e·lec·tric·i·ty

ilek'trisitē

Kyle Bradbury
Postdoctoral Energy Fellow
Duke University Energy Initiative

What is electricity?

How do we generate it?

How do we “transport” it?

How do we consume it?

expanding the lexicon

alternating current

direct current

reactive power

power factor

combined cycle gas turbine (CCGT)

independent system operator (ISO)

line frequency

power system facts of life

- Supply and demand must be continuously balanced
- Electrons take the path of least resistance, which is not always the path of greatest convenience
- Forecast demand does not match real demand
- System reliability must be enforced

important electricity concepts

Voltage

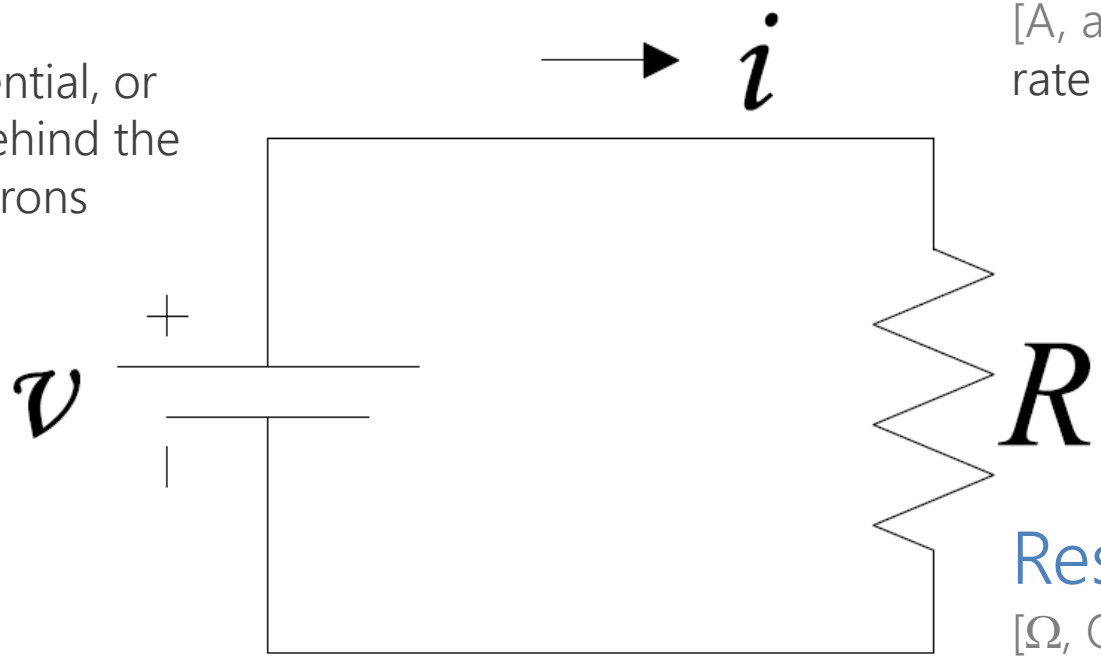
[V, volts]

electric potential, or "pressure"behind the flow of electrons

Current

[A, amperes]

rate of flow of electrons



Resistance

[Ω, Ohms]

Ohm's Law: $V = IR$

Power [Watts]: $P = VI$

adapted from Lincoln Pratson's Energy & Environment Course Slides

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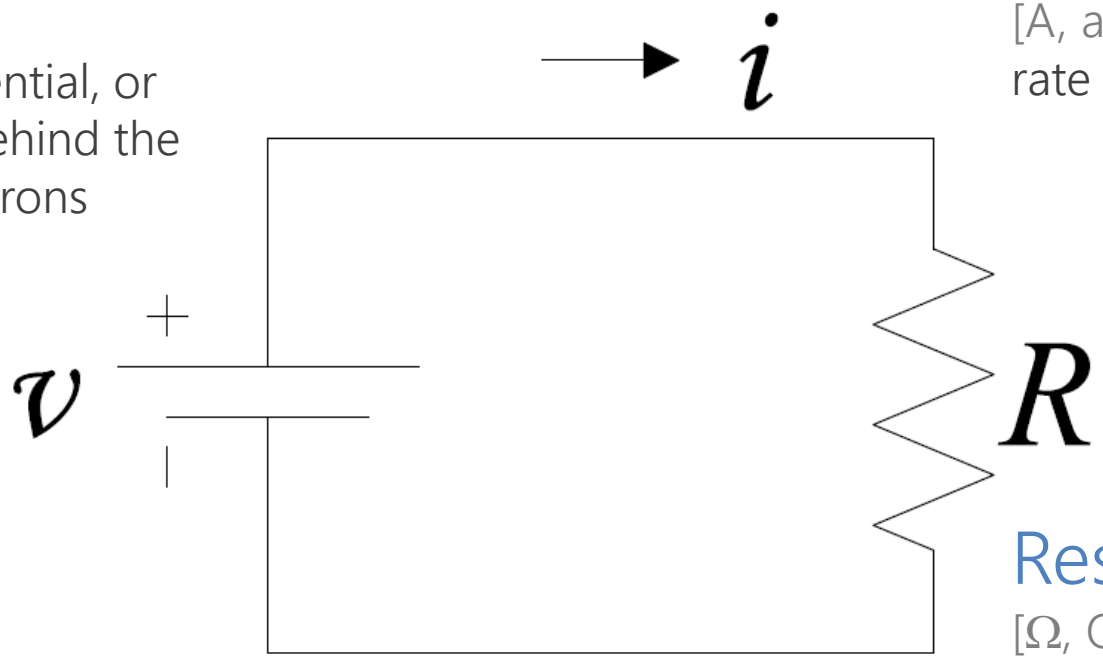


Resistance
[Ω, Ohms]

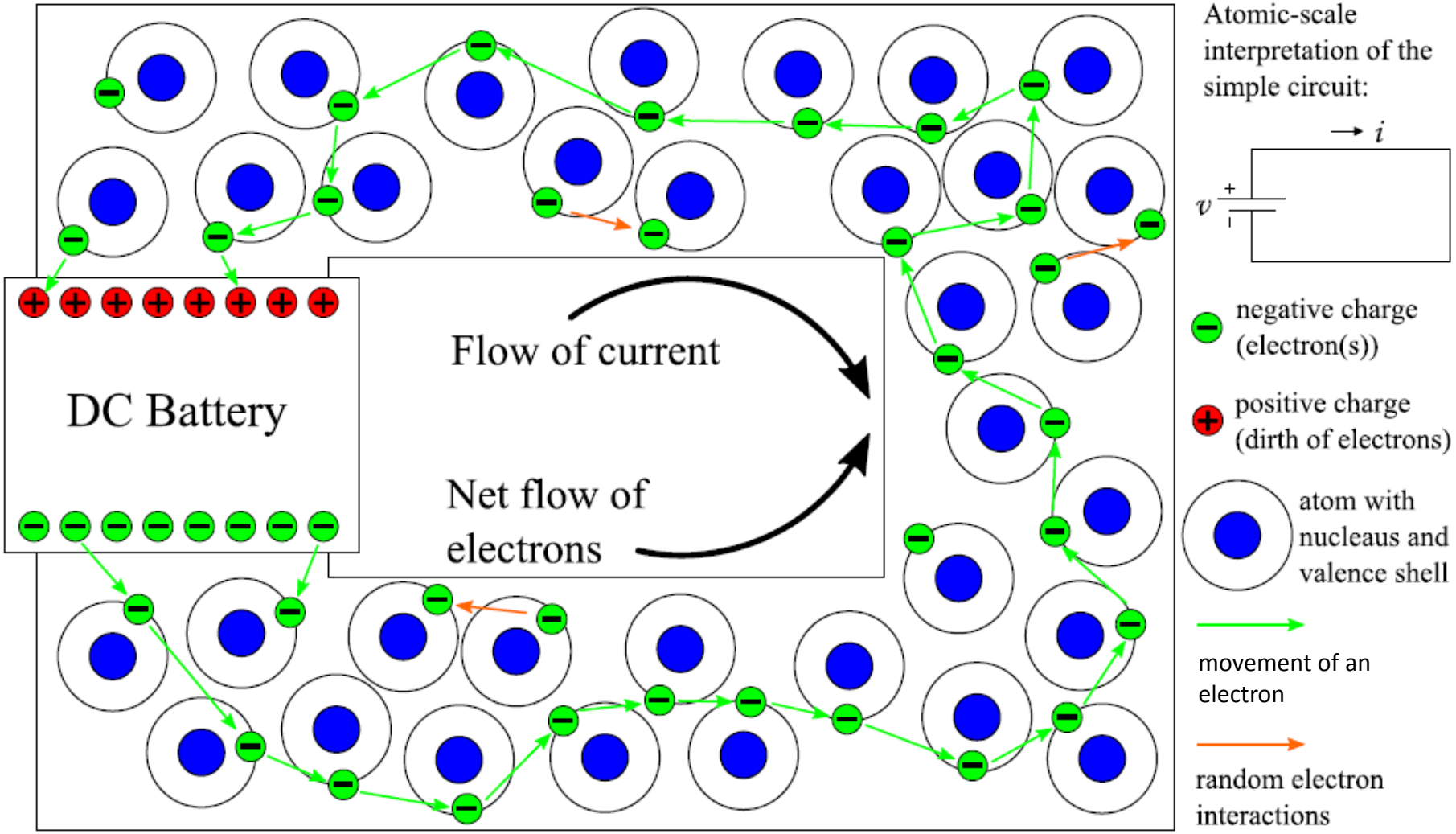
Proper use of terminology:
Voltage across…
Voltage with respect to…
Current through…

Ohm's Law: $V = IR$

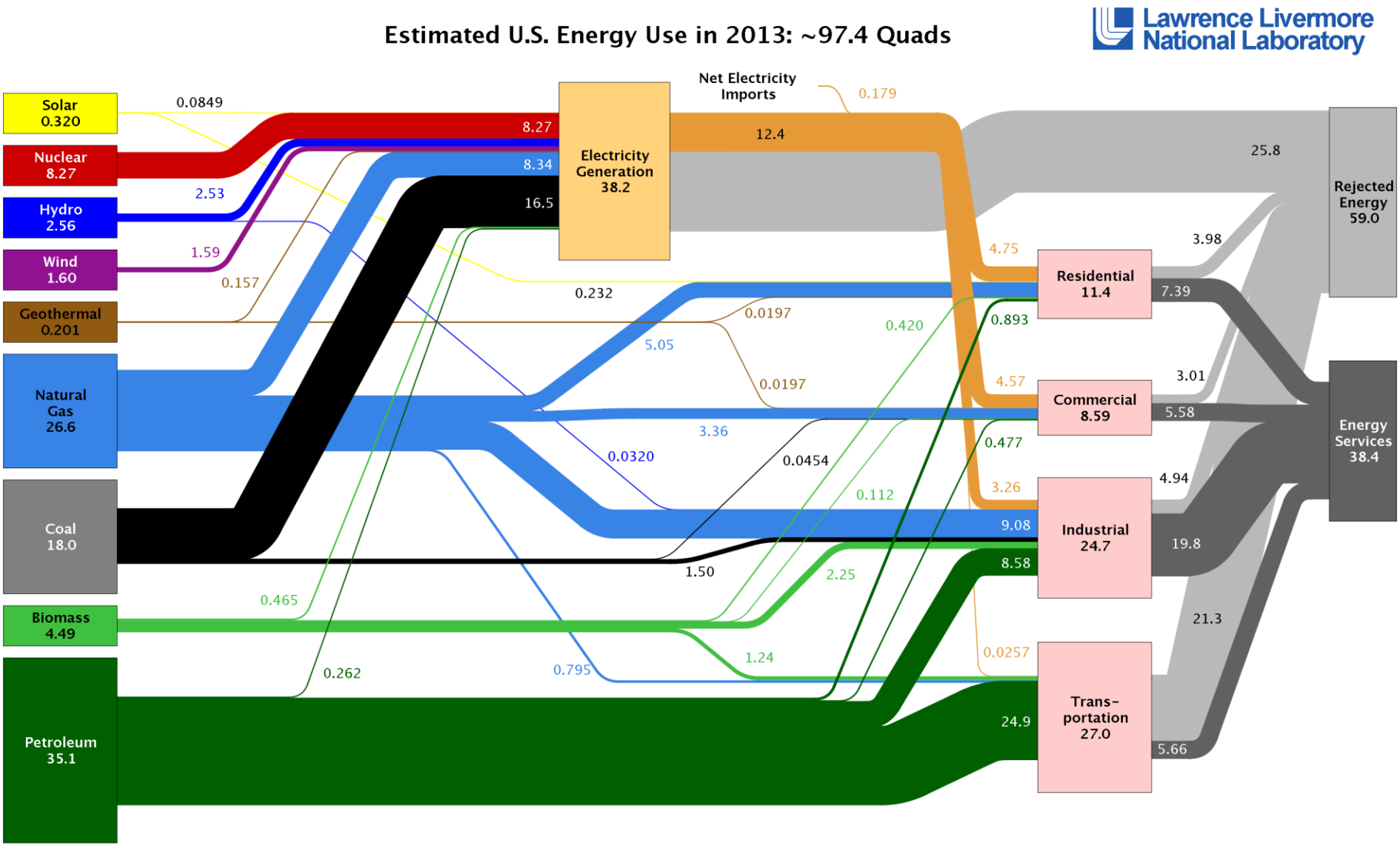
Power [Watts]: $P = VI$

adapted from Lincoln Pratson's Energy & Environment Course Slides

electron "flow"

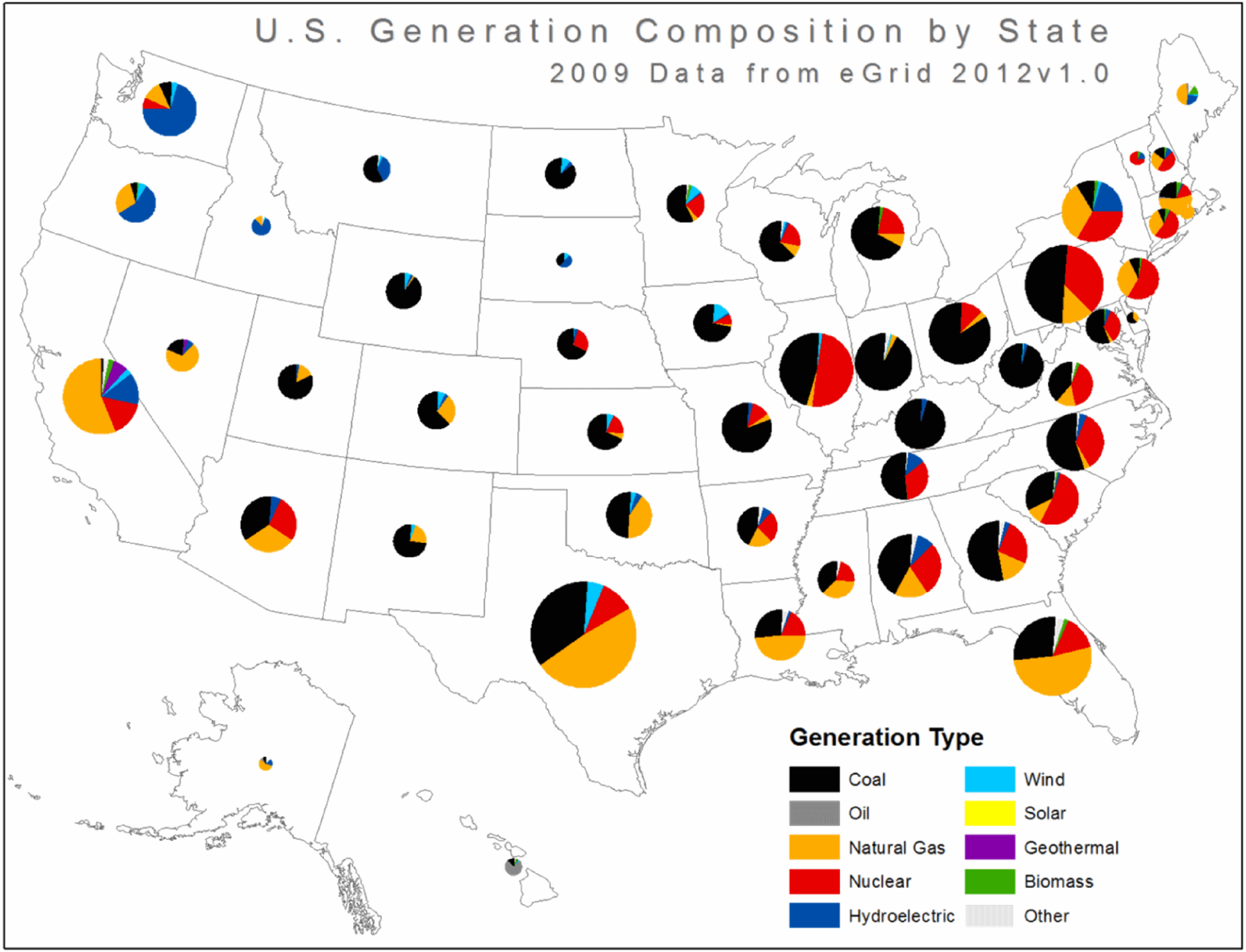


the famous Sankey diagram



Source: LLNL 2014. Data is based on DOE/EIA-0035(2014-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

image from: https://flowcharts.llnl.gov/


U.S. Generation Composition by State
2009 Data from eGrid 2012v1.0
Generation Type
Coal
Oil
Natural Gas
Nuclear
Hydroelectric
Wind
Solar
Geothermal
Biomass
Other

electric power systems

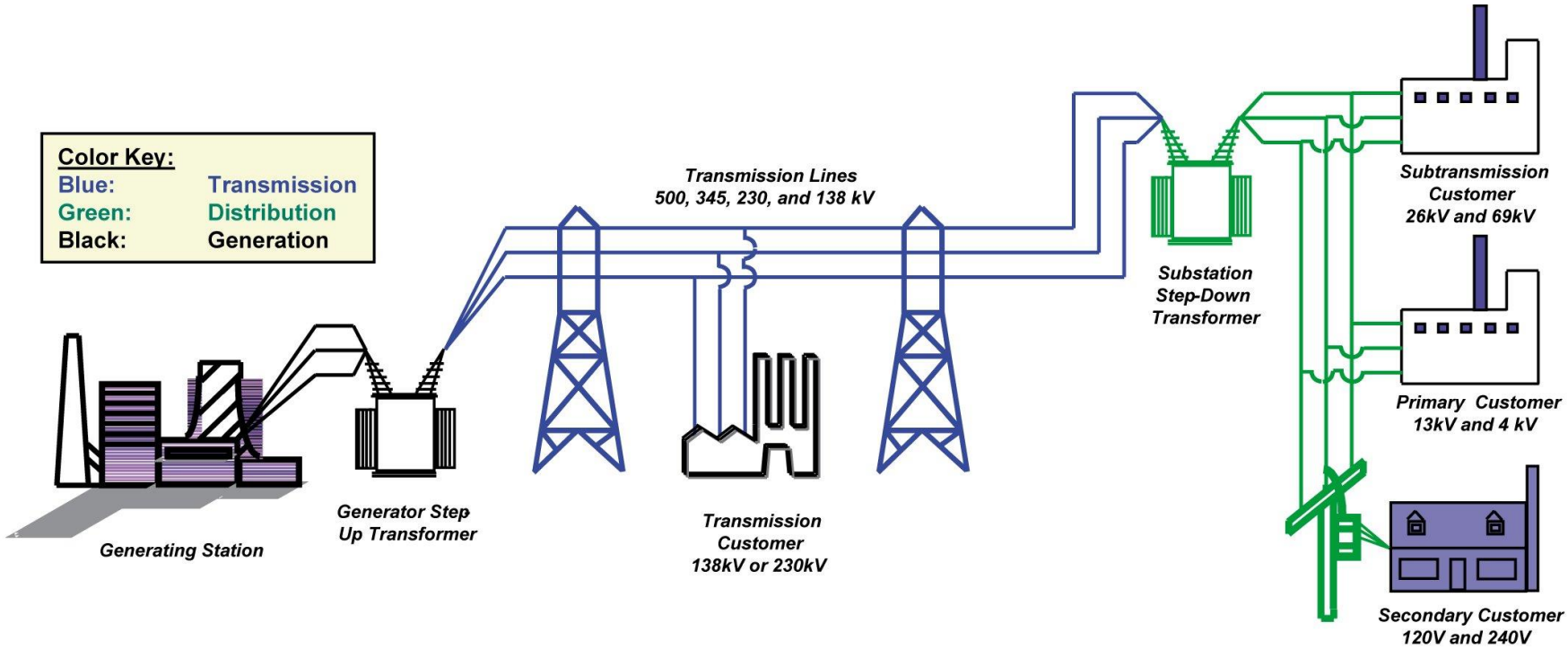
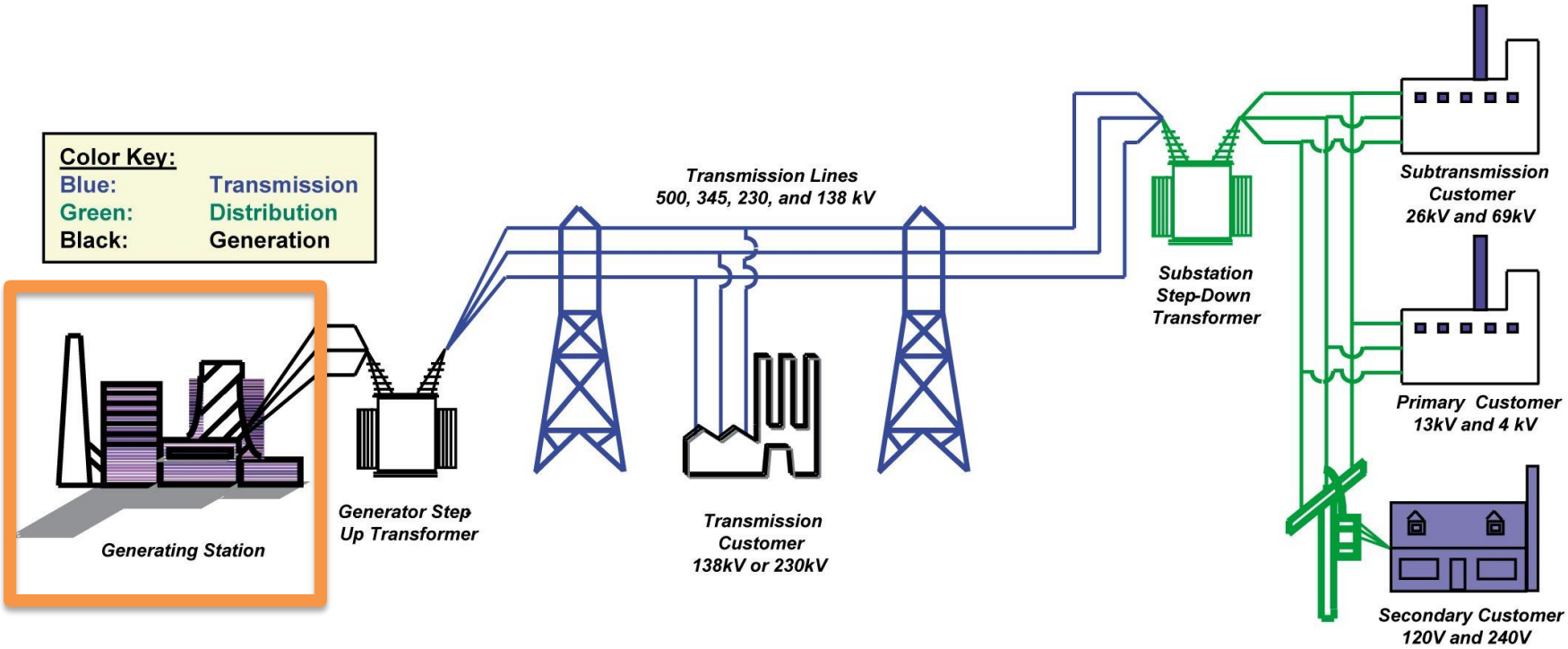


image from http://www2.econ.iastate.edu/

electric power systems



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thermal power station

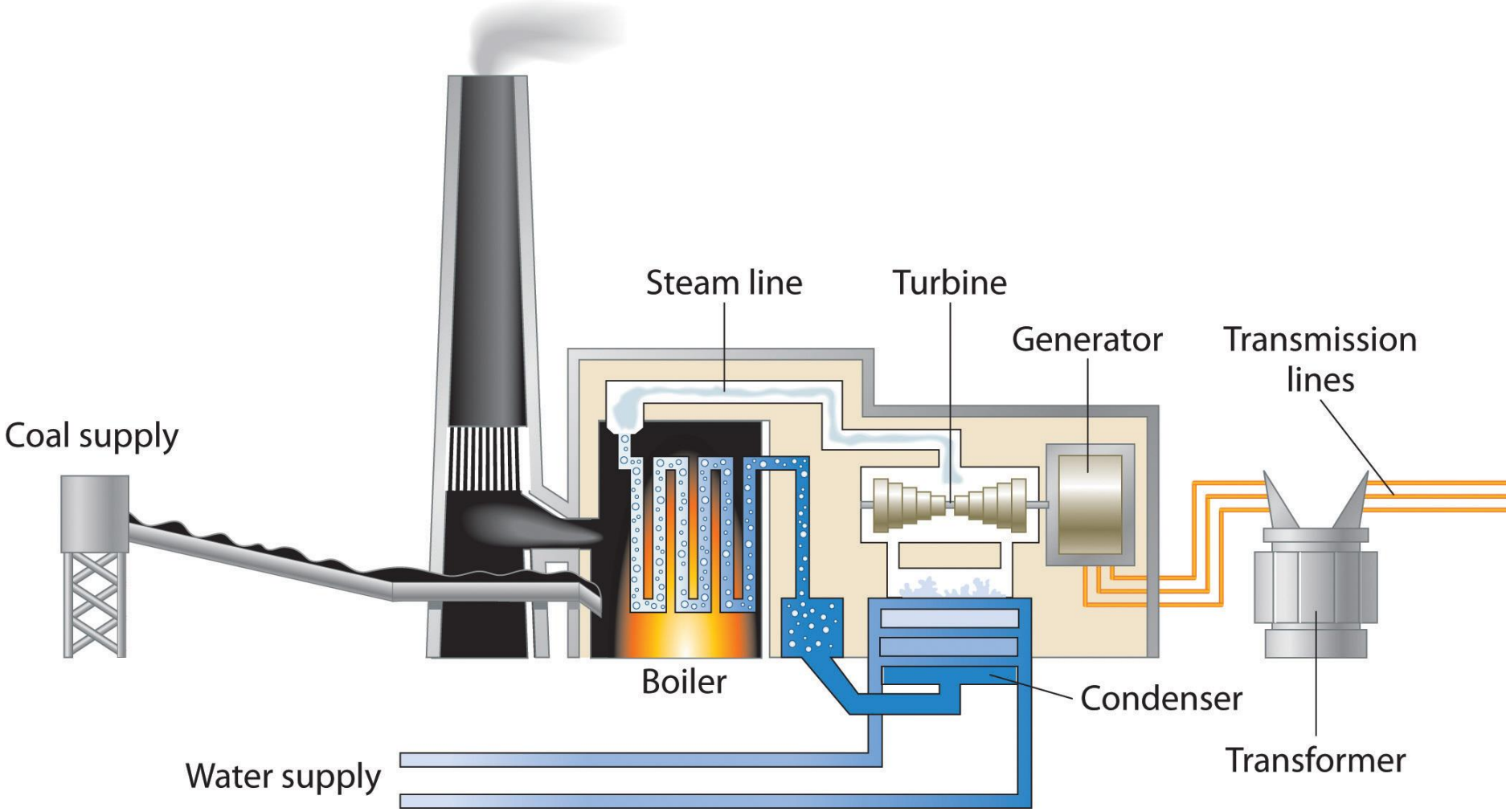

Image from General Chemistry: Principles, Patterns, and Applications, v. 1.0 (2 Volume Set) by Bruce Averill and Patricia Eldredge

Turbine Deck at Diablo Canyon Power Station

1,100 MW Generator

image from: http://depletedcranium.com

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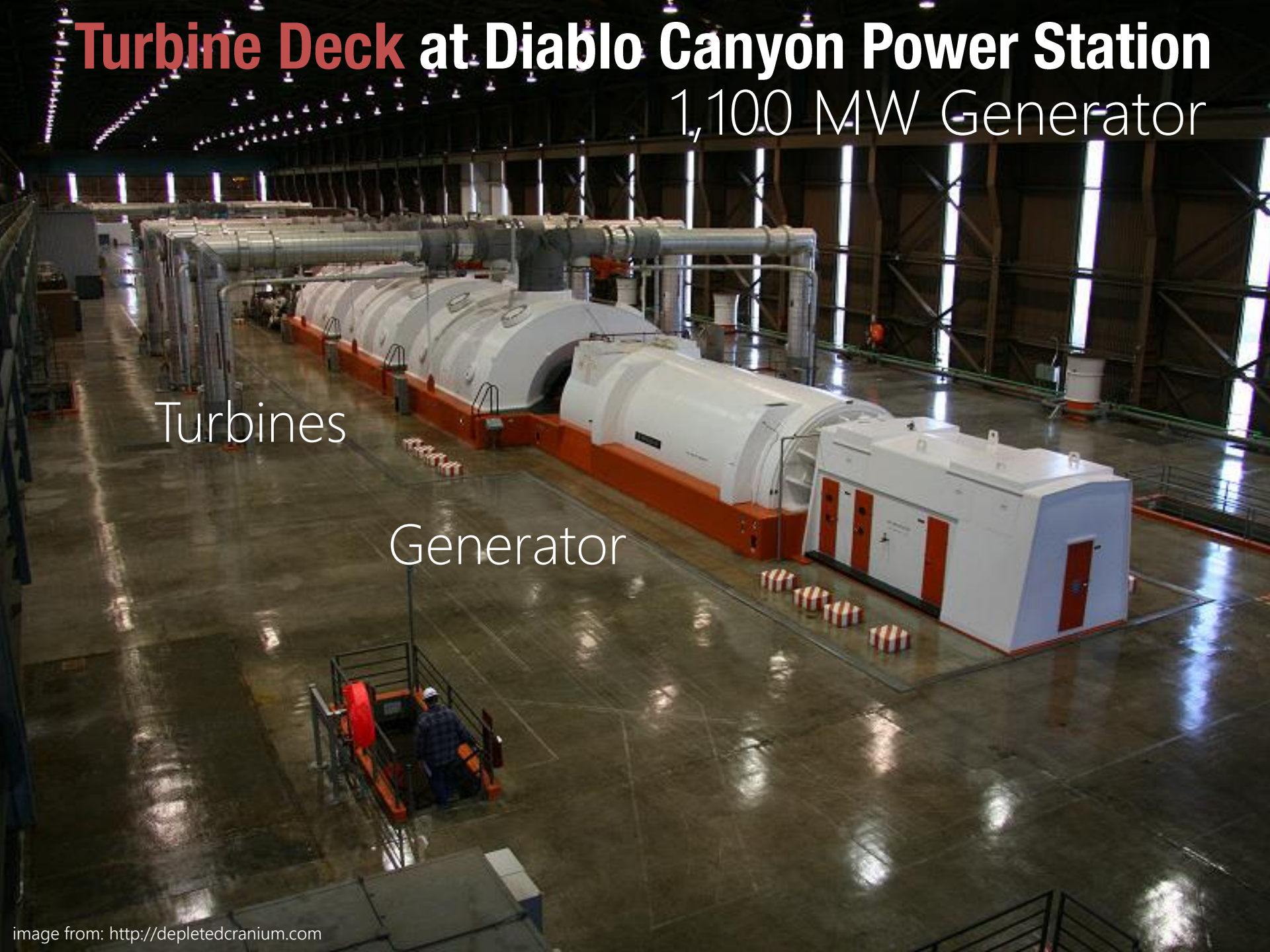

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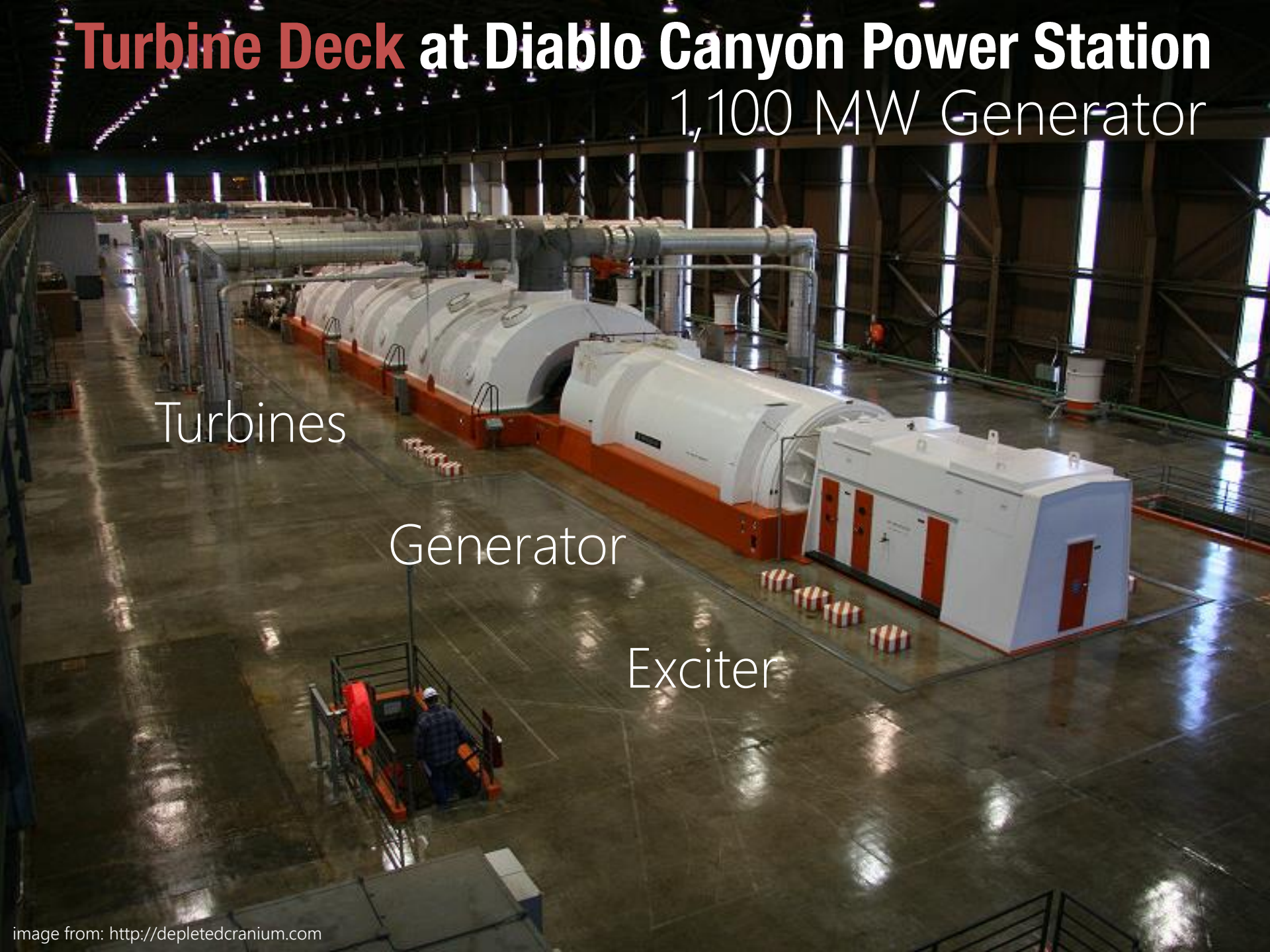


image from: http://depletedcranium.com

turbines

Low Pressure Turbine

High Pressure Turbine

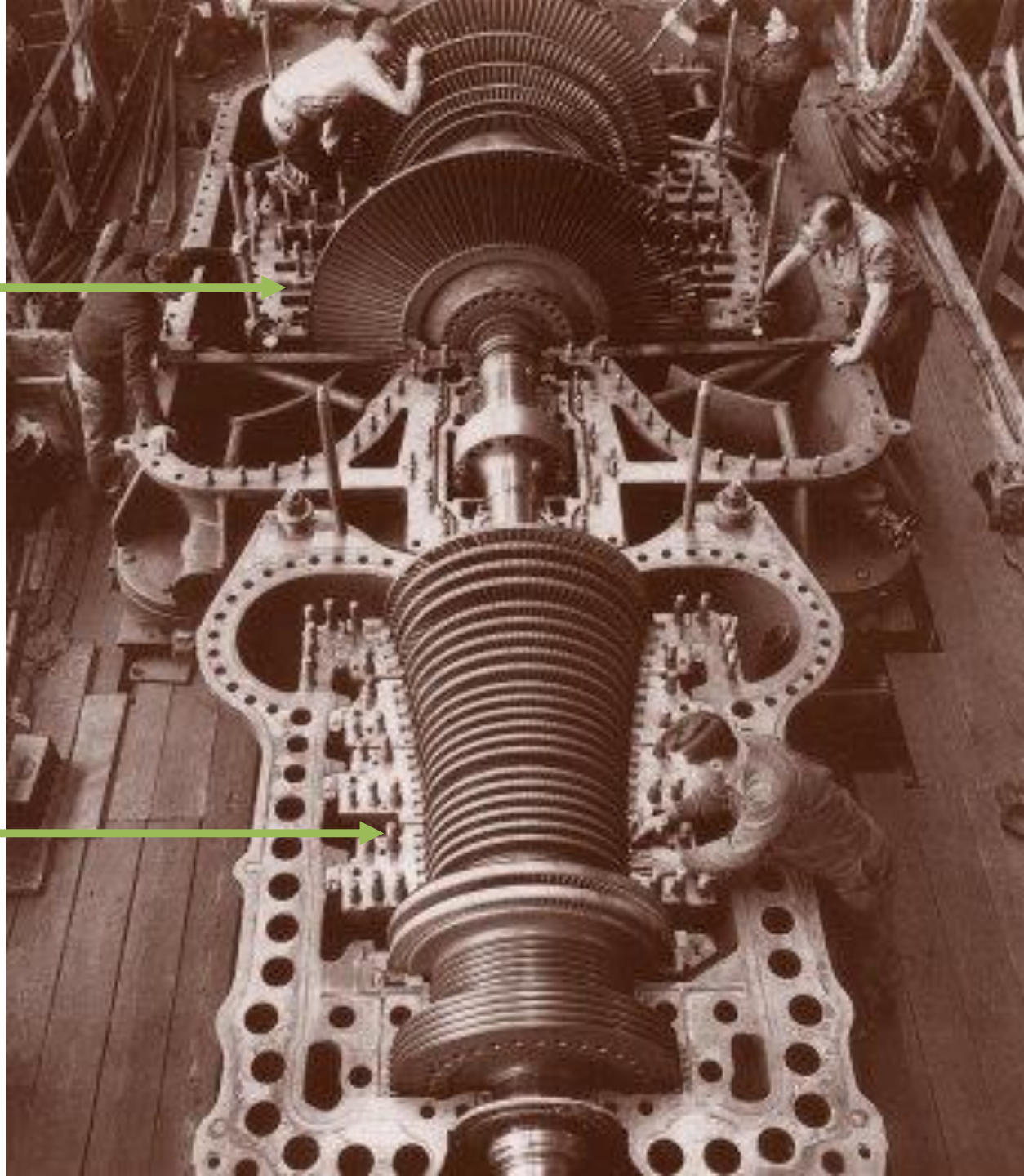


Photo from http://www.allposters.com

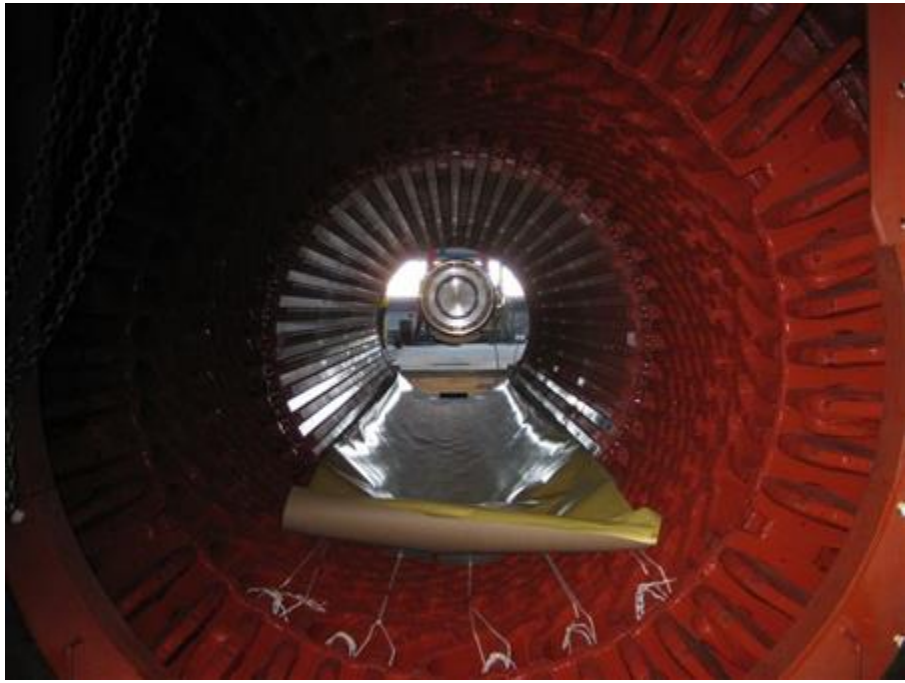
low pressure turbine

Image: "Turbine Philippsburg-1" by Christine und David Schmitt from Vienna, Austria, Austria - Flickr photo page "Dampfturbine"

generator

ROTOR

this is the "magnet" that spins (*weighs 61 tons*)



STATOR

stationary component that contains wound wire for the power to flow through

Images from http://basinelectric.wordpress.com/2009/08/14/generator-coming-together-at-dry-fork-station/

this is a synchronous machine

spins at 3600 rpm, 60 cycles per second (Hz)

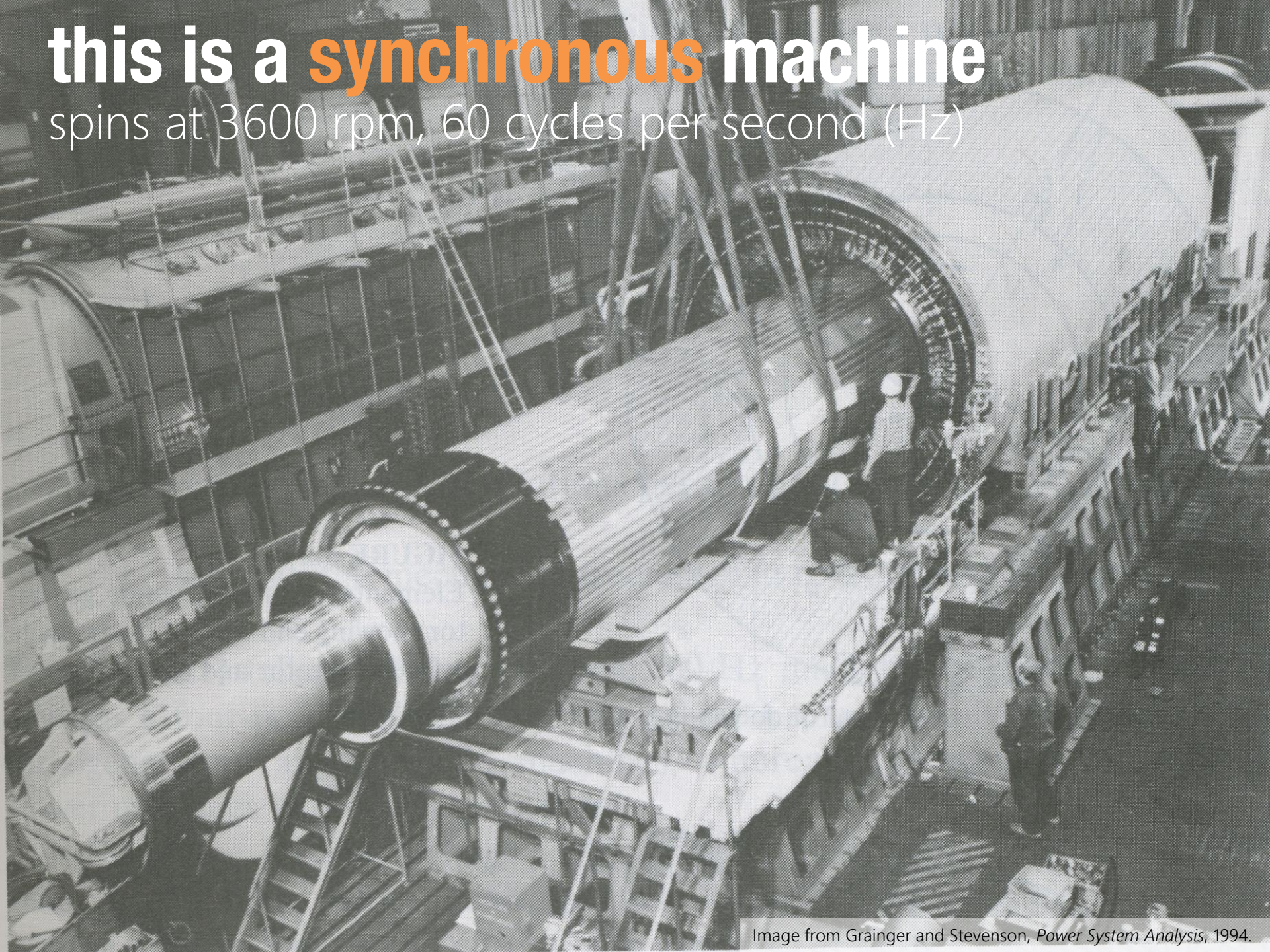
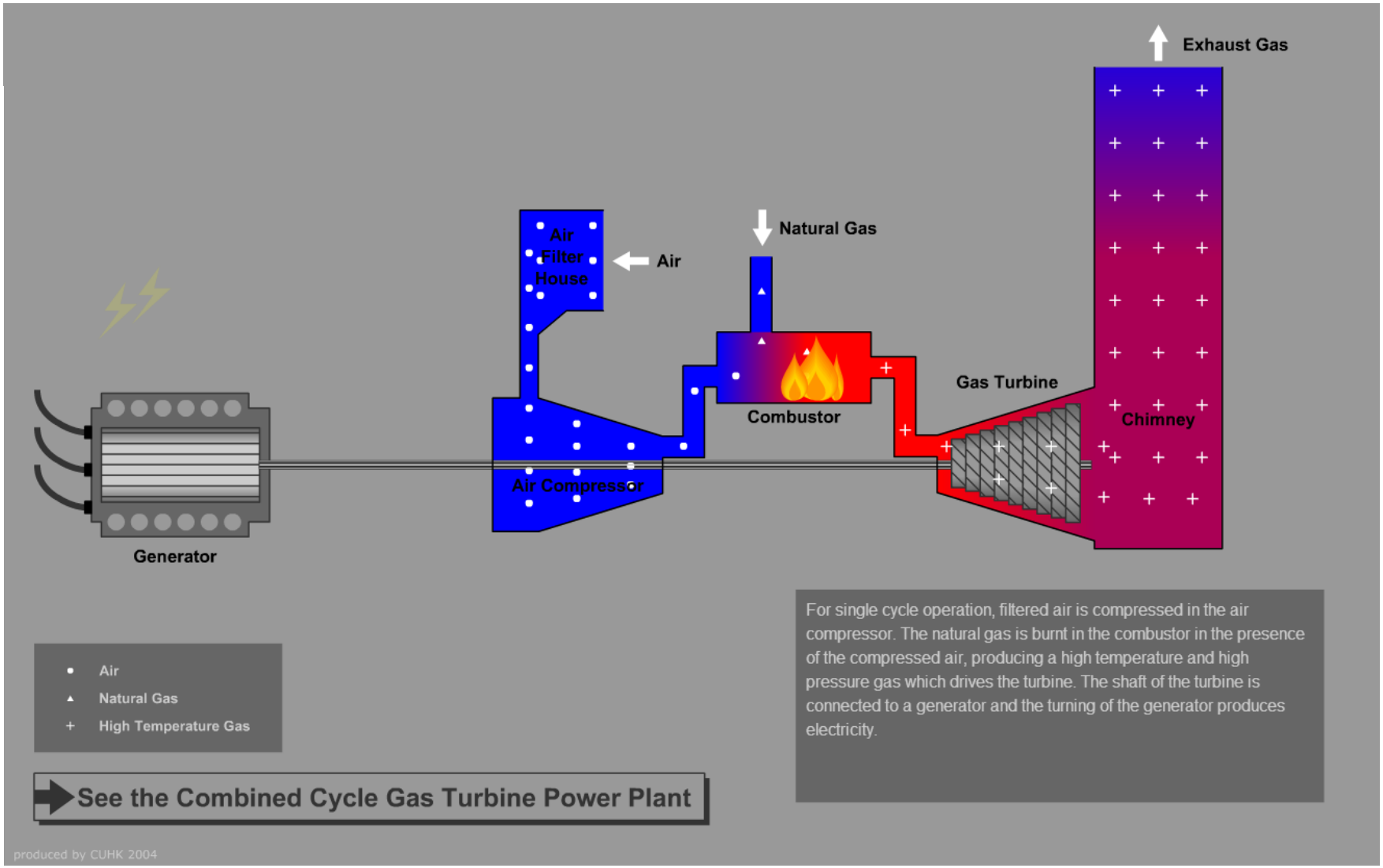


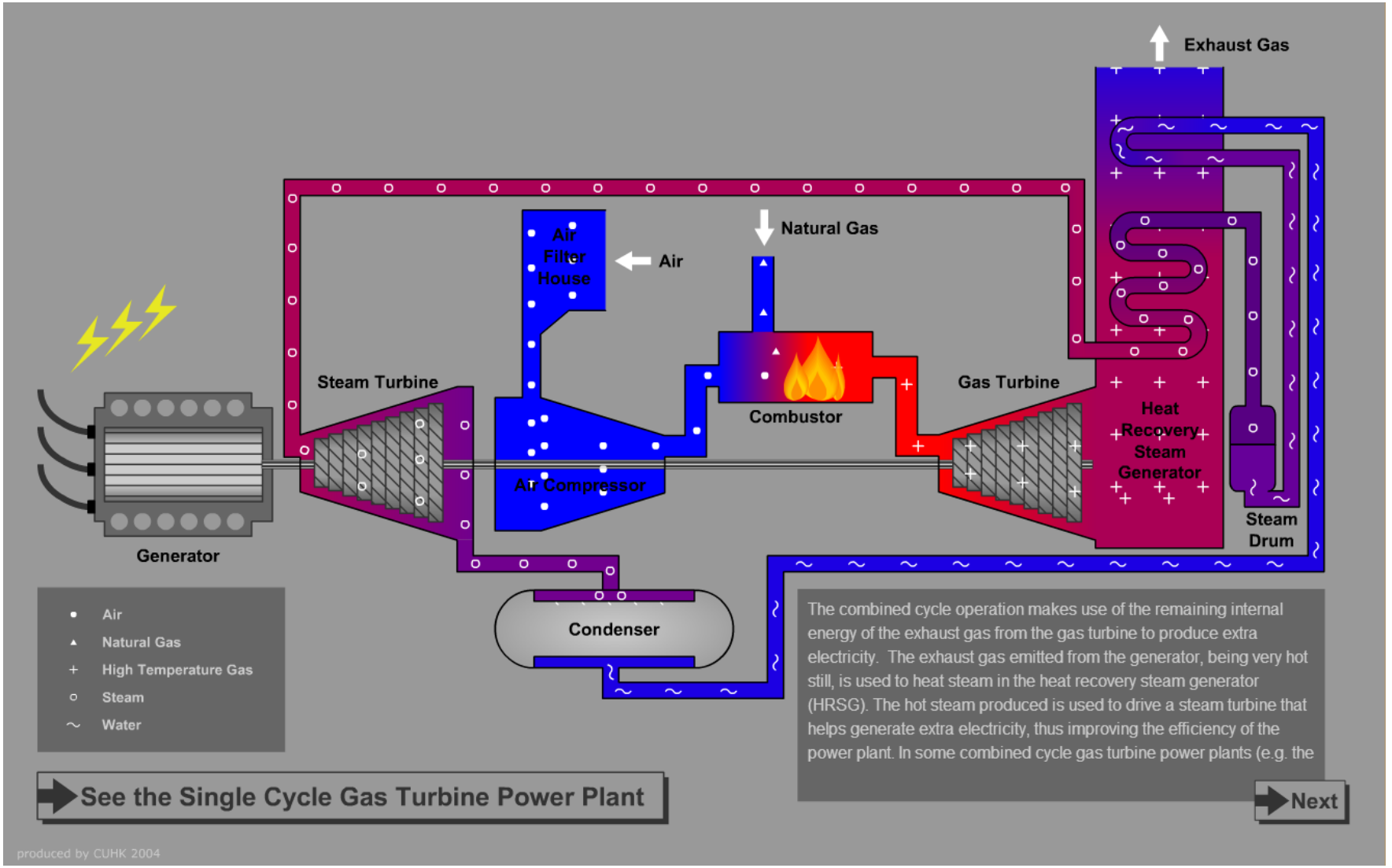
Image from Grainger and Stevenson, *Power System Analysis*, 1994.

single cycle gas turbine



http://www.hk-phy.org/energy/power/elect_phy/flash/powerplant_e.html

combined cycle gas turbine



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hydroelectric plant

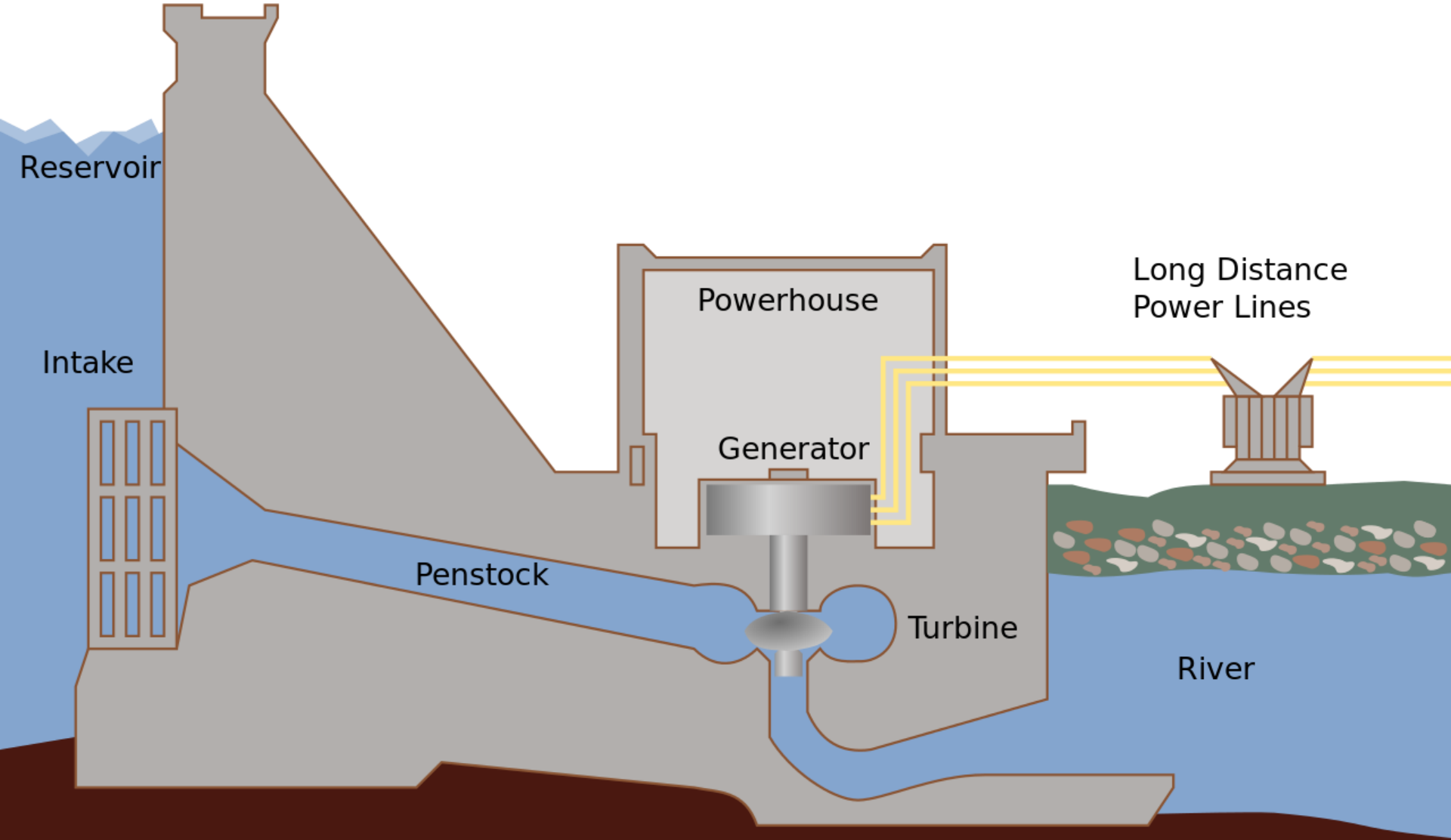

Image: "Hydroelectric dam" by Tomia - Own work. http://en.wikipedia.org/wiki/Hydroelectricity#mediaviewer/File:Hydroelectric_dam.svg

electric power systems

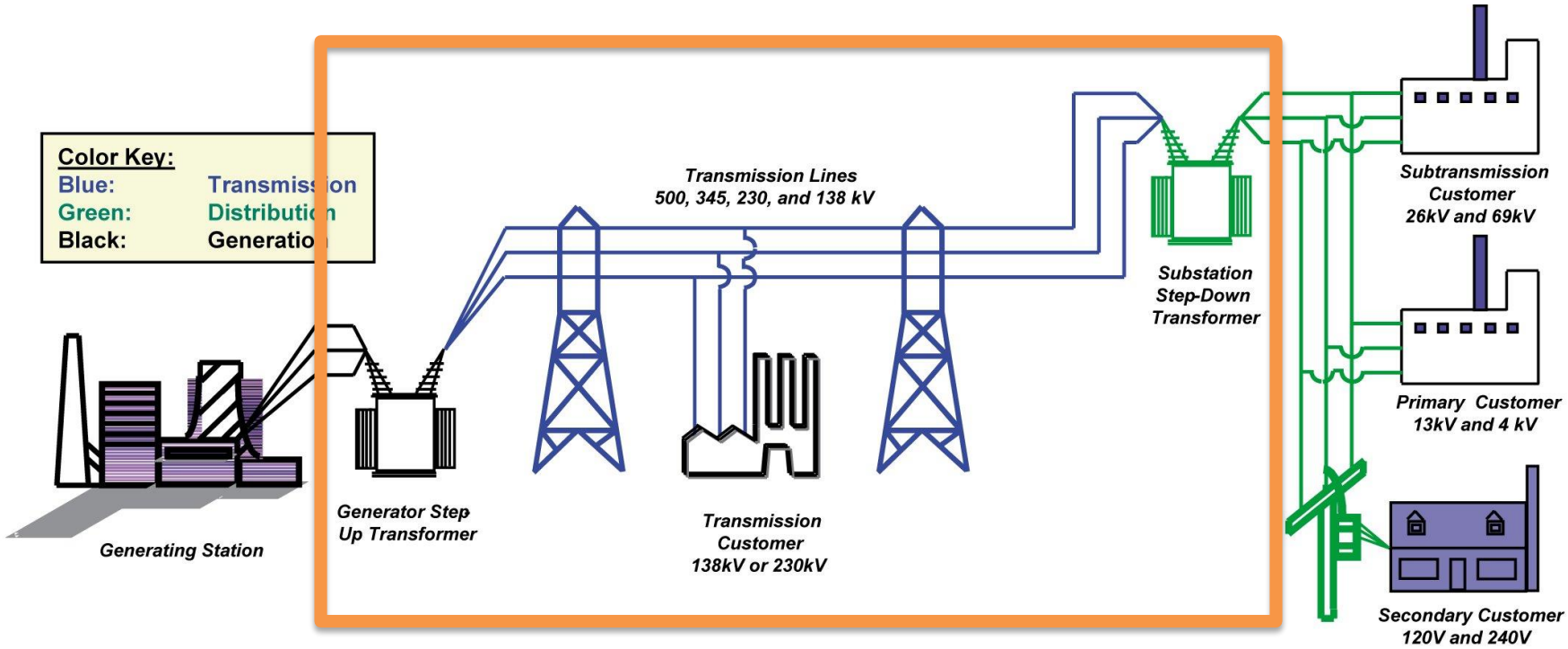

image from http://www2.econ.iastate.edu/

why high voltage transmission?

Ohm's Law: $V = IR$

Power (Watts): $P = VI$

Resistive power losses:

$P_L = I^2 R$

Power loss is proportional to the square of the current

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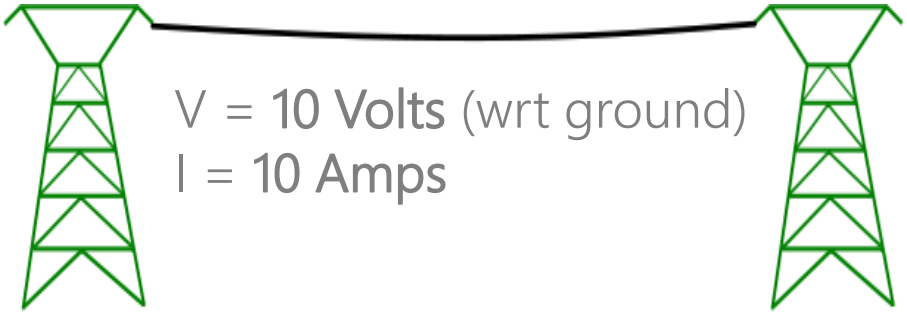

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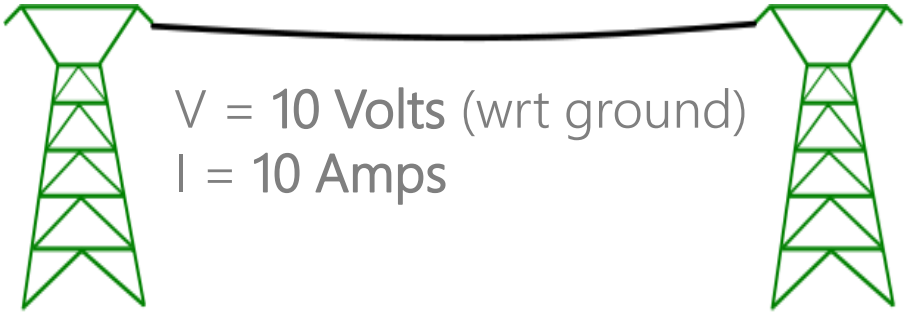

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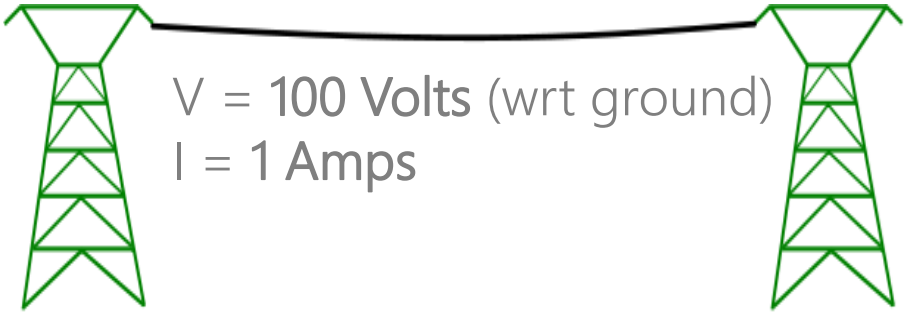

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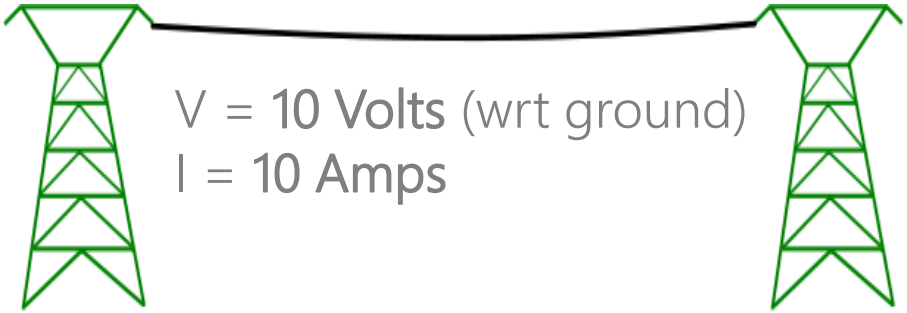

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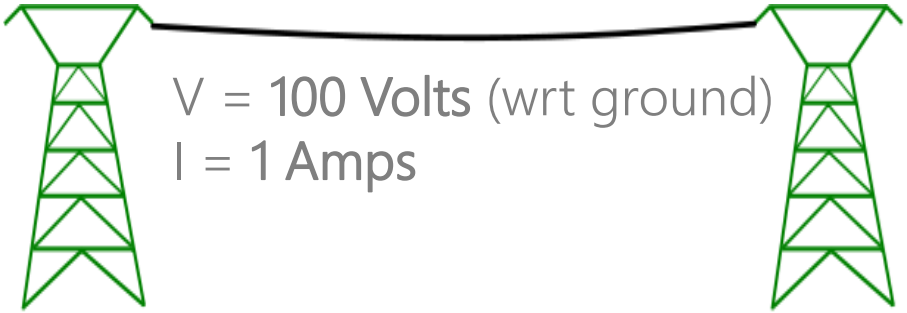

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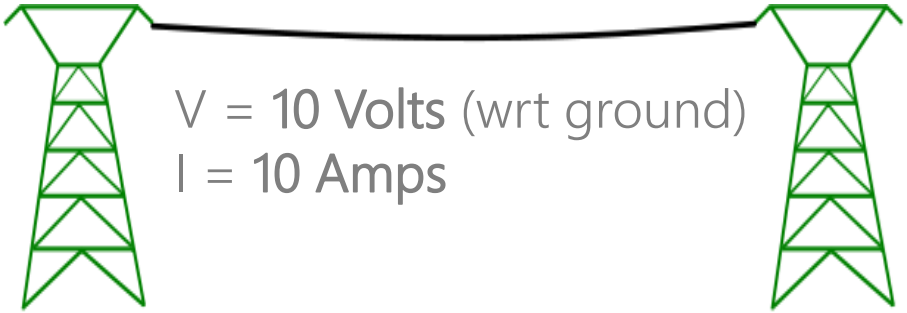
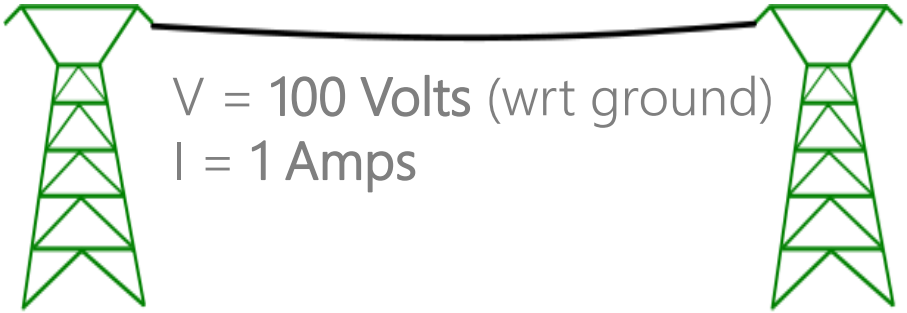


V = **10 Volts** (wrt ground)
I = **10 Amps**

$P_L = I^2R = (100)(0.1)$
= 10 Watts

Scenario 2:



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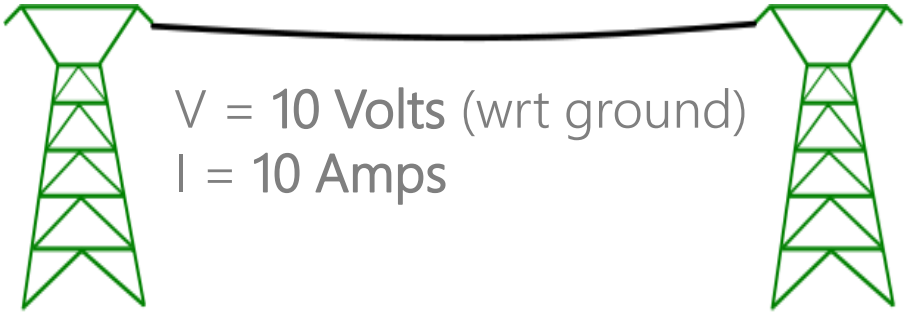

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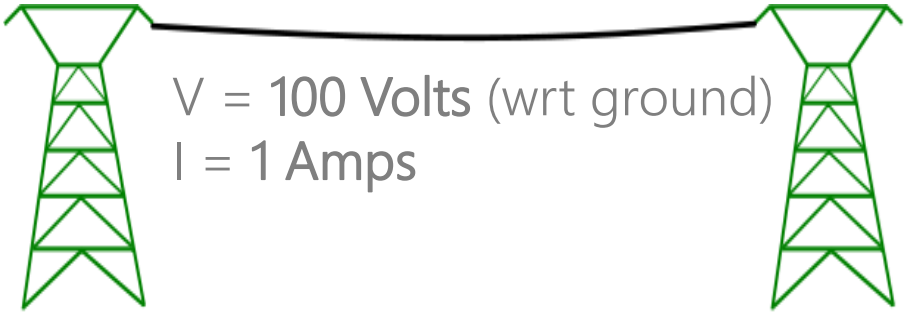
Scenario 2:



V = **100 Volts** (wrt ground)
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$= 0.1$ Watts

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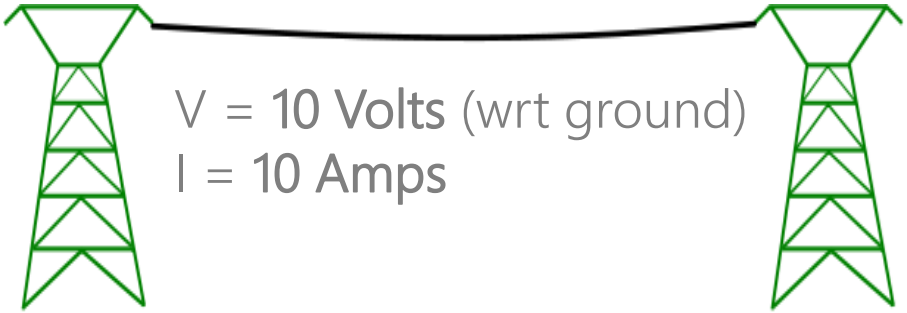

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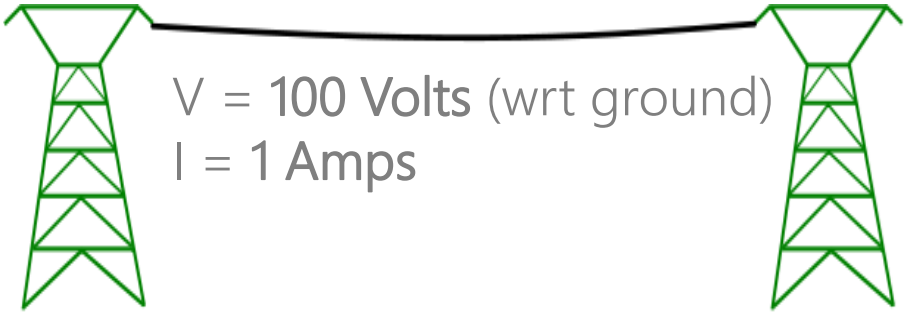
Scenario 2:



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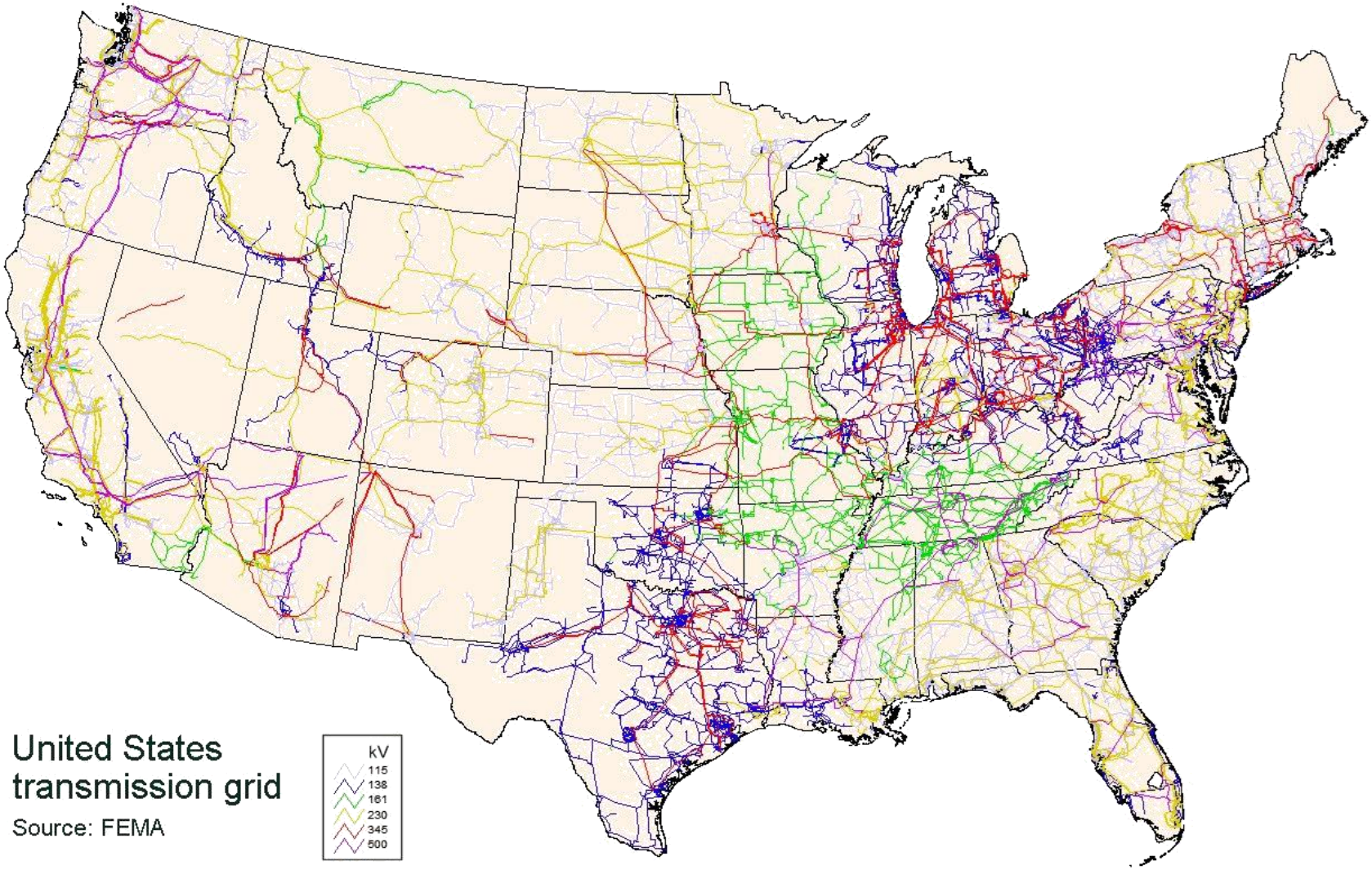
Note: In practice, high voltage is > 35kV

transmission



United States
transmission grid

Source: FEMA

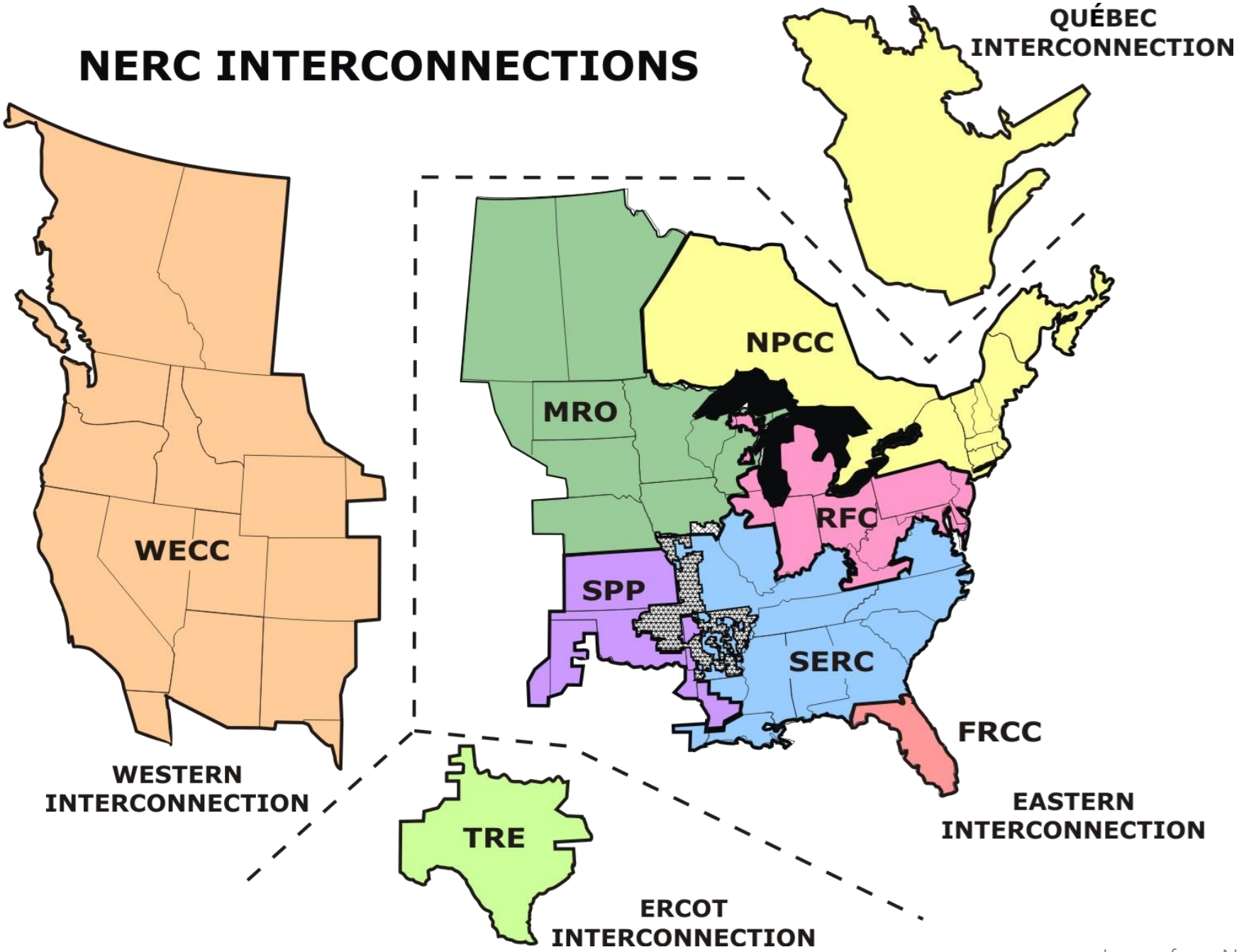
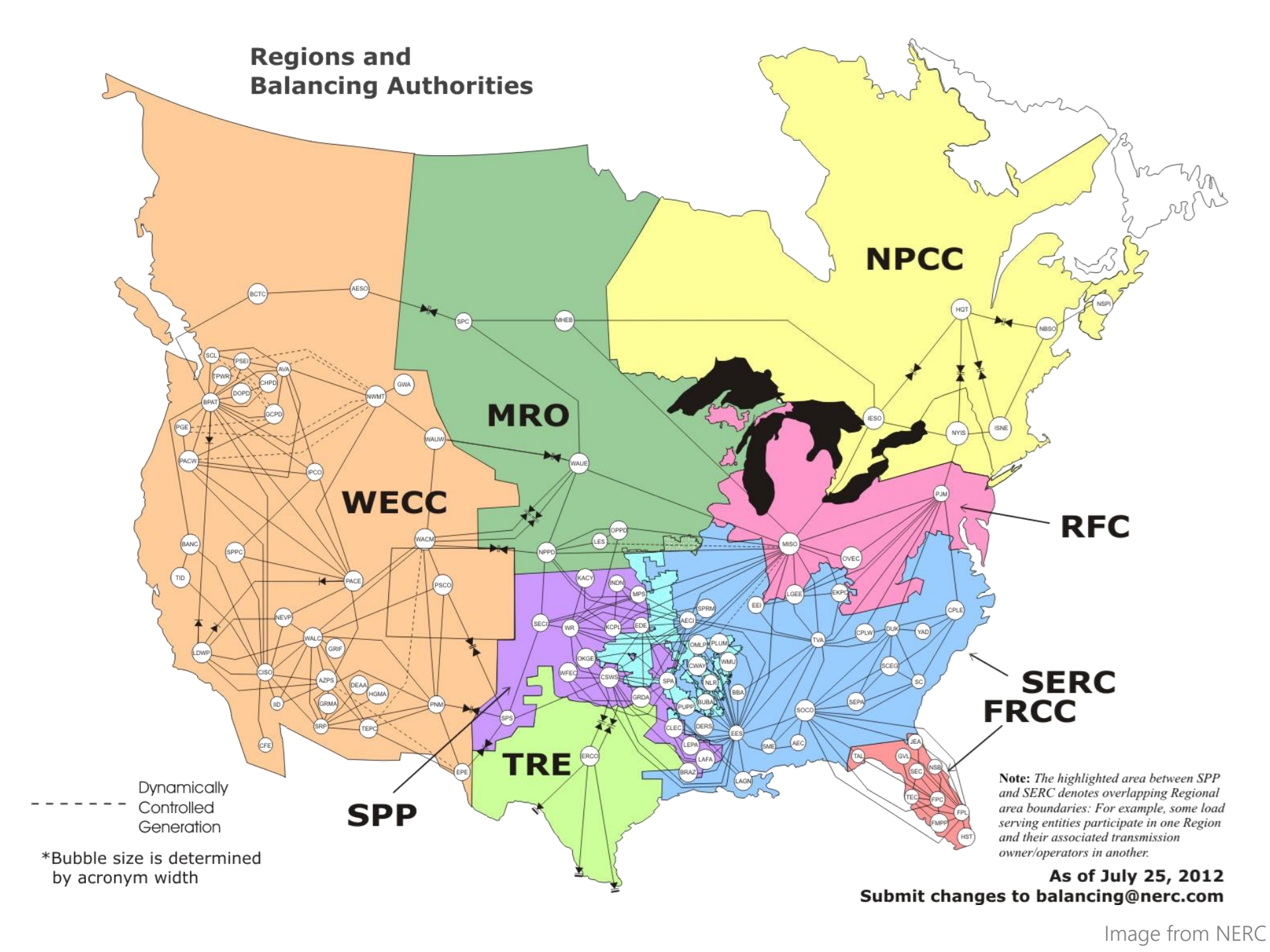


Image from NERC



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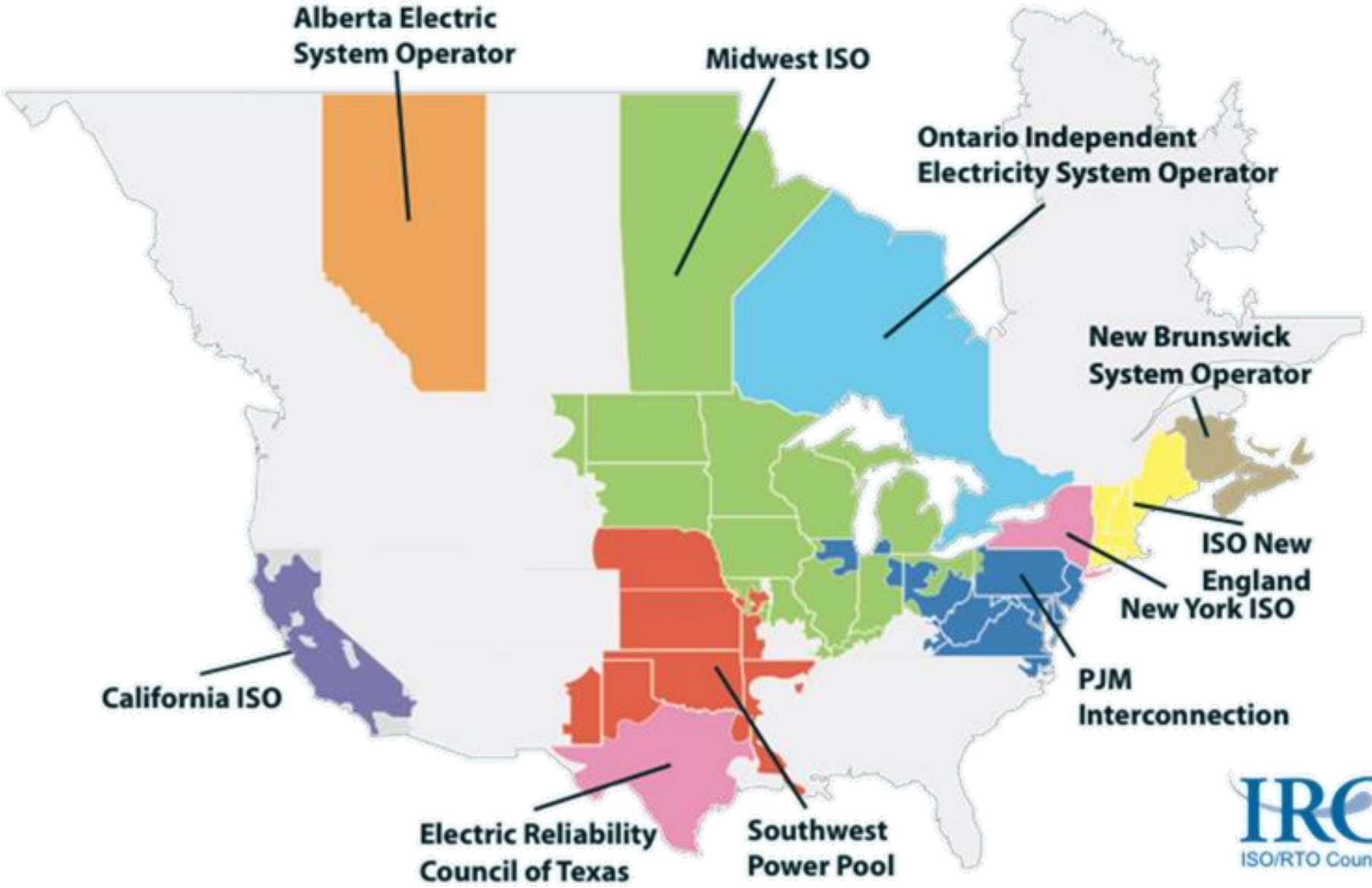


image from http://www.opuc.texas.gov/ERCOT.html

generator outage

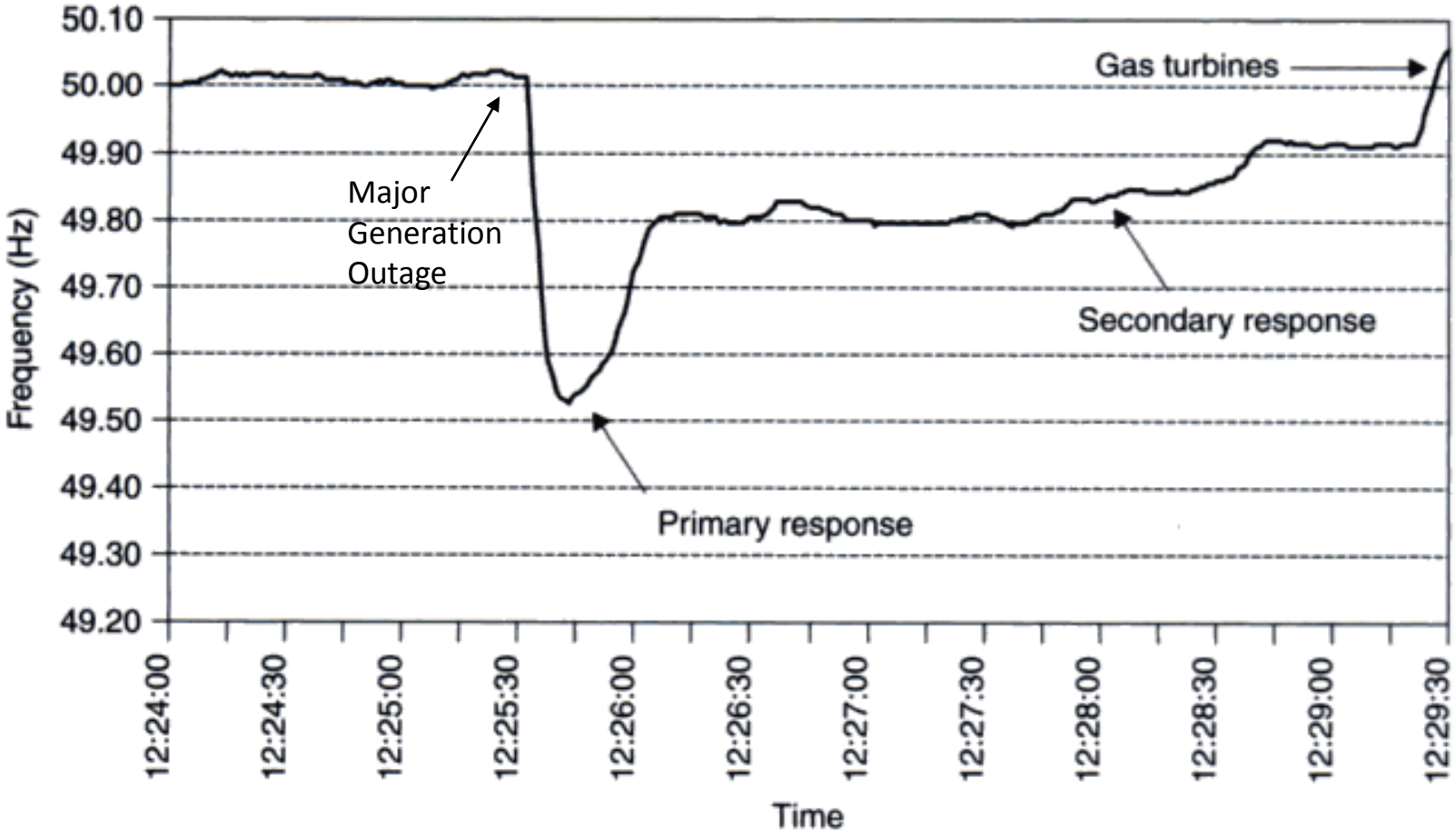
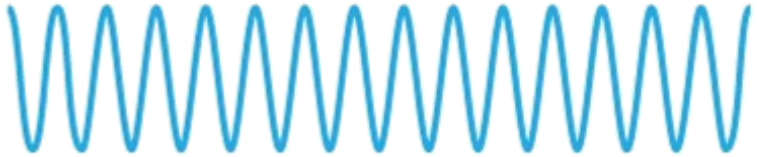


Image from Kirschen and Strbac, Power System Economics, 2005

image from http://images2.fanpop.com/

Alternating Current



Direct Current

	AC	DC
pros	• Cheap to step up and down • Power generated at high voltage AC	• Requires 2 conductors • Fewer losses at higher voltage • Smaller power lines required
cons	• Power lines must be larger and more expensive • Losses are greater over these lines • Requires 3 conductors	• Electric power is not generated at high voltage DC • Expensive to step up and down the voltage

reactive power

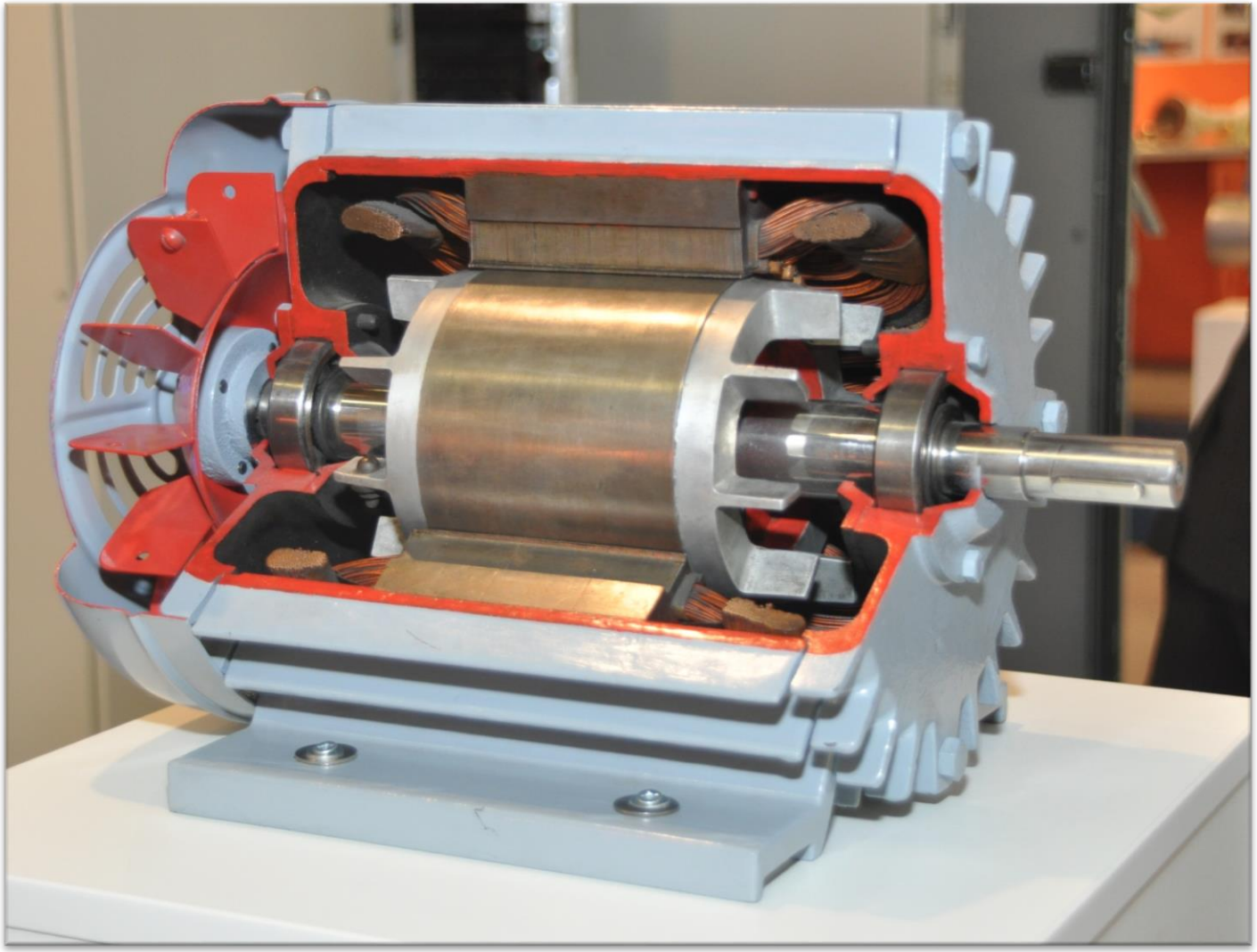
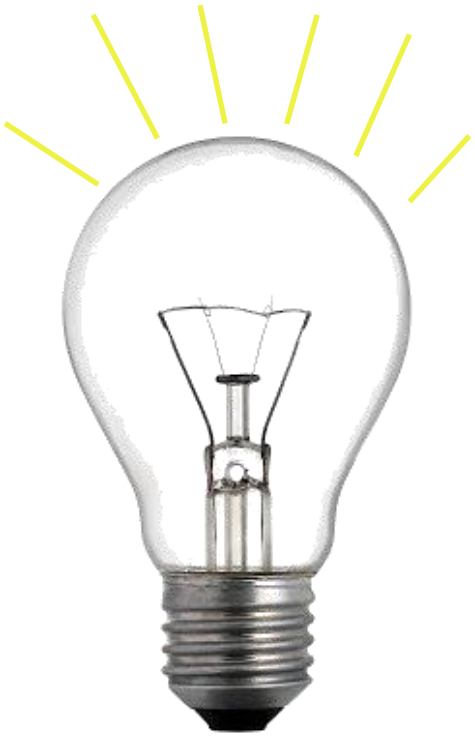


Image from http://en.wikipedia.org/

real power

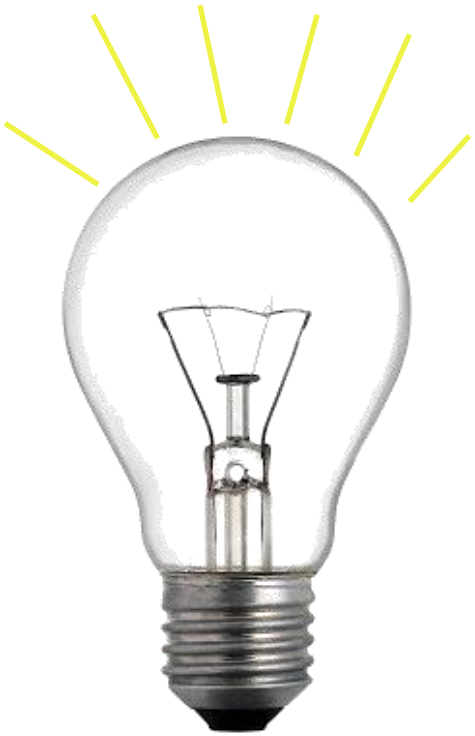


real + reactive power

Left image from http://asimoicedtea.blogspot.com/

Right image from http://image.made-in-china.com/

real power **real + reactive power**



Power Factor = fraction of total power that is real power

Left image from http://asimoicedtea.blogspot.com/

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electric power systems

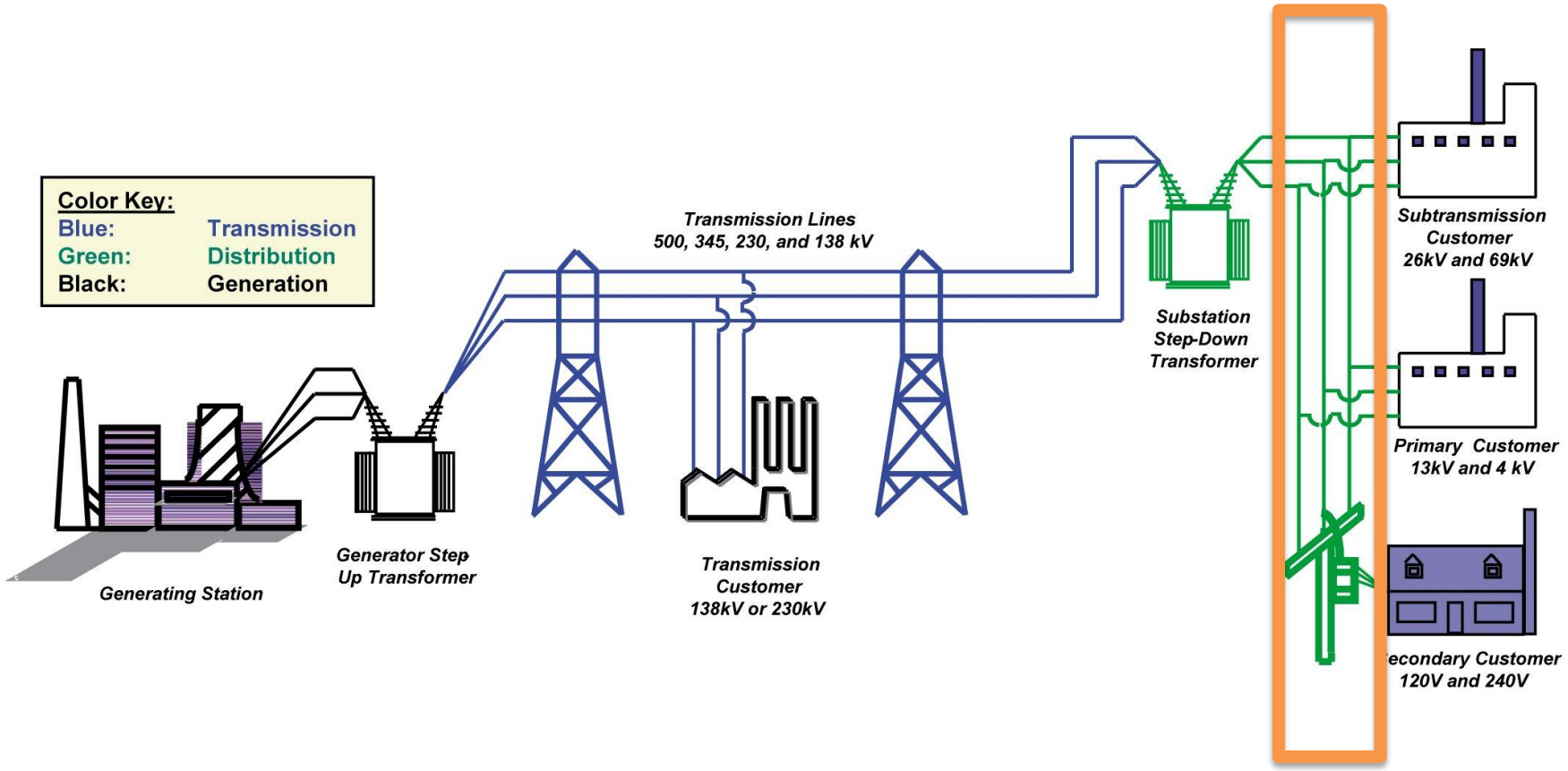
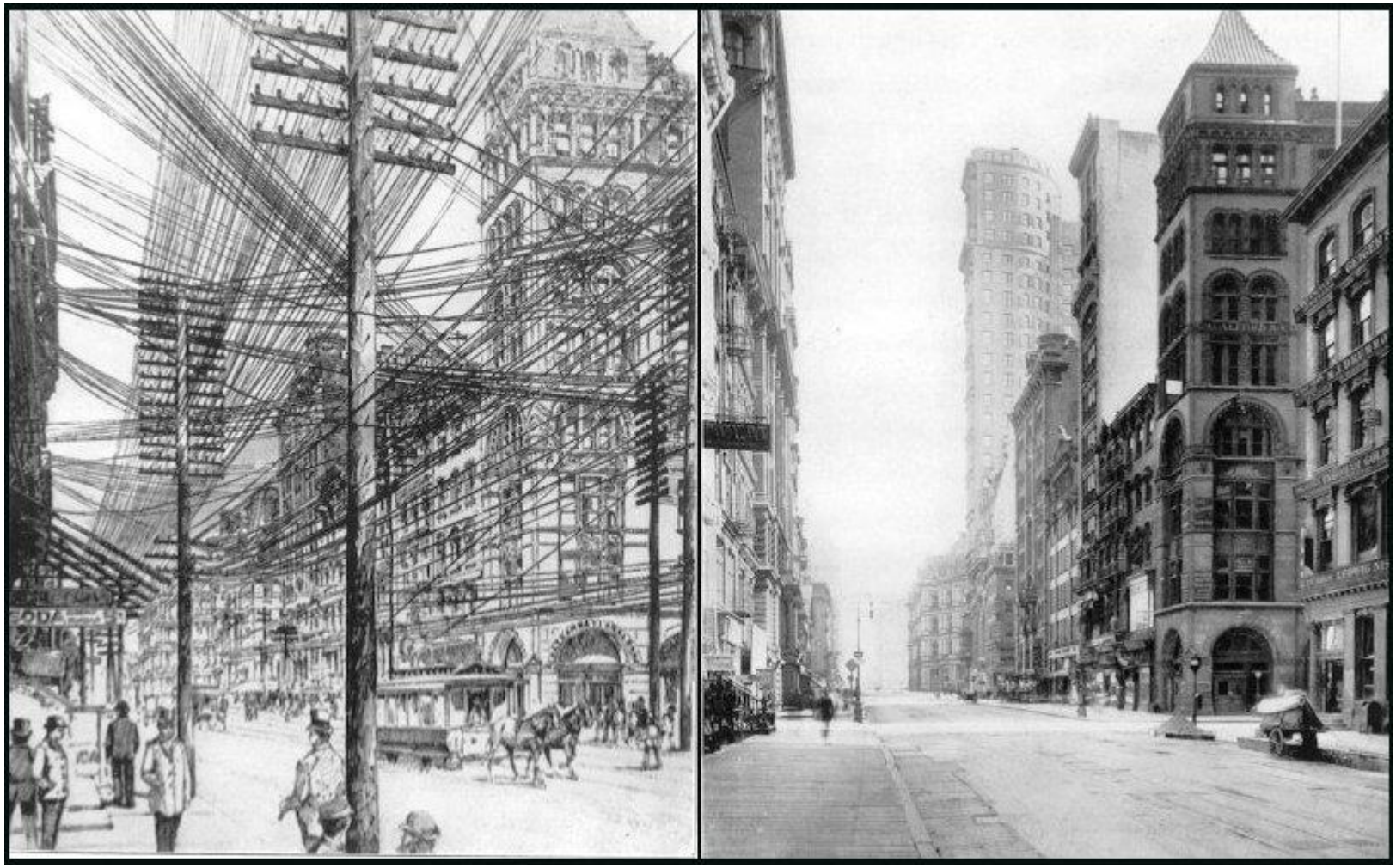


image from http://www2.econ.iastate.edu/

evolution of distribution



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electric power systems

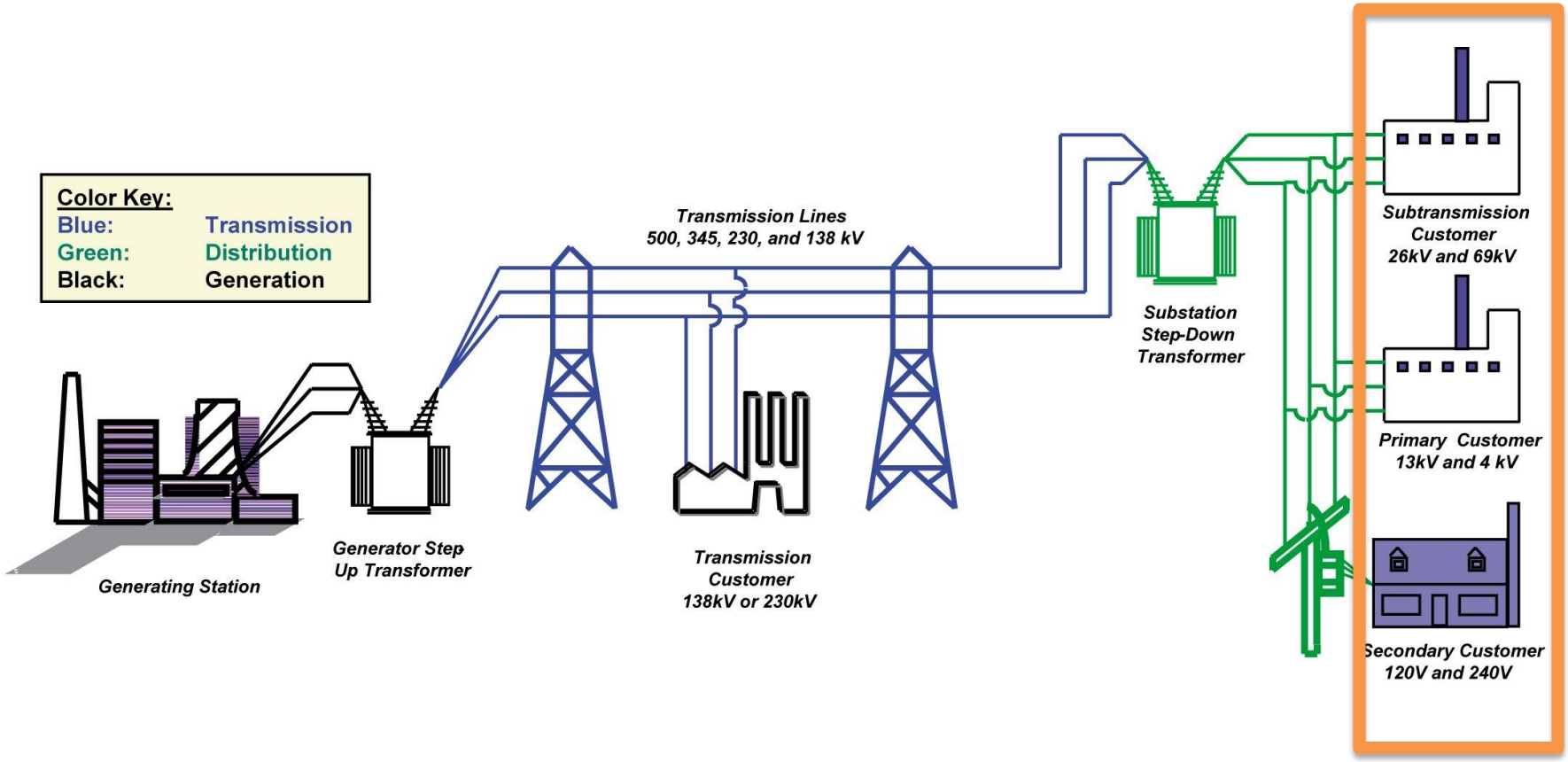
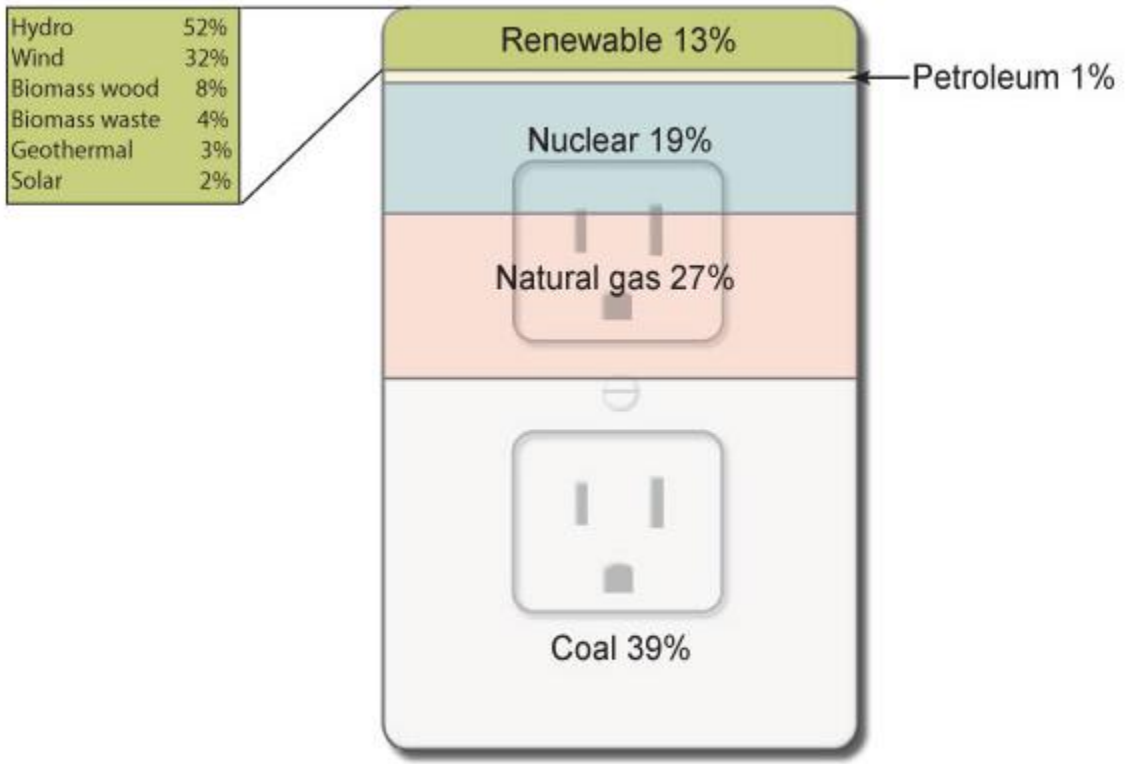


image from http://www2.econ.iastate.edu/

electricity sources and end use

Sources

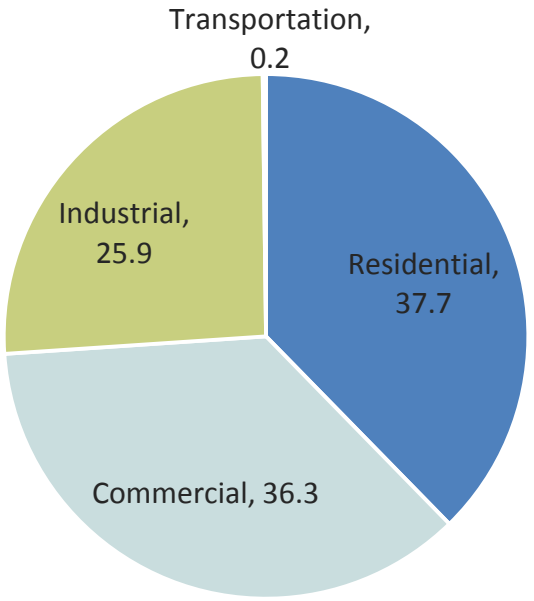


Source: U.S. Energy Information Administration, *Electricity Power Monthly* (February 2014). Percentages based on Table 1.1 and 1.1a; preliminary data for 2013

Note: Sum of components may not equal 100% due to independent rounding.

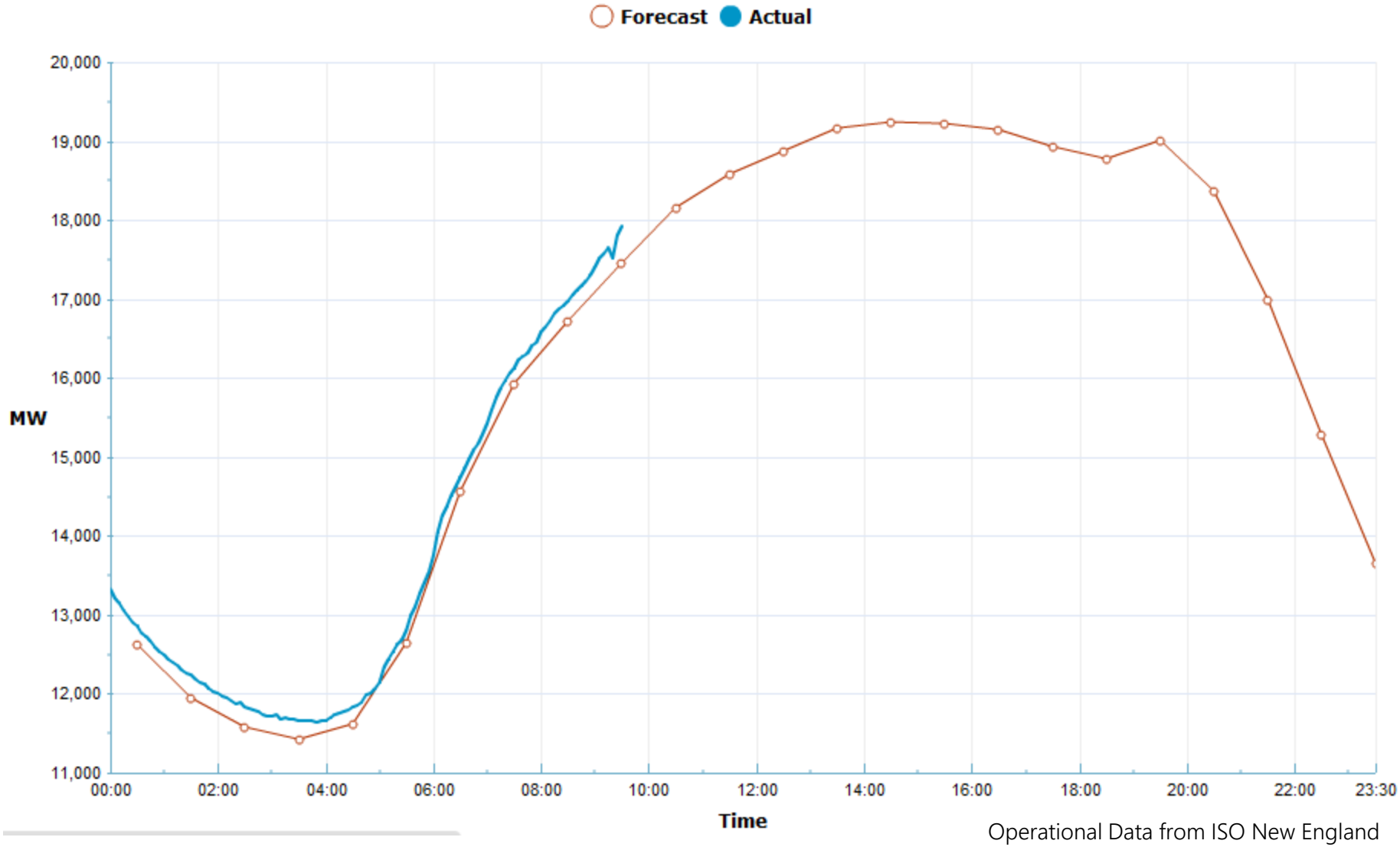
eia

End Uses



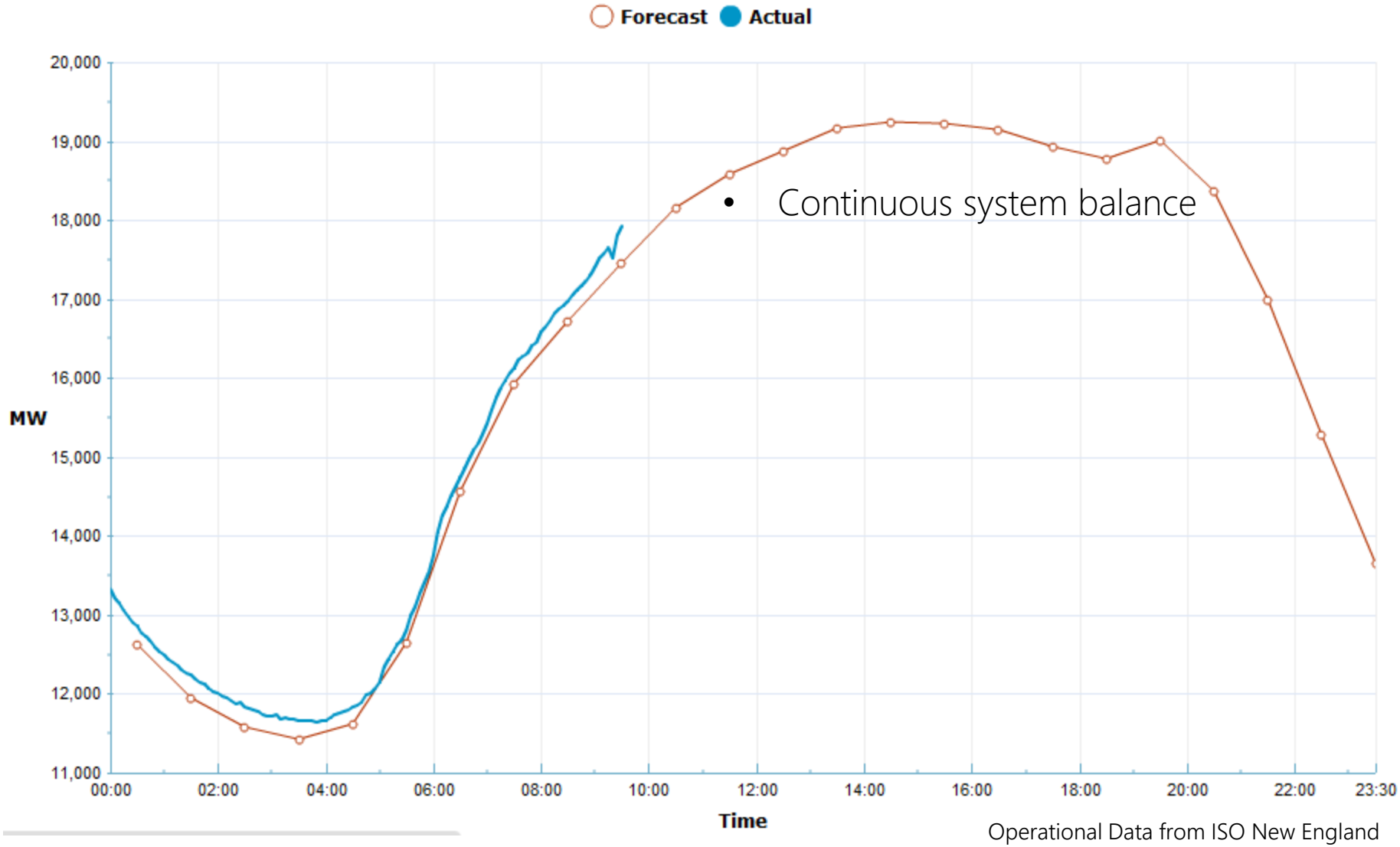
Source: http://www.eia.gov/energyexplained/index.cfm?page=electricity_use

electric system operations



Operational Data from ISO New England

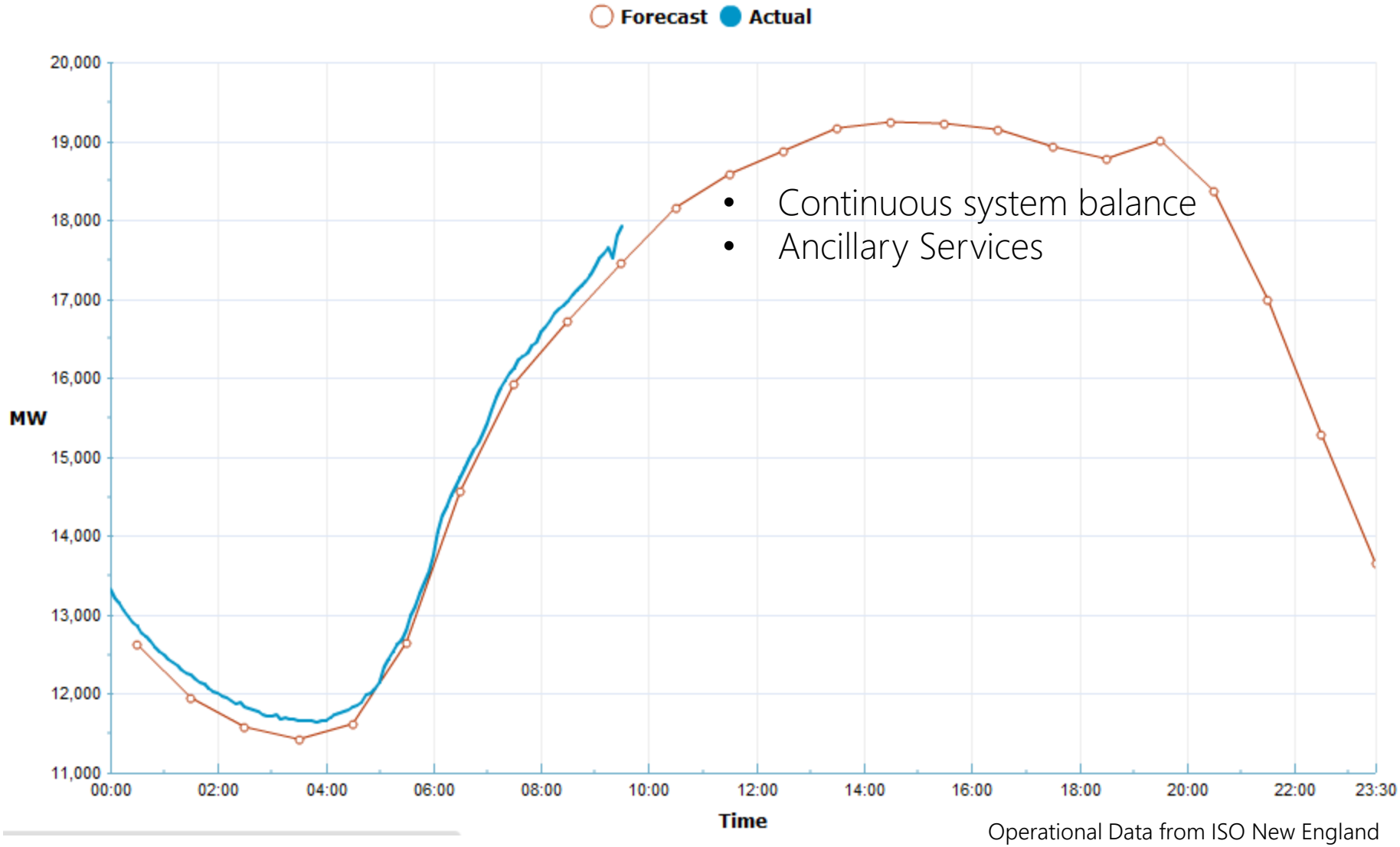
electric system operations



- Continuous system balance

Operational Data from ISO New England

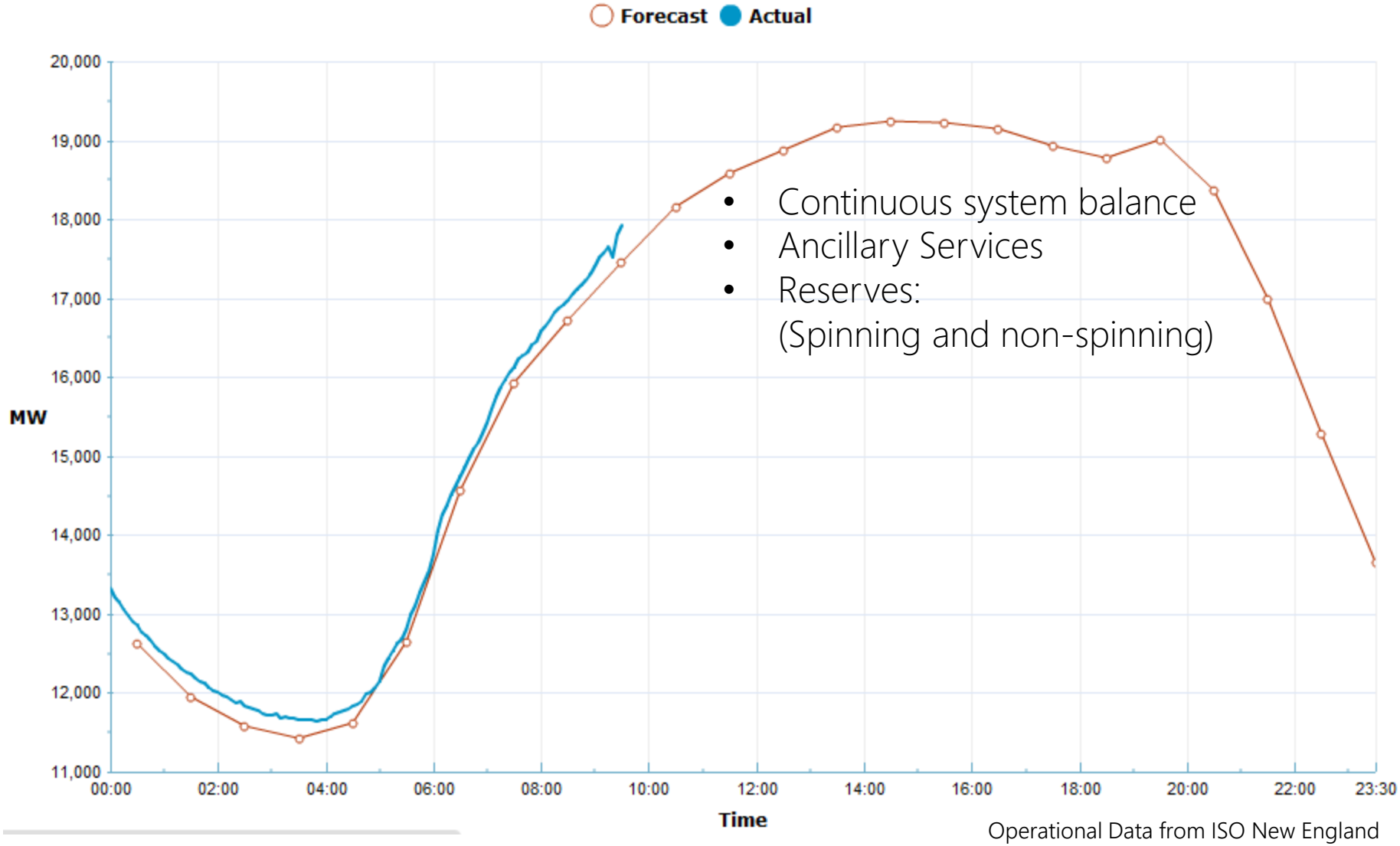
electric system operations



- Continuous system balance
- Ancillary Services

Operational Data from ISO New England

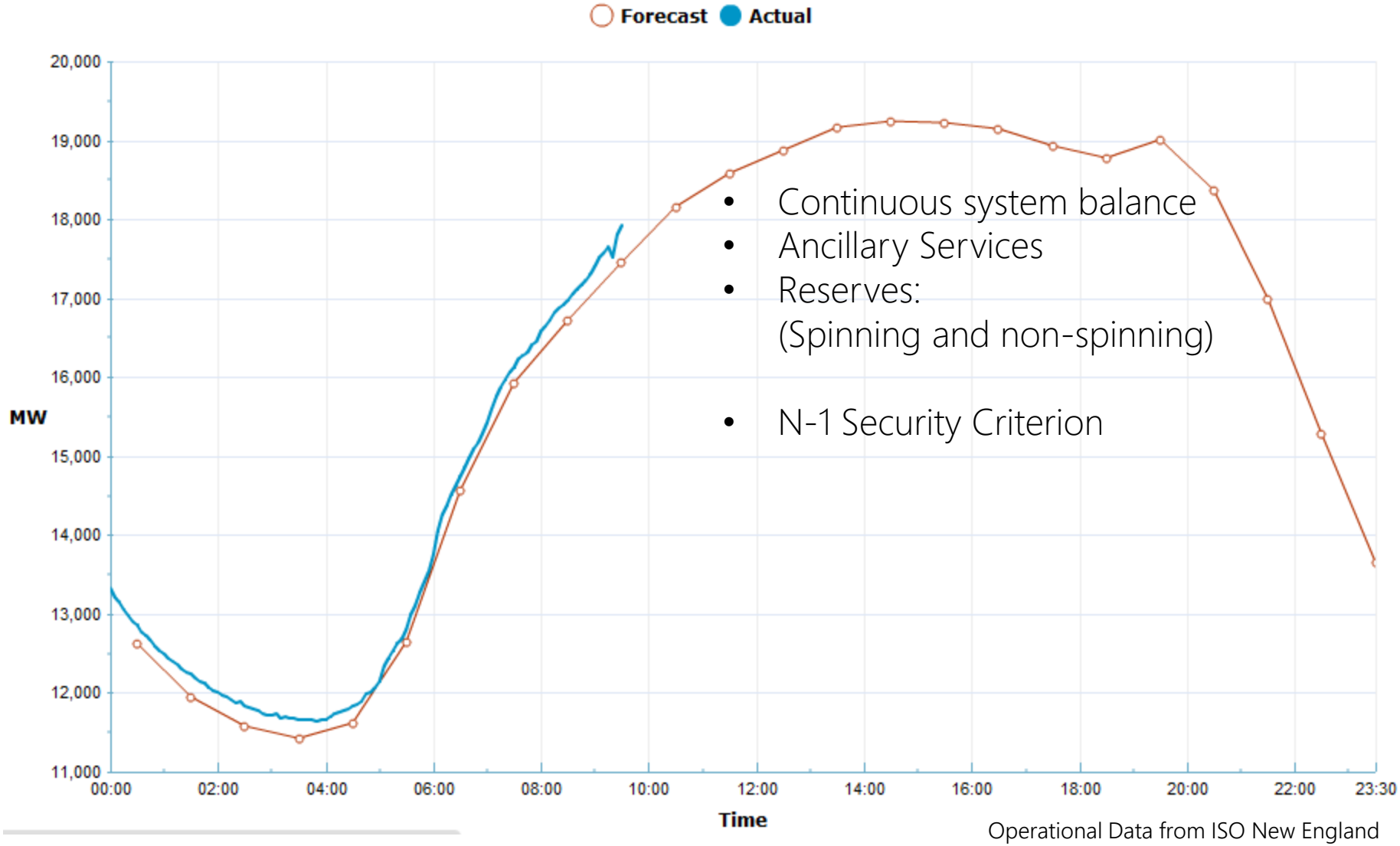
electric system operations



- Continuous system balance
- Ancillary Services
- Reserves:
  (Spinning and non-spinning)

Operational Data from ISO New England

electric system operations



- Continuous system balance
- Ancillary Services
- Reserves:
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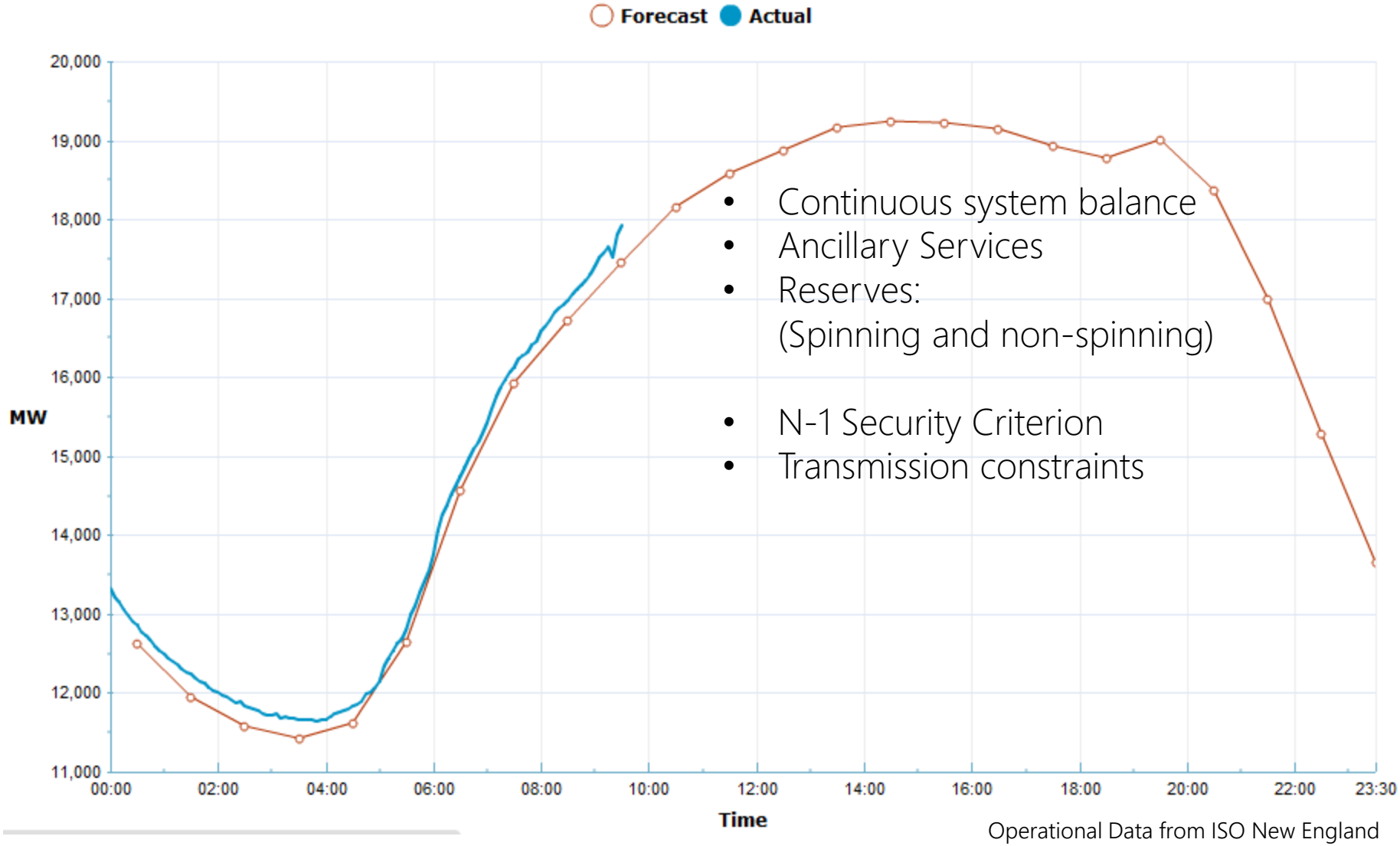
- N-1 Security Criterion

Operational Data from ISO New England

electric system operations



- Continuous system balance
- Ancillary Services
- Reserves:
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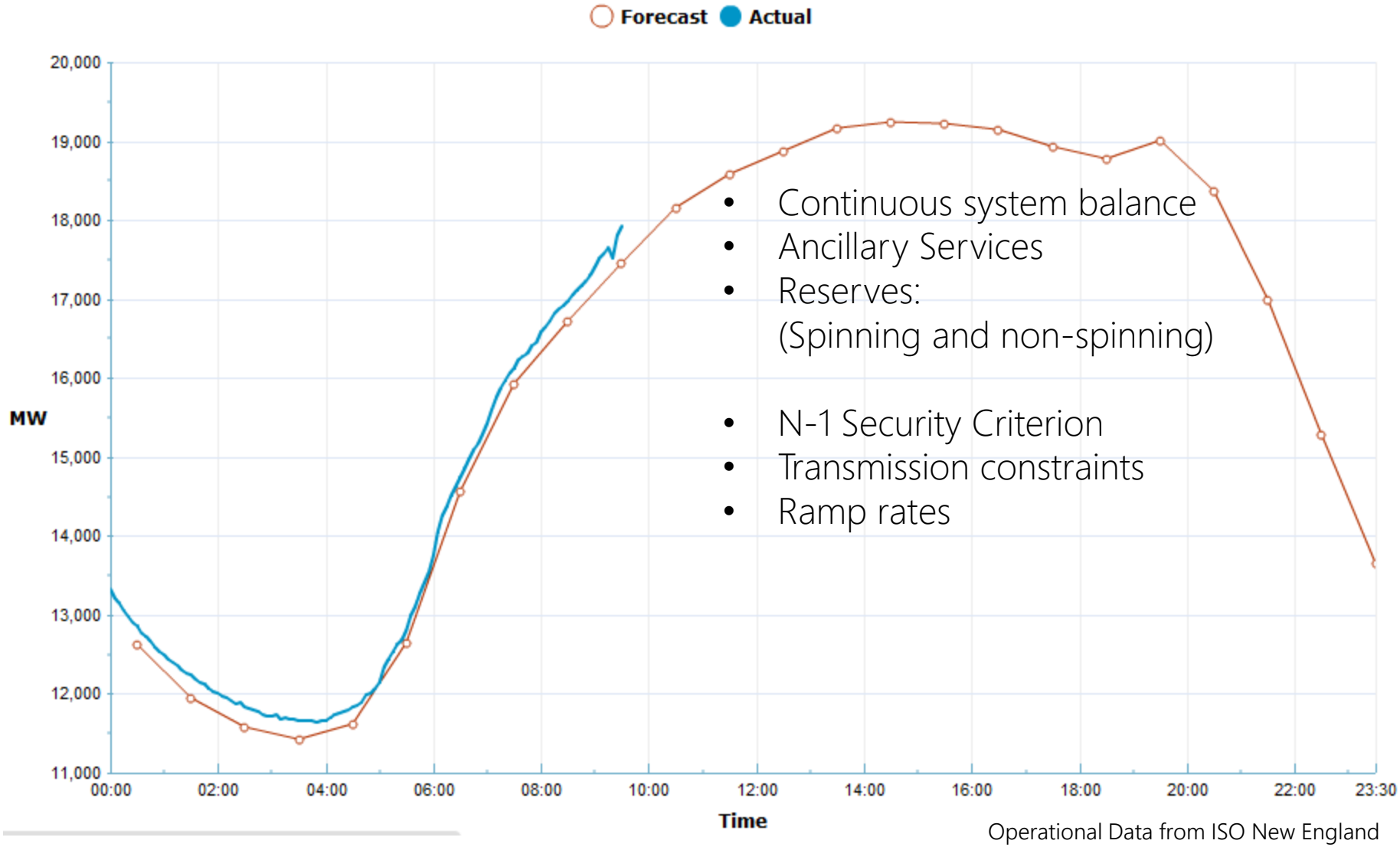
- N-1 Security Criterion
- Transmission constraints

Operational Data from ISO New England

electric system operations

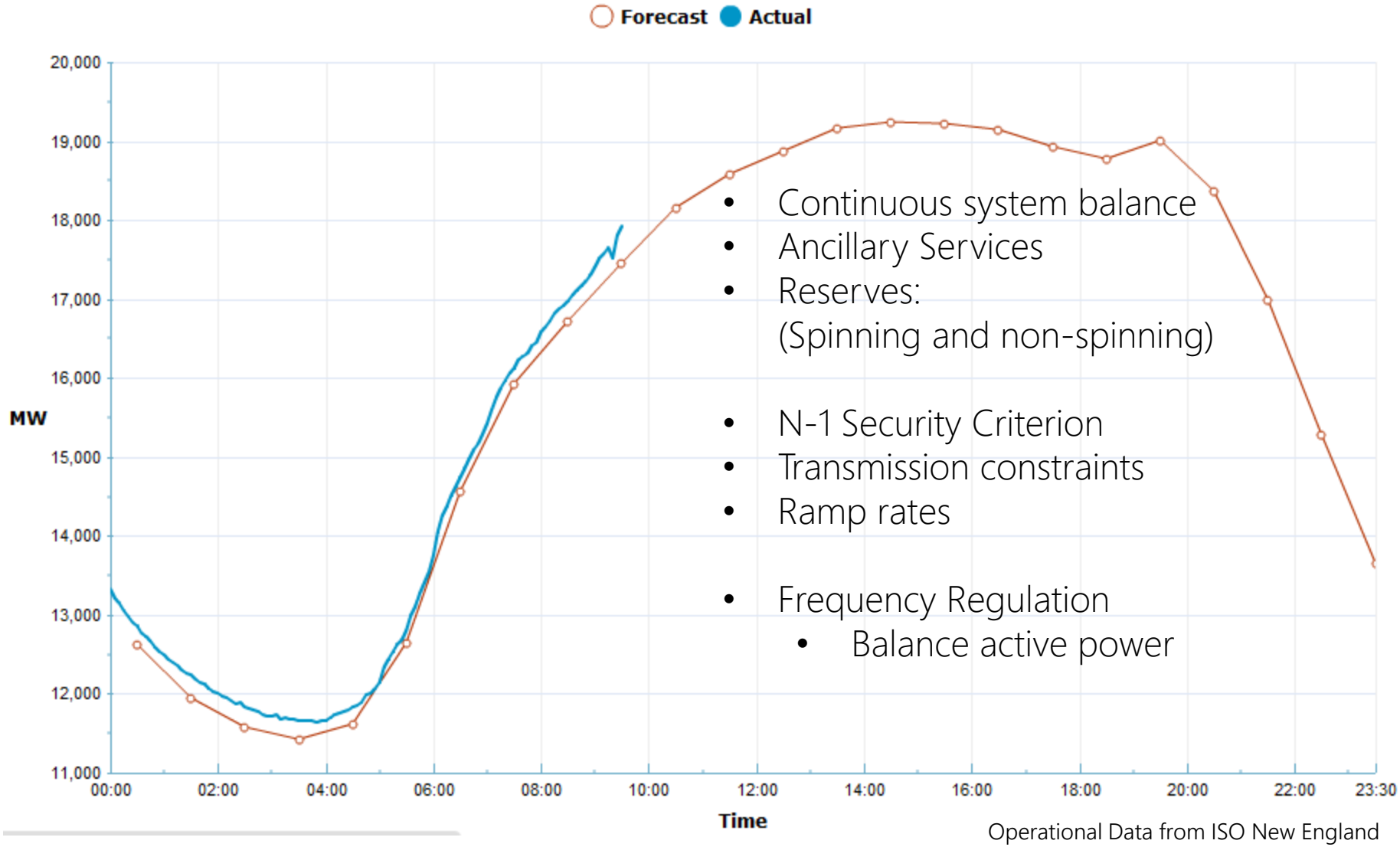


- Continuous system balance
- Ancillary Services
- Reserves:
  (Spinning and non-spinning)

- N-1 Security Criterion
- Transmission constraints
- Ramp rates

Operational Data from ISO New England

electric system operations



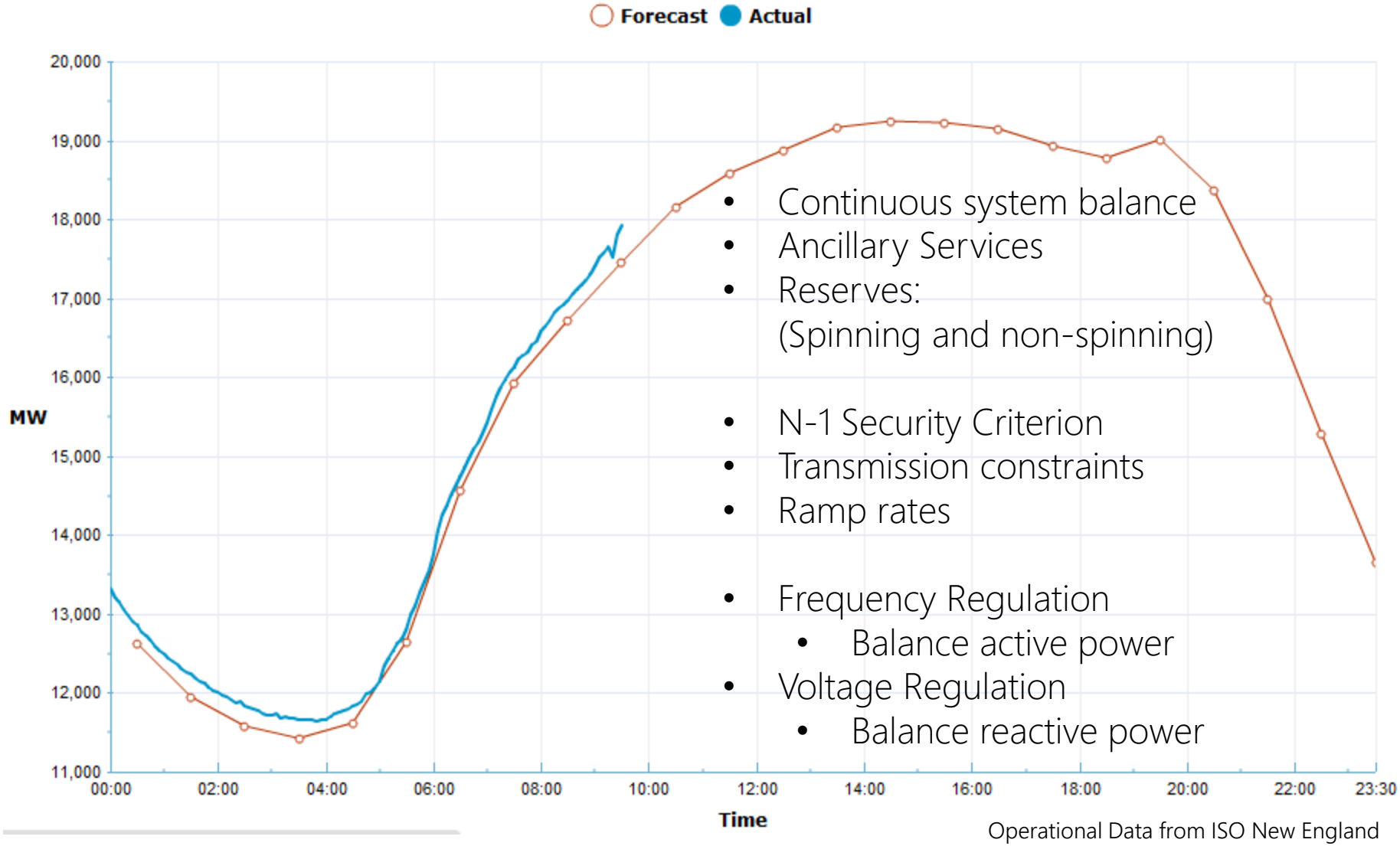
- Continuous system balance
- Ancillary Services
- Reserves:
  (Spinning and non-spinning)

- N-1 Security Criterion
- Transmission constraints
- Ramp rates

- Frequency Regulation
  - Balance active power

Operational Data from ISO New England

electric system operations



- Continuous system balance
- Ancillary Services
- Reserves:
  (Spinning and non-spinning)

- N-1 Security Criterion
- Transmission constraints
- Ramp rates

- Frequency Regulation
  - Balance active power
- Voltage Regulation
  - Balance reactive power

Operational Data from ISO New England

open electrical energy markets

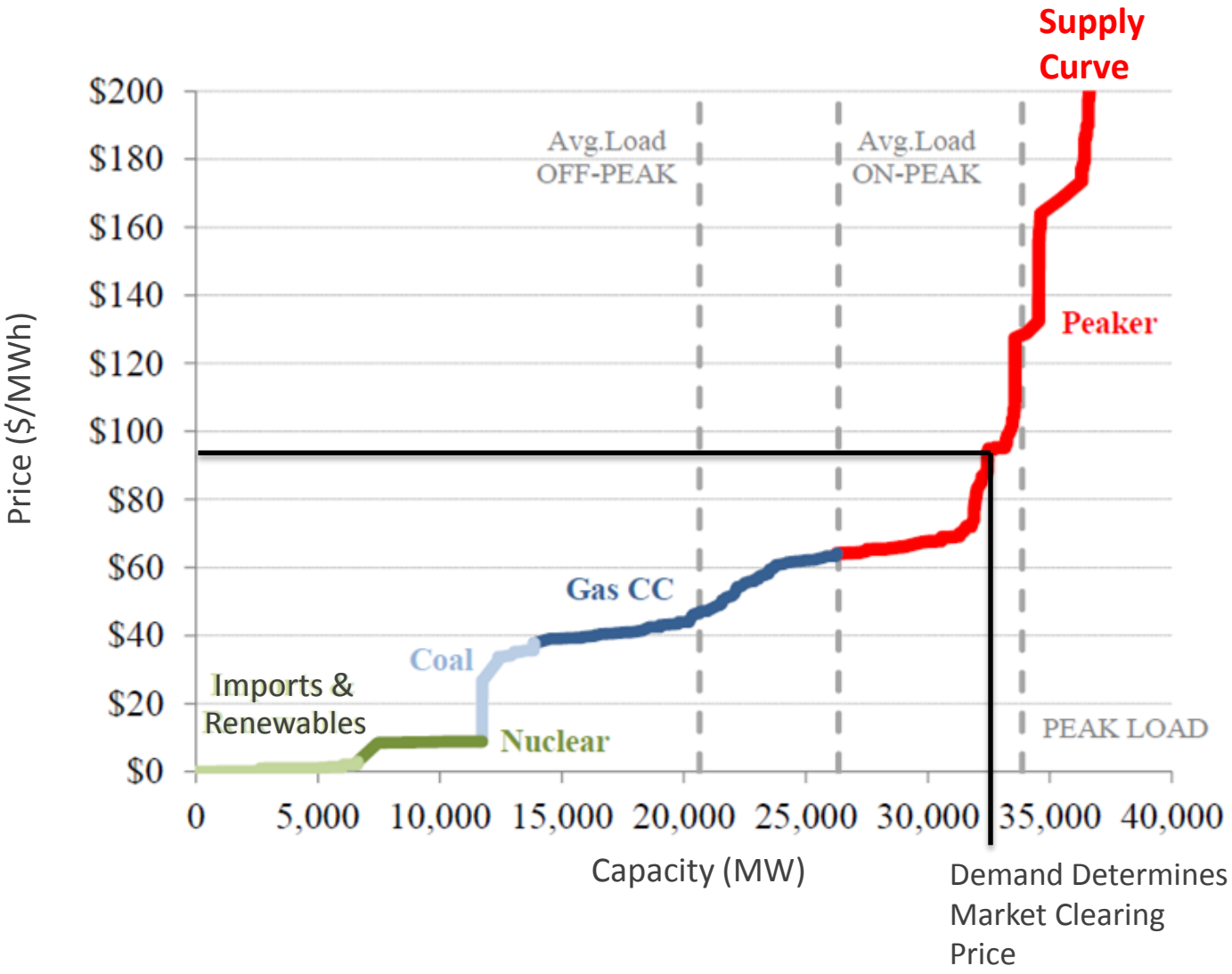


Image from http://www.seia.org/

expanded lexicon

alternating current

direct current

reactive power

power factor

combined cycle gas turbine (CCGT)

independent system operator (ISO)

line frequency

take-aways

take-aways

- Working knowledge of technology will enhance successful interactions/innovation in the energy space
  - Diverse fuels and generation technologies power the U.S.
  - Coal remains the largest source of electricity in the U.S., but renewables and natural gas are on the rise
  - High voltage transmission reduces losses

take-aways

- Working knowledge of technology will enhance successful interactions/innovation in the energy space
  - Diverse fuels and generation technologies power the U.S.
  - Coal remains the largest source of electricity in the U.S., but renewables and natural gas are on the rise
  - High voltage transmission reduces losses
- The complexity of power systems and need for instantaneous balancing of supply and demand motivate unique market structures

throughout space there is energy... it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature.

Nikola Tesla, 1892

thank you! questions?

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