Answer three questions today: two are about generation, one about correlation to high school courses.
First, correlation to high school courses.

When will I ever use this *fill in your topic here*?

High school math classes: linear equations
\[ L = L_0 + \alpha L \Delta T \]
Turbine thermal expansion

\[ Q = mc \Delta T \]
Heating up feed water

\[ Q = L \Delta T \]
Latent heat of vaporization

\[ V = IR; \quad v(t) = i(t)Z \]
Voltage, current, impedance relationship
Output power, efficiency, generated power

\[ \text{eff} = \frac{P_{\text{out}}}{P_{\text{in}}}; \quad P_{\text{out}} = \text{eff} \times P_{\text{in}} \]

Voltages and wires in a transformer

High school math classes: Quadratic equation

\[ P_{\text{losses}} = V_{\text{ac}} I_{\text{ac}} = I_{\text{dc}}^2 R \]

Parabola with axis of symmetry along y-axis, power loss as a function of line current
High school math classes: Complex numbers

\[ Z_L = j\omega L; \quad Z_C = \frac{1}{j\omega C} \]

Inductive and Capacitive impedance
High school math classes: Calculus
- Integral of entropy-temperature diagram is energy (heat added, heat rejected, work)
Bull Run is a supercritical system that includes reheat.

Fig. 13 Supercritical steam cycle with one reheat.

And there are connections to high school science classes.
Nitrous oxide removal:

\[ 4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \]

\[ NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O \]

Entrained fly ash removal

\[ E = \frac{F}{q_i} ; \quad F_c = k \frac{q_i q_c}{r^2} \]
SO₂ removal

\[ \text{CaCO}_3 (\text{solid}) + \text{SO}_2 (\text{gas}) \rightarrow \text{CaSO}_4 (\text{solid}) + \text{CO}_2 (\text{gas}) \]

\[ \text{CaSO}_4 + \text{H}_2\text{O} + \frac{1}{2} \text{O}_2 \rightarrow \text{CaSO}_4 \cdot \text{H}_2\text{O} \]

NOTE: \( \text{CaSO}_4 \cdot 2\text{H}_2\text{O} = \text{gypsum} \)

Gypsum plant,
NIPSCO
Schaeffer Station
Summary: this connects to high school courses

Second and third questions are about generating electricity from coal....
- Conceptually, how is this done?
- Physically, how is this done?
I have emailed you three files; I will anchor the next several slides on these.
- system_diagram.pdf
- SWUP furnace.pdf
- Emission control equipment.pdf

First, system_diagram.pdf, which shows four cycles
- Coal
- Air
- Water/steam
- Exhaust gases
Coal

- Where does it come from?
- There are different types of coal, is one better than another?
- How much coal does Ball Run, or a plant like it, use per day when generating at full capacity?
Lignite
- Lowest rank
- Soft, brown to black
- Heating values of 
  \[ \frac{<19,306 \text{ kJ}}{\text{kg}} \left( <8,300 \text{ BTU/lb} \right) \]

Anthracite
- Highest rank
- Shiny black, hard and brittle
- Low volatile content therefore slow burning
- Very low moisture content
- Low in sulfur
- Heating values of \[ \frac{34,890 \text{ kJ}}{\text{kg}} \left( 15,000 \text{ BTU/lb} \right) \]
### Surface Coal Reserve Base of the U.S. (Million tons)

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**Coal cycle**
- Bring it in by barge or railroad or both
- Store it in large piles
- Dry it
- Bring it into the building
- Crush it into a very fine powder (~75µm)
- Entrain it with combustion air, heat it up
- Blow it into the boiler and ignite it
  - Turbulent flow
Air cycle
- Forced Draft Blowers (FDBs) force air into the burners and boiler plenum
- FDBs generate enough pressure to push exhaust gases through environmental equipment and out the stack
- Some plants also use ID (Induced Draft) fans to draw exhaust gases out of the boiler
Water\steam cycle: There are actually two separate water cycles
  - Boiler feed water: extremely pure
  - Condensate cooling water

NOTE: can follow me via the SWUP diagram...

Boiler Feed Water (not on the SWUP diagram):
  - The pure water is pumped into the boiler using Boiler Feed Pumps (BFPs)
  - BFPs are turbine driven, using superheated steam
  - Water boils to steam
Bull Run
- Superheated steam drives the High Pressure (HP) turbine, which spins at 3600 RPM
- HP exhaust steam is returned to the boiler where it is reheated (raising its internal energy again)
- Reheat steam returns to the Intermediate Pressure (IP) turbine stages
- IP steam exhausts to the Low Pressure (LP) turbine, which spins at 1800 RPM
Steam (now the SWUP diagram)
- Steam is removed from the boiler, so that it can be superheated
- Superheated steam is created by bringing steam back into the boiler for additional heating, raising its internal energy
Low Pressure steam is condensed (using cooling water from the Clinch River) back to pure water,
- BFPs pump it into the boiler
- Etc.etc.
Steam drives turbines
- Adiabatic thermodynamic process
- Internal Energy of steam is converted to mechanical energy
- Mechanical energy spins generator at far end of turbine
- Generator "creates" electricity

Turbine
- Heavily instrumented
- Has rotor/stator clearances measured in thousands of inches (mils)
- Grows as it heats up
- Can develop "gravity bow" because of its own weight
- Spins at a multiple of 60 Hz (US), 50 Hz (many other countries)
Tight clearances, remember

\[ L = \alpha L_0 \Delta T \]

Nozzles

Rotor
Exhaust gas cycle

- *(Will refer to file Emission Control Equipment.pdf)*
- HUGE equipment that removes entrained particles and selected gases from the exhaust gas
  - In about 4 seconds
Fly ash
- Some collects on boiler tubes
  - Soot blowers
- Some drops to bottom of boiler
- Some is entrained in exhaust gases
  - Precipitators (large)
Nitrous Oxides:
- Choice of coal can lower amount
- Controlled burning
- SCR (Selective Catalytic Converter, also large)
Nitrous oxide removal:

\[ 4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \]

\[ NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O \]
Sulfur Dioxide:
- Wet or dry scrubber (large)
CO₂ Removal

- EPA released a proposal this year, that is to reduce CO emissions
- Thermal power plant companies are very concerned about the cost to achieve goals, and the existence of technology to do so
Second, courtesy
- Ask questions when given the opportunity
- Thank anyone who answers your question