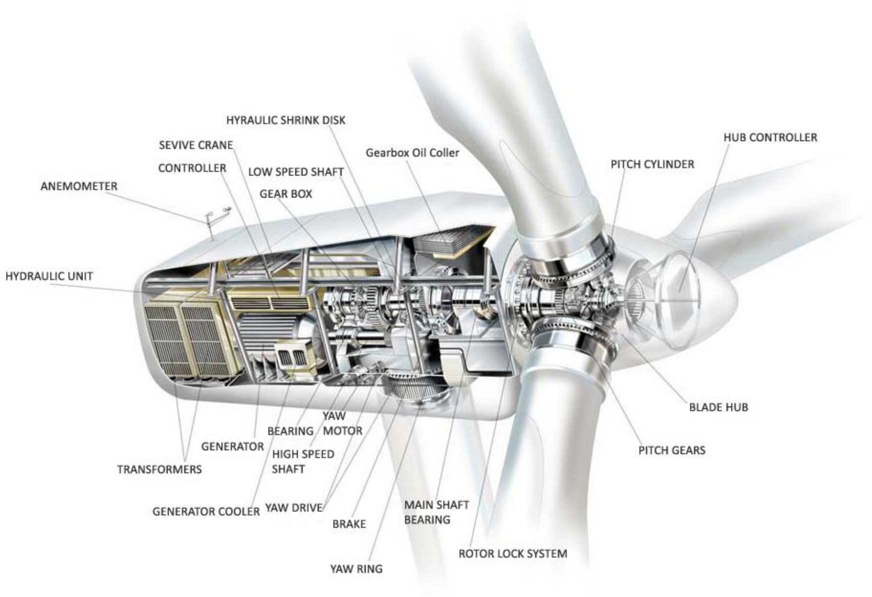
Generating Plants
Size of Wind Turbines

Utility-scale turbines range in size from 100 kilowatts to as large as several megawatts.

Generating Plants
How Wind Turbines Work



Generating Plants
How Wind Turbines Work



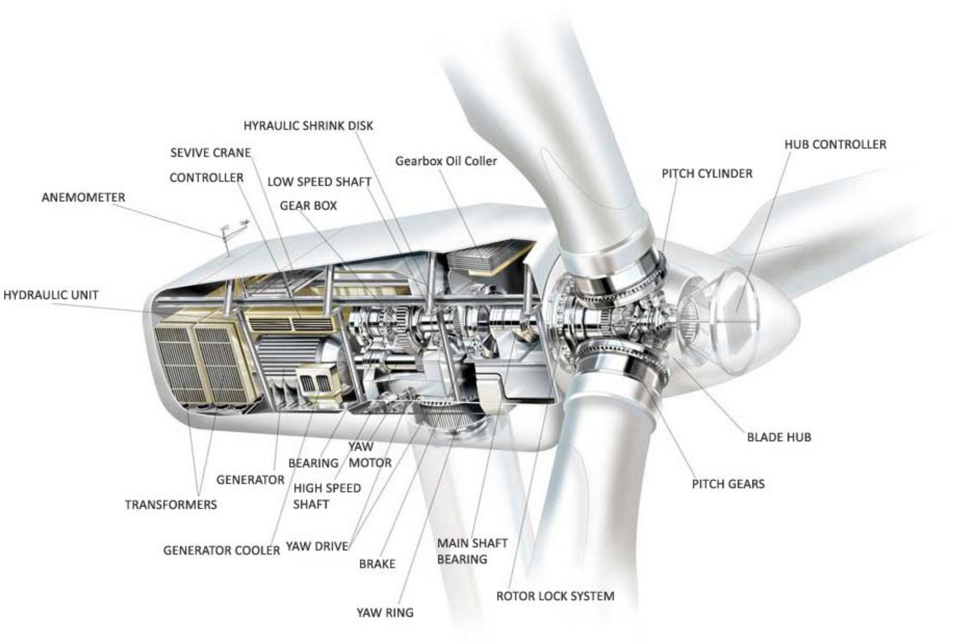
1. **Anemometer**
   Measures wind speed and transmits data to the controller.

2. **Blades**
   Most have either 2 or 3 blades. Wind blowing over the blades causes the blades to “lift” and rotate.

3. **Brake**
   A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

4. **Controller**
   The controller starts up the machine at wind speeds of about 8 to 16 miles per hour and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above 55 mph because they might be damaged by the high winds.

Generating Plants
How Wind Turbines Work



5. Gear Box

Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from 30 to 60 rpm's to 1000 to 1800 rpm. The gear box is a costly (and heavy) part of the wind turbine. Engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

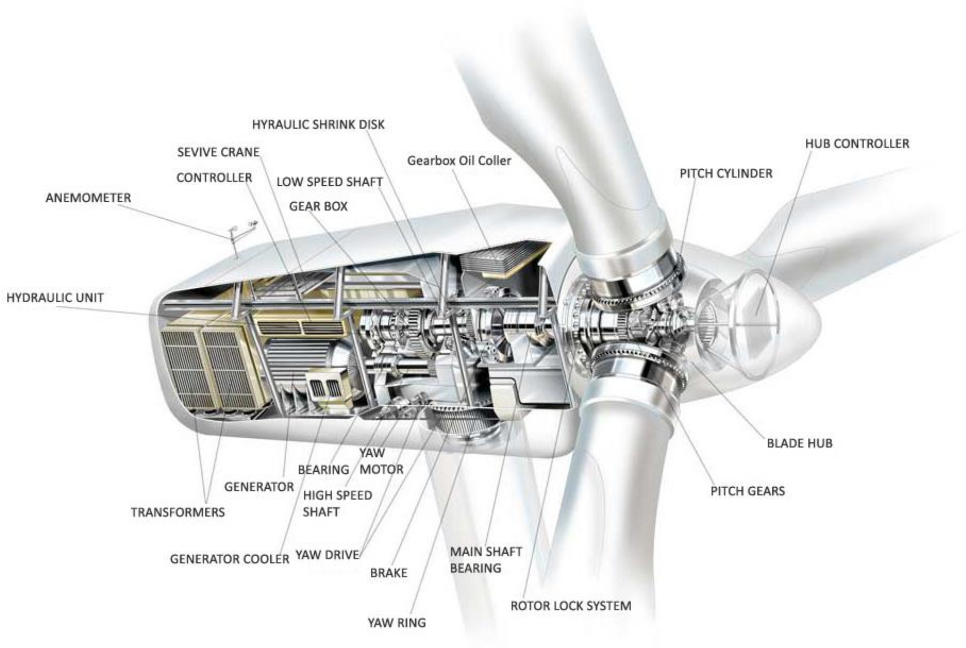
6. Generator

Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

7. High speed Shaft

Drives the generator.

Generating Plants
How Wind Turbines Work



8. Low-speed Shaft

The rotor turns the low-speed shaft at about 30 – 60 rpms.

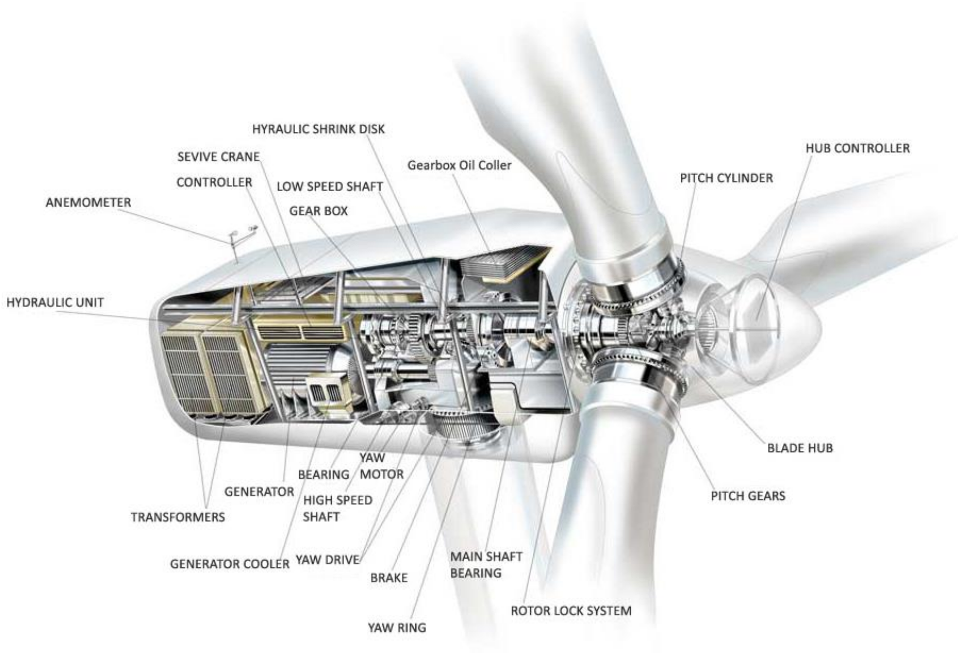
9. Nacelle

The nacelle sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller and brake. Some nacelles are large enough for a helicopter to land on.

10. Pitch

Blades are turned, or pitched, out of the wind to control rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.

Generating Plants
How Wind Turbines Work



11. Rotor

The blades and the hub together are called the rotor.

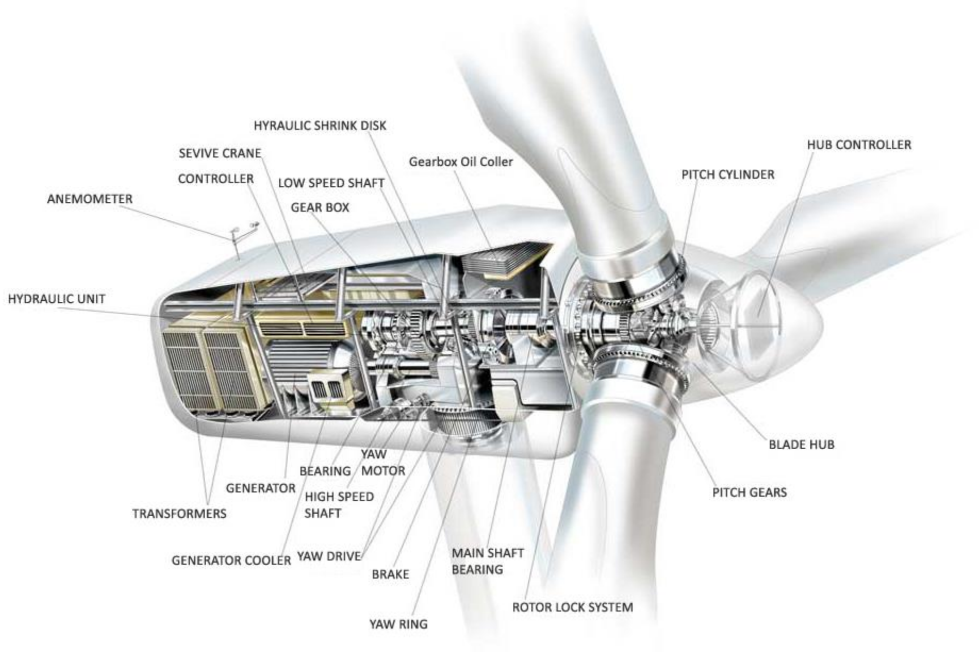
12. Tower

Towers are made from tubular steel, concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

13. Wind Direction

This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind.

Generating Plants
How Wind Turbines Work



14. Wind Vane

Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

15. Yaw Drive

Upward turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don’t require a yaw drive, the wind blows the rotor downwind.

17. Yaw Motor

Powers the yaw drive.

Generating Plants
Wind Farms

- A typical wind farm may use 60 to 100 individual wind turbines
- Each Turbine may produce 1 to 2 MW each
- Turbines will be spaced about 700 to 1500 feet apart side-to-side and a half mile apart front to back
- Layout depends on terrain – try to side turbines on the tops of ridges or hills

Generating Plants
Wind Farms

- Such a wind farm may be situated on a 10,000 to 15,000 acre site (15 – 23 square miles)
- Farming and cattle grazing is relatively un-disturbed
- Up to 25 miles of road will be constructed connecting the turbines
- Turbines are connected by 34.5kV underground cable
- Cables terminate at a Collector substation where voltage is stepped up for the grid

Generating Plants
Advantages & Disadvantages of Wind Energy

- Wind energy offers many advantages, which explains why it's the fastest-growing energy source in the world
- Research efforts are aimed at addressing the challenges to greater use of wind energy

Generating Plants
Advantages of Wind Energy

- Fueled by the wind so it is a clean fuel source
- Doesn't pollute like fossil fuel plants
- Doesn’t produce atmospheric emissions that cause acid rain and greenhouse gasses
- Domestic source of energy
- Wind supply is abundant

Generating Plants
Advantages of Wind Energy

- Relies on the renewable power of the wind
- One of the lowest priced renewable energy technologies available
- Costing between 4 and 6 cents per kilowatt hour, depending on the wind source, this is to cover project financing
- Operation and maintenance costs are very small

Generating Plants
Advantages of Wind Energy

- Built on farms and ranches benefitting economy in rural areas
- Wind farm owners rent the land from the landowner to site turbines
- Major tax breaks for companies installing wind generation

Generating Plants
Disadvantages of Wind Energy

- Wind power must compete with conventional generation on a cost basis
- Depending on how energetic a wind site is, it may not be cost competitive
- Technology requires a higher initial investment than fossil fuel generators
- Wind is intermittent and does not always blow when electricity is needed

Generating Plants
Disadvantages of Wind Energy

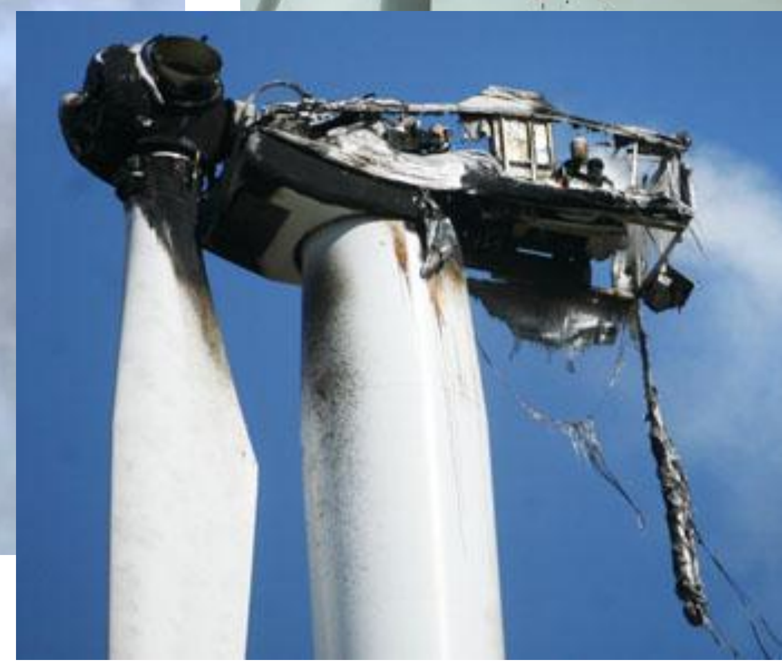
- Wind energy cannot be stored in significant quantities
- Not all winds can be harnessed to meet timing requirements
- Good sites are often located in remote areas far from the load
- Cannot be controlled by AGC systems.
- No reserves

Generating Plants
Disadvantages of Wind Energy

- Must generate when the wind blows, other generation must be backed off to accommodate
- Some concern over the noise produced by the rotor blades. (usually you don't notice this because the wind is blowing so hard)
- Danger to birds and bats
- Maintenance of large components requires a very large-costly crane

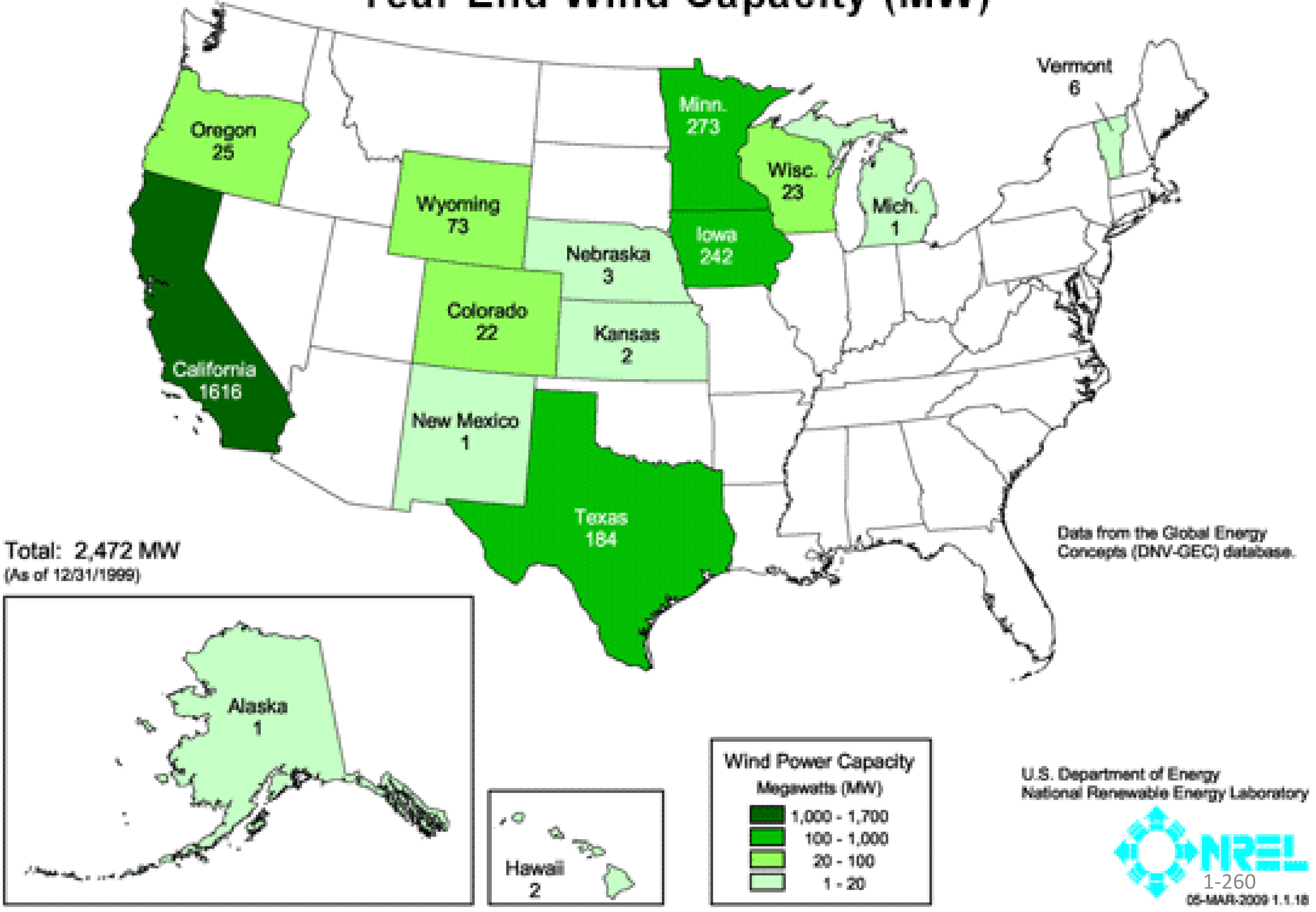
Disadvantages of Wind Energy

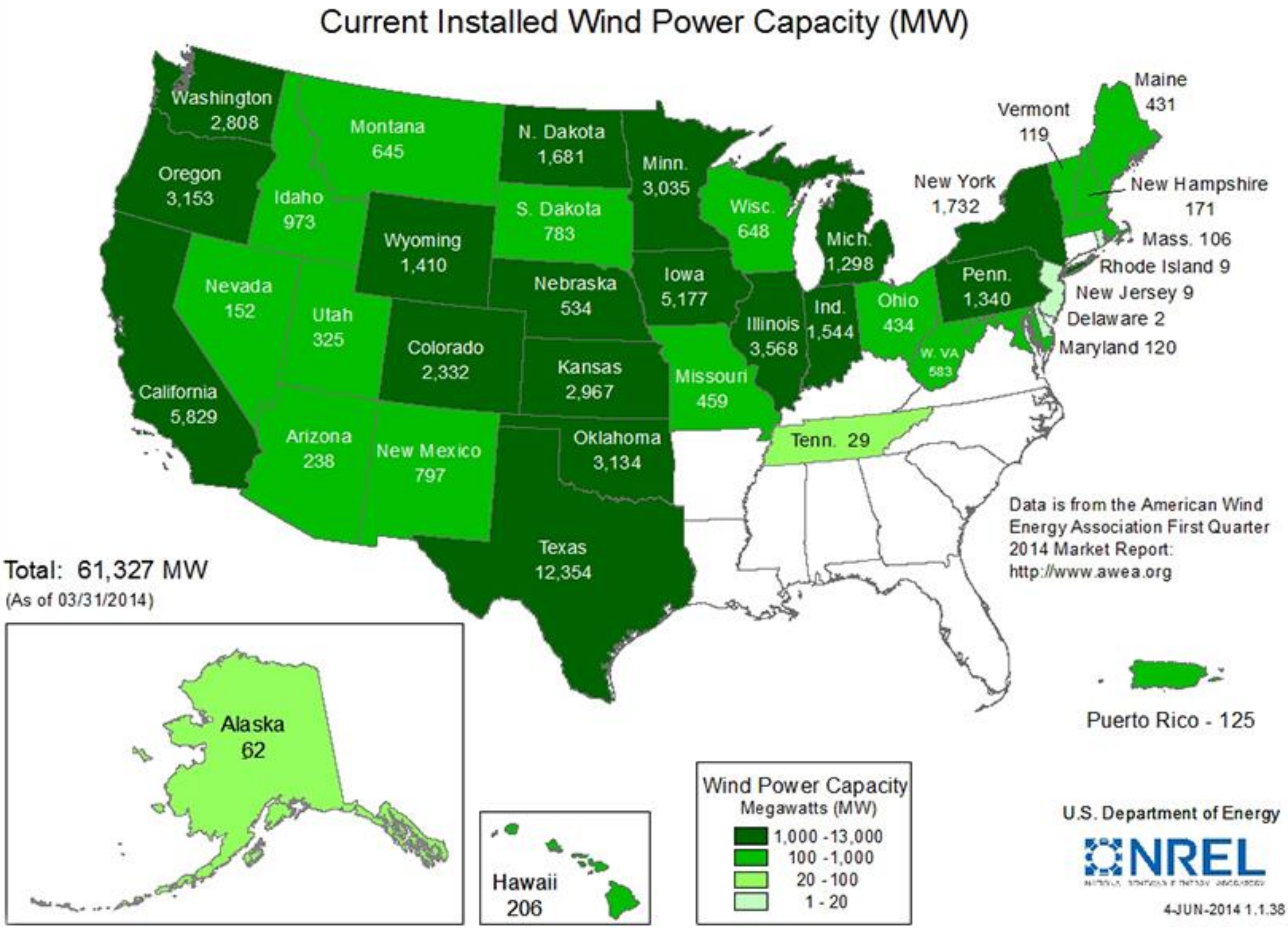
Disadvantages of Wind Energy



Disadvantages of Wind Energy

1999
Year End Wind Capacity (MW)




Current Installed Wind Power Capacity (MW)
Washington 2,808
Oregon 3,153
California 5,829
Montana 645
Idaho 973
Nevada 152
Utah 325
Arizona 238
Wyoming 1,410
Colorado 2,332
New Mexico 797
N. Dakota 1,681
S. Dakota 783
Nebraska 534
Kansas 2,967
Oklahoma 3,134
Texas 12,354
Minn. 3,035
Iowa 5,177
Missouri 459
Wisc. 648
Illinois 3,568
Mich. 1,298
Ind. 1,544
Ohio 434
W. VA 583
Tenn. 29
Penn. 1,340
New York 1,732
Vermont 119
Maine 431
New Hampshire 171
Mass. 106
Rhode Island 9
New Jersey 9
Delaware 2
Maryland 120
Data is from the American Wind Energy Association First Quarter 2014 Market Report: http://www.awea.org
Total: 61,327 MW
(As of 03/31/2014)
Alaska 62
Hawaii 206
Puerto Rico - 125
Wind Power Capacity
Megawatts (MW)
1,000 -13,000
100 -1,000
20 - 100
1 - 20
U.S. Department of Energy
NREL
4-JUN-2014 1.1.38

Generating Plants
Solar

Two main types of Solar Generation

- Photovoltaic – solar panels convert light directly into electrical energy
- Solar-Thermal – Light is concentrated into heat collecting pipes or a tower to produce steam to power a steam turbine

Generating Plants
Solar - Photovoltaic

- **Photovoltaic** solar panels consist of a semi-conductor material that reacts with light
- Photons knock electrons free to travel in a circuit
- **Direct current** from multiple photovoltaic cells flows in collector circuits
- Direct current is **Inverted** to AC power for the grid

Arizona Public Service 2 MW Photovoltaic

Generating Plants
Solar - Thermal

- Solar Thermal plants focus the suns rays to a central tower or collector pipes containing water
- The heat creates steam which is used to run a steam turbine generator
- Individual Heliostats must be controllable to track the sun and reflect light to the central tower

Solar Thermal One 10MW – Barstow, CA

eSolar Thermal
Sierra SunTower 5 MW
Lancaster, CA

Planta Solar
10MW & 20MW
Near Seville, Spain

Solana Solar Arizona 280 MW

Generating Plants
Solar

Output of a solar plant depends on…

- Area covered (100 watts/square foot down to 5 watts/square foot(Solar One Plant))
- Sun Intensity (southern areas have more direct sun light)
- Cloud cover
- Efficiency of the collection system (improving all the time)

Generating Plants
Solar

Disadvantages include

- Cost
- Non-dispatchable – only generates when the sun is shining
- Uses a large amount of land
- Concern over danger to birds – either mistake the panels for water, or fly through hot-focal area

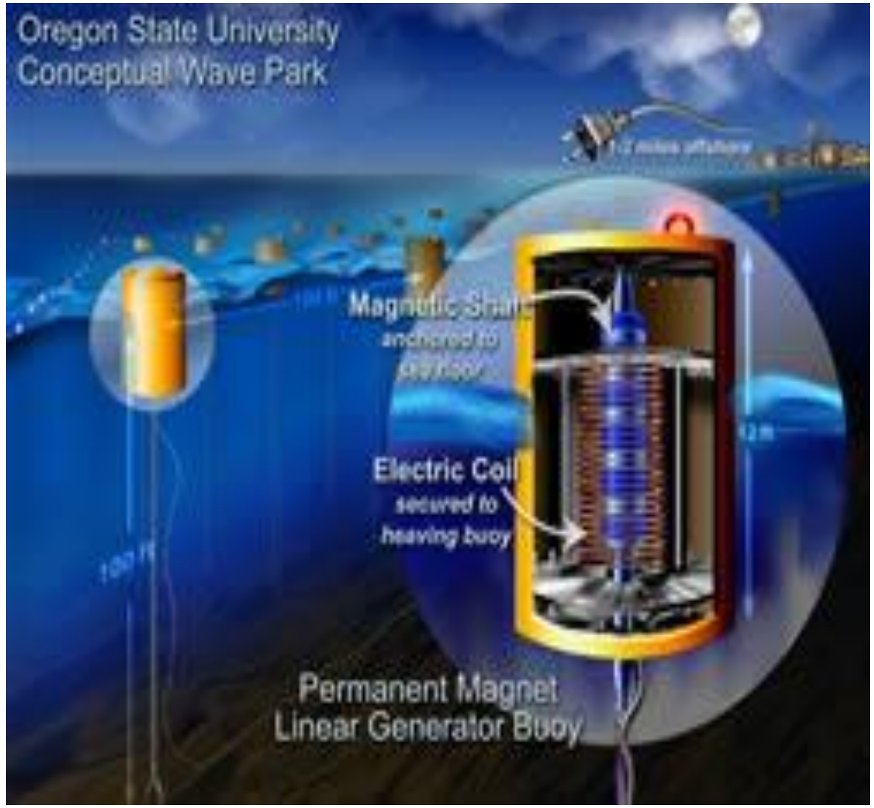
Generating Plants
Generation Technologies

- Wind
- Photovoltaic
- Solar thermal
- **Fuel cells**
- Battery storage
- Ocean wave
- Compressed air
- Coal gasification
- Fluidized bed

The "Bloom Box"

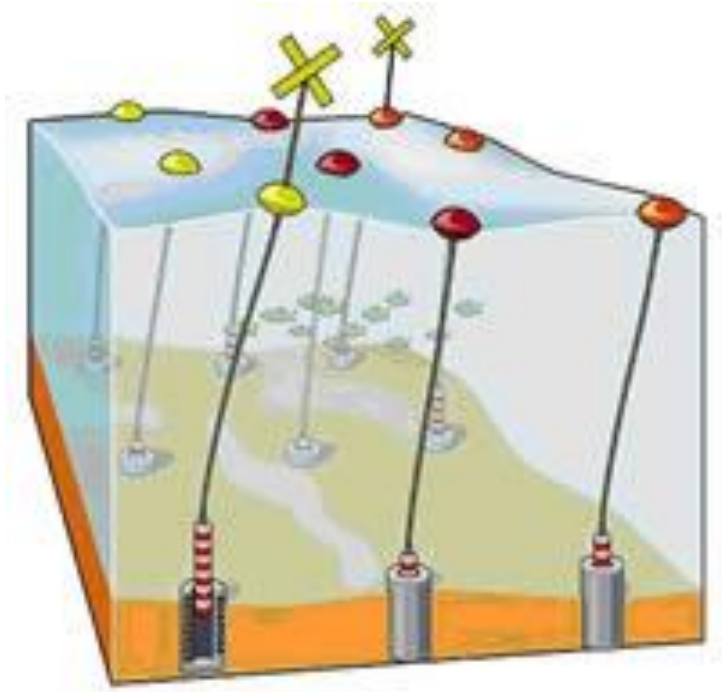
Generating Plants
Generation Technologies

- Wind
- Photovoltaic
- Solar thermal
- Fuel cells
- **Battery storage**
- **Ocean wave**
- **Compressed air**
- **Coal gasification**
- **Fluidized bed**



Rendition of a Wave Farm made up of a Permanent Magnet Linear Generator Buoy

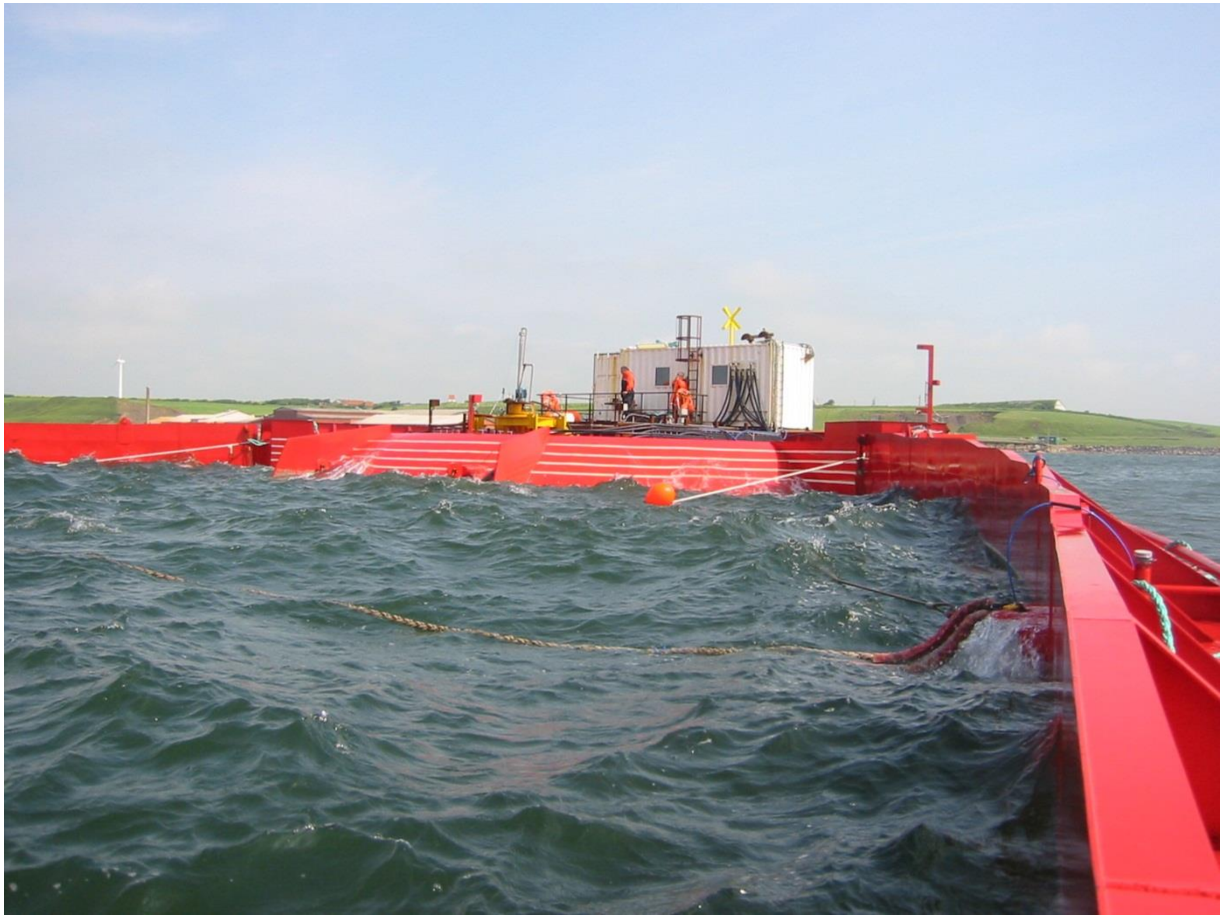
Generating Plants
Pictures of Ocean Wave Technology



Point Absorber Wave Farm

Point Absorber Operation

Attenuator Wave Device



Overtopping Devices

Generating Plants
Generating Unit Operating Characteristics

Each type of generating unit has different operating characteristics:

- Efficiency
- Unit Capability and Minimum Load
- Response Rate

Generating Plants Efficiency

***Efficiency* –** Output/Input

Measured at

- – the terminals (**gross output**).
- – at the step-up transformer (**net output**).

- **Output** is megawatt hours
- **Input** is barrels of oil, tons of coal, cubic feet of water, or other fuel resources; depending on the type of plant

Generating Plants Efficiency

- Higher efficiency - good – lower fuel cost, more output
- Lower efficiency - bad – higher fuel cost, more losses, less output

Generating Plants Efficiency: Steam Generating Units

- Fossil-fired units use massive quantities of fuel
- A slight increase in efficiency means great savings for the customers
- Fuel purchases are the highest expense for most utilities, amounting to hundreds of millions of dollars annually
- Dollar savings from efficiency can be substantial

Generating Plants Efficiency: Heat Rate

A measure of Efficiency for thermal generating units is ***heat rate***

- ***Heat rate*** is the amount of heat measured in BTUs (British Thermal Units) required to produce a kilowatt hour of electrical output
- More efficient units have a lower heat rate than less efficient units

Generating Plants Efficiency: Heat Rate

- The most efficient fossil-fired units have a heat rate of around 9,800 BTU/kWh. The average efficiency is about 10,500 BTU/kWh
- Steam generating units are designed to have the lowest heat rate when operating close to maximum load
- Unit heat rate improves as loading increases, up to the rating of the generating unit
- Heat rate may get worse (higher) as loading increases past its rating

Generating Plants Efficiency: Hydro Units

Is efficiency important for Hydro Units?

- Is water free?
- Is there a limited amount that can be used by the generator?
- If you could generate more electricity for the same amount of water flow, would you want to?

Generating Plants Efficiency: Hydro Units

- Water is a limited resource and hydroelectric plant efficiency is an important issue
- In drought-stricken areas, the small streams and lakes that normally feed the reservoirs used by hydroelectric plants may be low
- This limits the amount of water available for use by the plant
- Water used by pumped storage stations is not "free"
- The price of the water is the cost of the energy it takes to pump the water to the upper reservoir
- It is important to get as much energy as possible out of every drop of water

Generating Plants
Unit Capability & Minimum Load

Unit capability refers to the maximum possible megawatt output that the generating unit can safely produce.

- Unit capability is dependent on the design of the boiler, turbine, and generator; and on the coolant conditions, such as the ambient air temperature and the hydrogen pressure in the generator cooling system

Generating Plants
Unit Capability & Minimum Load

Minimum load is the smallest amount of generation that a unit can sustain for an extended period.

- At minimum load, unit efficiency is much lower than at the rated load

Generating Plants
Unit Capability & Minimum Load

Steam Generating Units

- For steam generating units, a **Unit Rating**, is the most efficient operating point, it is generally slightly lower than the unit's maximum capability
- Fossil-fired generating units, may have difficulty maintaining stable fuel combustion at low loads

Generating Plants
Unit Capability & Minimum Load

Hydro Units

- Hydroelectric units may experience ***cavitation*,** which can seriously damage the turbine
- Cavitation is the formation of water vapor bubbles that can implode (burst inward) or collapse, resulting in turbulence that can cause "pitting" in metallic surfaces
- Cavitation may be caused by low water levels in the tailrace

Generating Plants Response Rate

Response Rate or Ramp Rate is the rate of load change that a generating unit can achieve for normal operating purposes in MW/min.

- Steam generating plants must change load relatively slowly. This is because the boiler or steam generator responds fairly slowly to changing load demands
- Steam generating units must be started up slowly and they must pause frequently during start-up to allow components to gradually rise to their rated temperature

Generating Plants Response Rate

- When on-line, changes in unit loading must be applied relatively slowly to maintain stability of the unit controls. Newer units are designed to respond faster
- As a result, steam-generating units are generally held at a steady load or regulated within limits set at the plant. Once a steam unit is on-line, it is usually kept on-line as much as practical to avoid unnecessary and frequent unit start-ups and shutdowns

Generating Plants Response Rate

- Combustion turbines (like a jet engine) can be started up in a short amount of time, often within 10 or 15 minutes. Since they do not depend on a boiler to produce heated steam
- Combustion turbines can change load rapidly on request
- Combustion turbines make the best "peaking" units
- During peak-load periods when load demand is high for a short period of time, it is common practice to start peaking units, run them for a few hours then shut them down

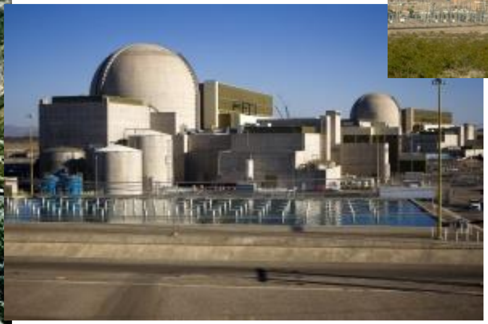
Generating Plants Response Rate

Regulating Units

- Hydroelectric units can respond rapidly to load changes. Since they are on-line as much as possible (due to their low operating cost), utilities usually use them as ***regulating units***
- ***Regulating units*** adjust their outputs up or down as load increases and decreases or energy schedules change

Summary…





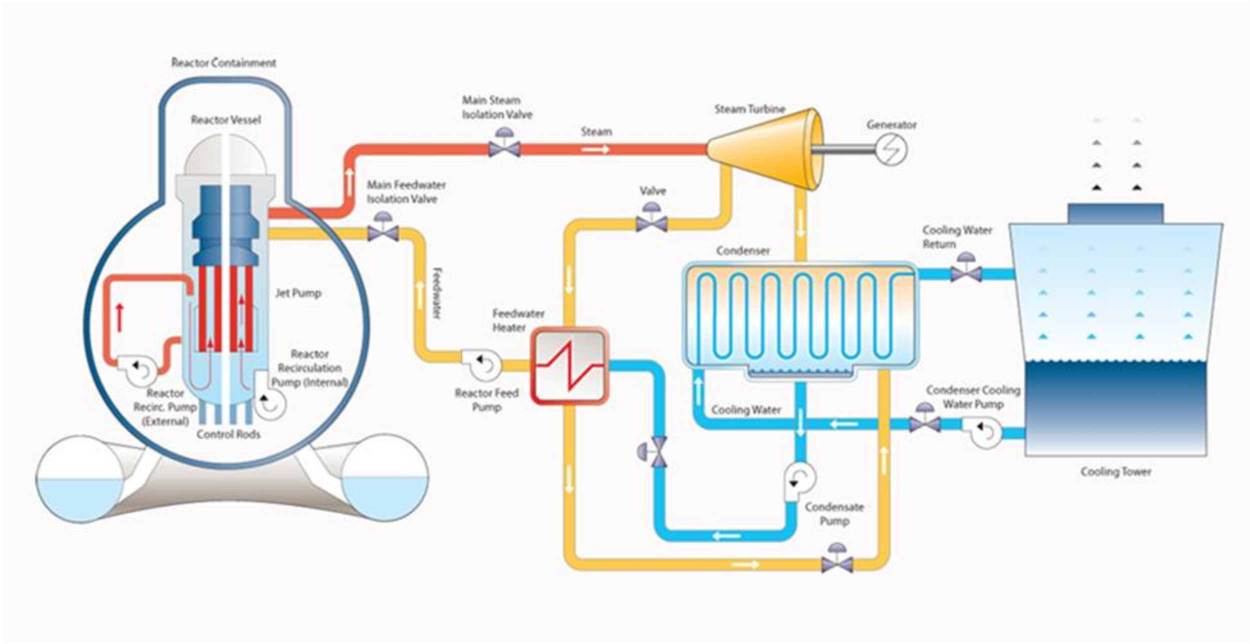

Each energy source has its Pros & Cons…

The Power Grid needs a MIXTURE of energy sources…

and ONE single source cannot meet all the grid's needs.

Check Your Knowledge

What are the key components and function of this type of Power Plant?



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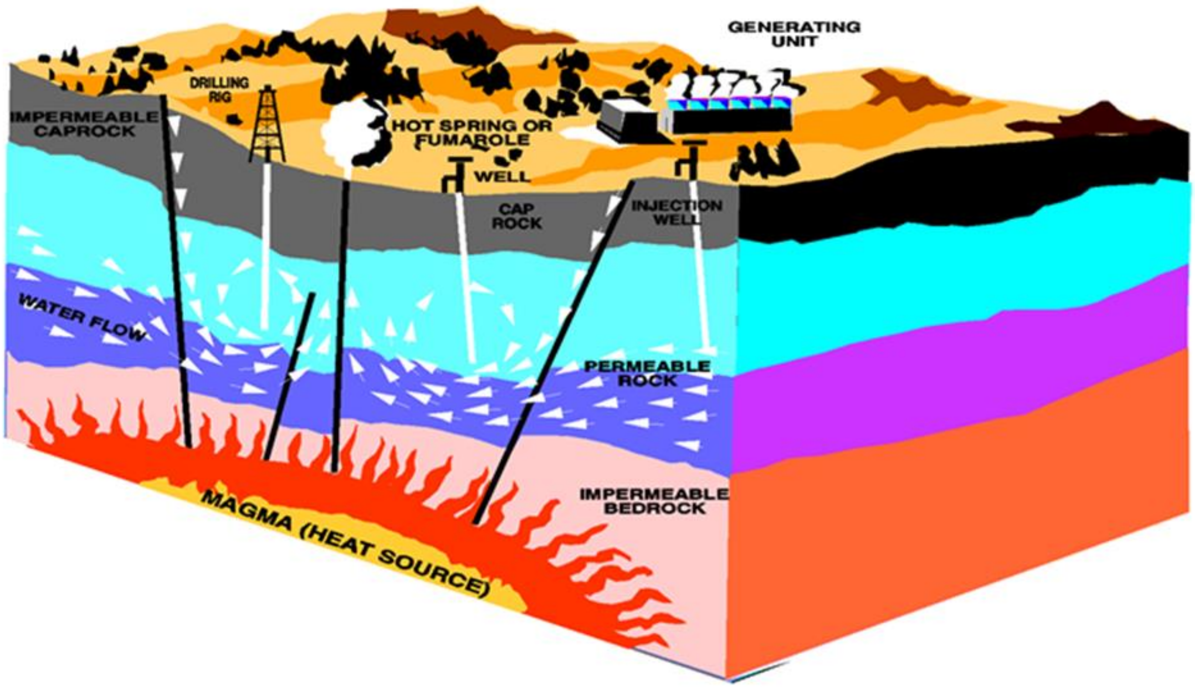

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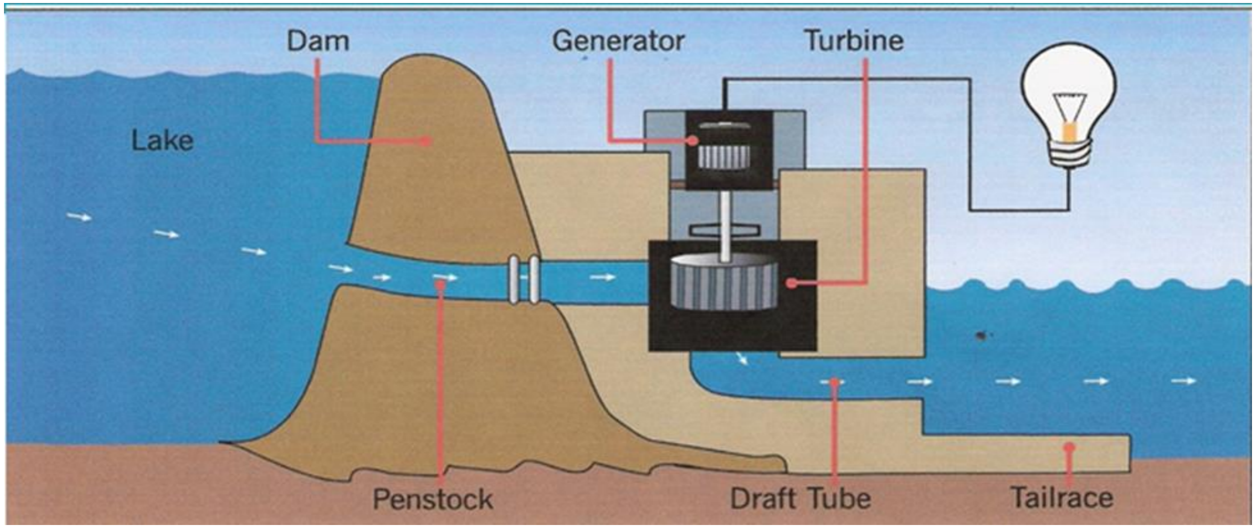

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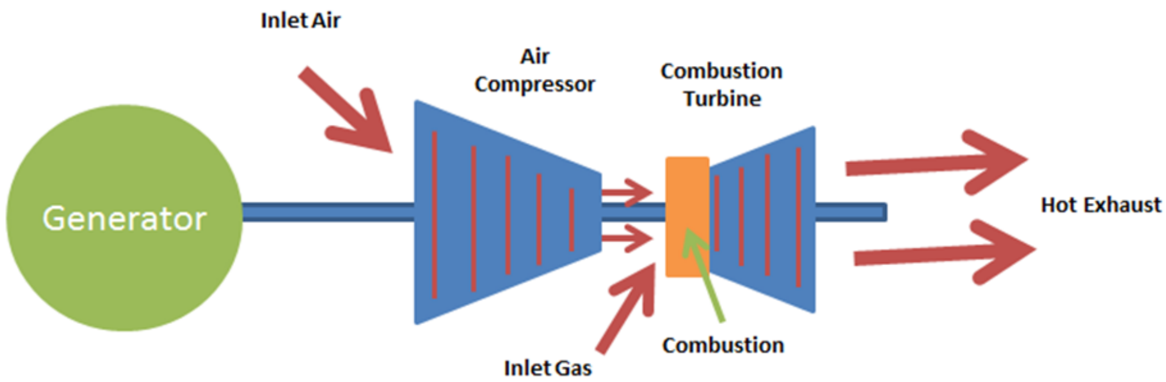

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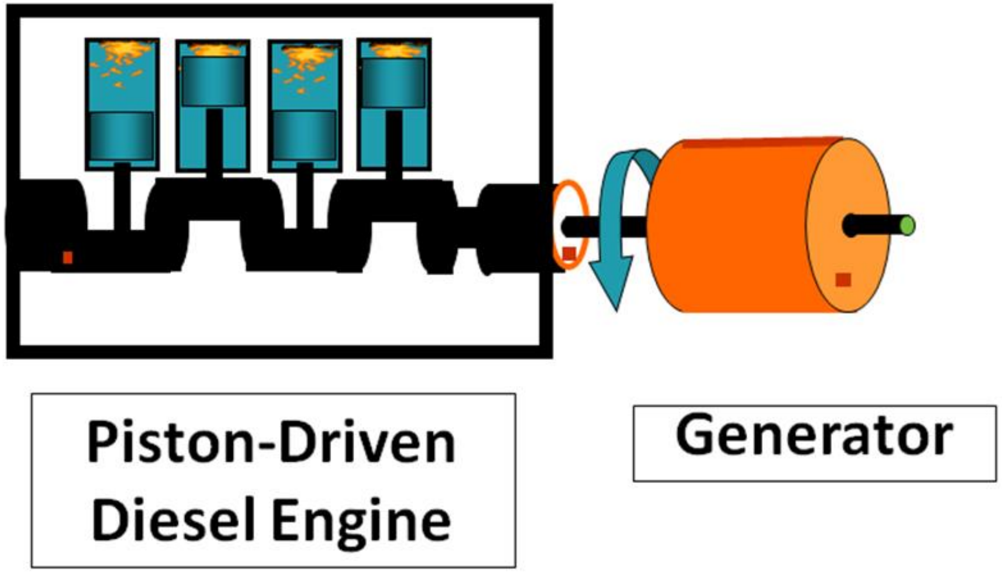

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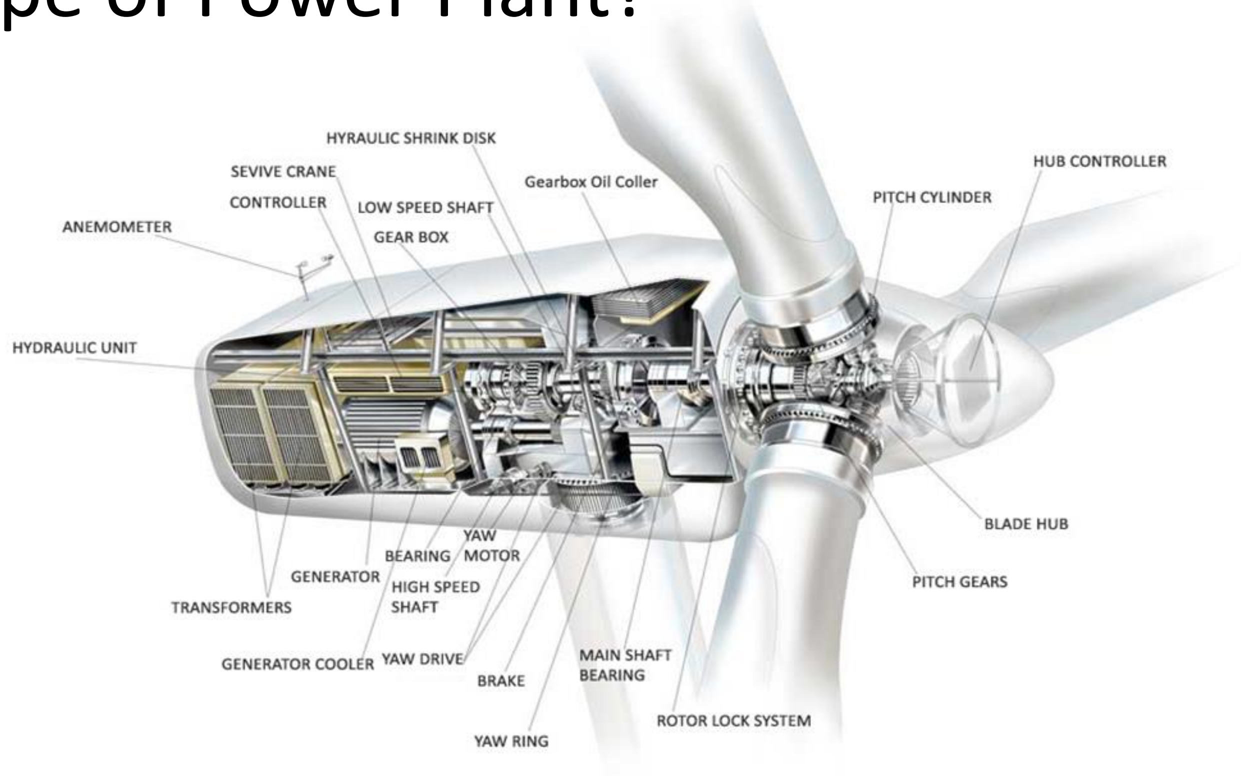

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