University of Massachusetts Amherst

Module 6-1 – Power

ENGIN 112 – Introduction to Electrical and Computer Engineering

Logistics

- Me: Prof. Paul Siqueira

pronounced as "cicada", or "si-care-a"

but not sequoia or squirrel!

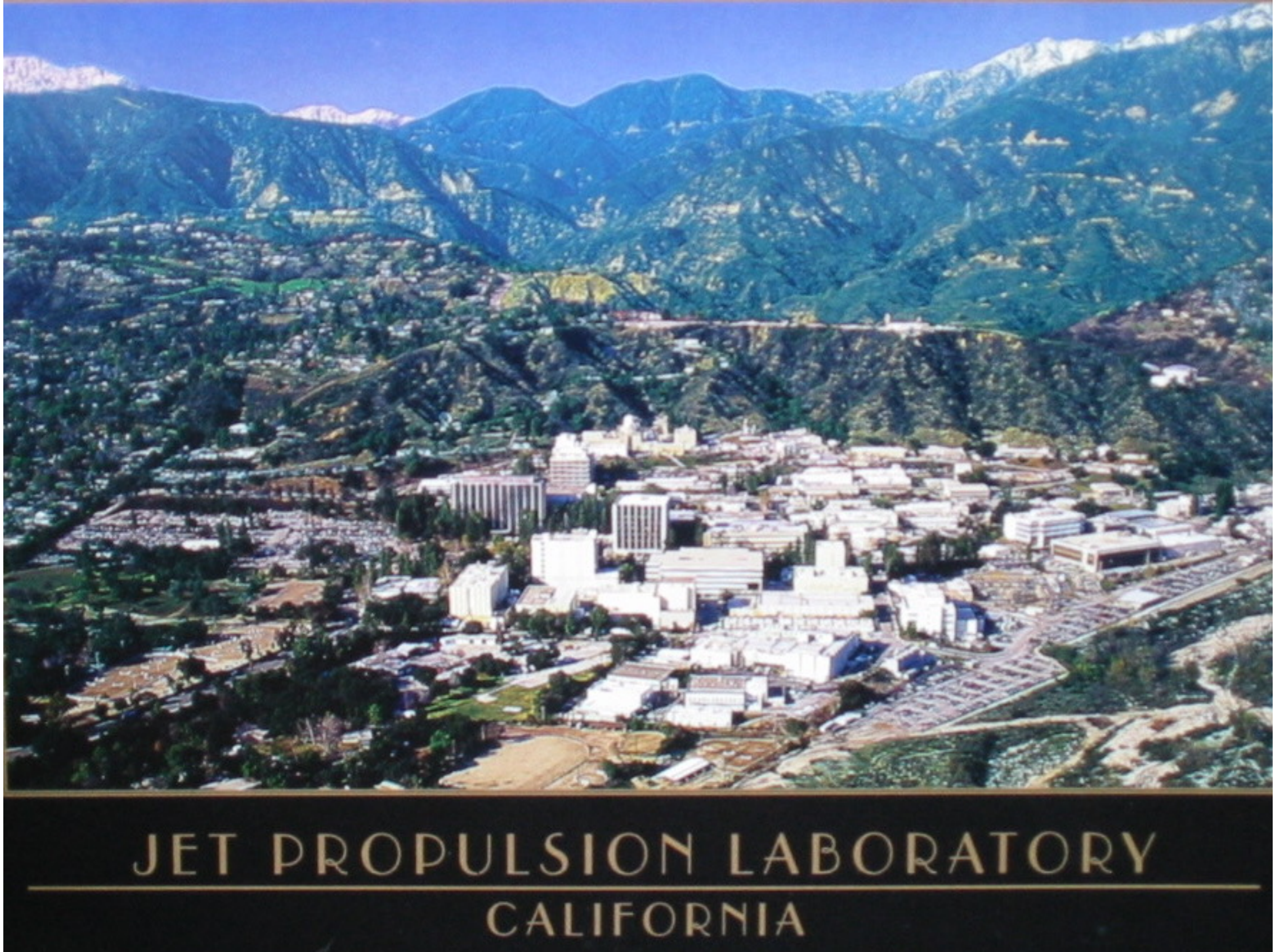
- Office hours: Thurs, 9-10 a.m. on days of lecture/discussion,
  or by appointment
  Location: On Zoom or 113E Knowles Engineering

- Email: siqueira@umass.edu
  (put "Engin 112 question" in the subject line)

A little about my background

- Professional:
  - Professor in ECE (15 years at UMass)
  - Teaching: Electromagnetics, Microwave Engineering, Remote Sensing
  - Research: Remote Sensing and Microwave Engineering
- Education:
  - PhD: University of Michigan
  - BS & MS, Iowa State University
- Work Experience
  - Triple-X Chemical packaging company, Des Moines Register
  - Gurnee photo developing
  - University of Chicago, Molecular Biology Department
  - NASA’s Jet Propulsion Laboratory (Pasadena, CA)
  - Joint Research Center of the European Commission, Italy
  - Harvard University, Forest Field Station
- Personal:
  - My last name is Brazilian (father), grew up in Chicago

NASA Centers


JET PROPULSION LABORATORY
CALIFORNIA

The subject this week?

Module Organization

- Lecture 1: Power generation
- Lecture 2: Power transmission and distribution
- Lecture 3: Electricity storage and usage

Energy ⇔ Life

Different Kinds of Power

- Man power
  - ATP/food derived
  - Kreb’s cycle
- Horse power
  - ATP/food
  - Kreb’s cycle
  - someone else’s muscles!
- Water power
  - Gravity
- Hydrocarbon
  - Stored solar energy
- Electric power
  - Mechanically derived (usually)

- Many others! Nuclear, Solar, Wind, Ocean

What is Electric Power?

- Electric power is calculated by multiplying current, I, by voltage, V

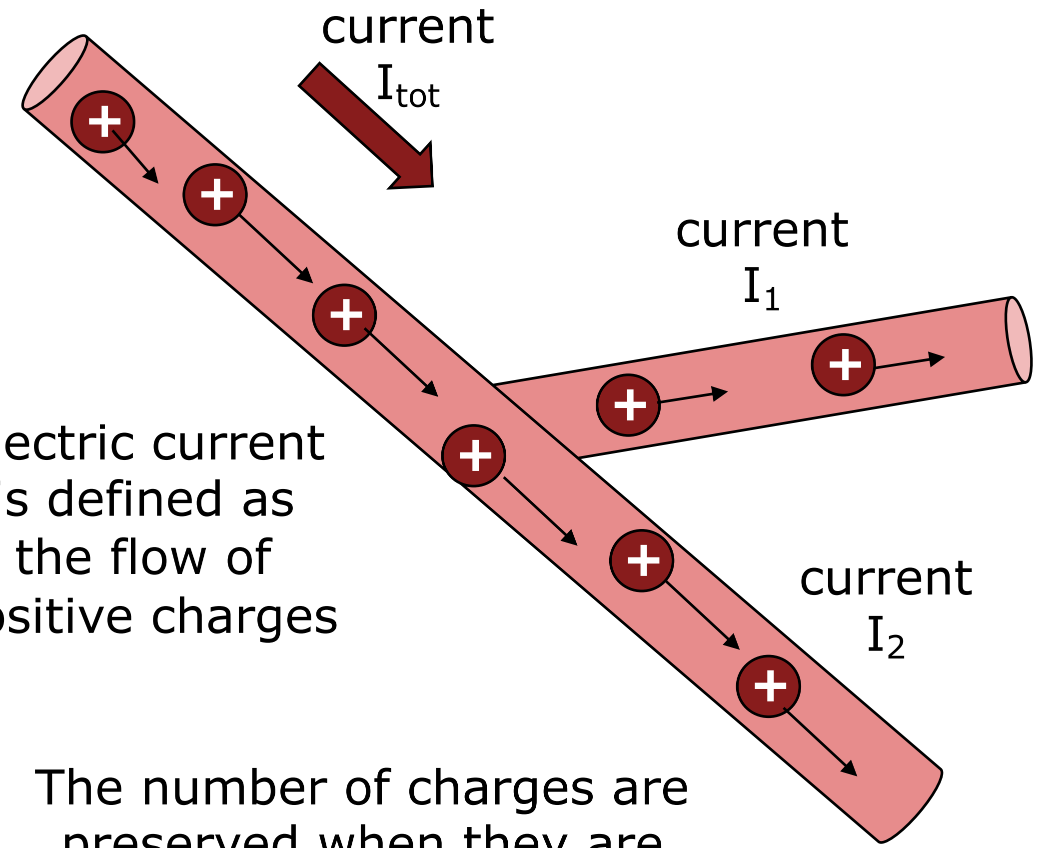
$$P = I \times V$$

- Can be cleanly and efficiently transmitted by Electric Power Cables

- Efficient conversion (~85%)
  - Mechanical -> Electric
  - Electric -> Mechanical

- Early forms of electricity difficult to control
  - Lightning!
  - Electrostatic Shock

What is Electric Current?



electric current is defined as the flow of positive charges

The number of charges are preserved when they are split into different directions

$$I_{tot} = I_1 + I_2$$

Conventional Current & Electron Flow

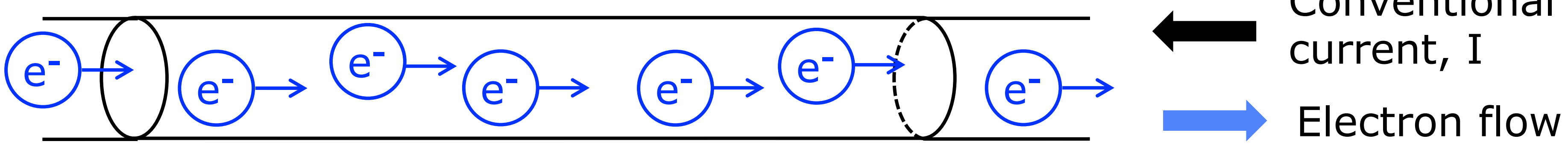
- The concept of electric current was first conceived by Benjamin Franklin in the 1750's.

- It wasn't until J.J. Thompson discovered electrons in 1897 that it was realized that negatively charged particles were responsible for this current

- There are two types of current

  Conventional Current – the flow of positive charges

  Electron Flow – the flow of electrons. The mathematical opposite of conventional current



When working with circuits & analysis, we use <u>conventional current</u>

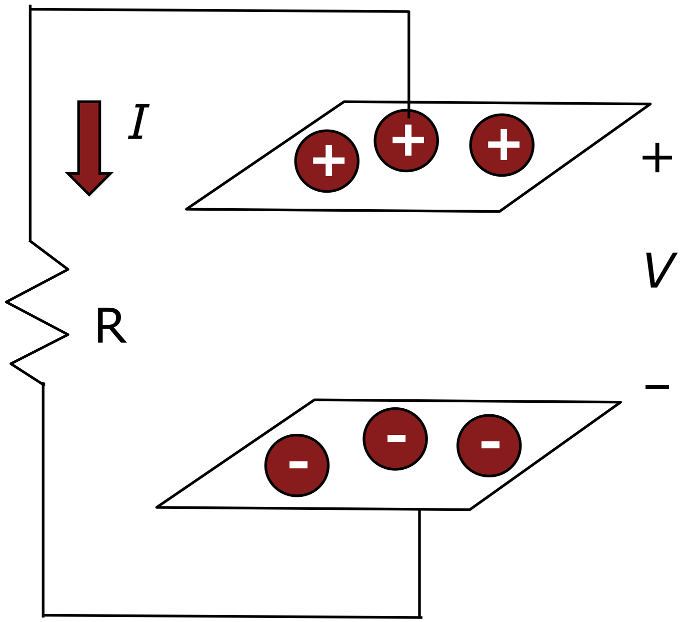
Conventional Current & Electron Flow

- Want to learn more about current?

https://youtu.be/kYwNj9uauJ4

What is Voltage Potential?

Voltage potential is the separation of charges which requires work

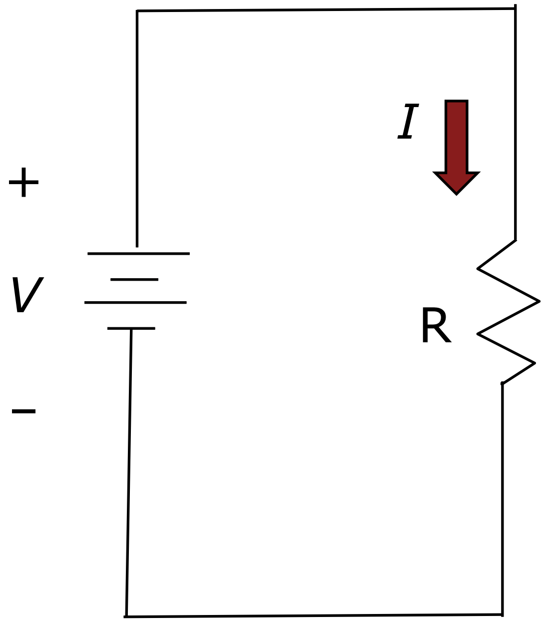


The potential can be "realized" by allowing a current to flow

The Power of a system is the product of Voltage and Current

$$P = V \times I$$

Ohm's Law



- When a source of potential energy is connected to a resistor, current will flow and dissipate the electric energy.
- This electric energy is transformed into heat energy
- The relationship between voltage and current through a resistor is described by Ohm's Law

$$V = I \times R$$

Energy versus Power

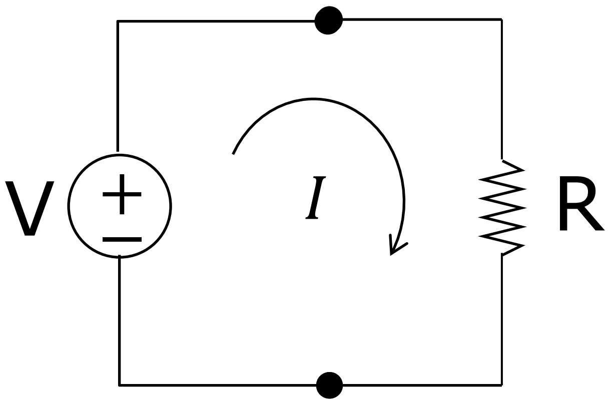
- Energy is the total amount of work done
- Power is the rate at which you expend energy

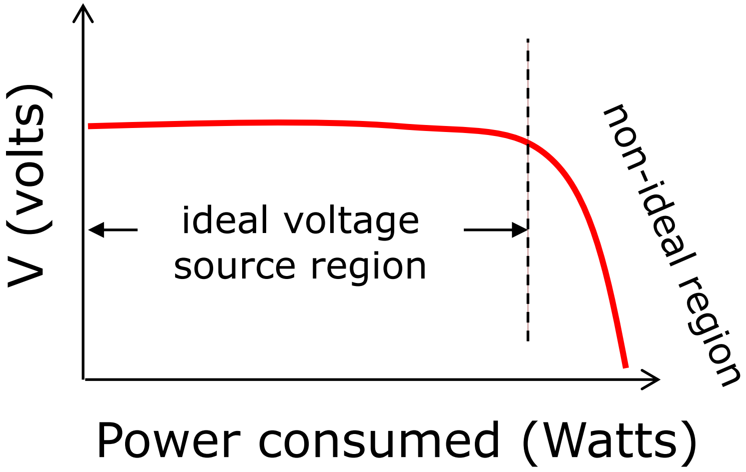
	Energy	Power
Definition	The amount of work performed by a physical system.	The rate at which work is done, or the speed at which energy flows.
Unit	Joules = Watt-second	Watts = Joule/second
Symbol	$W = P * \Delta T$	$P = V*I$
Example	A Duracell AA 1.5V Alkaline battery can deliver 1.8 A-h of energy under a 0.2A load	The power delivered by the AA battery is 3 Watts

The energy stored in the Alkaline battery is 9.72 kW-sec for a 24g package or 405 J/g.
By comparison, a Lithium-Ion battery can carry 875 J/g
or TNT, has an energy density of 4200 J/g

Idealized Models for Sources of Electric Energy

Ideal Voltage Source





Ohm's Law

$$V = I \times R$$

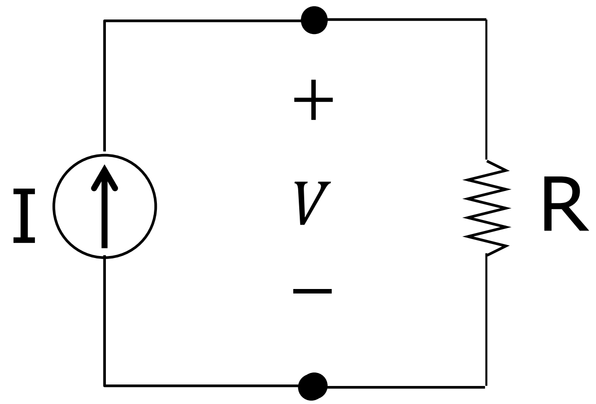
leads to

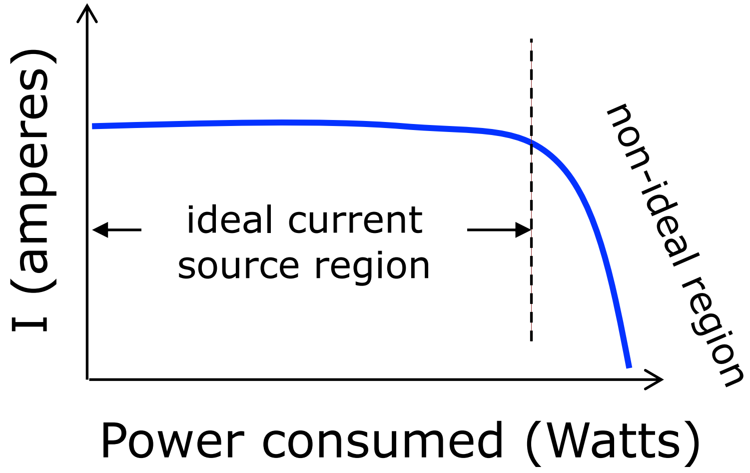
$$P = I^2 R$$

and

$$P = \frac{V^2}{R}$$

Ideal Current Source

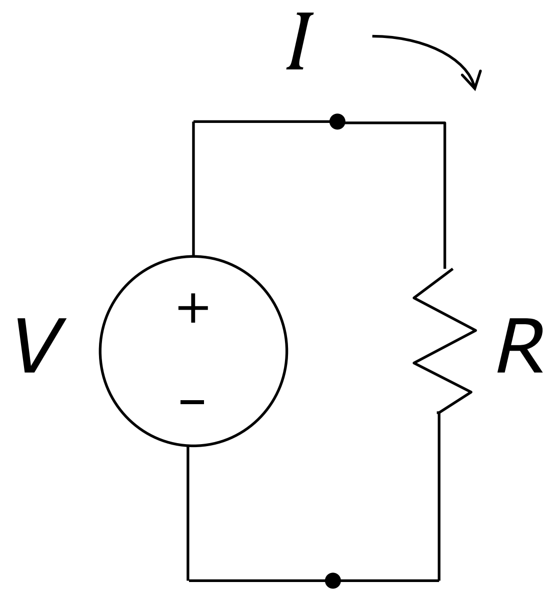


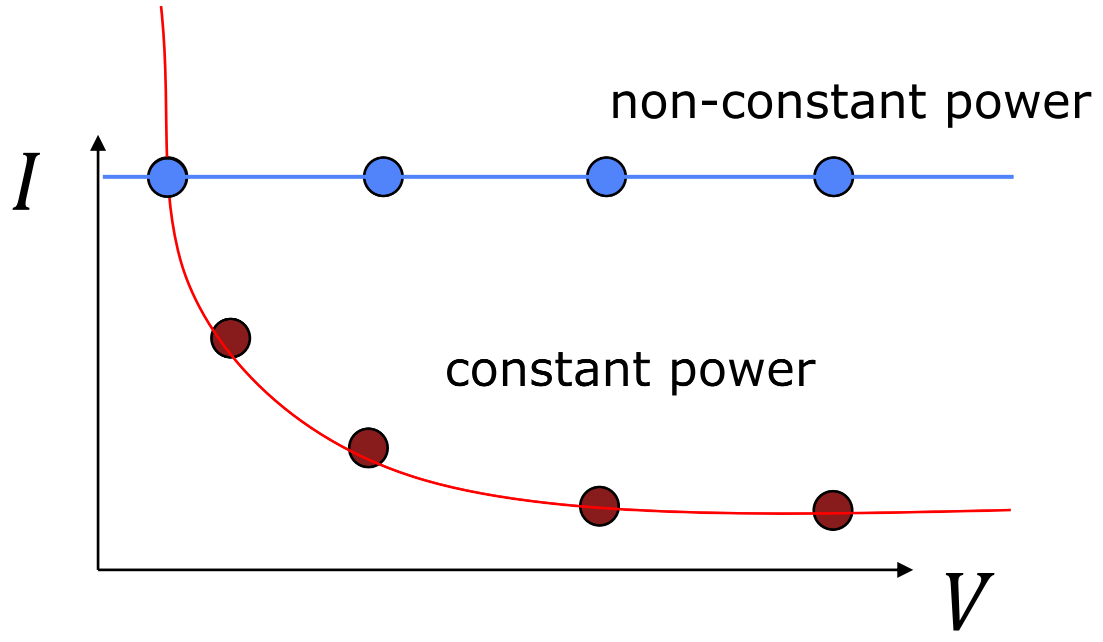


Plotting Current vs. Voltage

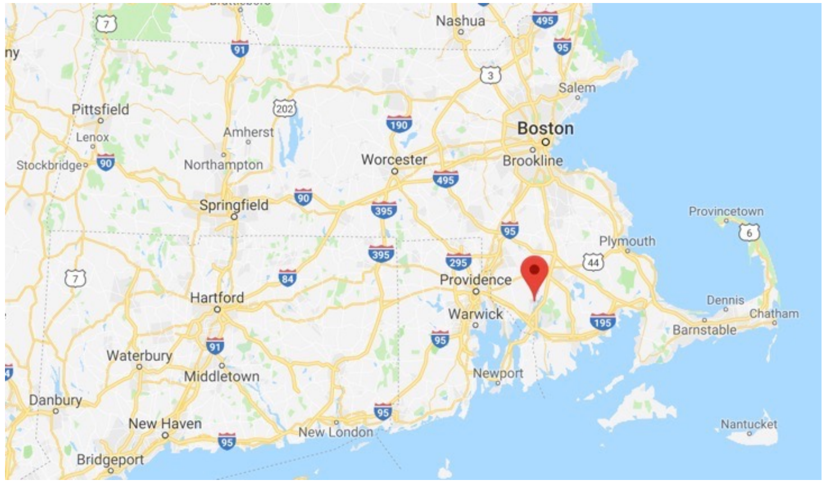
- We can also plot current versus voltage, the product of which would be power

$$I = P \,/\, V$$





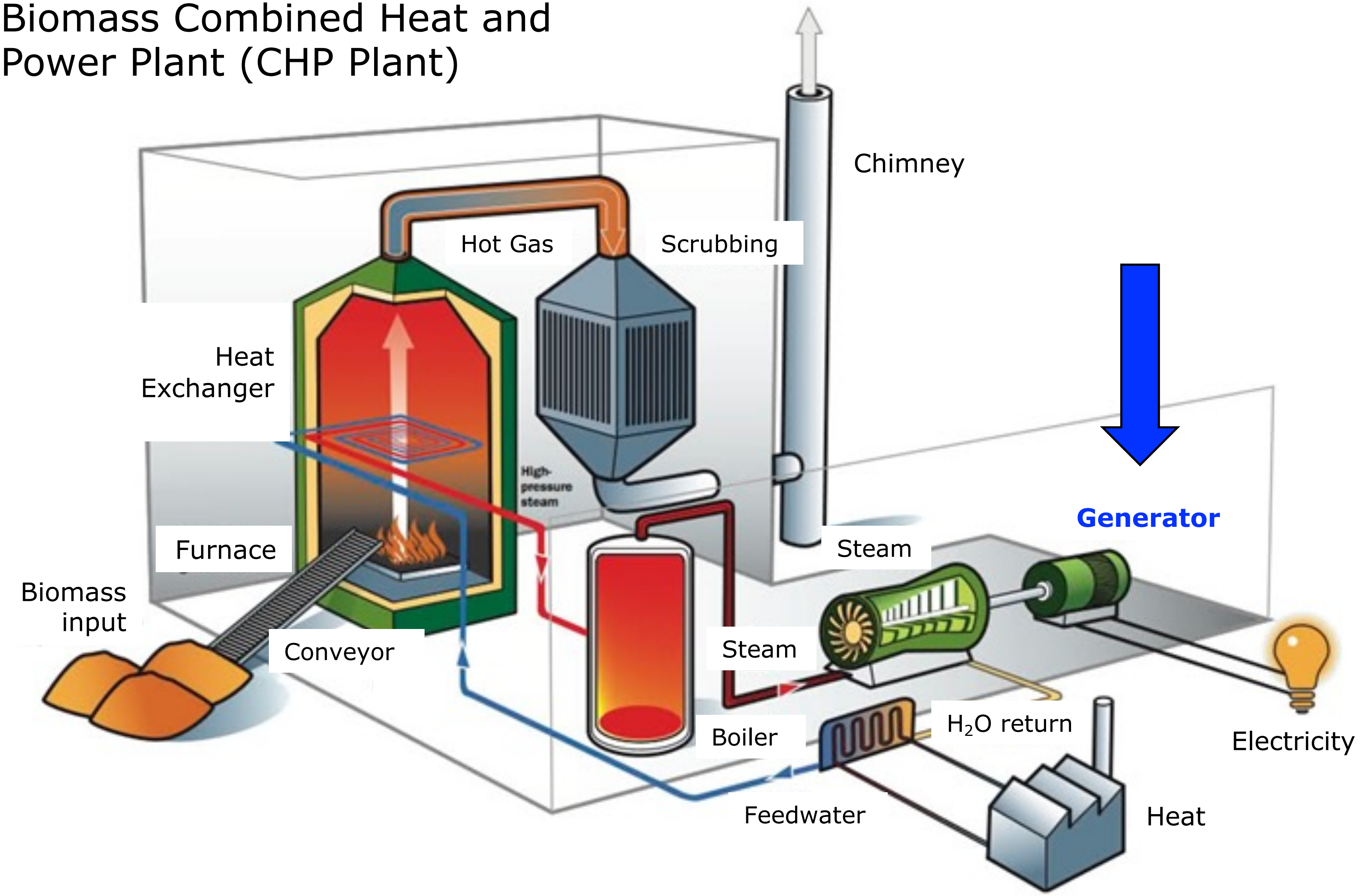
A Thermal Power Plant



- Brayton point power station is an example of coal and other fossil-fuel fired power plant once located in Somerset, MA
- Shut down in 2017

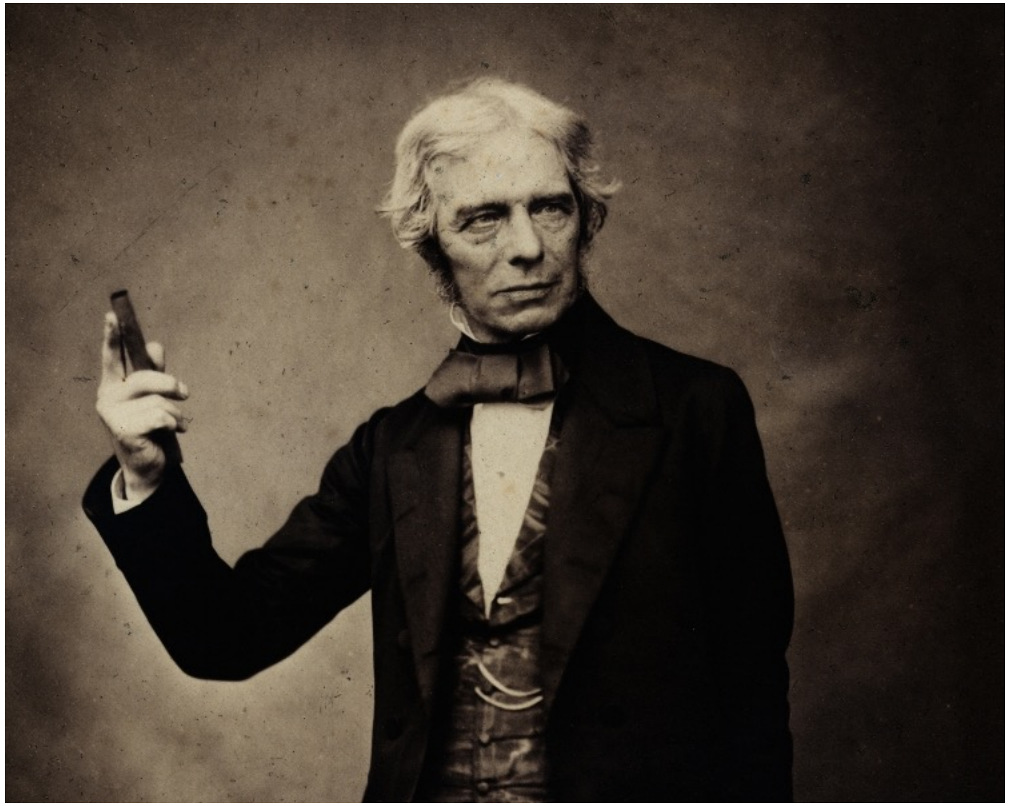
Converting heat to electricity

Biomass Combined Heat and
Power Plant (CHP Plant)



Michael Faraday

- A simple bookbinder with no formal education
- Born 1791
- Created the basis of Electricity generation from mechanical motion (1822; Age 31)



Connected Electric and Magnetic Fields

Created the concept of Lines of Flux

Discovered Electrolysis at the Age of 20

Experiments led to development of Electromagnetic theory

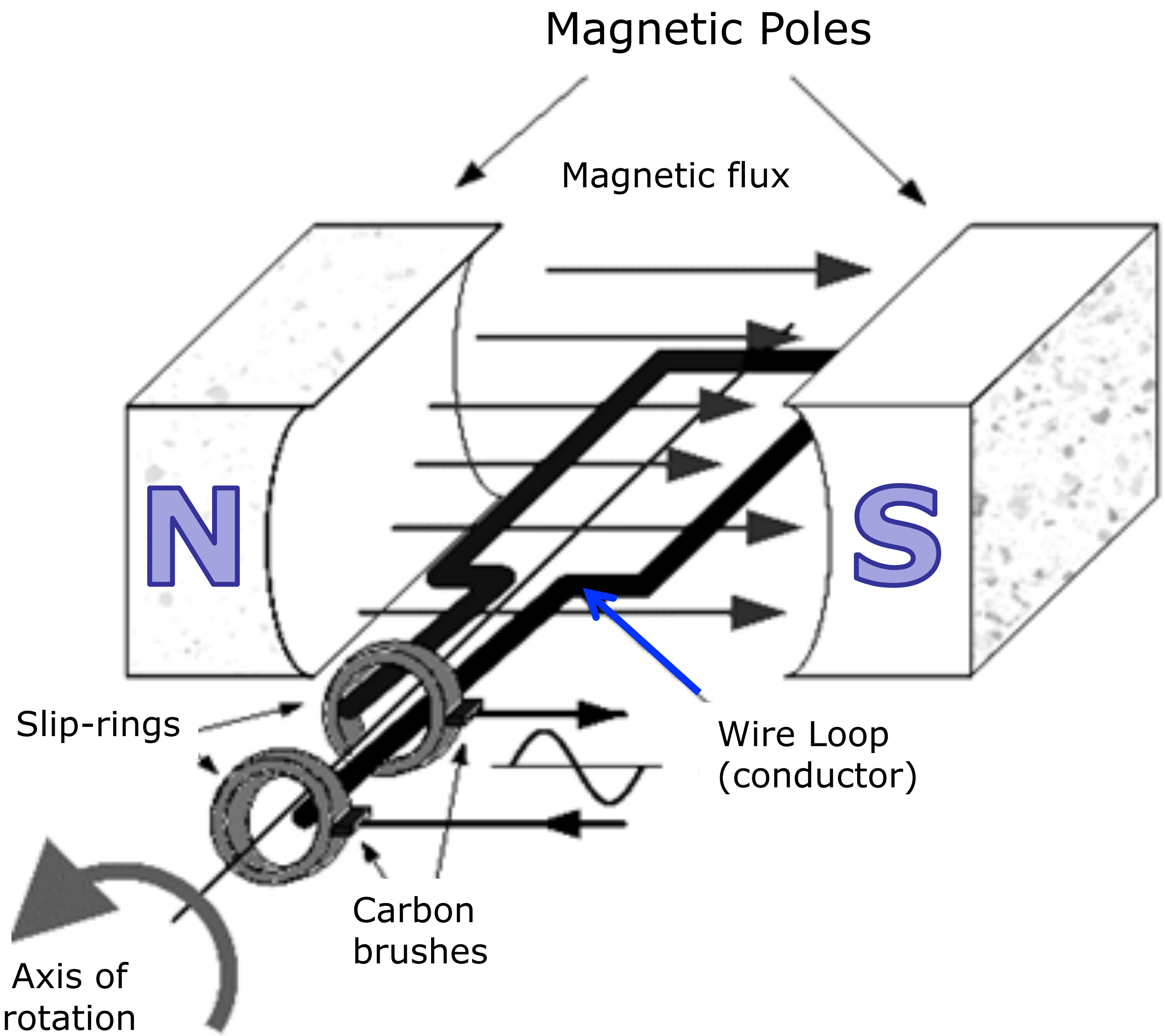
Faraday's Law

$$\oint \bar{E} \cdot \overline{dl} = \frac{d}{dt} \int \bar{B} \cdot \overline{dS}$$

A "line" integral: voltage changes around a circuit

time derivative: how much is this magnetic field changing over time?

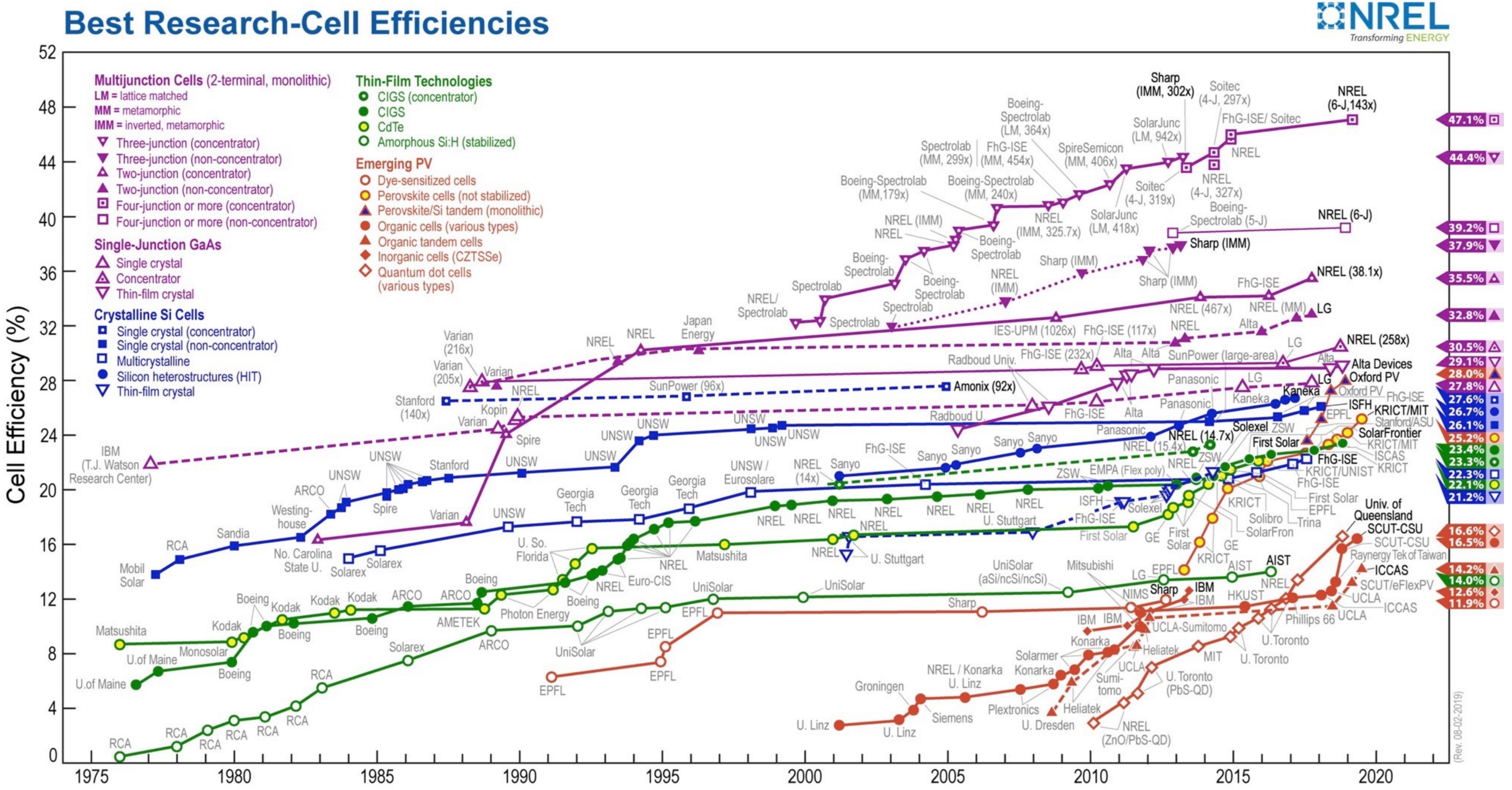
A "surface" integral: magnetic field going through the surface defined by the line integral



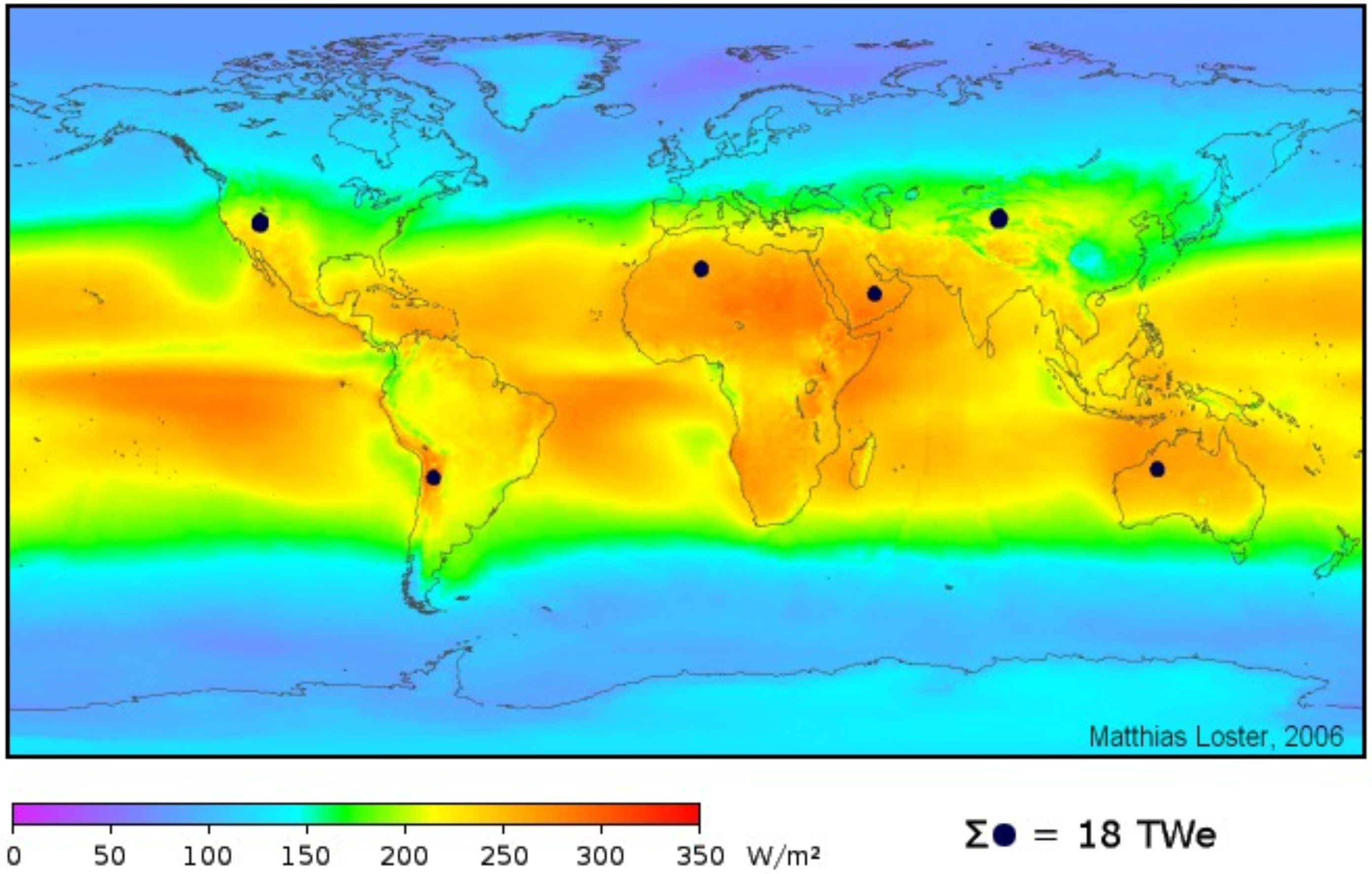
Other means of generating electricity

- Chemical
  - Efficiency of lead-acid batteries ~ 85%
  - Lemon batteries, etc:
- Thermal-Electric
  - Solid-state
  - Efficiency 5 – 8%
- Solar
  - Solid-state
  - Efficiency 37 – 47%

Efficiency

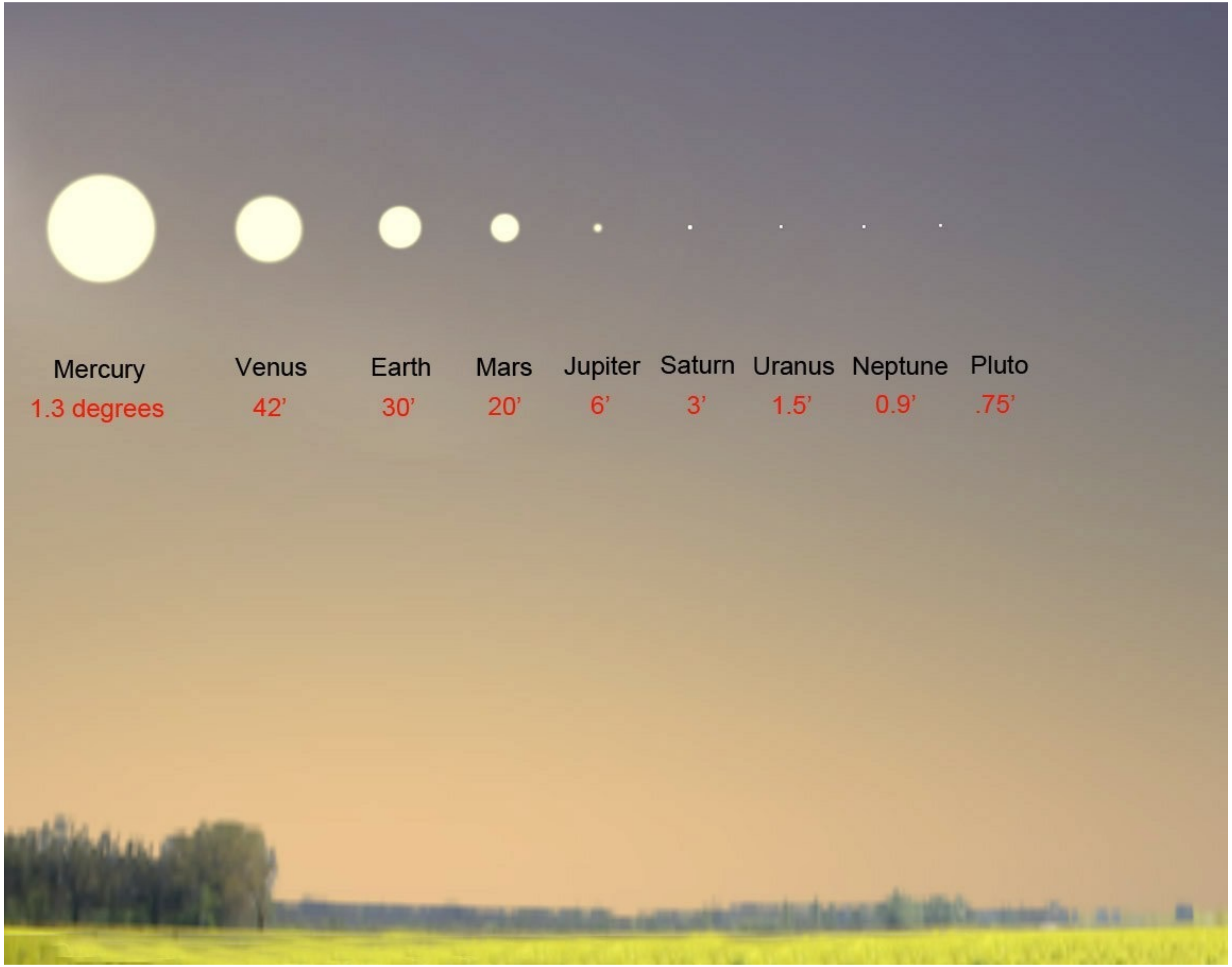

Best Research-Cell Efficiencies
NREL
Transforming ENERGY
Multijunction Cells (2-terminal, monolithic)
LM = lattice matched
MM = metamorphic
IMM = inverted, metamorphic
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Two-junction (non-concentrator)
Four-junction or more (concentrator)
Four-junction or more (non-concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal (concentrator)
Single crystal (non-concentrator)
Multicrystalline
Silicon heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
CIGS (concentrator)
CIGS
CdTe
Amorphous Si:H (stabilized)
Emerging PV
Dye-sensitized cells
Perovskite cells (not stabilized)
Perovskite/Si tandem (monolithic)
Organic cells (various types)
Organic tandem cells
Inorganic cells (CZTSSe)
Quantum dot cells (various types)
Cell Efficiency (%)
52
48
44
40
36
32
28
24
20
16
12
8
4
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
47.1%
44.4%
39.2%
37.9%
35.5%
32.8%
30.5%
29.1%
28.0%
27.8%
27.6%
26.7%
26.1%
25.2%
23.4%
23.3%
22.3%
22.1%
21.2%
16.6%
16.5%
14.2%
14.0%
12.6%
11.9%
(Rev. 08-02-2019)

Solar Energy



Matthias Loster (2006): A three-year average of solar irradiance hitting the Earth's surface, including nights and cloud coverage. Sun hitting the black disks at 8% efficiency would generate 18 TeraWatts of electrical power; more than all other energy sources combined.

Solar power for satellites



What does the sun look like from other planets?

Solar power on other planets

- Moving to Mars?
  - Distance from the Sun to Mars is R_{Mars} = 228 x 10^6 km
  - Distance from the Sun to Earth is R_{Earth} = 150 x 10^6 km

  - Solar Radiation intensity above the Earth atmosphere is

$$I_{Earth} = 1384 \text{ W/m}^2$$

(on the Earth surface, it is 1000 W/m^2)

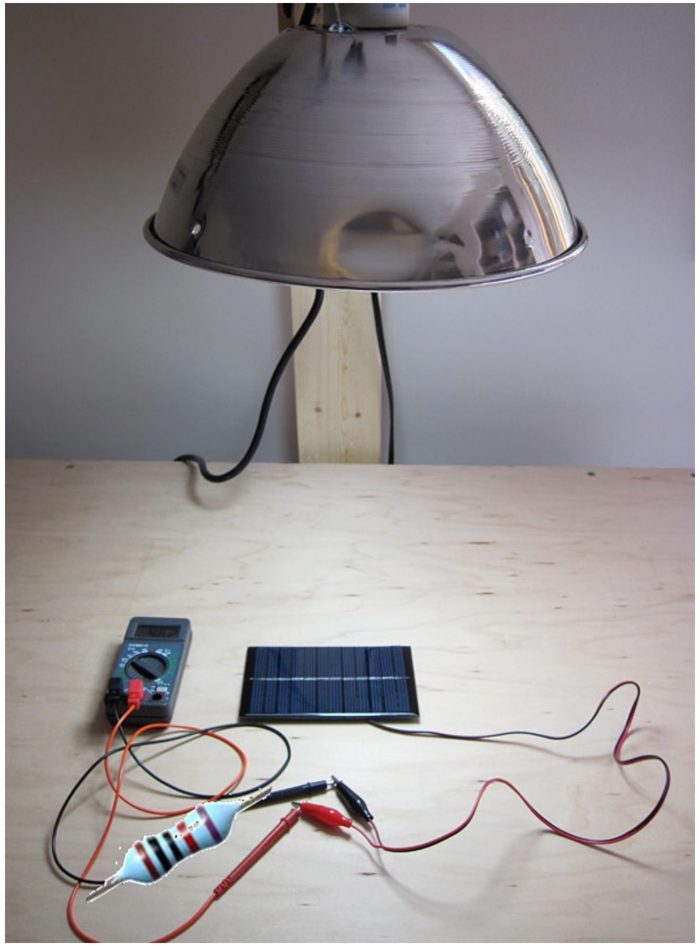
  - What is the Radiation intensity on Mars?

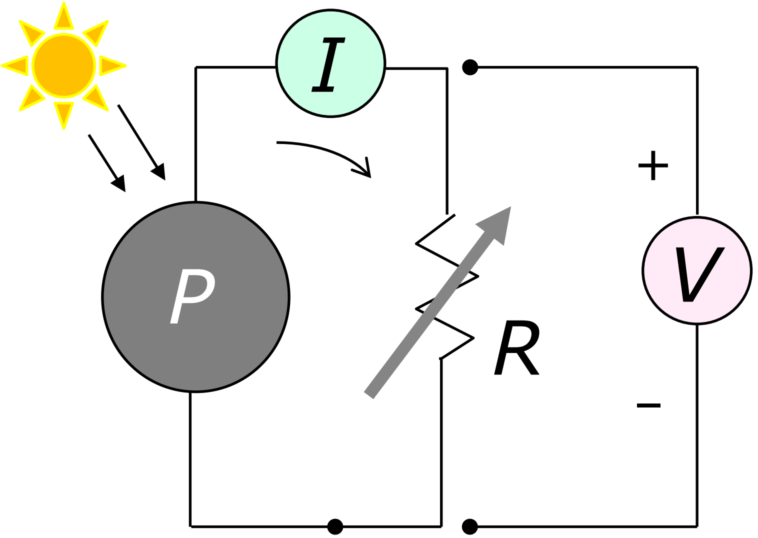
$$I_{Mars} = \frac{4\pi R_{Earth}^2}{4\pi R_{Mars}^2} I_{Earth} = 590 \text{ W/m}^2$$

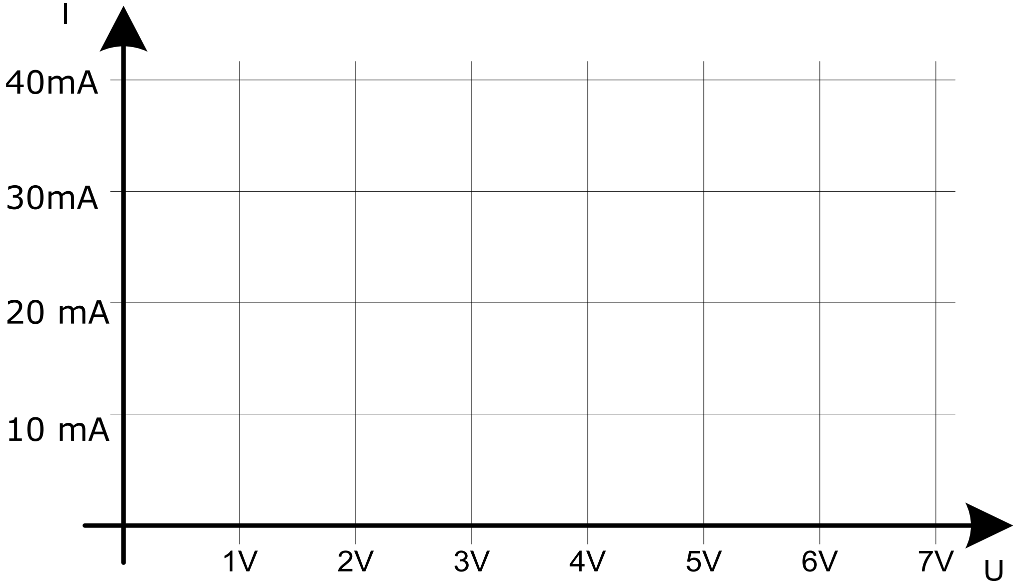
  - If a typical family consumes 3600 W, what is the area of 50% efficient solar panels necessary to meet that need at peak illumination on Earth? On Mars??

Demo for solar panel

- We will measure the current and voltage of real solar cell
  - Changing resistance (potentiometer) to “move along characteristic curve”
  - Question: Does it act like an idea voltage source? an ideal current source?? (let’s see)



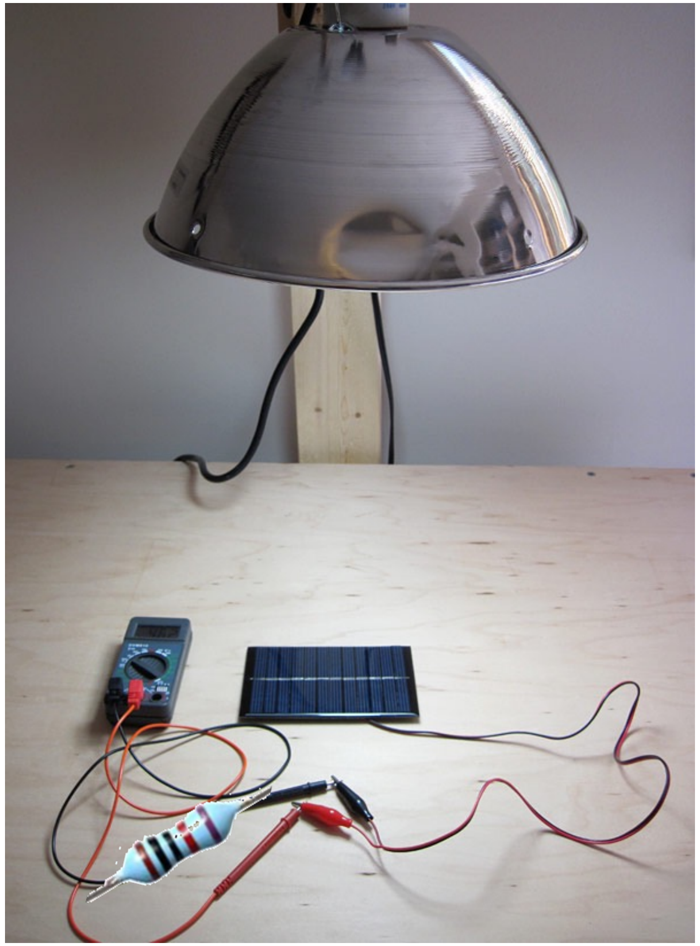


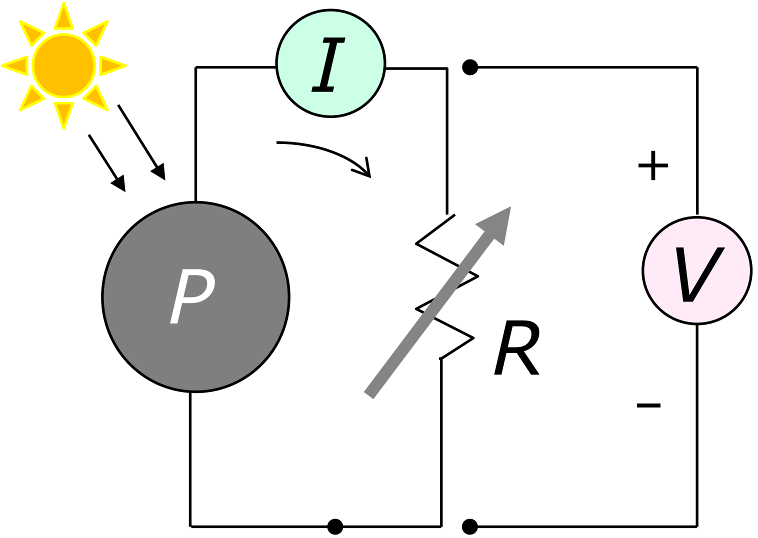


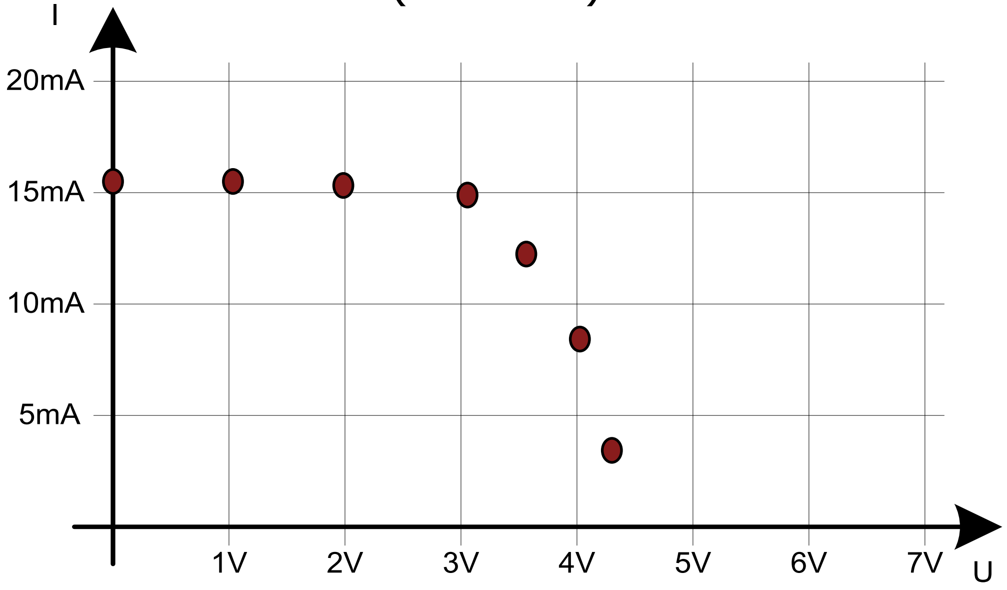
Ω							
V	0 V	1 V	2 V	3 V	V	V	V
A	mA	mA	mA	mA	mA	mA	mA

Demo for solar panel

- We will measure the current and voltage of real solar cell
  - Changing resistance (potentiometer) to “move along characteristic curve”
  - Question: Does it act like an idea voltage source? an ideal current source?? (let’s see)

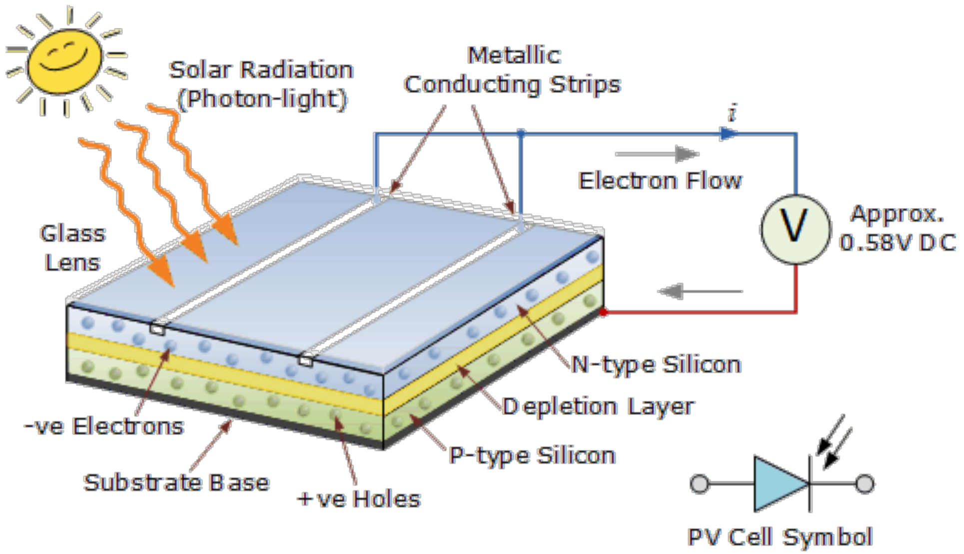


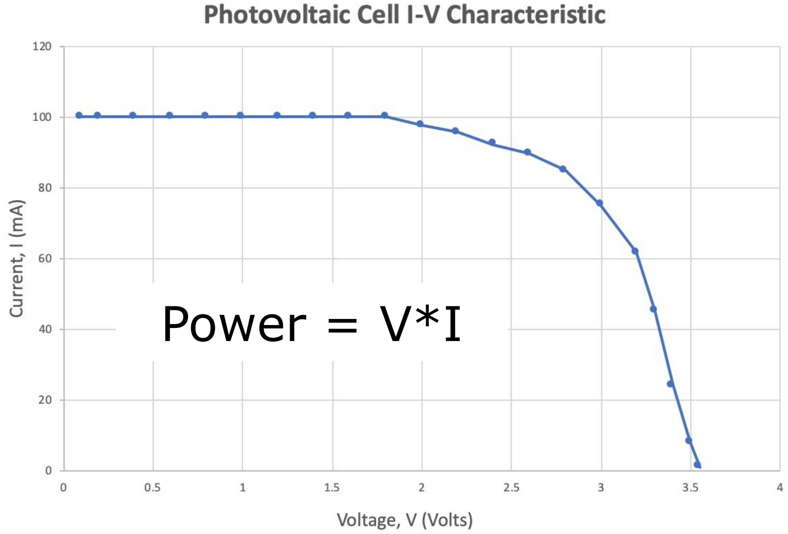


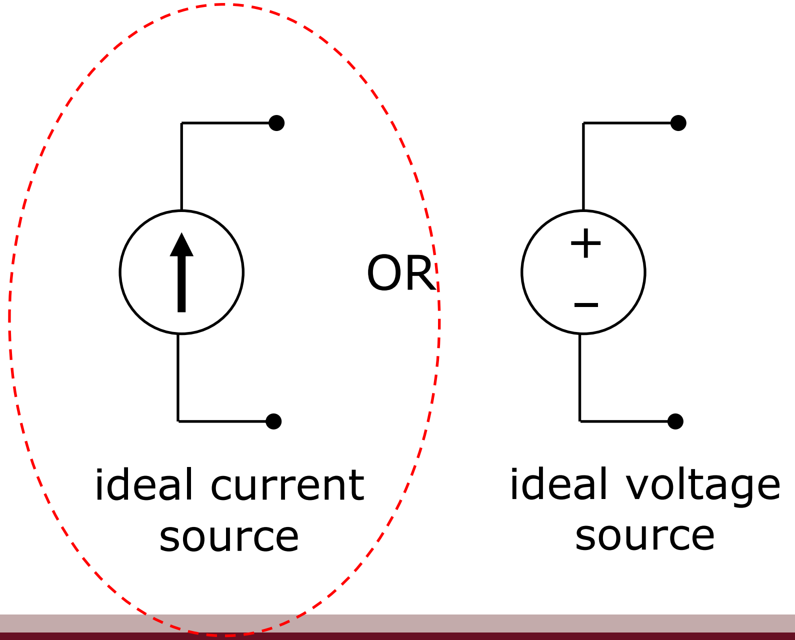


Ω	0 Ω
V	0 V
A	15.1 mA

How Solar Power works







Solid State PV Up Close

Video placeholder

https://www.youtube.com/embed/2AX0qvnjSnM

Solar Cell: Voltage and Current

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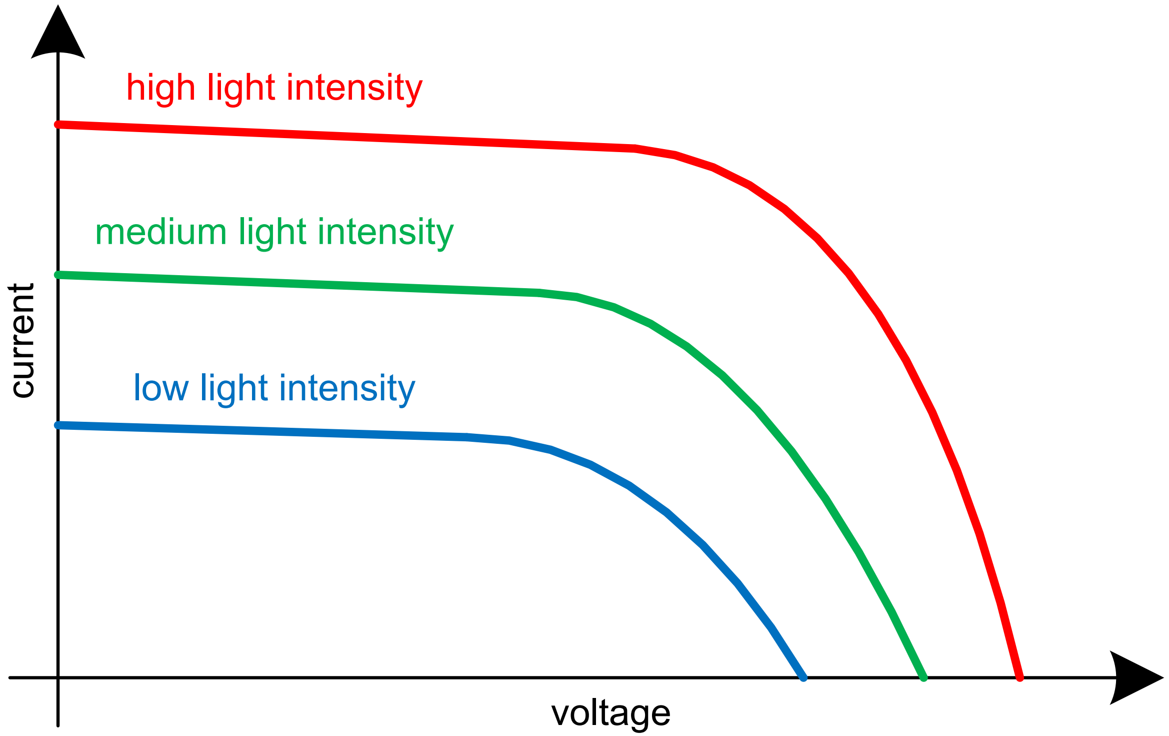
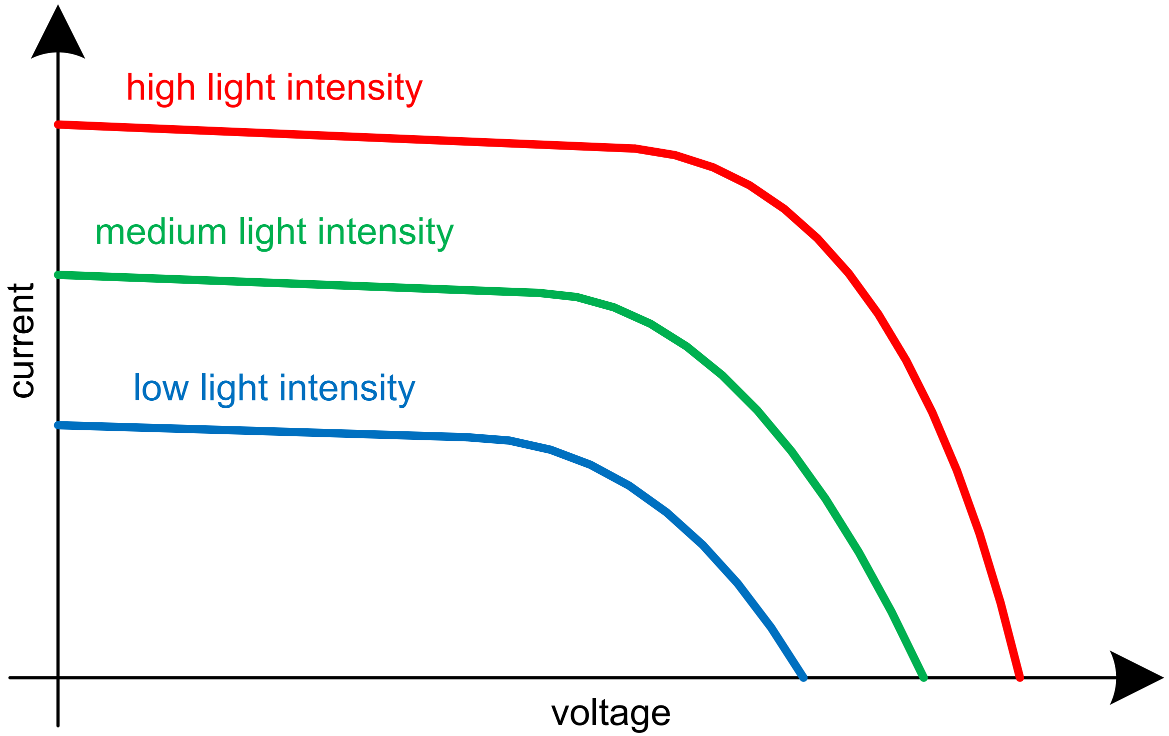
- "Characteristic curve" of solar cell
  - Relationship between current and voltage
  - Curve depends on light intensity, temperature, etc.



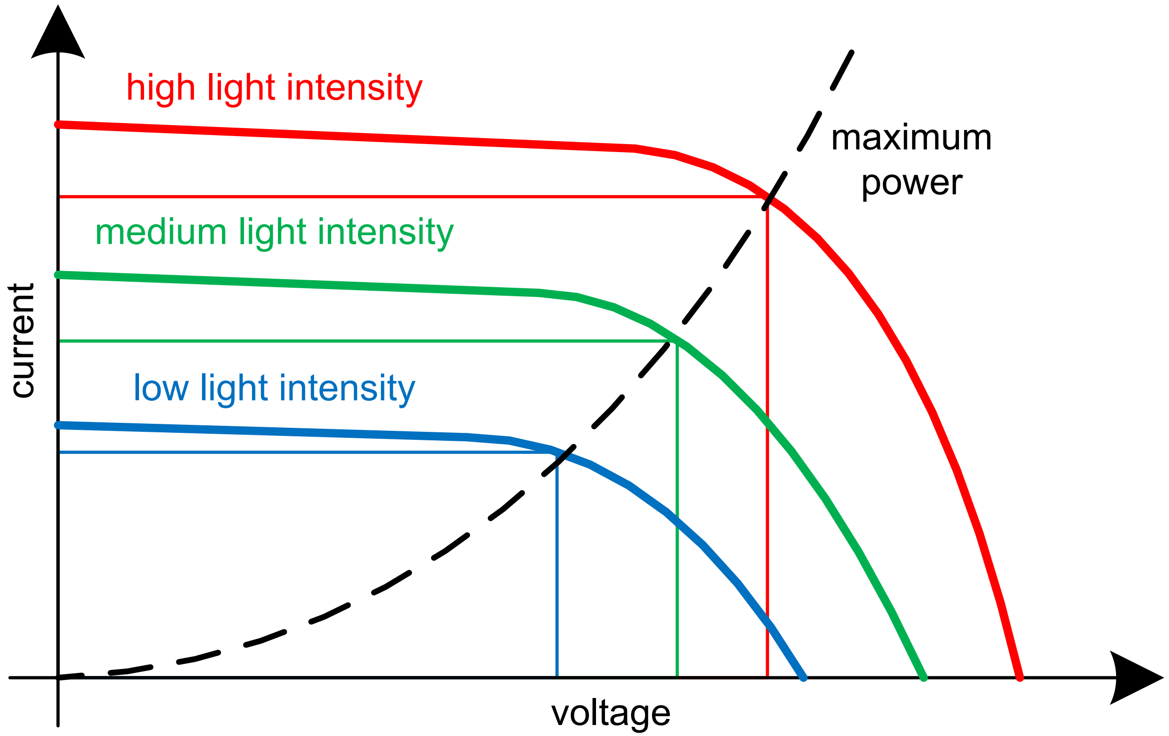
System Optimization

- How to get maximum power out of the solar cell?



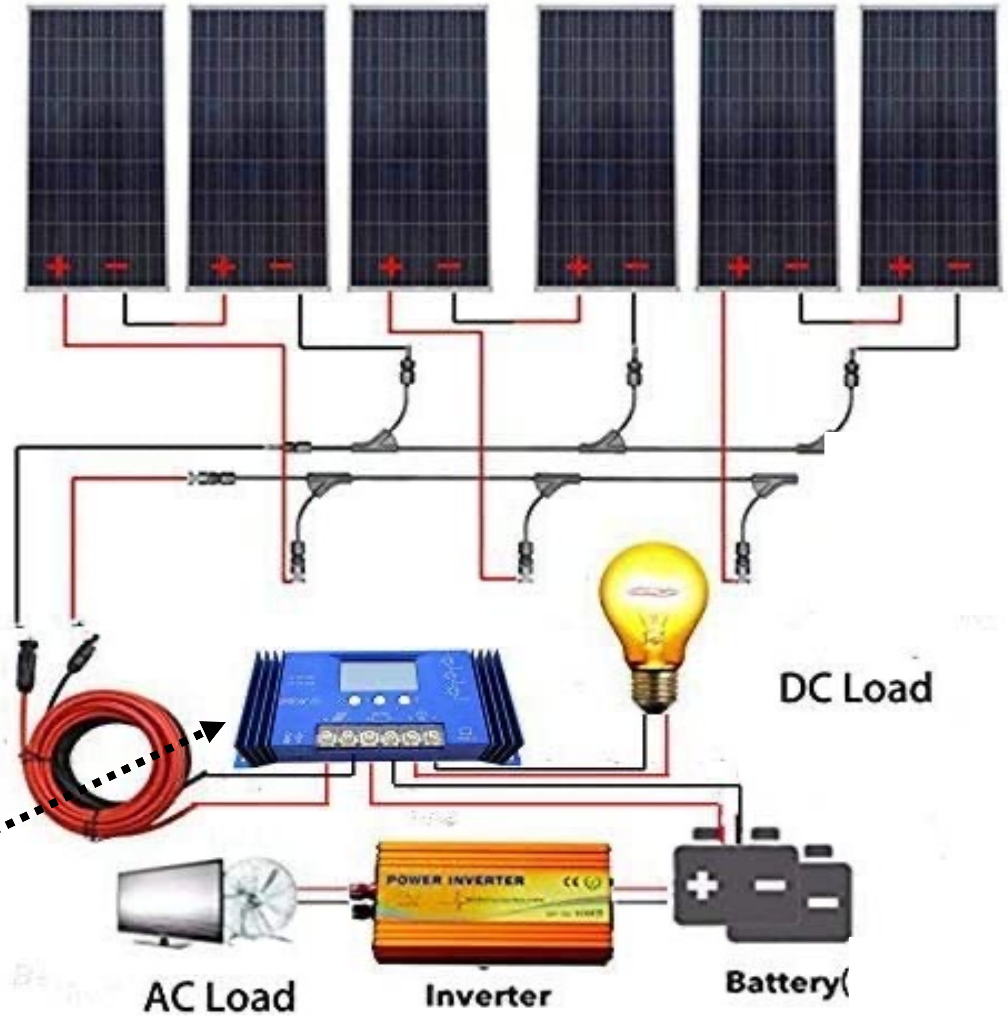
System Optimization

- How to get maximum power out of the solar cell?
  - Power is P=I·V
  - Maximize "P area" under curve



System Optimization

- Problem: optimal operation point changes with conditions
  - "Maximum power point tracker"
    - DC-to-DC converter
    - DC voltage on solar cell side: voltage of optimal operation
    - DC voltage for battery charging
- Typical installation:



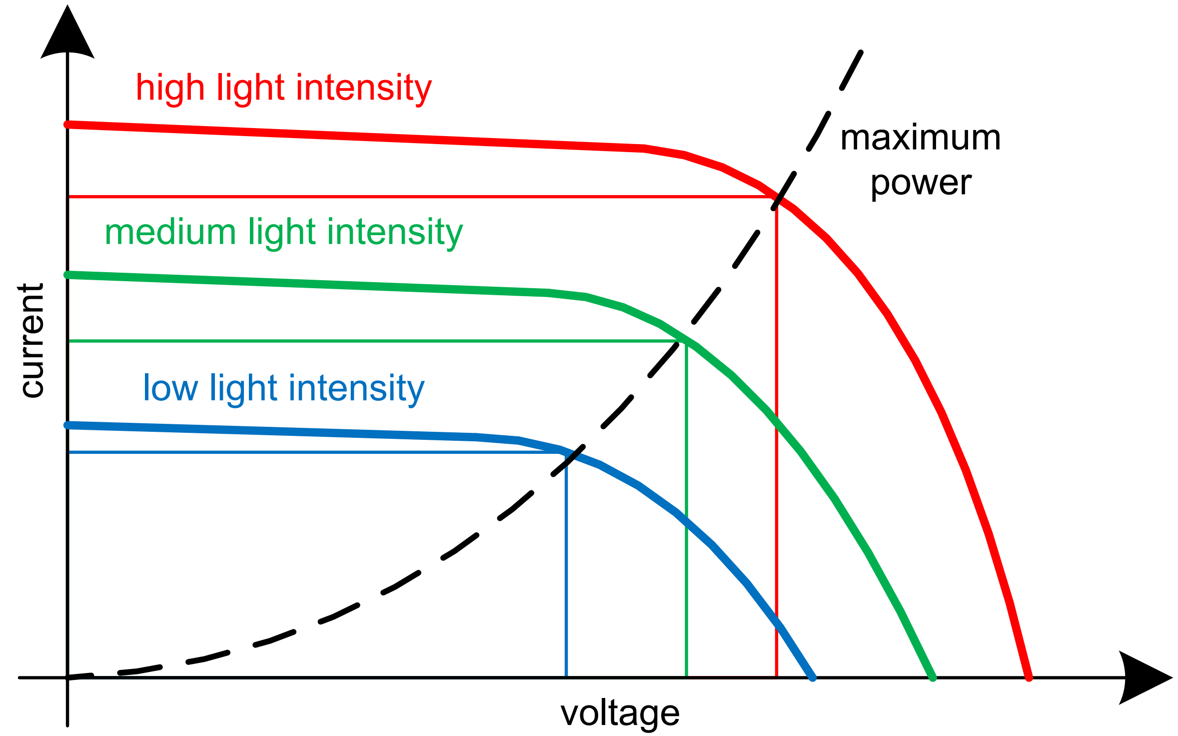
Solar Installation

- Example installations:

- Amount of solar exposure and operation determines effectiveness of system

System Optimization

- How to get maximum power out of the solar cell?
  - Power is P=I·V
  - Maximize "P area" under curve



How to calculate power efficiency

- Power efficiency is determined by taking the ratio of power output divided by power input

$$efficiency(\%) = \frac{power\ output}{power\ input} \times 100$$

- A 90% efficient 2 m² solar panel on Earth would deliver how much power?

$$power\ output = \frac{efficiency(\%)}{100} \times power\ input$$

$$= 0.90 \times 1384 \frac{W}{m^2} \times 2m^2$$

$$= 2491\ W$$

notice that the algebra can be used for determining the dimensions as well!
This is called
Dimensional Analysis

Efficiency over time

beginning efficiency	90%	88.5%	81.2%	77.2%	73.3%	70.0%	ending efficiency
	95% loss	95% loss	95% loss	95% loss	95% loss		
	year 1	year 2	year 3	year 4	year 5		

- Power efficiency can degrade over time
- If we start with 90% efficiency the first year, and only have 95% of that starting efficiency after the first year, how much efficiency do we have for the second year?

$$\begin{aligned} \textit{efficiency (after year 1)} &= 0.95 \times \textit{starting efficiency} \\ &= 0.95 \times 0.90 \\ &= 0.885 = 88.5\% \text{ efficieny} \end{aligned}$$

- After five years of such degradation, what would be the efficiency?

$$\begin{aligned} \textit{efficiency(after year 5)} &= 0.95 \times \textit{efficiency after year 4} \\ &= 0.95^{(5)} \times \textit{ starting efficiency} \\ &= 0.700 = 70.0\% \text{ efficiency} \end{aligned}$$

Main Concepts

- Power Generation ✓
- Solar Cells ✓
- Calculating Efficiency
- Power Transmission
- Power Distribution & Control
- Electricity Storage
- Power Usage

University of Massachusetts Amherst

Module 6-2 – Power Distribution

ENGIN 112 – Introduction to Electrical and Computer Engineering

Main Concepts

- Power Generation ✓
- Solar Cells ✓
- Calculating Efficiency
- Power Transmission
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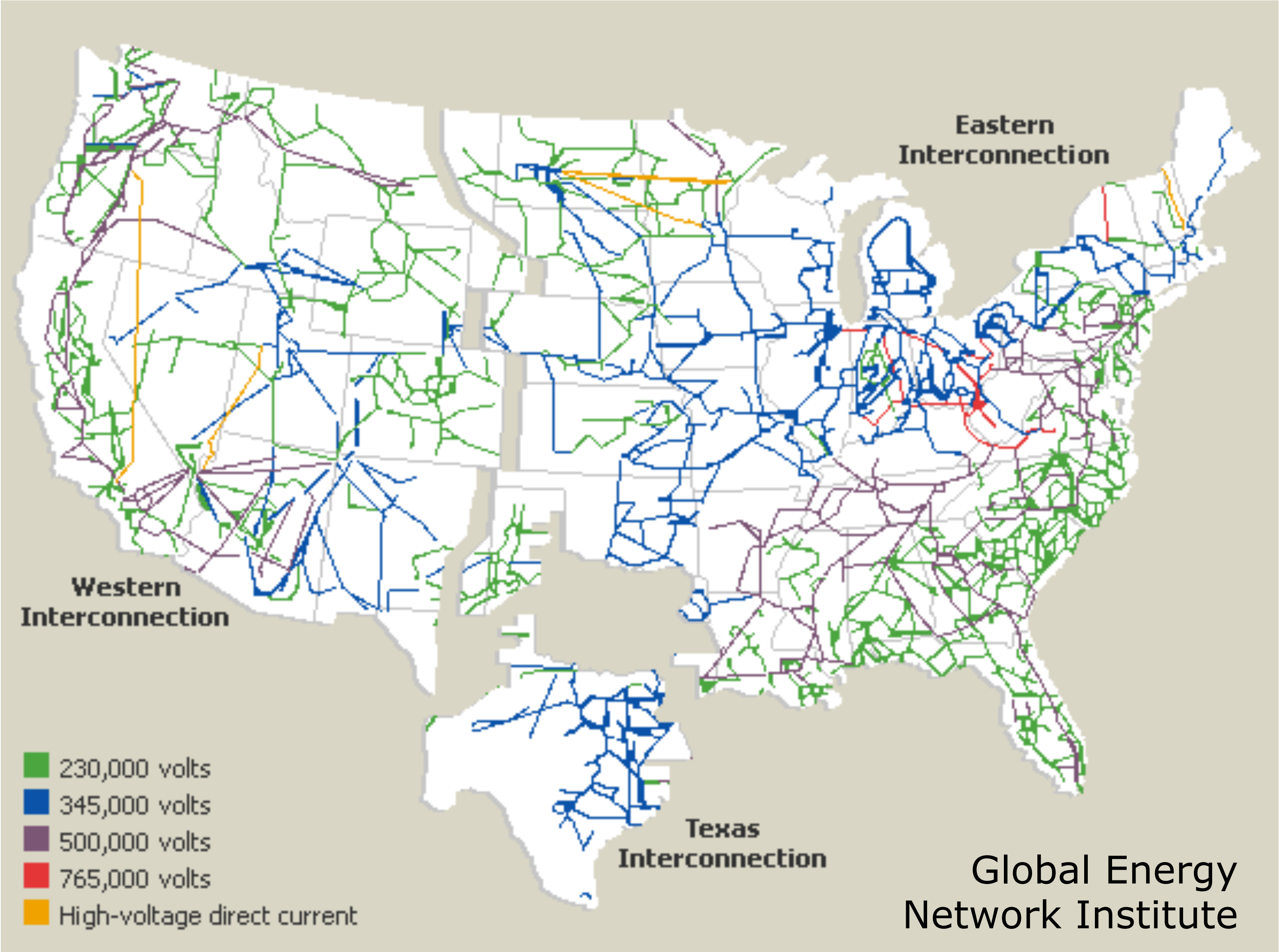
The US Power Grid



- Three basic components of the US power grid

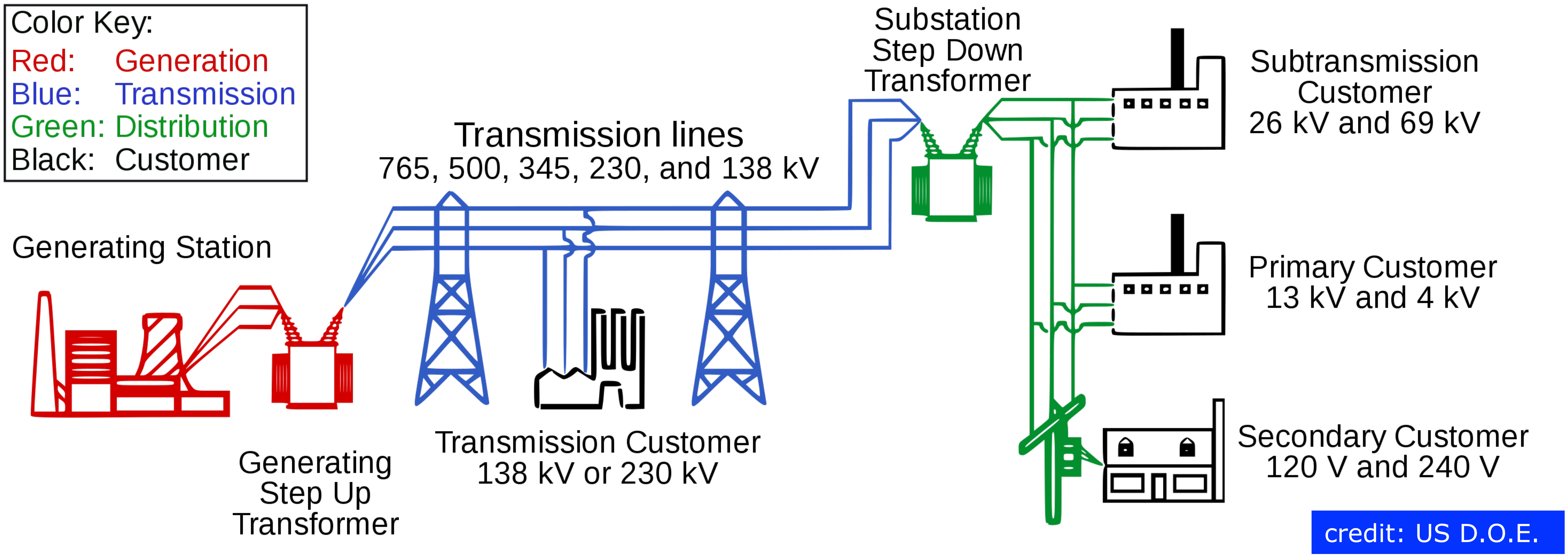
- 1.) Eastern
- 2.) Western
- 3.) Texas

How a Power Grid Works

- Electricity is generated in a power plant
- The electricity enters a sub-station with a **step-up transformer** that raises the voltage extremely high
- The high-voltage electricity is carried over **transmission lines** to local substations
- A step-down **transformer** reduces the voltage to levels suitable for customer loads.
- **Distribution lines** carry the lower-voltage electricity from the local **substations** to customer sites.

Transmission

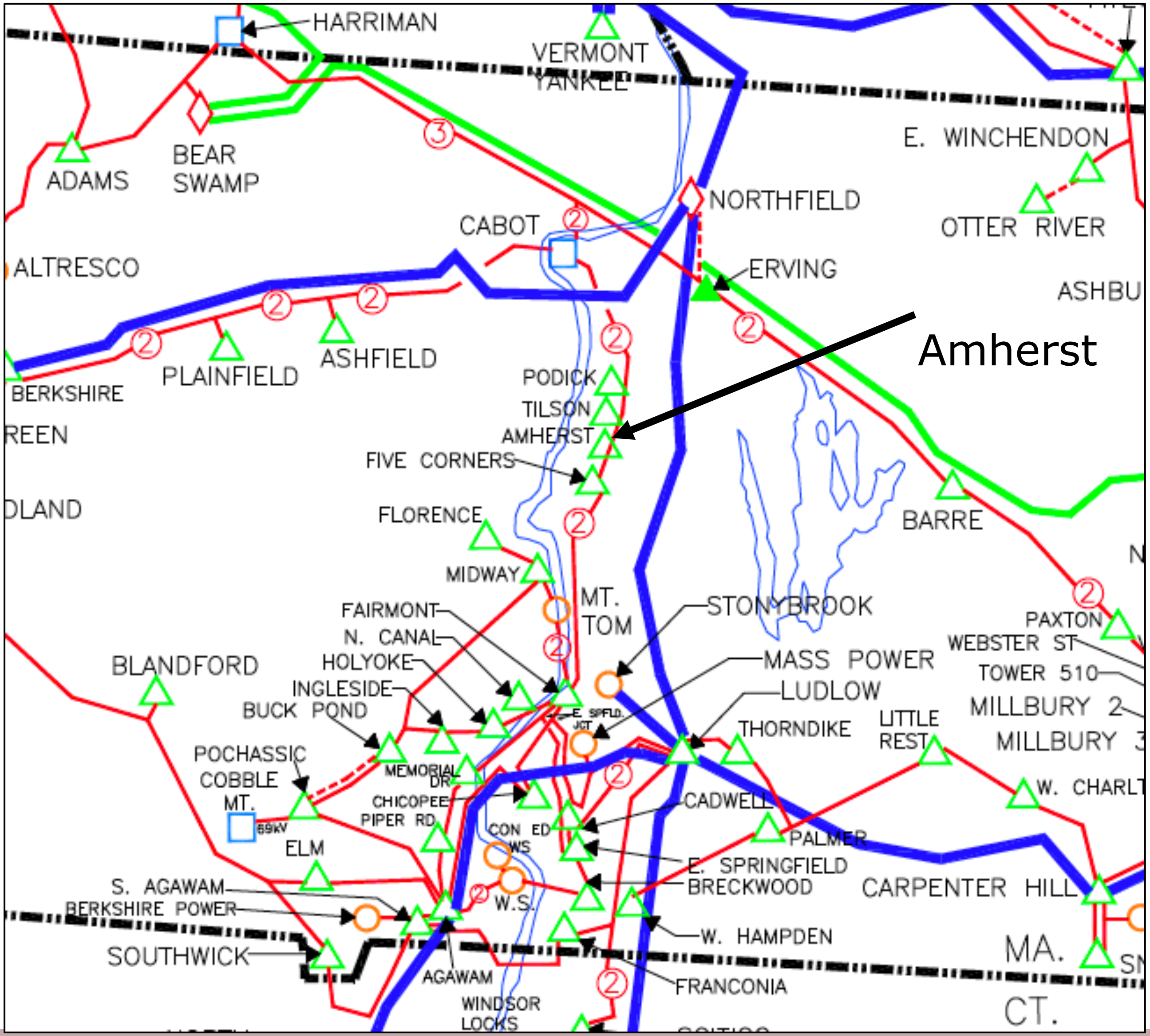
- Moving Electricity from the Power Station to you

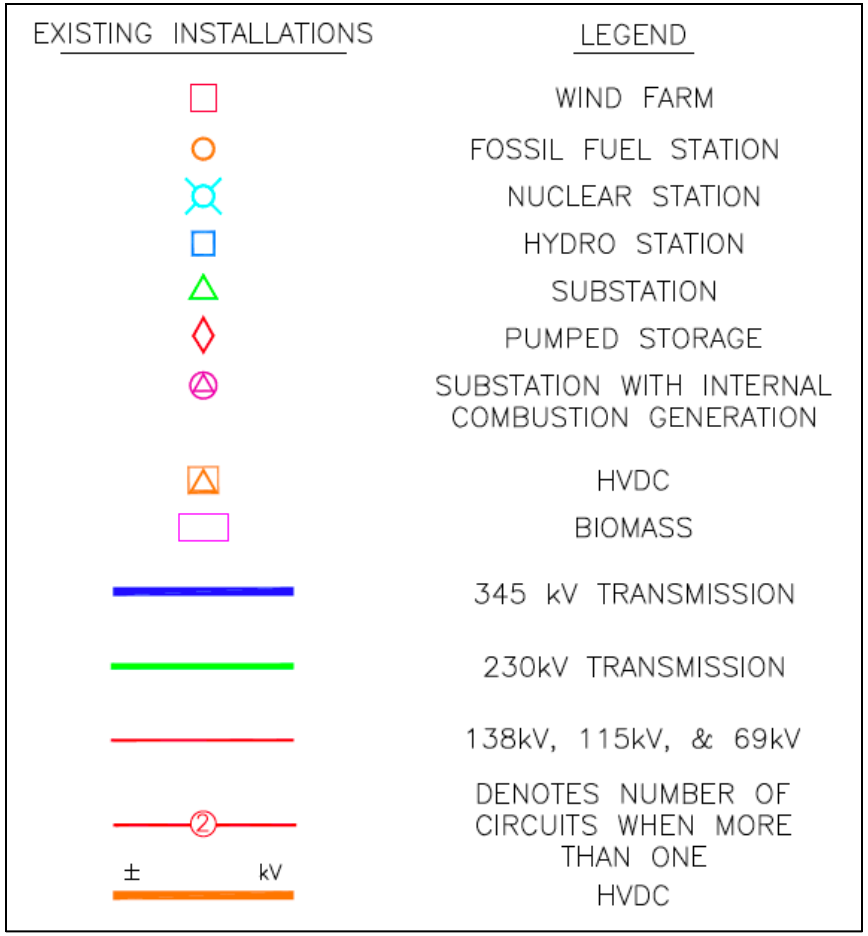


Transformer Efficiency: 95 – 98.5%

Local Grid

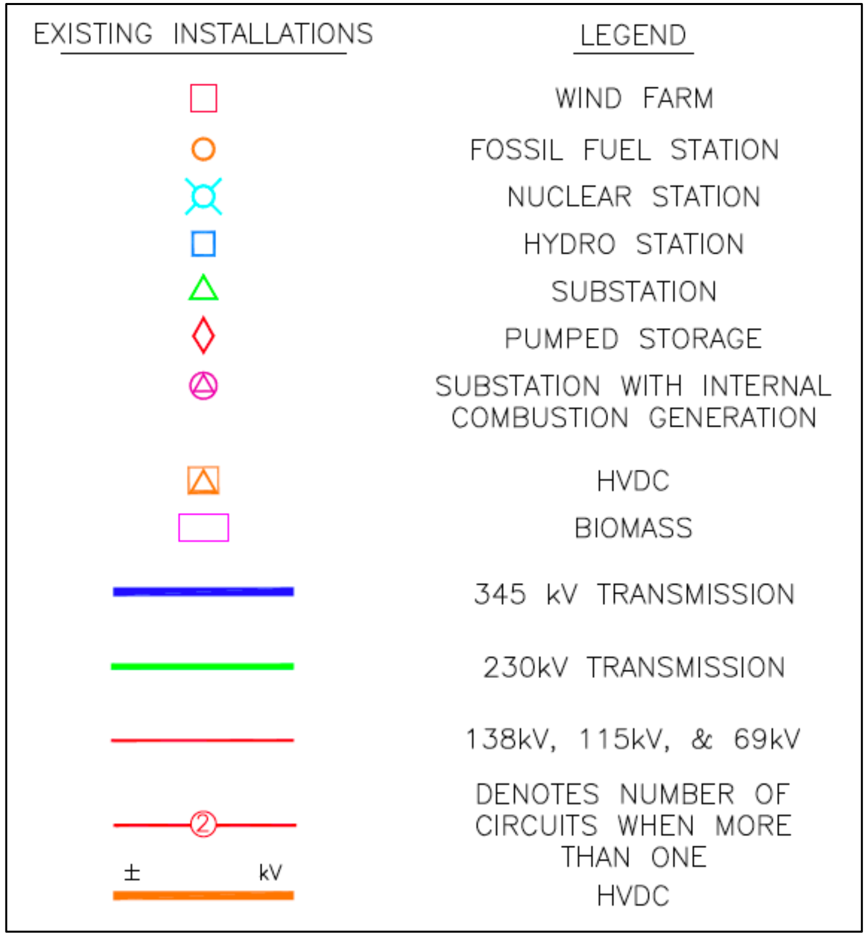
From ISO New England





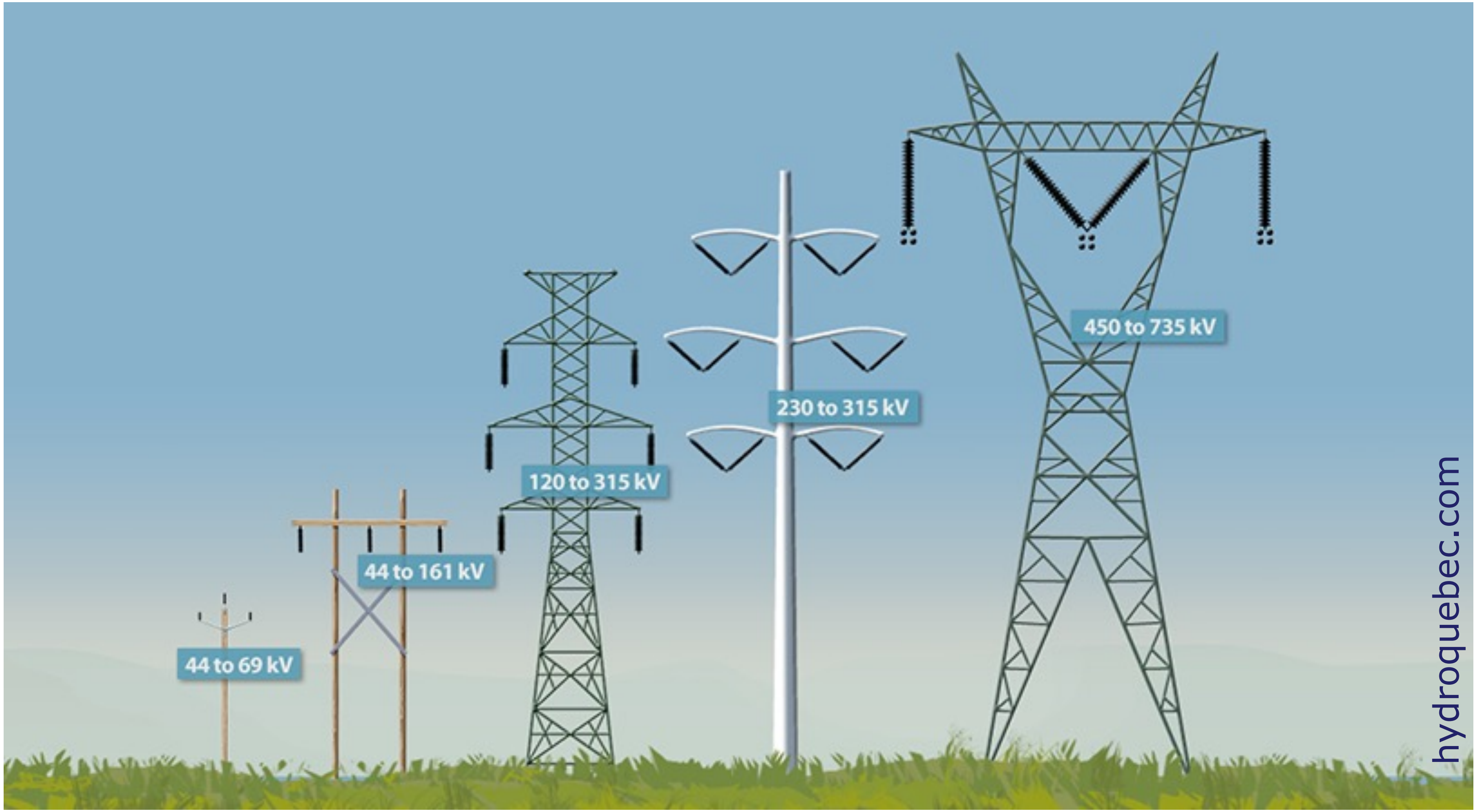
From ISO New England

Regional Grid



From ISO New England

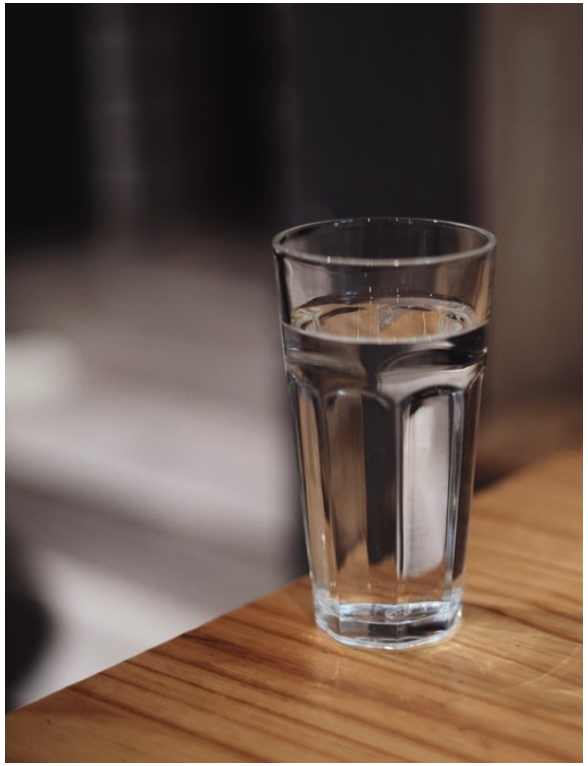
Transmission Towers



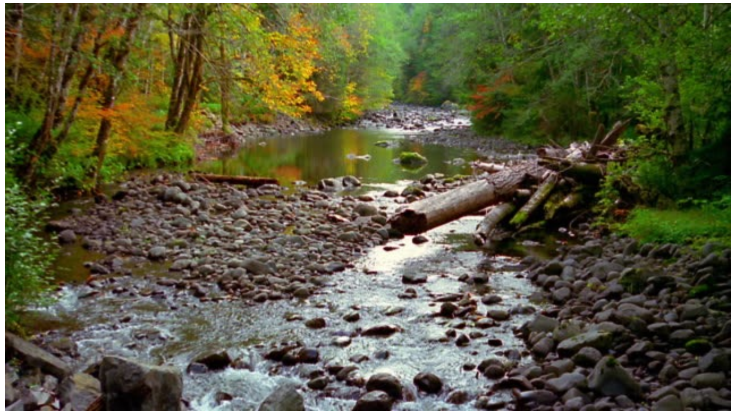
Voltage × Current = Power

- Voltage is a measure of an electron's potential energy
- Current measures the kinetic energy

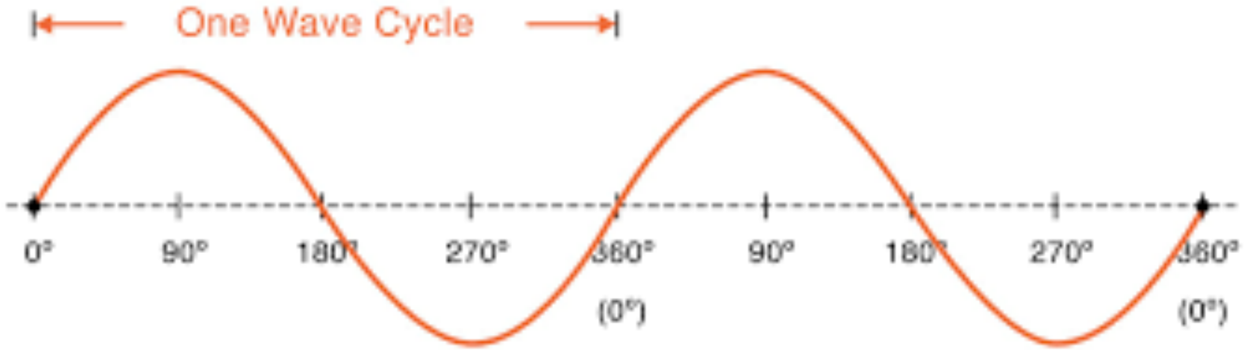
Which one of these has more potential energy (i.e. has the higher "voltage")?

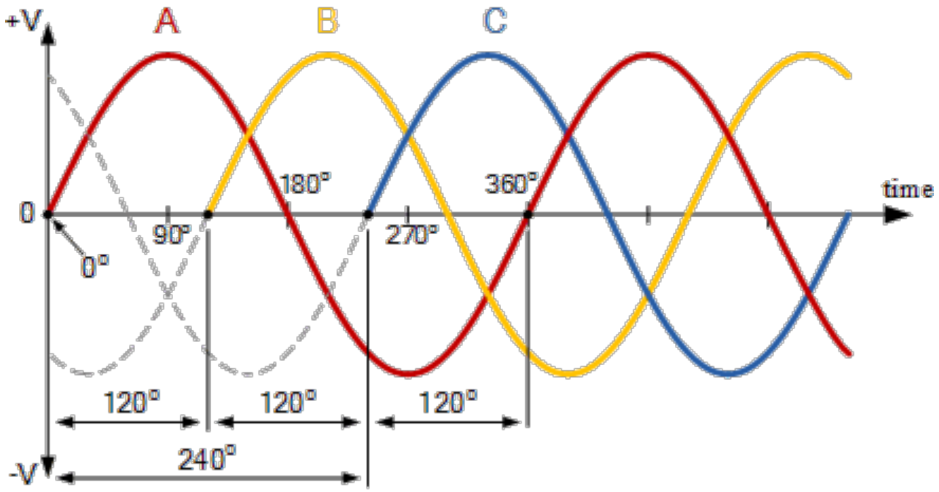


Which one of these rivers can carry more water (i.e. can sustain more current)?



A High-voltage tower





The voltage on any one power line fluctuates over time (60 cycles per second, or 60 Hertz).

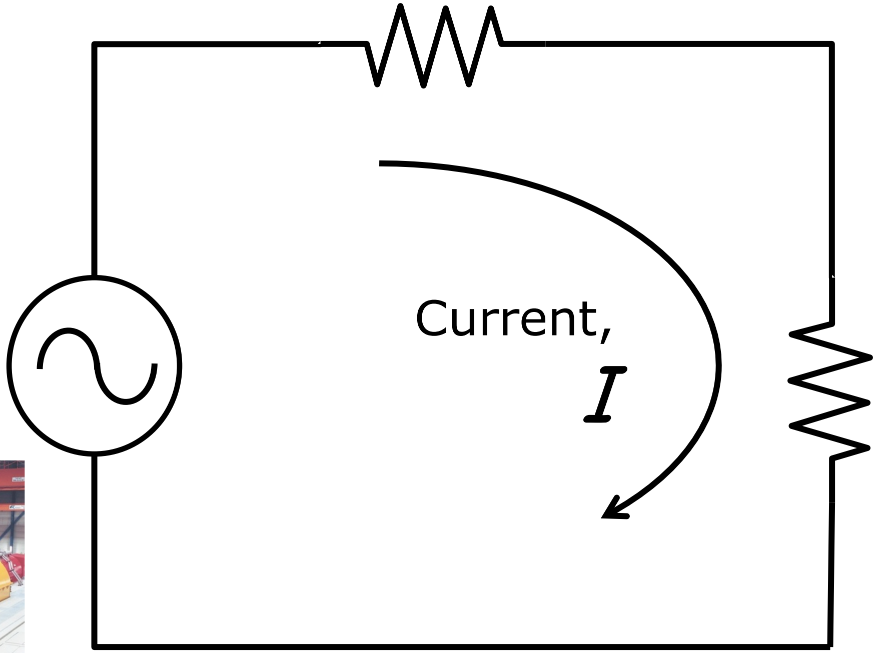
The voltage gradient between lines can be many kV per meter. Breakdown voltage of air: ~3000 kV/m

The voltages on a three-phase are offset from one another by 1/3 of a cycle (120 degrees), which is important for power balancing

Getting power to customers

<u>Ohm's Law</u>

$$I = \frac{V_{gen}}{R_{trans} + R_{cust}}$$



Transmission of current

- Choice of conductor is based on line-losses and cost of manufacture/materials

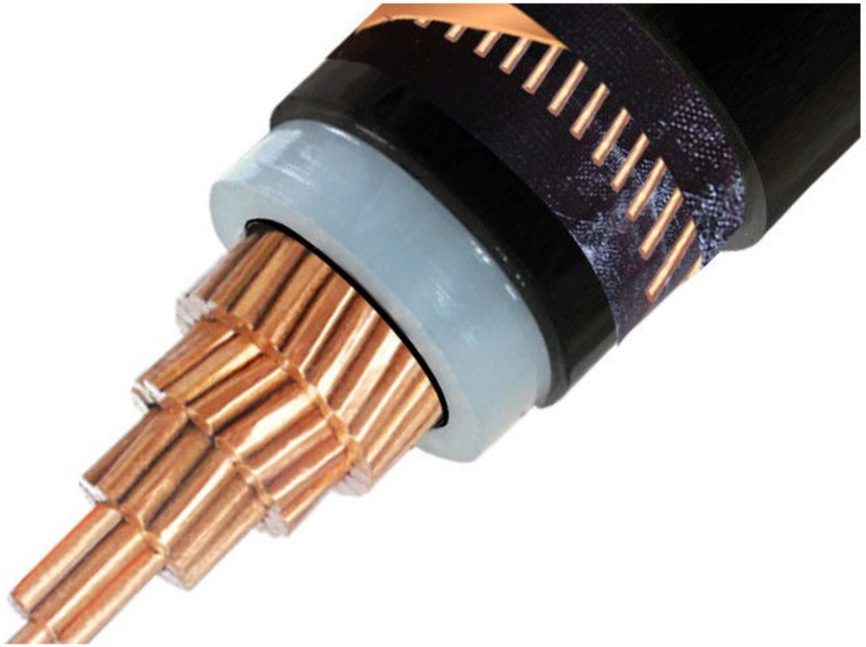
$$R = \rho \frac{l}{A}$$

l - length
A - area
R - total resistance

Aluminum

Very common for high-power lines

Copper



Local transmission & low-voltage lines

Conductor	Resistivity, ρ (μΩ – cm)
Silver	1.6
Copper	1.7
Gold	2.2
Aluminum	2.65
Tungsten	5
Superconductor (-211° F, 138 K)	0!

High Voltage vs. Low Voltage

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- For a fixed power, higher voltages means lower current

$$P = I*V$$

- Power loss in a conductor is proportional to the current

$$P_{loss} = I^2R$$

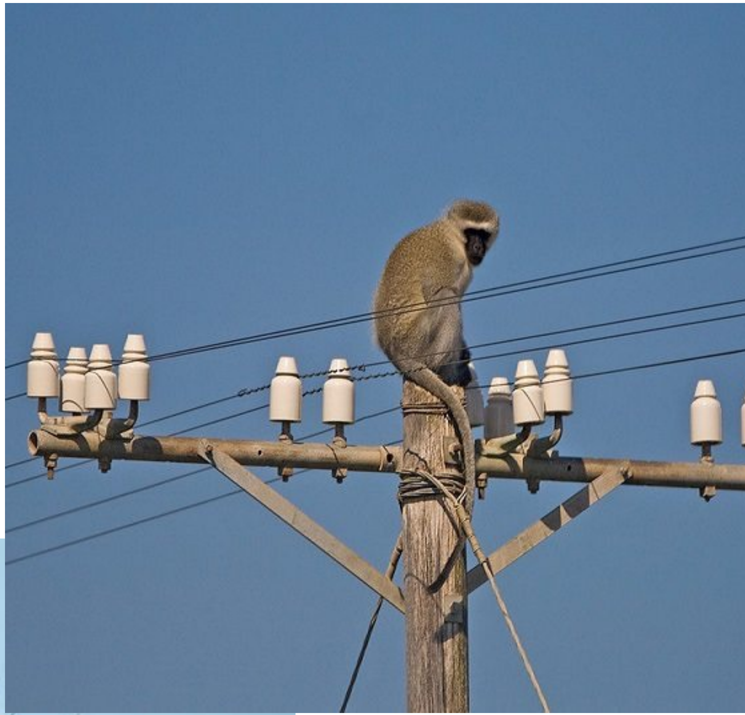
- Comparing Copper to Aluminum, the improvement of Copper over Aluminum is

$$\text{Improvement} = \frac{P_{loss\text{-}Al} - P_{loss\text{-}Cu}}{P_{loss\text{-}Al}} = \frac{R_{Cu} - R_{Al}}{R_{Al}} = 36\%$$

- Other factors to take into account
  - Cost of materials
  - Weight of materials (Copper is 3.3 times heavier than Aluminum)
  - Strength of materials

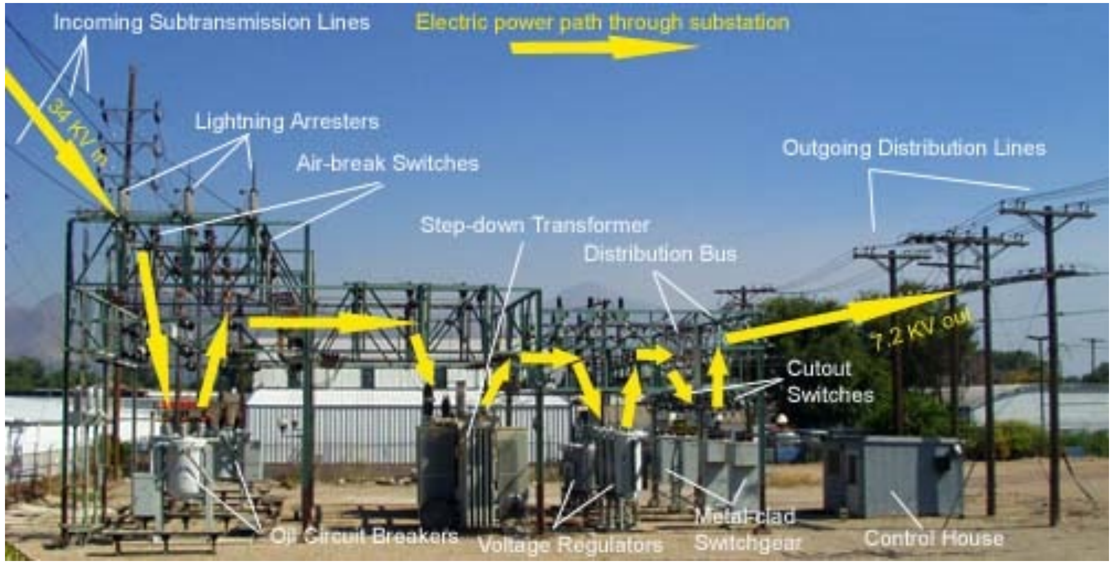
Safety

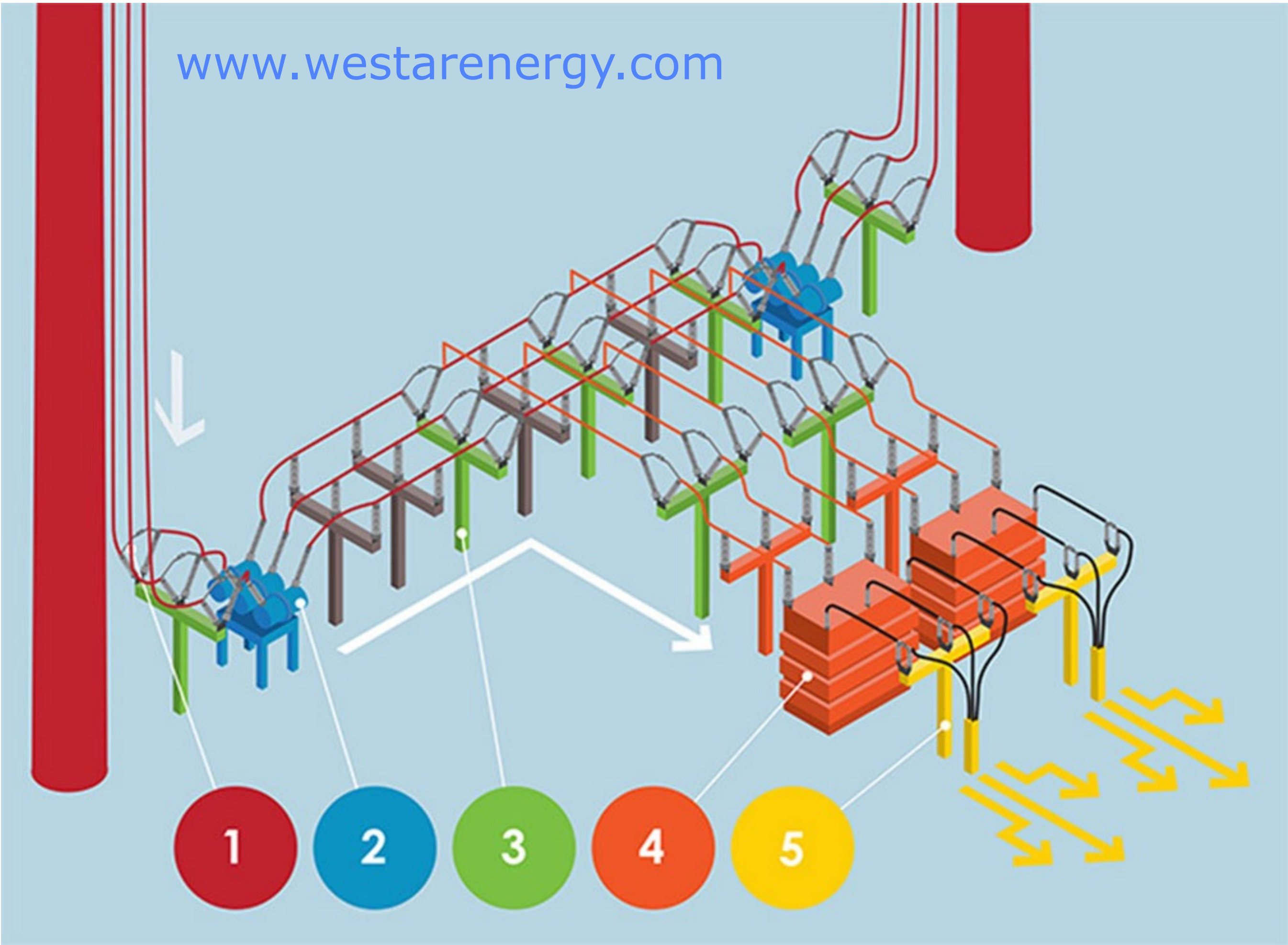
- High-voltage is hazardous!



Substation

- Conversion from high-voltage to lower voltage

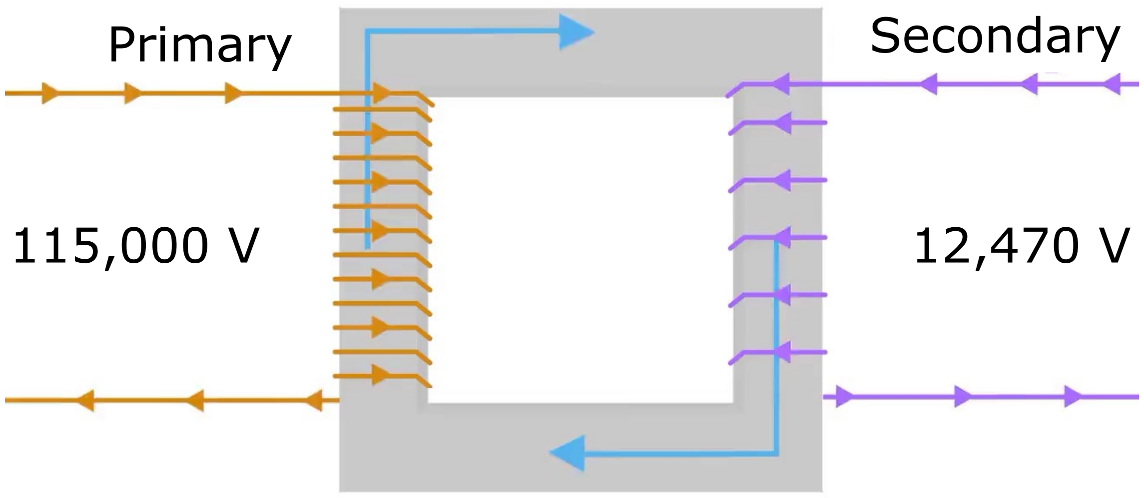




1. Power line input (may be multiple)
2. Circuit breakers
3. Power switches
4. Step-down transformers
5. Distribution Lines

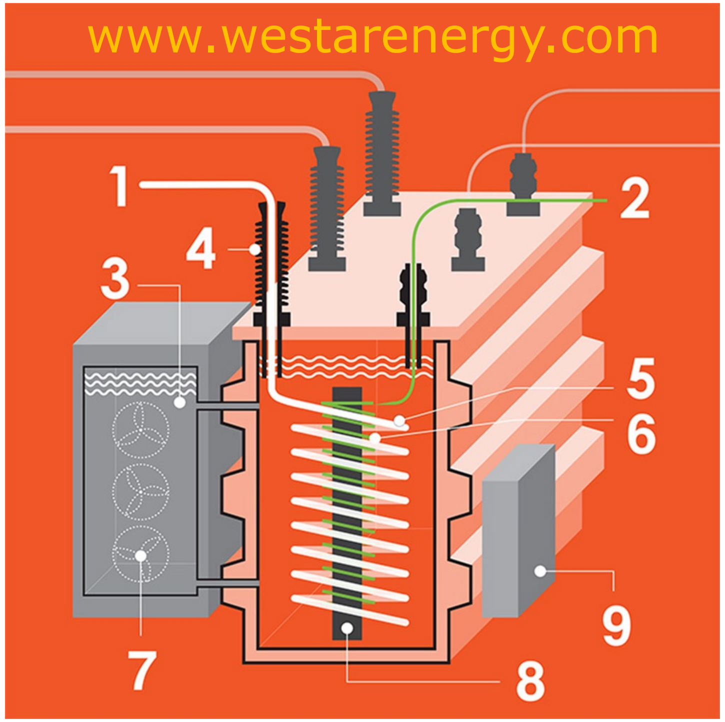
Transformers

- Step-Up and Step-Down Transforms change the voltage using a "magnetic" circuit
- The ratio of turns that enclose magnetic lines of flux sets the voltage conversion ratio



www.homdor.com

1. High voltage (115,000 V)
2. Low voltage (12,470 V)
3. Oil cooling radiator
4. Insulator
5. Primary coil
6. Secondary coil
7. Cooling fans
8. Iron core (magnetic conductor)
9. Control box



Physics of a transformer

- Transformer is made from two coils, one called the primary and the other the secondary.
- It can increase (step up) or decrease (step down) the voltage)
- Faraday's Law: Any change in the magnetic environment of a coil will cause a voltage to be induced in the coil
- Power remains a constant. If voltage increases, then current will decrease, and vice a versa

<u>Faraday's Law</u>

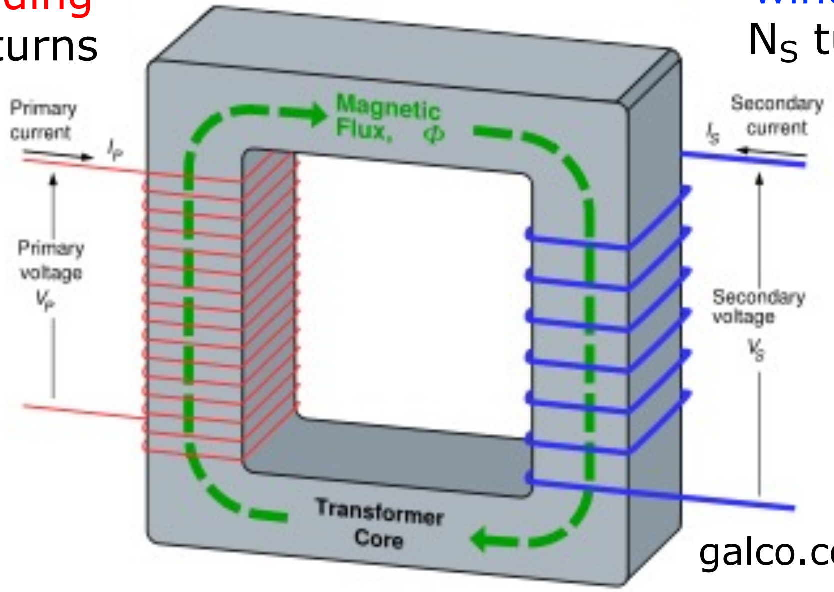
$$\oint \bar{E} \cdot \overline{dl} = \frac{d}{dt} \int \bar{B} \cdot \overline{dS}$$

leads to

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} = \frac{I_P}{I_S}$$

Primary winding N_P turns

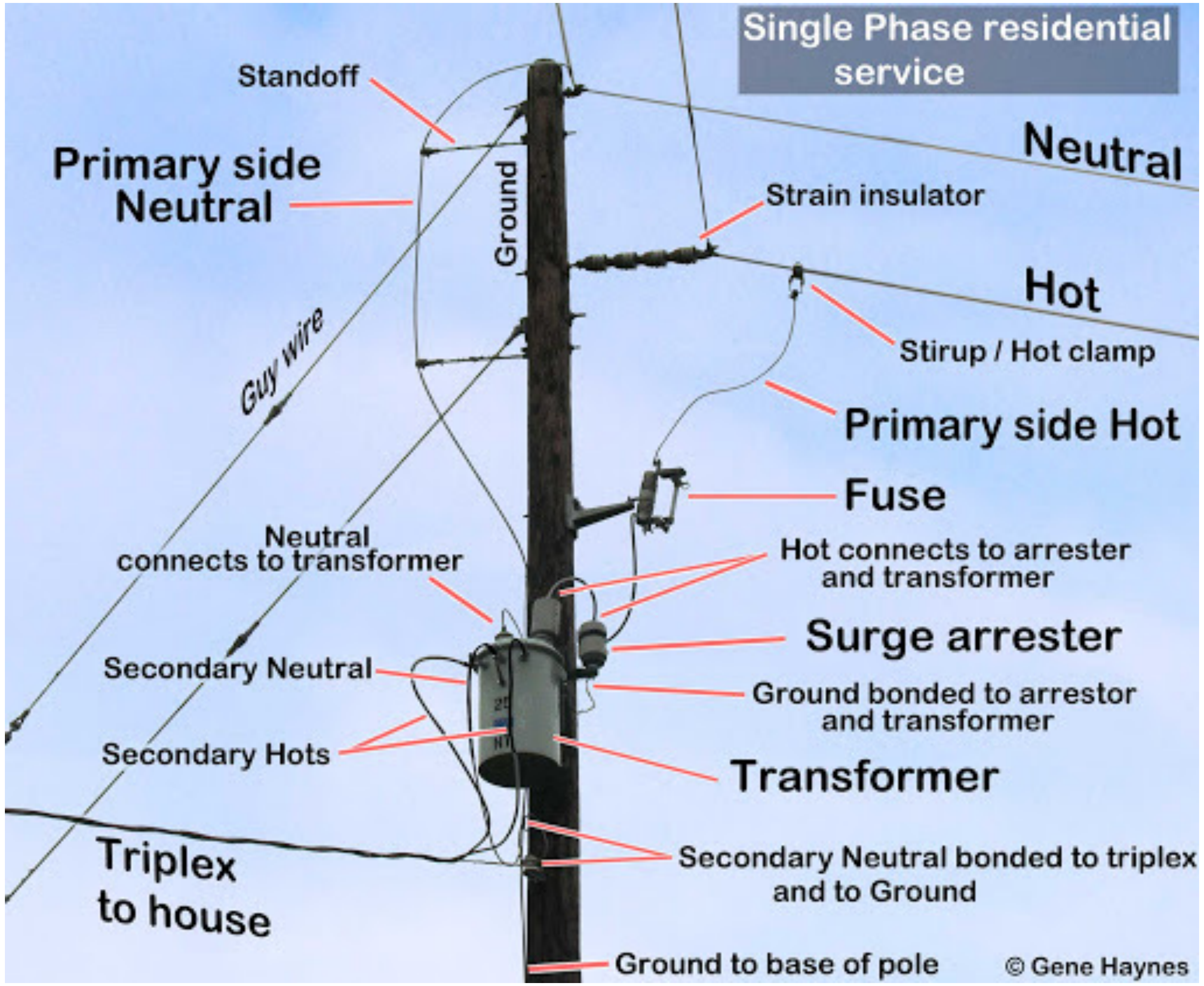
Secondary winding N_S turns



galco.com

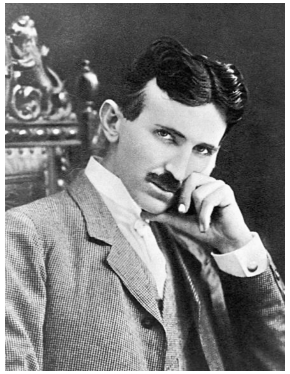
Transformers and Service Lines

- Utility pole transformer converts distribution voltage, 5 – 15kV, down to 120V

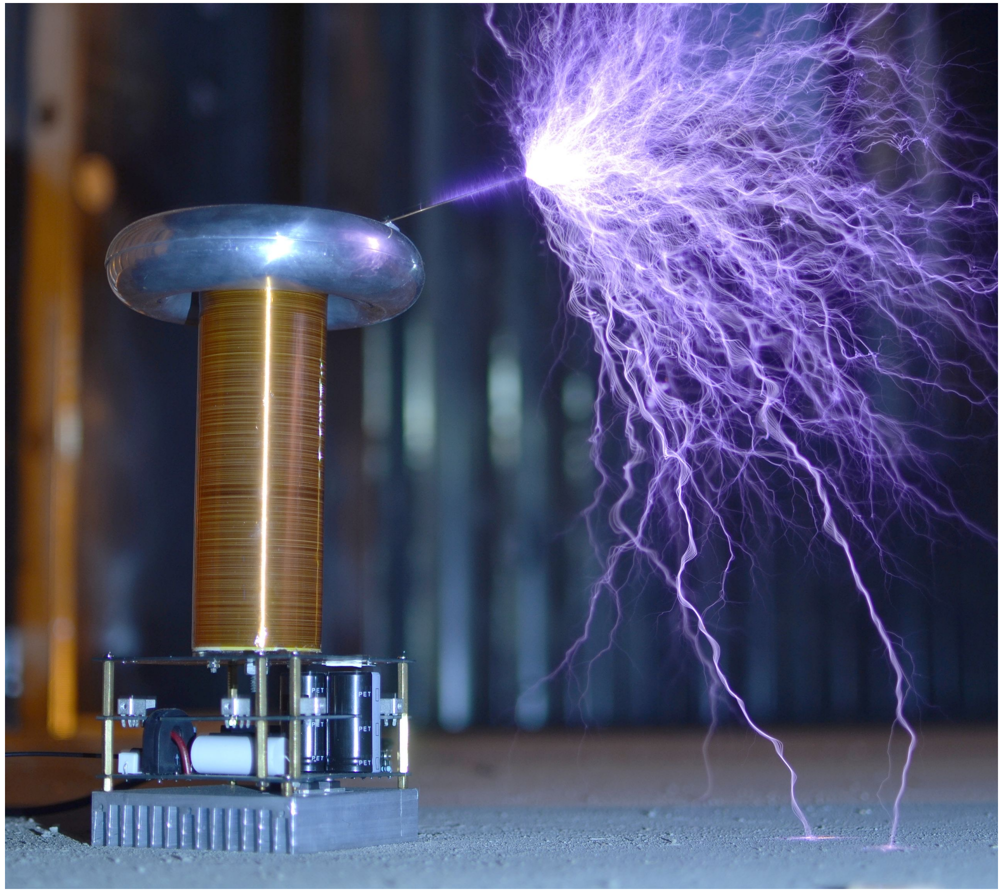


Tesla Coil (1899)

- Nikola Tesla (1856 – 1943)
- Unit of Magnetic Flux Density



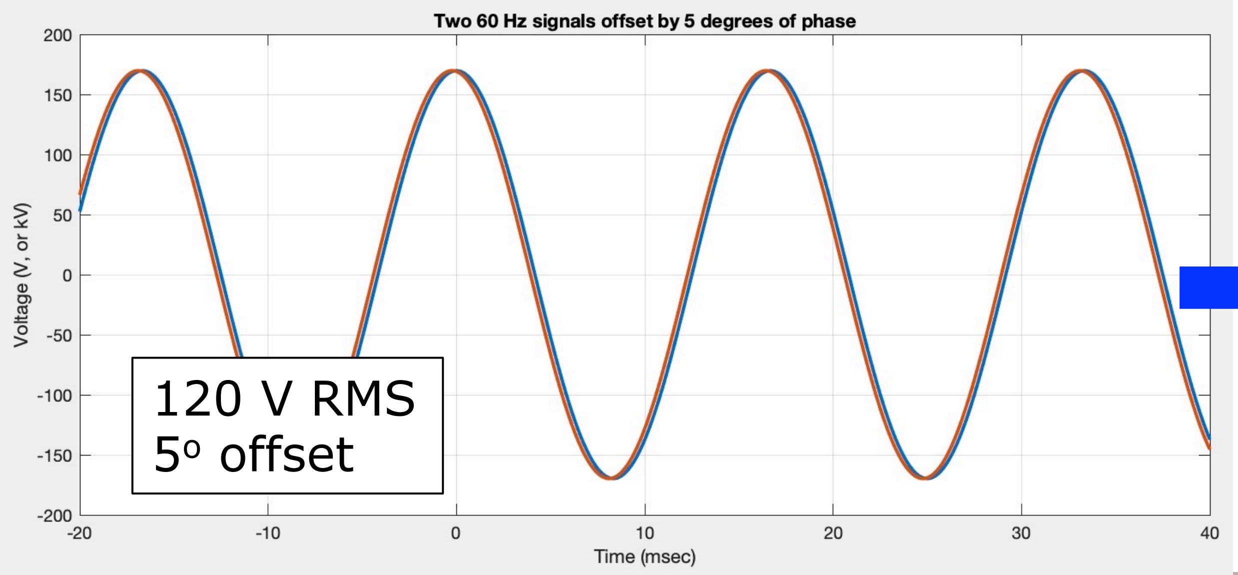
- Advocate of power delivery from Alternating Current

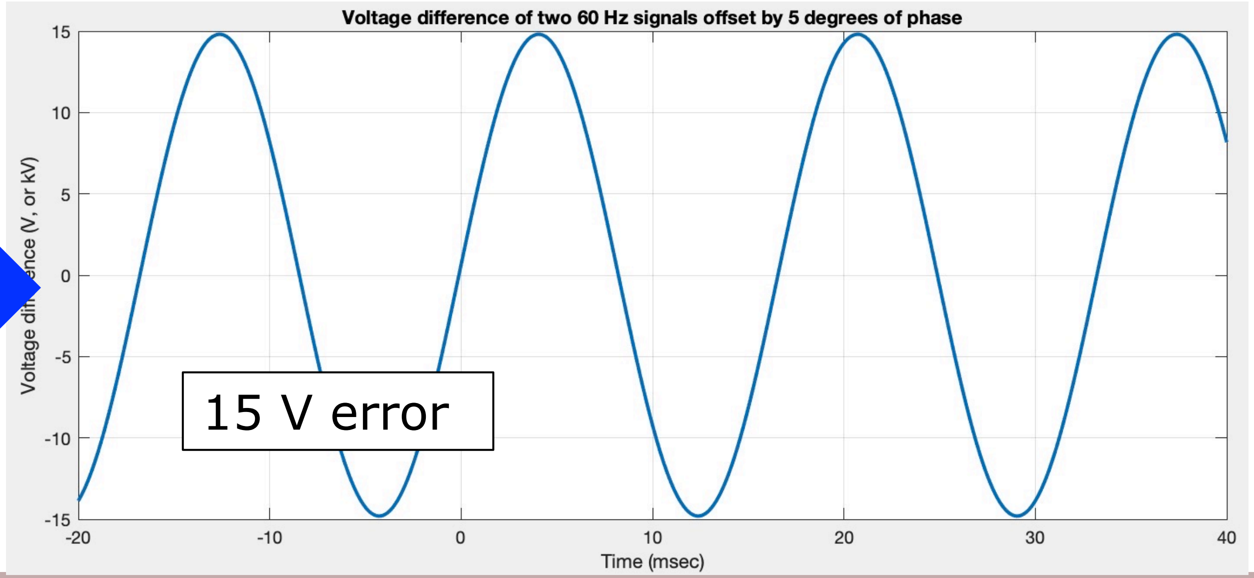


Grid Dynamics

- What do we need to worry about when operating a power grid?

- Dynamics
  - » Changing demand
  - » Changing supply
  - » Phasing
- Difficulty of storage
  - Supply and demand need to match – it's a balancing act!
- Robustness
  - Handling failures





Adaptation

- Turn power plants on and off
  - Slow process
    - » Plants take time to come online
    - » Need to run for a while to make it worthwhile
- Move power around
  - Divert power from low-demand to high-demand area
  - Transmission losses limit range where this makes sense
- Control problem
  - What to do when? How to avoid failures?

Electricity Market

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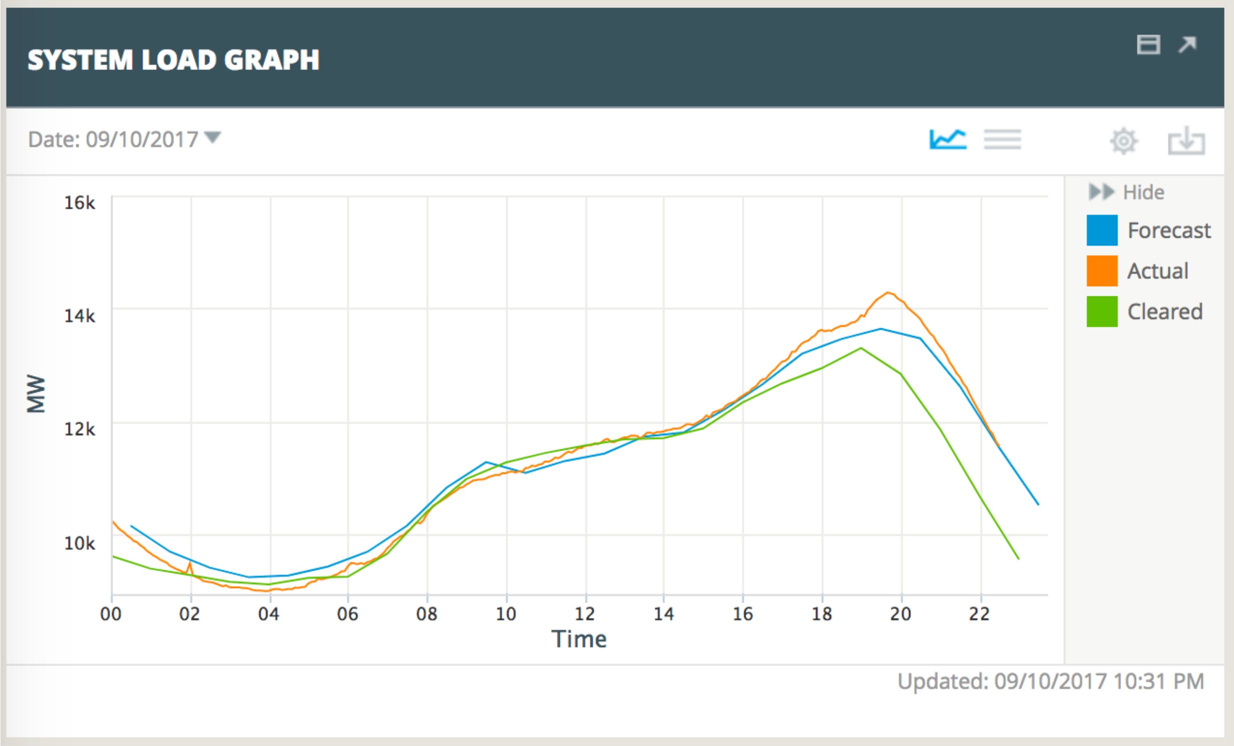
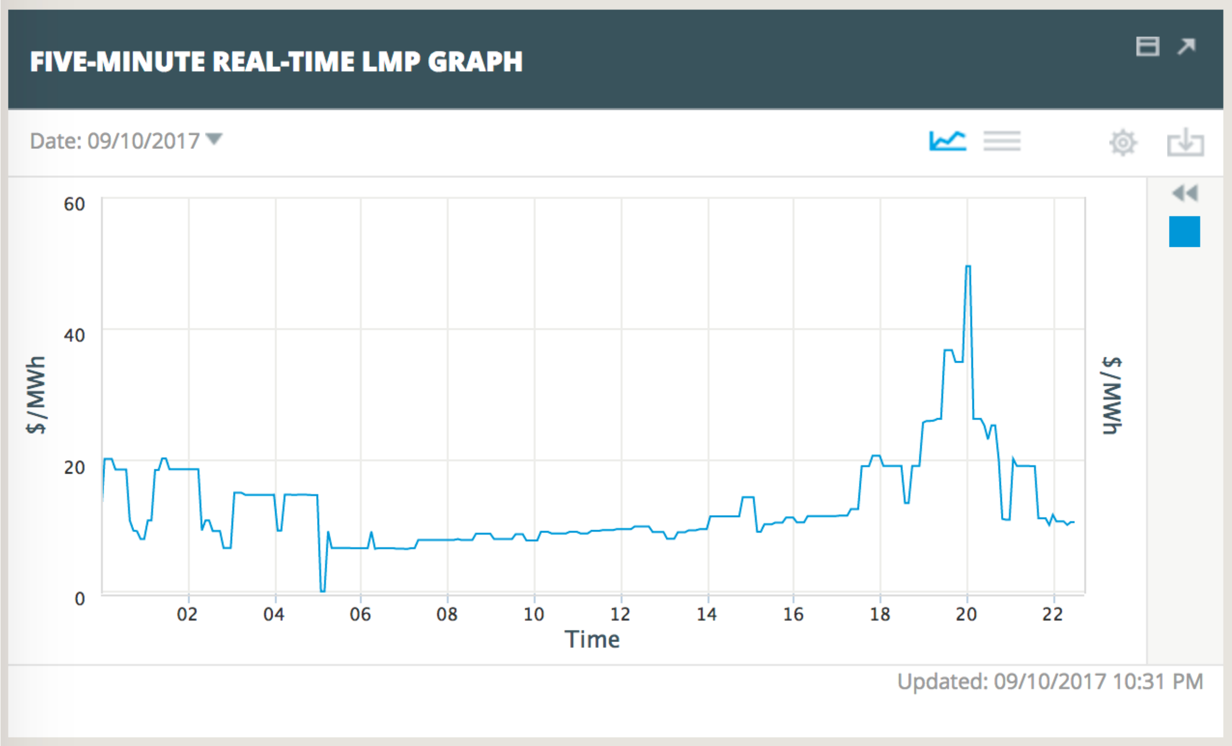
- Electricity can be traded as a commodity
  - Two types: power and energy
- Suppliers
  - Power companies
- Retailers
  - Utility companies selling to customers
- Market
  - Trading based on supply and demand
  - Allows for risk management
  - Market organized into regions (ISO New England)
- Smart Grid
  - Two-way communication between utility and customers
  - Better integration between supply and demand

Electricity Prices

- Very dynamic – even during a single day
  - Plots show system load and price per MWh

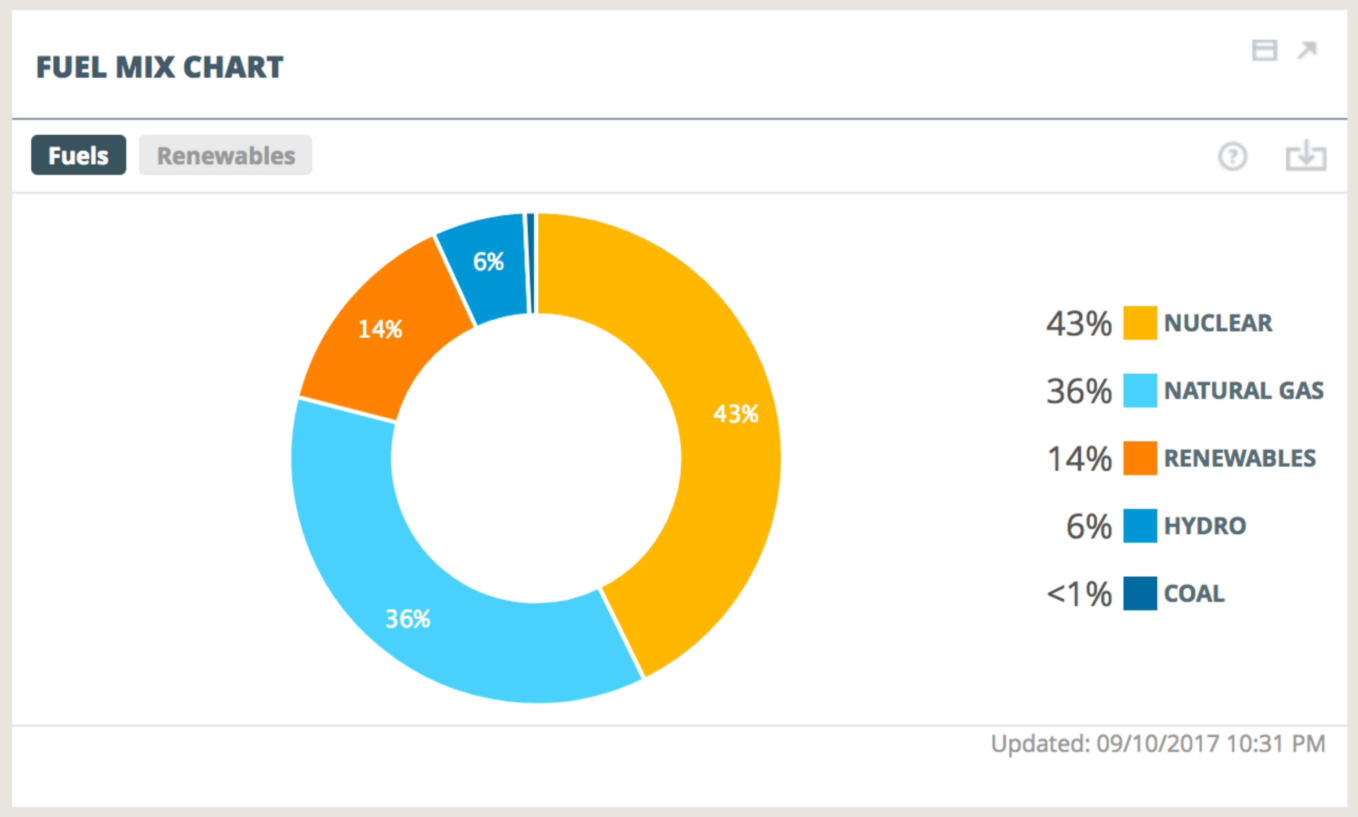




From ISO New England

Renewable Energy Sources

- Integration of new power sources into grid
  - Commercial and residential solar systems
  - Wind energy systems
- Sources of energy not co-located with demand
  - Often away from existing power grid
  - Problem of moving power into grid (signal phase & storage)



From ISO New England

Careers in Electricity

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- Utilities and system operators (e.g., Eversource, NE-ISO, etc.)
  - Repair, maintenance, energy markets, and more!
- Renewables engineers (e.g., solar and wind firms (especially offshore!), large companies like Google, GE, and Microsoft)
- Environmental / Energy consulting
- Battery engineers – Tesla, Samsung, Apple, rideshares, etc.
- Science + research – the field is changing faster than ever before

Main Concepts

- Power Generation ✓
- Solar Cells ✓
- Power Transmission ✓
- Power Distribution & Control ✓
- Electricity Storage
- Power Usage

University of Massachusetts Amherst

Module 6-3 – Power Storage

ENGIN 112 – Introduction to Electrical and Computer Engineering

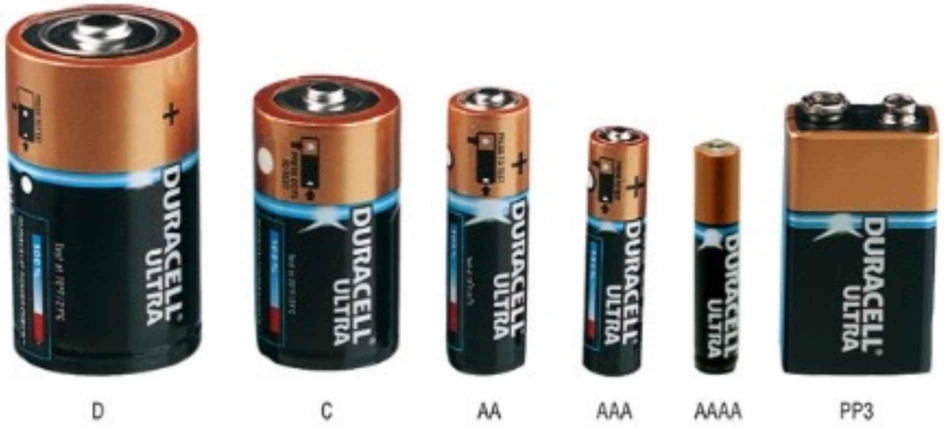
Main Concepts

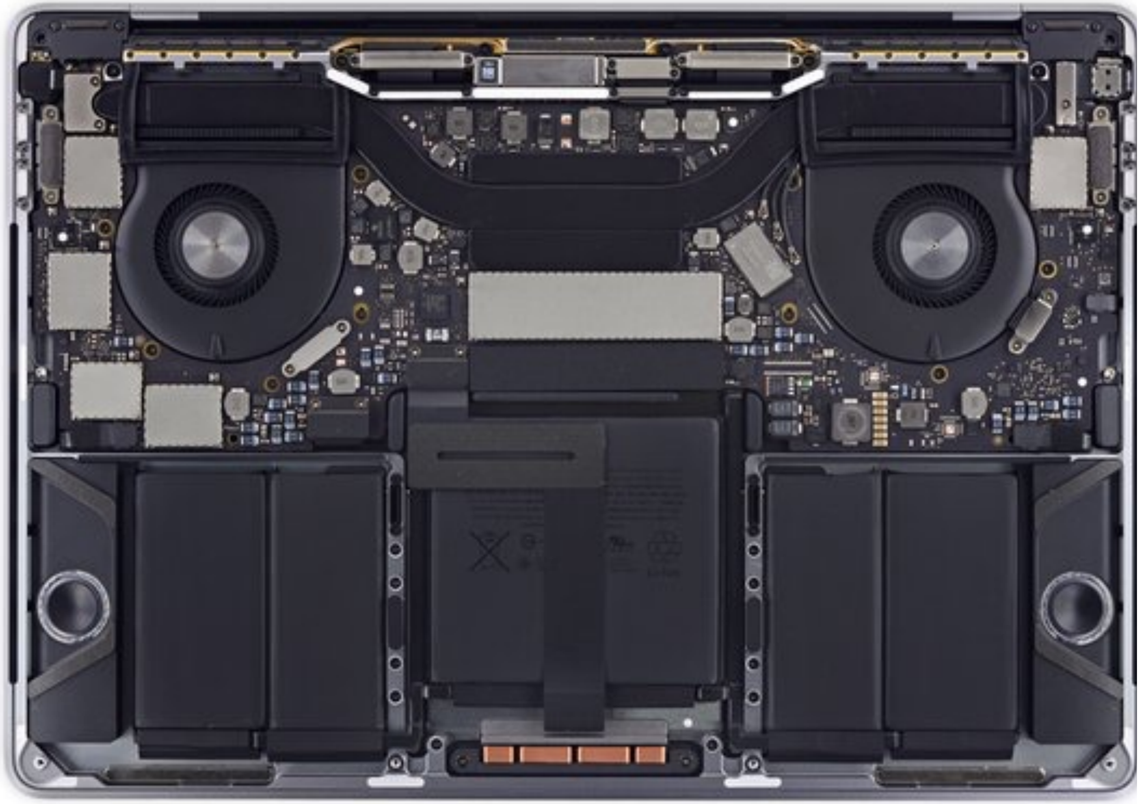
- Power Generation ✓
- Solar Cells ✓
- Power Transmission ✓
- Power Distribution & Control ✓
- Electricity Storage

Ways of storing energy

- Batteries
- Ultracapacitors
- Flywheels
- Compressed Air
- Pumped Hydropower
- Other ?
  - Superconductors
  - Material phase changes (gas <-> liquid <-> solid)
  - Fuel Cells
  - Etc.

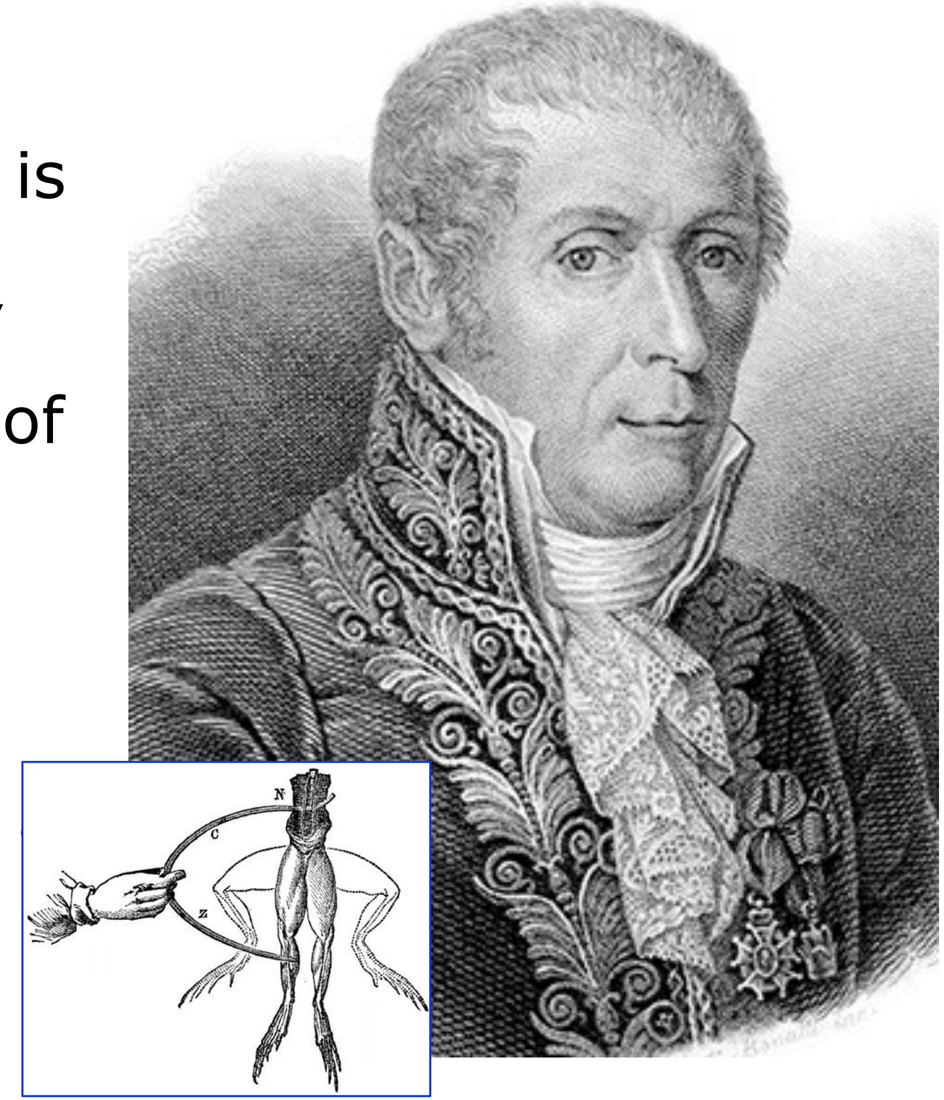
Batteries in our daily life





Alessandro Volta

- 1799 battery, then called a ”voltaic pile”
- Benjamin Franklin is known for coining the term “battery”
- Alternating layers of Copper, Zinc and Cloth-soaked with brine (salt water)
- Showed that electricity was not biological phenomenon (as Galvani argued)



Basics of a battery

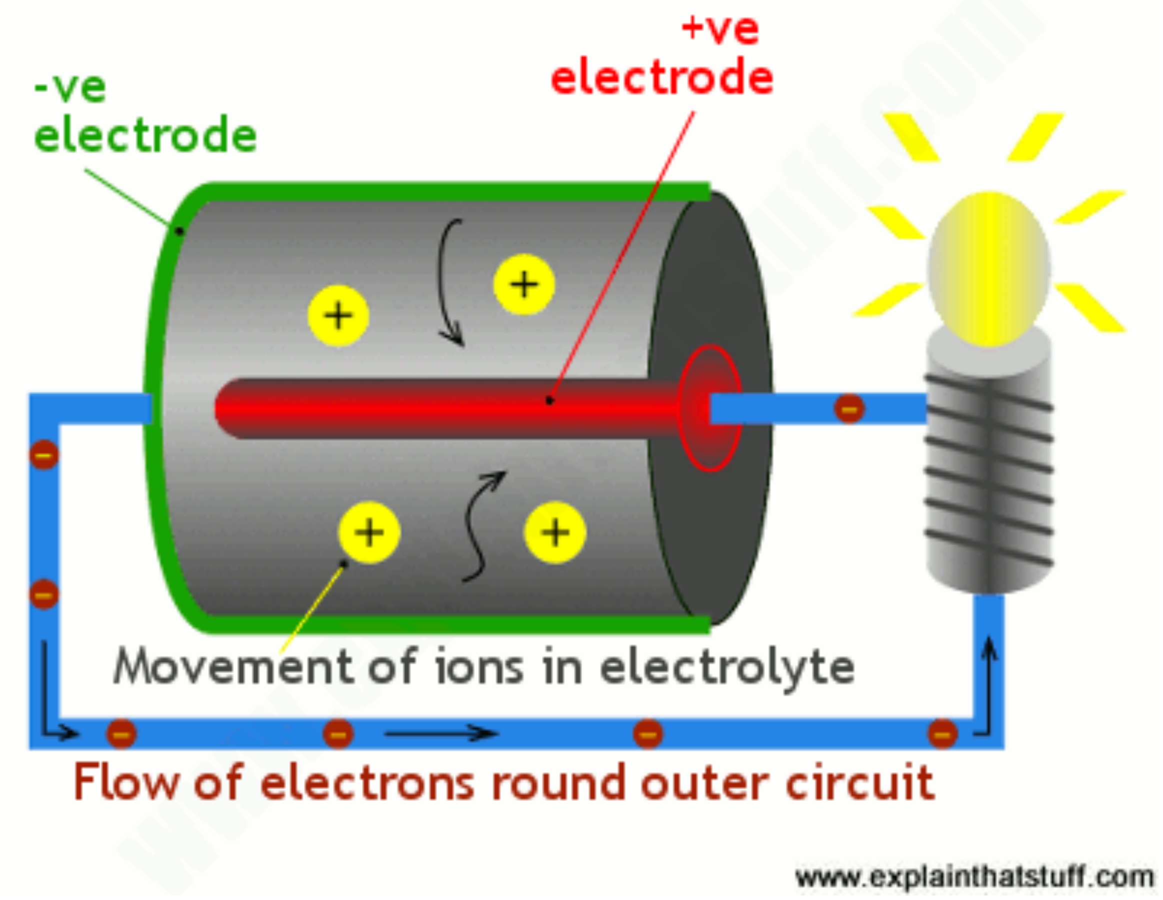
- A battery is a device consisting of two or more electro-chemical cells that convert stored chemical energy into electrical energy
  - Consider what this means in contrast to an electric generator, which converts mechanical energy into electrical energy
- Circuit Symbol

- Cathode: the electrode from which a conventional current leaves (or electrons flow into)
- Anode: the electrode into which conventional current flows into (or electrons flow out of)
- Electrolyte: a catalyst that allows the movement of ions from the cathode to the anode. Can contain salts, acids or bases in liquid, gelled or dry media.

How a battery works

- The Electrolyte serves two purposes:

1. It prevents electrons from flowing from one electrode to the other
2. It allows positive charges to pass through



Note the direction of the electron flow!

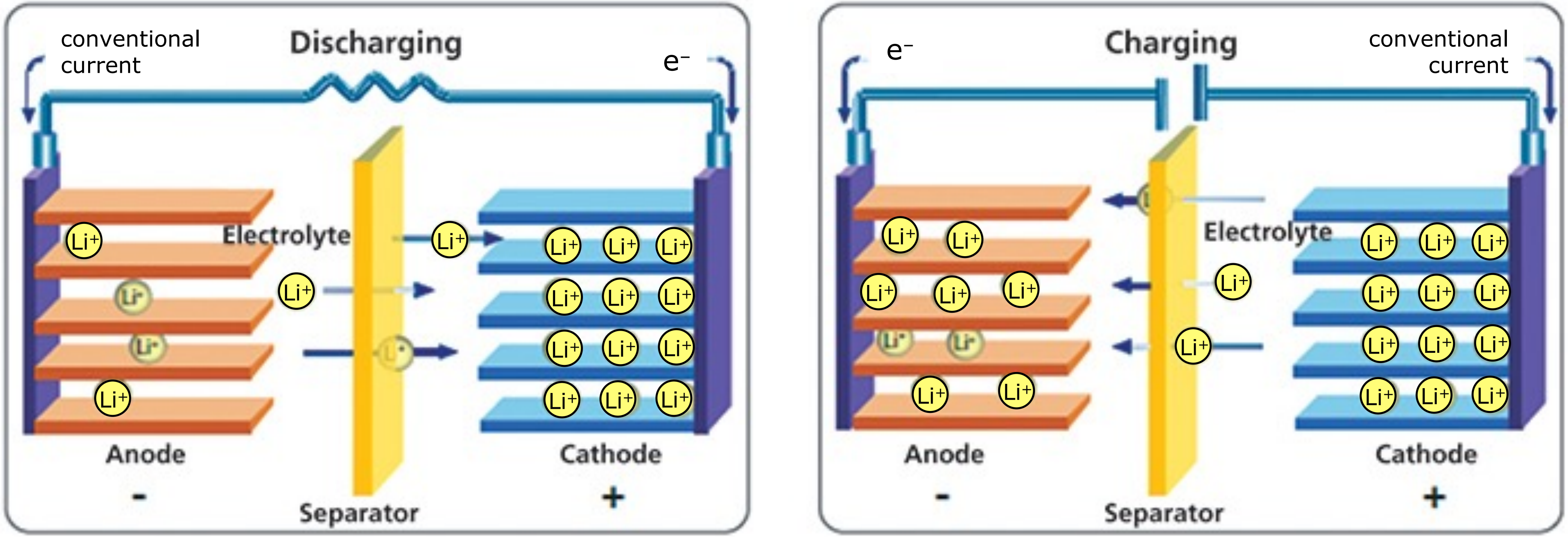
Q: for a typical battery, what is the positive terminal? What is the negative terminal??

Cathode

Anode

Rechargeable batteries

- separating layers at the Anode and Cathode are composed of graphite or other types of metals.



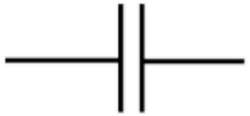
Battery characteristics

- Physical sizes: button, AAA, AA, C, D, etc.
- Voltages: 1.5 V; 3.7 V; 9 V; 12 V, etc.
- Energy density: W-h/kg
- Capacity: A-h (or equivalently, Coulombs)
- Number of recharge cycles
- Materials: liquid, solid or other
- Discharge characteristics

Capacitors

- A capacitor is a passive two-terminal electrical component that is used to temporarily store electric energy in the form of an electric field

- Symbol for a parallel plate capacitor



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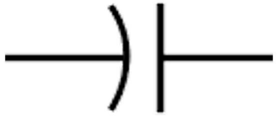
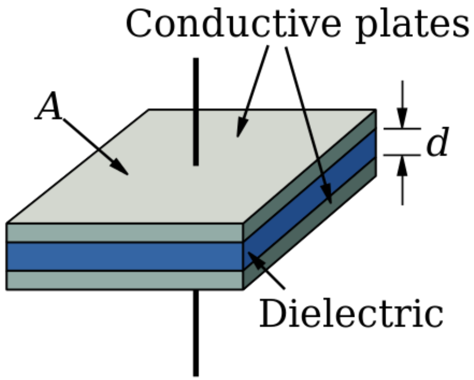
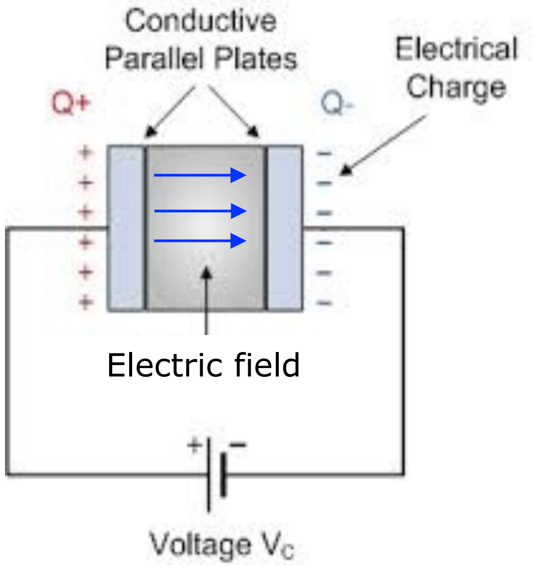






- Capacitance: $C = \epsilon \frac{A}{d}$

- Energy stored: $E = \frac{1}{2} C V^2$

- Ultracapacitors (supercapacitors), are electrochemical capacitors that have an extremely high energy density greater than a normal high-energy electrolytic capacitor

Improving storage capacity

Electrolytic capacitor

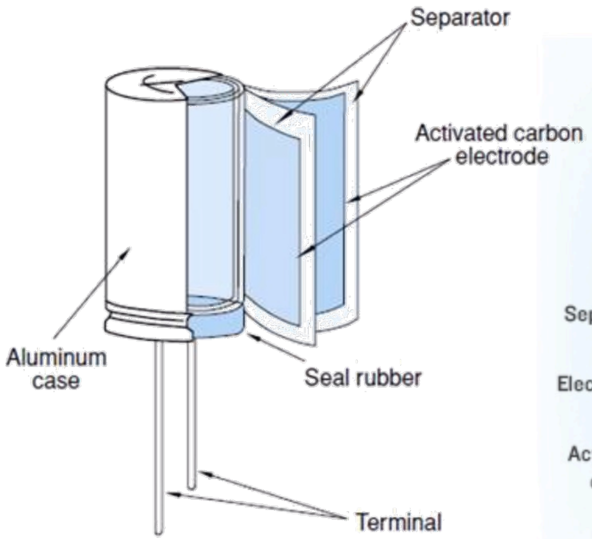
- Plates of capacitor are rolled into a cylinder
- Electrolyte used to separate charges without allowing them to pass through

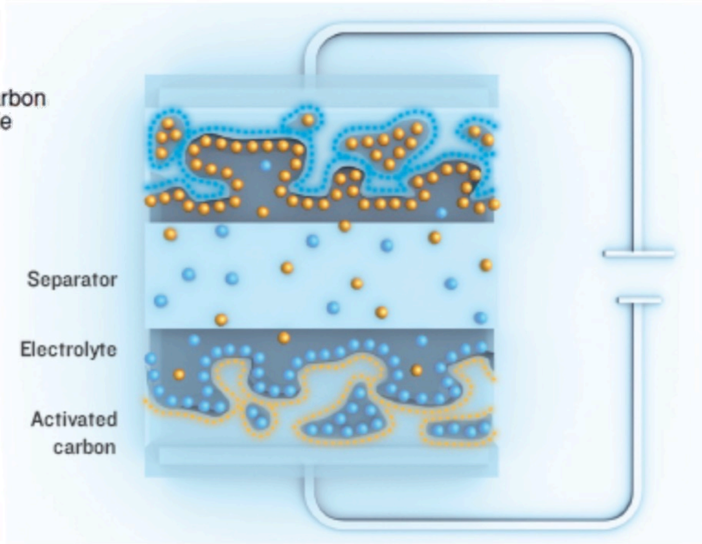
Ultracapacitor

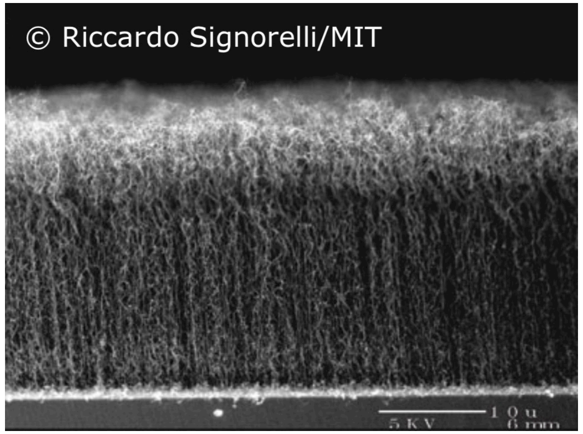
- Structure is used to increase surface area, A between plates (1000 m² – 2000 m²)
- Capacitances up to 2.7 kF

$$\boxed{C = \epsilon \frac{A}{d} = \epsilon_r \epsilon_o \frac{A}{d}}$$

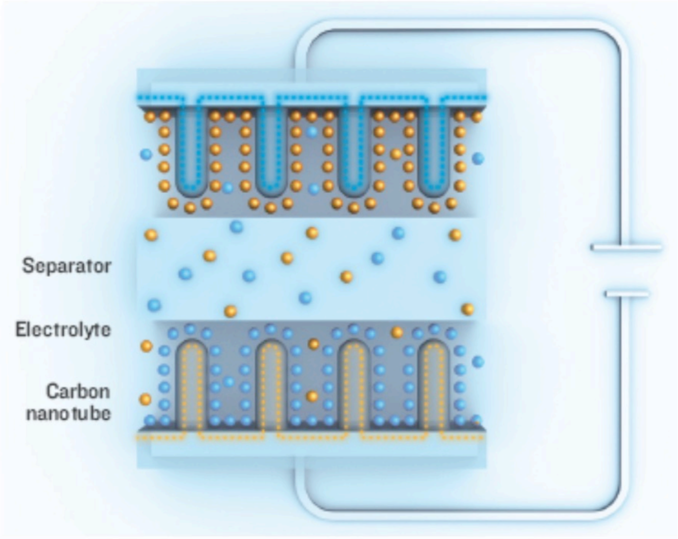
where ϵ_0 is equal to the permittivity of free space, $\epsilon_0 = 8.854 \times 10^{-12}\ F/m$







a forest of carbon nanotubes



Batteries

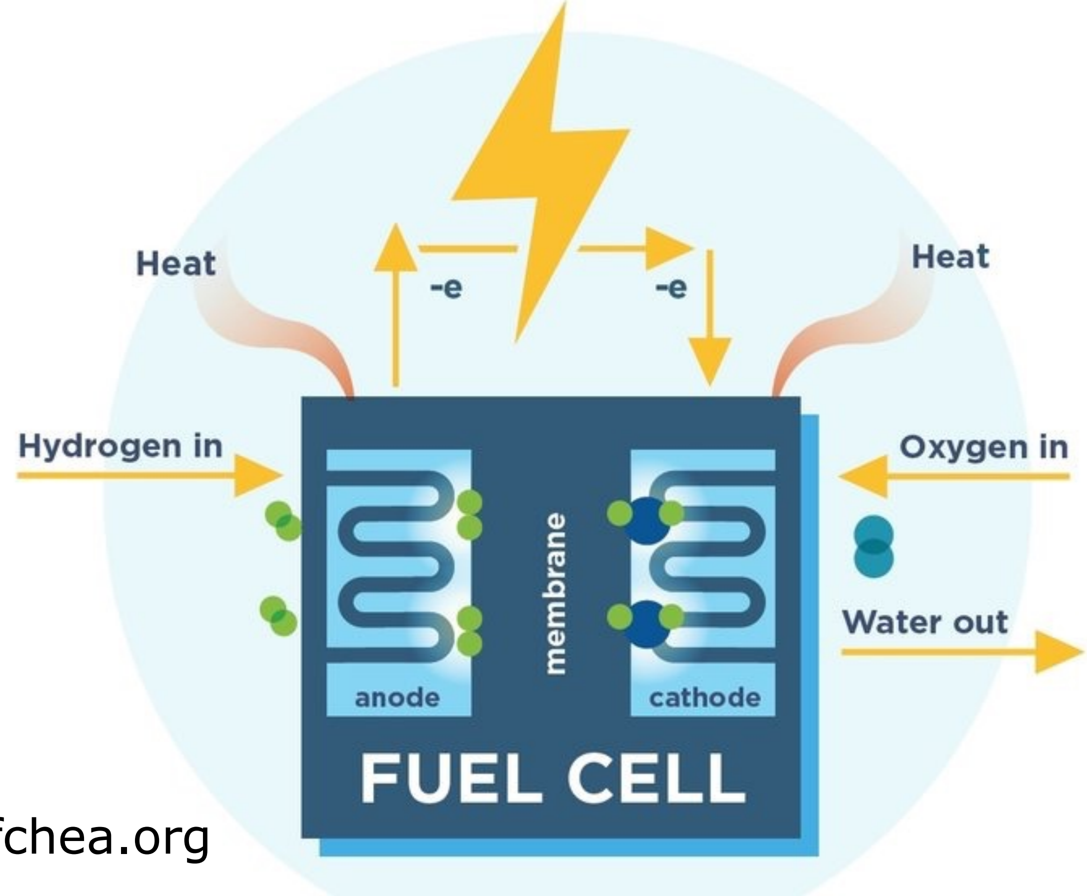
- No chemical reactions in ultracapacitors
- Ultracapacitors are best used when many rapid charge/discharge cycles are more important than long term compact energy storage

Characteristics	Lead Acid Battery	Ultracapacitor	Normal Capacitor
Charge time	1 – 5 hours	0.3 to 30 sec	0.001 to 1 msec
Discharge gime	0.3 to 3 hours	0.3 to 30 sec	0.001 to 1 msec
Energy	10 to 100 Wh/kg	1 to 10 Wh/kg	< 0.1 Wh/kg
Cycle Life	1000 cycles	> 500,000 cycles	> 500,000 cycles
Charge/discharge efficiency	70 – 85%	85 – 98%	> 95%
Operating temperature	-20^{o} to 100^{o} C	-40^{o} to 65^{o} C	-20^{o} to 65^{o} C

Fuel Cells

- Fuel cells are like batteries
- Charge carriers are Hydrogen and Oxygen

Typical efficiency 17% - 36%,
80 – 90% if heat is captured



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Fly Wheels

- Mechanical storage of energy
- Interia (I) is proportional to the mass (*m*) and the square of the radius (*r*)

$$I = \frac{1}{2}mr^2$$

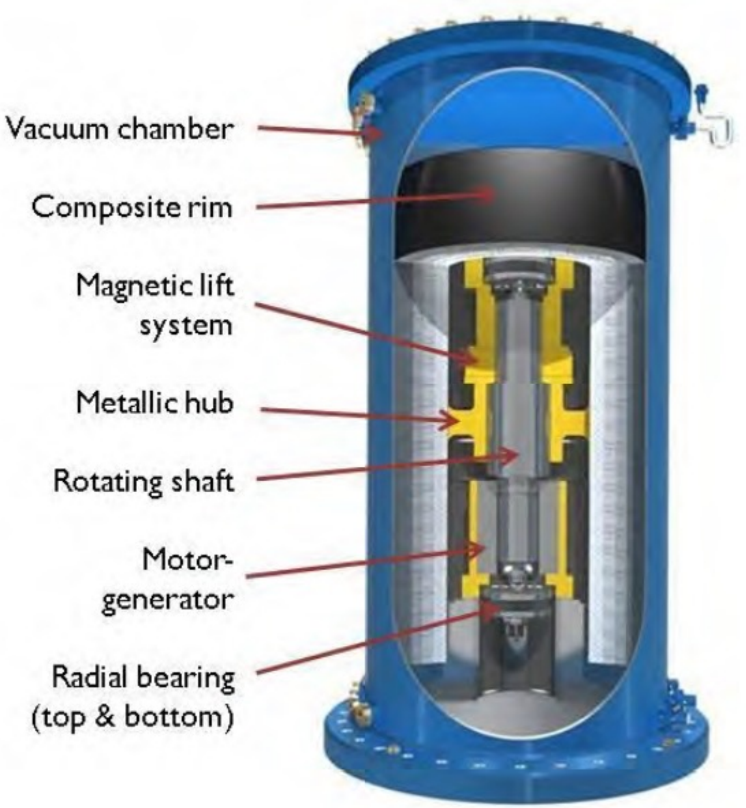
- rotational energy (*E*) stored in a flywheel is proportional to the inertia and angular velocity (ω)

$$E = \frac{1}{2}I\omega^2$$

- E increases with ω and I. The inertia can be increased by locating as much mass on the outside of the cylinder as possible.

Flywheel energy storage

- 20 MW Flywheel storage facility located in Stephentown, NY (just east of Albany)
- Flywheels used to stabilize energy supply on the local grid

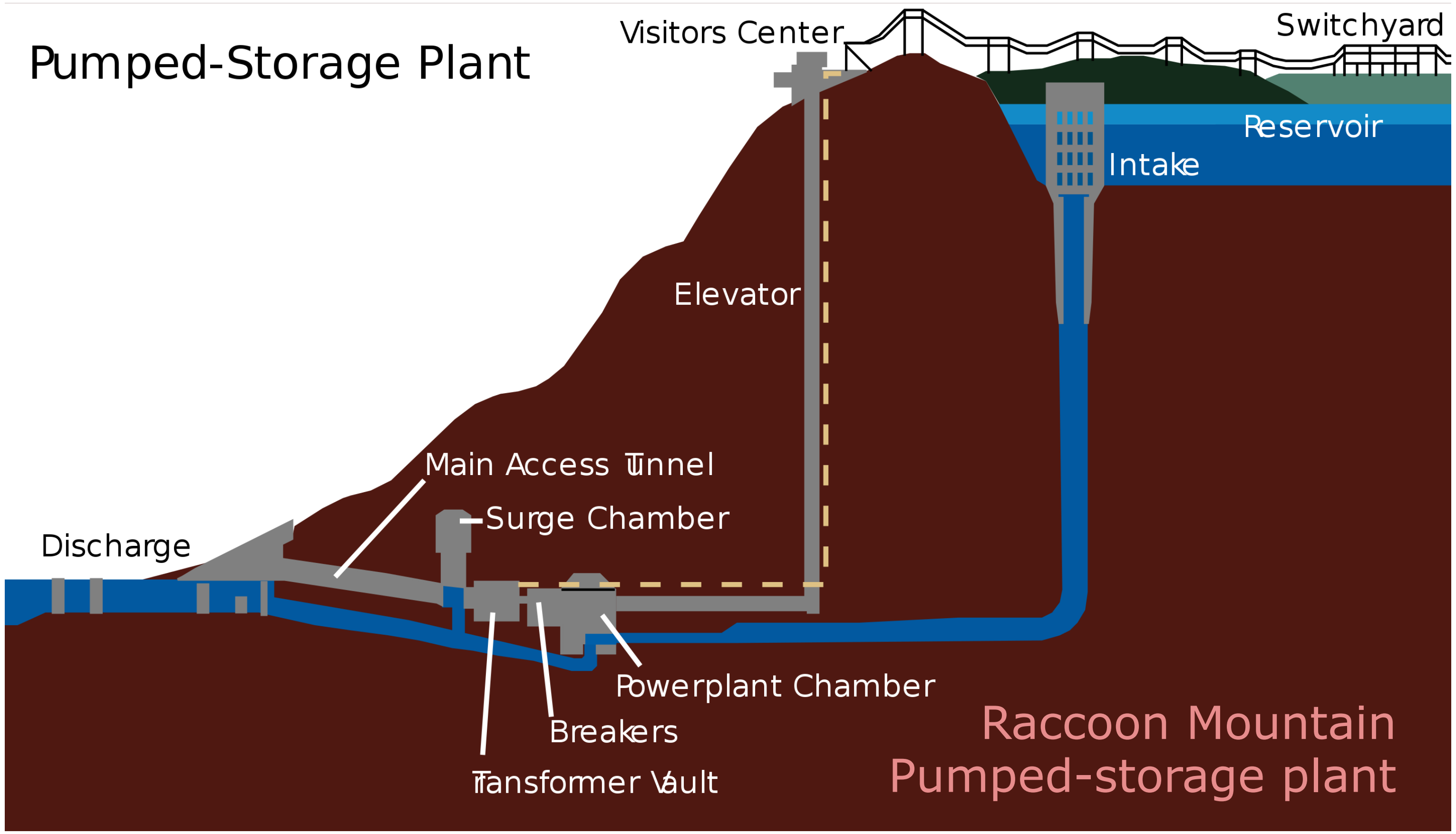


Flywheels in space

- Cubesats are small satellites that are launched using the spare capacity in rocket payload fairings
- Flywheels (or reaction wheels) are used on 3-axes to give satellites control over their orientation

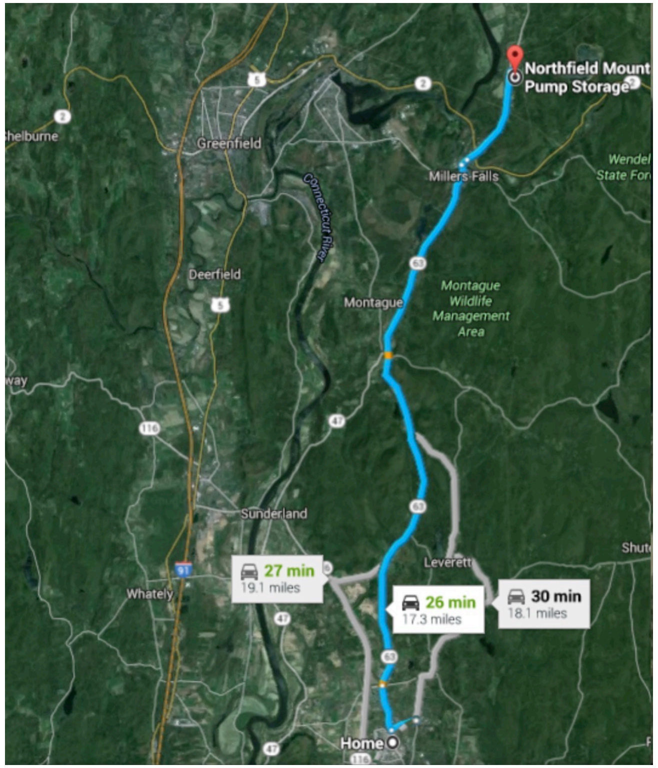
Pumped-storage hydroelectricity

- Low-cost off-peak electric power is used to pump water to a higher reservoirs. To meet periods of high demand, energy is released by passing the water through turbines.



Pumped-storage hydroelectricity

- Northfield mountain, just 20 mi north of Amherst, is a 300 acre, 5.6 billion gallon, 1080 MW facility that stores water 800 feet above the Connecticut river.
- First opened in 1972 and was the largest in the world at the time.



1 Watt = 1 N-m/s

1 Newton = 1 kg-m/s^2

Acceleration due to gravity: 9.8 m/s^2

1 liter of water is equivalent to 1 kg

Therefore: one liter of water released from 1m height can produce 9.8 Joules of energy

Take home messages from this module

- Power and energy usage is a necessary part of sustaining populations
- Michael Faraday created the first electric generator
  - converted mechanical energy into electrical energy
- Solar energy uses semiconductors and photons from the sun for creating electricity
  - maximum efficiency operating point (in terms of volts/amps) will change as a function of incident light intensity
- Transmission lines deliver energy from one location to another
  - constructed out of copper or aluminum
  - line loss is a function of current
- Transformers are used for stepping up and stepping down the line voltage
- Energy can be stored using electrochemical and other forms of converting kinetic energy into potential energy

Next time

- Next Monday, you will begin the module on Electromagnetics (Hollot)
- I will see you next in 3 weeks (Module 6: Optical Sensors)

Have a great day!