Facility Dynamics Engineering

Controlling Analog Processes

Ripple Effects

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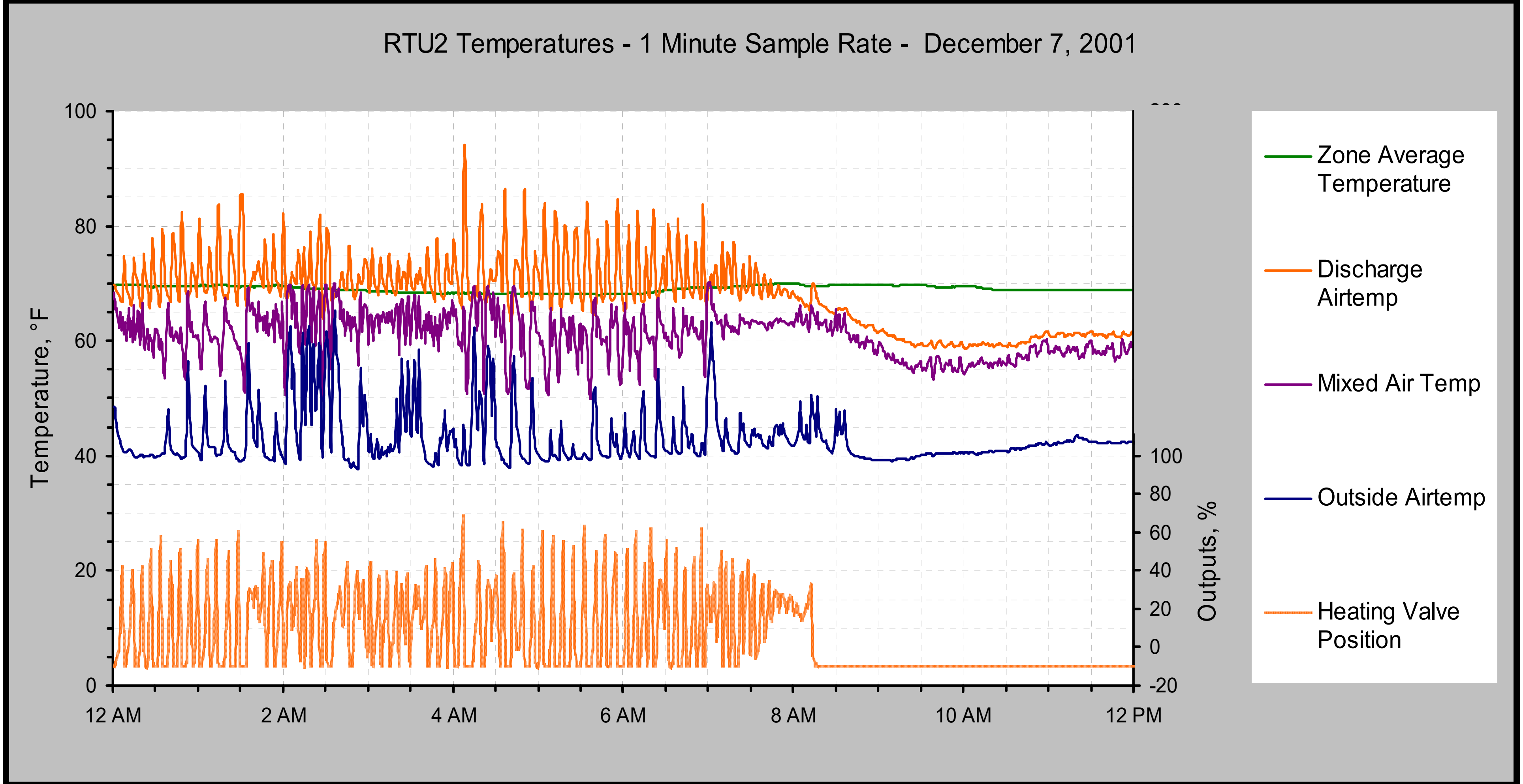
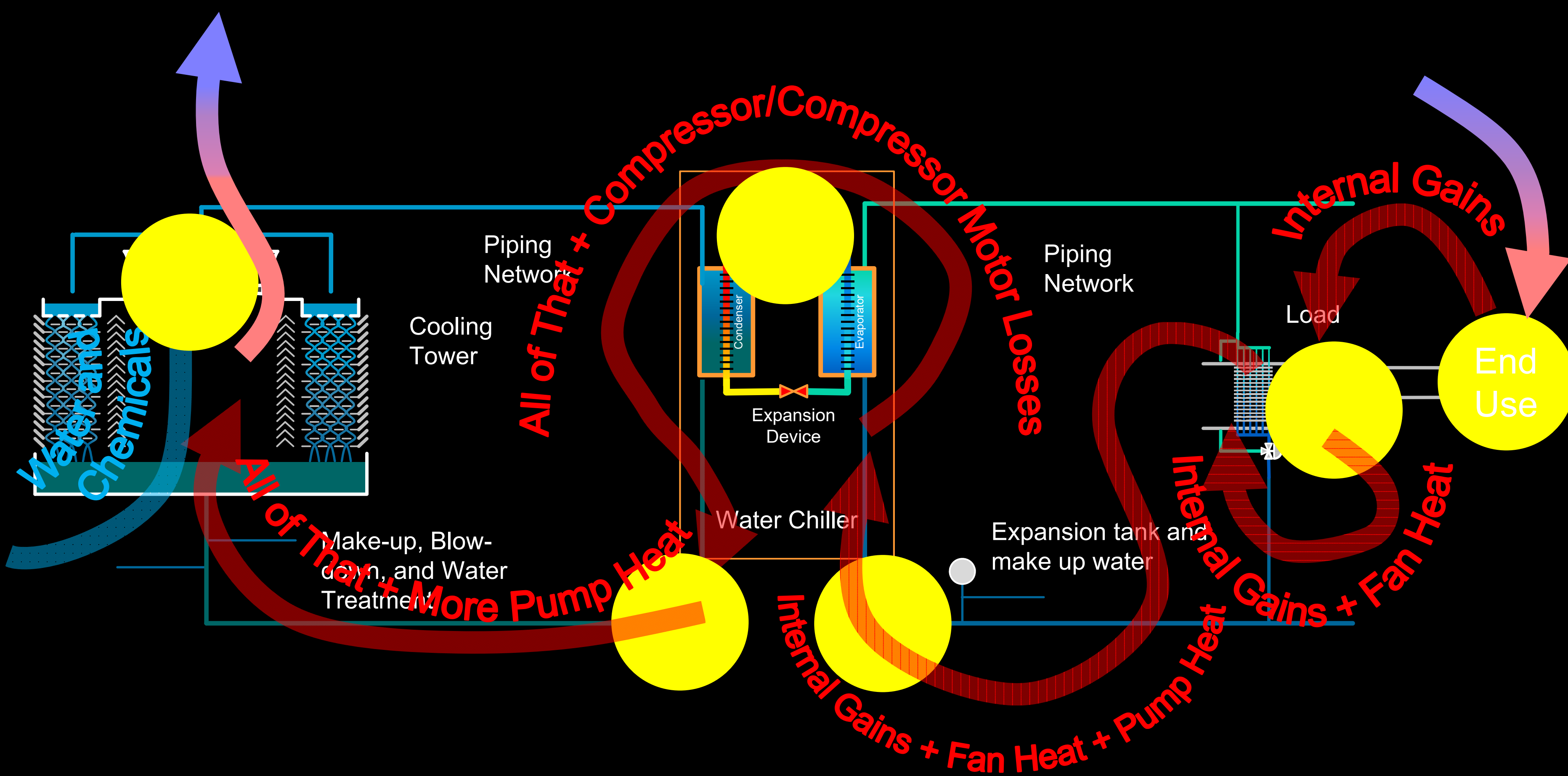
HVAC Systems are Highly Interactive



The Interactions Don't Stop at the AHU



The Bottom Line

All of the system elements are interactive with each other

Control System

Loads interact with:

- Each other
- Occupants
- Processes
- Ambient climate
- The pumps and piping

Pumps interact with:

- Each other
- Loads
- Piping system
- Chillers and towers
- Power distribution system

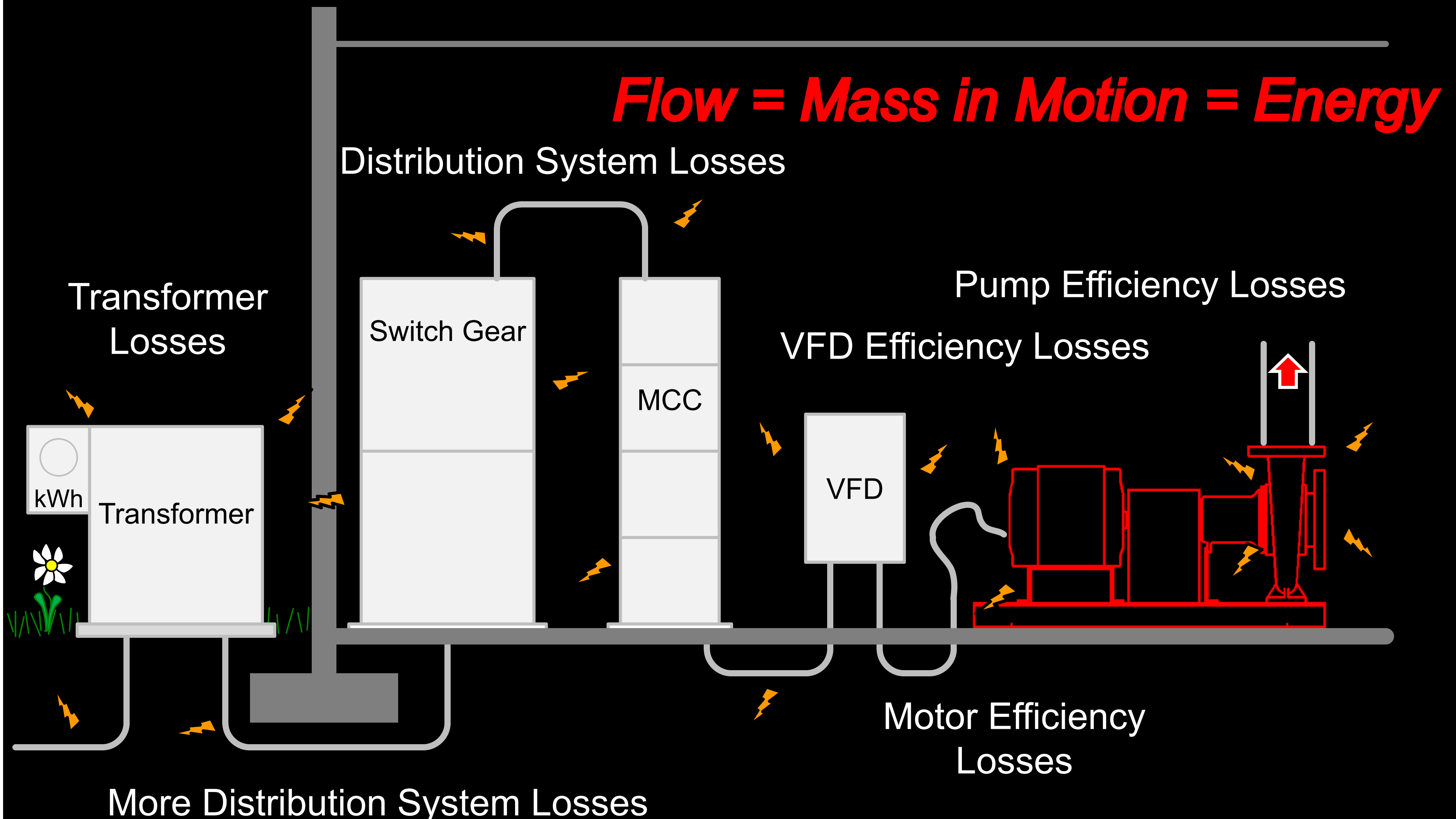
Chillers interact with:

- Each other
- Pumps and piping
- Loads
- Towers
- Power distribution system

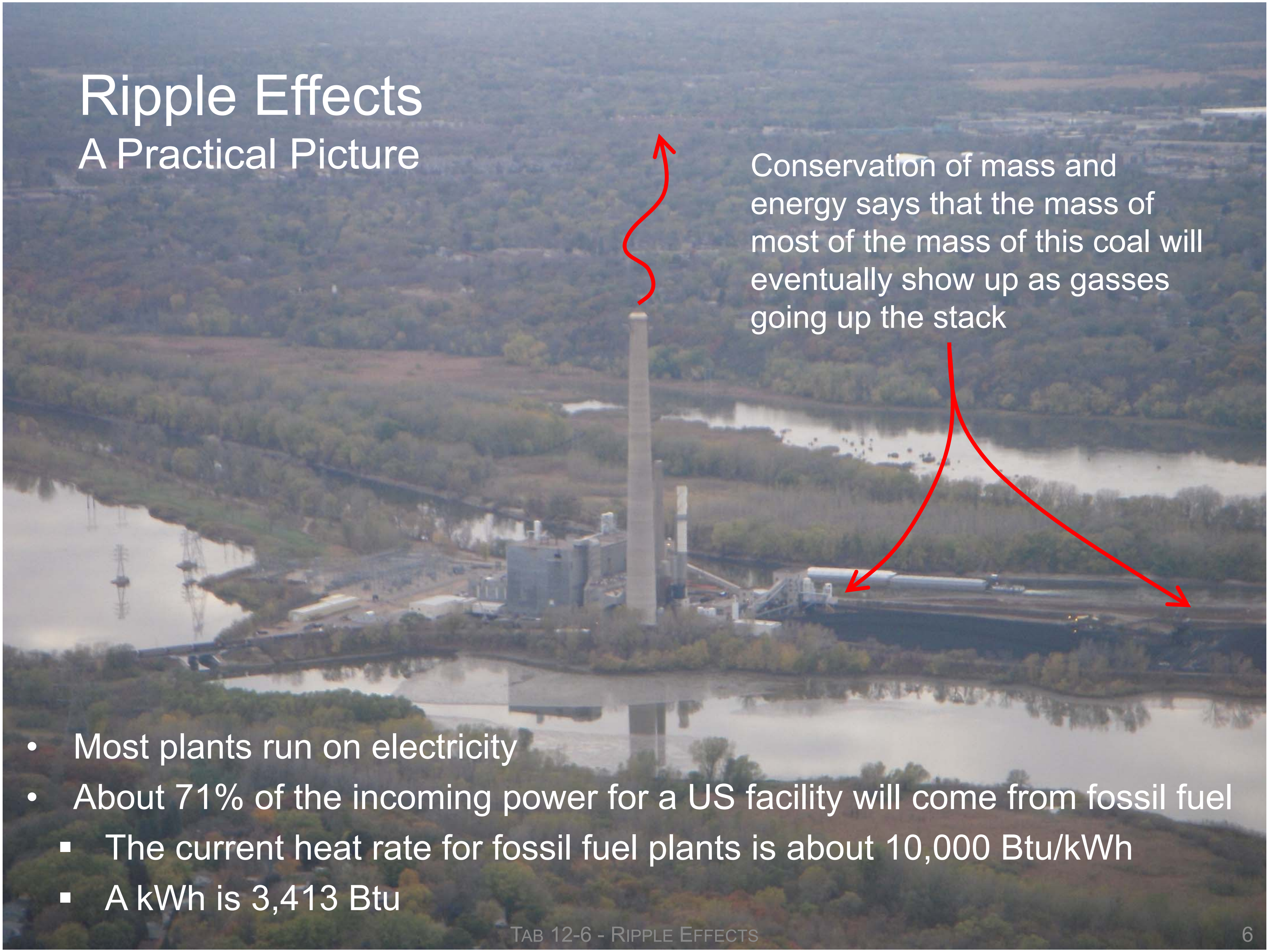
The towers interact with:

- Each other
- Pumps and piping
- Chillers
- Power distribution system
- Ambient climate

The Fundamental Goals of the Control System can have Ripple Effects



Ripple Effects
A Practical Picture



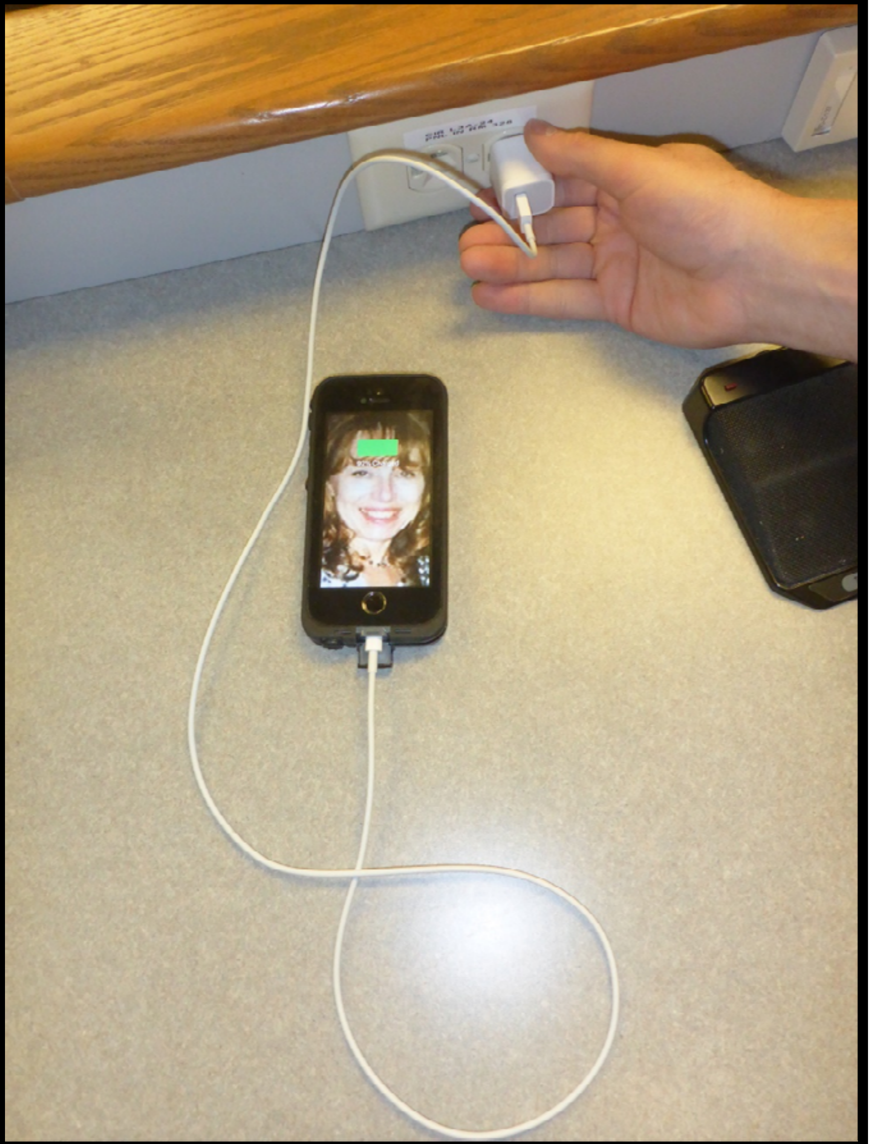
Conservation of mass and energy says that the mass of most of the mass of this coal will eventually show up as gasses going up the stack

- Most plants run on electricity
- About 71% of the incoming power for a US facility will come from fossil fuel
  - The current heat rate for fossil fuel plants is about 10,000 Btu/kWh
  - A kWh is 3,413 Btu

State	% of Total Electric Power Generation											Non-renewable Percent of Total	Renewable Percent of Total	Non-hydro Renewable Percent of Total	Combustion Process Generated Percent of Total	Non-combustion Process Generated Percent of Total
	Non-Renewable					Renewable					Nuclear					
	Combustion Processes						Non-Combustion Processes									
	Coal	Oil	Gas	Other Fossil Fuel	Purchased, Fuel Generated	Biomass	Hydro	Wind	Solar	Geothermal						
AK	9.2	13.9	55.6	0.0	0.0	0.1	21.1	0.2	0.0	0.0	0.0	78.7	21.3	[illegible]	78.7	21.3
AL	41.4	0.1	25.8	0.2	0.0	1.8	5.7	0.0	0.0	0.0	24.9	92.5	7.5	1.8	69.3	30.7
AR	46.2	0.1	20.4	0.0	0.0	2.7	6.0	0.0	0.0	0.0	24.6	91.3	8.7	2.7	69.4	30.6
AZ	39.1	0.1	26.6	0.0	0.0	0.2	6.1	0.1	0.0	0.0	27.9	93.6	6.4	0.3	65.8	34.2
CA	1.0	1.2	52.7	0.2	0.3	3.0	16.3	3.0	0.4	6.2	15.8	71.3	28.7	12.5	58.4	41.6
CO	68.1	0.0	21.9	0.0	0.1	0.1	2.9	6.8	0.1	0.0	0.0	90.1	9.9	7.0	90.2	9.8
CT	7.8	1.2	35.2	2.2	0.0	2.1	1.2	0.0	0.0	0.0	50.2	96.7	3.3	2.1	48.6	51.4
DC	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	[illegible]	0.0	100.0	0.0
DE	45.6	1.0	50.9	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	97.5	[illegible]	2.5	100.0	0.0
FL	26.1	4.0	56.2	0.6	0.7	1.9	0.1	0.0	0.0	0.0	10.4	98.0	2.0	1.9	89.4	10.6
GA	53.3	0.5	17.4	0.0	0.0	2.3	2.2	0.0	0.0	0.0	24.4	95.5	4.5	2.3	73.4	26.6
HI	14.3	74.8	0.0	3.5	0.0	2.5	0.6	2.4	0.0	1.9	0.0	92.6	7.4	6.8	95.1	4.9
IA	71.8	0.3	2.3	0.0	0.0	0.3	1.6	15.9	0.0	0.0	7.7	82.1	17.9	16.2	74.7	25.3
ID	0.7	0.0	14.0	0.0	0.7	4.2	76.1	3.7	0.0	0.6	0.0	15.4	84.6	8.4	19.6	80.4
													2.6	2.6	50.0	50.0
													2.9	2.6	97.3	2.7
													7.2	7.2	72.9	27.1
													3.1	0.4	97.4	2.6
													3.4	2.4	81.0	19.0
													4.4	2.8	84.7	15.3
													5.1	1.3	64.1	35.9
													46.7	24.3	74.7	25.3
													2.7	2.5	72.9	27.1
													13.9	12.3	64.4	35.6
													3.7	1.1	86.6	13.4
													2.8	2.8	82.3	17.7
													34.8	3.1	65.2	34.8
													5.6	1.6	64.5	35.5
													17.6	11.7	82.4	17.6
													4.9	1.3	65.1	34.9
													12.2	5.5	43.8	56.2
													1.2	1.2	50.2	49.8
													5.7	5.1	94.3	5.7
													12.6	6.5	87.4	12.6
NY	9.9	1.5	35.7	0.7	0.0	1.6	18.2	1.9	0.0	0.0	30.6	78.3	21.7	3.4	49.3	50.7
OH	82.1	1.0	5.0	0.2	0.0	0.5	0.3	0.0	0.0	0.0	11.0	99.2	0.8	0.5	88.7	11.3
OK	43.5	0.0	47.0	0.0	0.0	0.5	3.7	5.3	0.0	0.0	0.0	90.6	9.4	5.8	91.1	8.9
OR	7.5	0.0	28.4	0.1	0.0	1.5	55.4	7.1	0.0	0.0	0.0	36.0	64.0	8.6	37.5	62.5
PA	48.0	0.3	14.7	0.6	0.0	1.0	0.7	0.8	0.0	0.0	33.9	97.4	2.6	1.8	64.6	35.4
RI	0.0	0.2	98.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	98.1	1.9	1.8	99.9	0.1
SC	36.2	0.2	10.5	0.1	0.0	1.8	1.4	0.0	0.0	0.0	49.9	96.8	[illegible]	1.8	48.7	51.3
SD	32.8	0.1	1.3	0.0	0.0	0.0	52.1	13.6	0.0	0.0	0.0	34.2	[illegible]	13.6	34.2	65.8
TN	53.3	0.3	2.8	0.0	0.0	1.2	8.6	0.0	0.0	0.0	33.9	90.2	9.8	1.2	57.5	42.5
TX	36.5	0.8	45.3	0.2	0.1	0.4	0.3	6.4	0.0	0.0	10.1	93.0	7.0	6.7	83.3	16.7
UT	80.6	0.2	15.3	0.0	0.4	0.1	1.6	1.1	0.0	0.7	0.0	96.5	3.5	1.8	96.6	3.4
VA	34.9	1.8	23.3	0.6	0.0	3.0	0.0	0.0	0.0	0.0	36.4	97.0	3.0	3.0	63.6	36.4
VT	0.0	0.1	0.1	0.0	0.0	7.1	20.3	0.2	0.0	0.0	72.2	72.4	27.6	7.3	7.2	92.8
WA	8.3	0.3	9.9	0.1	0.0	1.8	66.2	4.5	0.0	0.0	8.9	27.5	72.5	6.3	20.4	79.6
WI	62.5	1.1	8.5	0.0	0.1	2.2	3.3	1.7	0.0	0.0	20.7	92.9	7.1	3.8	74.4	25.6
WV	96.7	0.2	0.2	0.1	0.0	0.0	1.7	1.2	0.0	0.0	0.0	97.1	2.9	[illegible]	97.1	2.9
WY	89.3	0.1	1.0	0.6	0.1	0.0	2.1	6.7	0.0	0.0	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.4	0.0	0.0	7.2	0.0
Maximum	96.7	100.0	98.0	3.5	0.9	21.4	76.1	15.9	0.6	6.2	72.2	100.0	84.6	24.3	100.0	92.8
Average	41.9	4.3	22.5	0.4	0.1	1.8	9.2	2.5	0.0	0.3	17.0	86.1	13.9	4.7	71.0	29.0

State	Non-renewable Percent of Total	Renewable Percent of Total	Non-hydro Renewable Percent of Total	Combustion Process Generated Percent of Total	Non-combustion Process Generated Percent of Total
Minimum	15.4	0.0	0.0	7.2	0.0
Maximum	100.0	84.6	24.3	100.0	92.8
Average	86.1	13.9	4.7	71.0	29.0

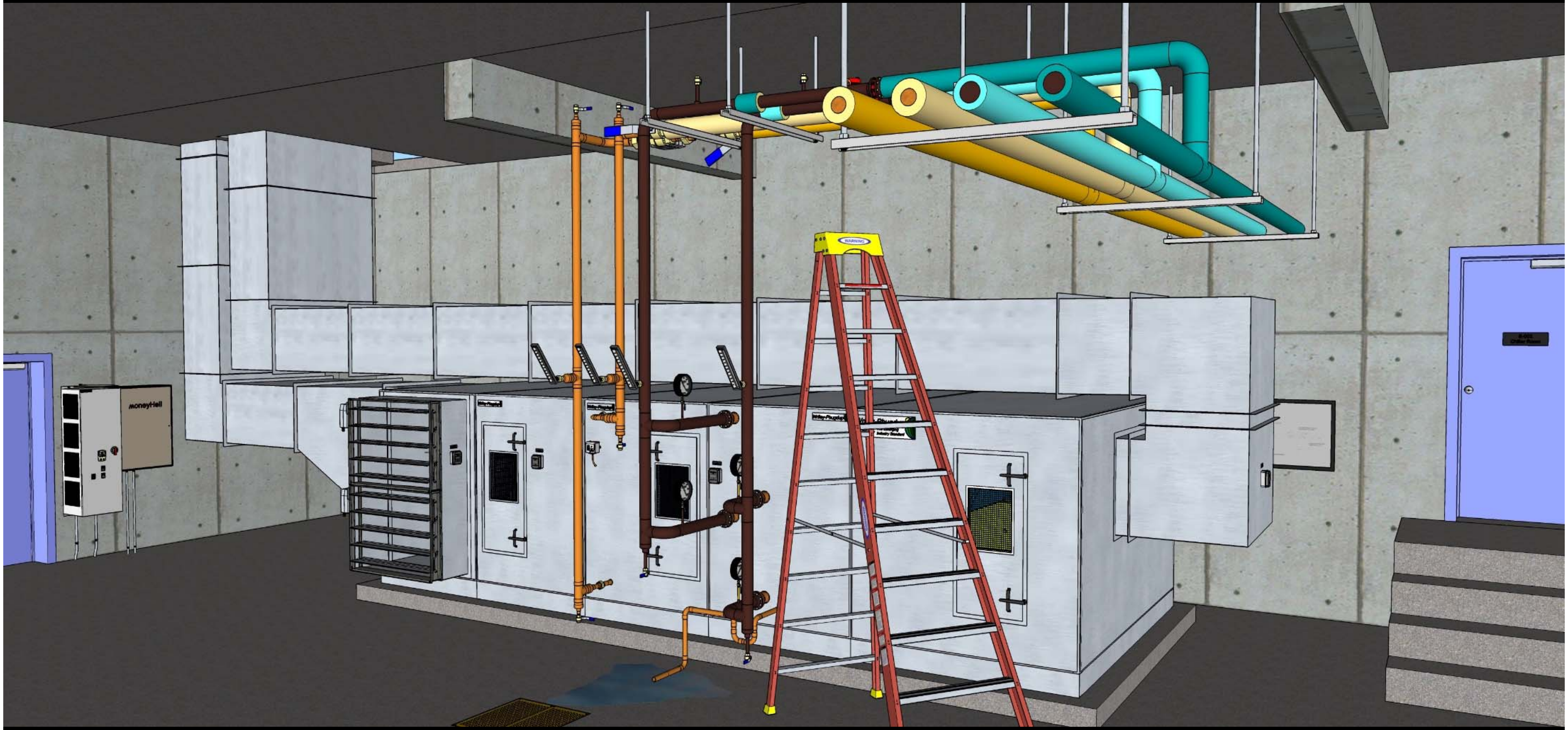
The iPhone Food Chain



Gas Fired Power Plant as the Energy Source						
Location in the "Food Chain"	Watt-hours at the point in the system	Conversion Loss				
		Device Efficiency	Loss at the Location		Accumulated Losses	
			watt-hours	%	watt-hours	%
End use - Provide a full charge for an iPhone SE Battery	6.17	End Use				
iPhone Charger	8.34	74.0%	2.17	26.0%	2.17	26.0%
Building Electical Distribution System Losses (wires, panels, terminations, etc.)	8.42	99.0%	0.08	1.0%	2.25	26.7%
Transformer Losses	8.50	99.1%	0.07	0.9%	2.33	27.4%
Transmission From the Power Plant to the Building Transformer	8.92	95.3%	0.42	4.7%	2.74	30.8%
Gas Fired Power Plant Efficiency	20.57	43.3%	11.66	56.7%	14.40	70.0%
Delivering Gas from the Natural Gas Well	21.66	95.0%	1.08	5.0%	15.49	71.5%
Bottom Lines						
Energy into the process - watt - hours	21.66					
Energy delivered - watt-hour	6.17					
Losses - watt-hours	15.49					
	71.5%					
Average price of electricity; $/kWh	Residential	Commercial				
(U.S. Average for May, 2017)	$0.1302	$0.1058				
Cost to charge an iPhone	$0.0008	$0.0007				
Annual charge cycles (1 per day)	365	365				
Annual cost to keep the iPhone charged	$0.2933	$0.2383				
Associated Emmissions for One Year, lb.						
CO_2 (Carbon Dioxide)	2.0762	Believed by some to be the primary greenhouse gas emitted by human activities; Respiratory problems occur at high concentrations.				
SO_2 (Sulfur Dioxide)	0.0022	Resiratory system harm and difficult breathing; Harms trees and plants by decreasing foliage and growth; Reacts to create haze.				
NOx (Nitrous Oxide)	0.0016	Reacts to form ozone, aerosols, and NO_2; Respiratory harm; Contributes to acid rain; Impacts water and air quality; Greenhouse				

Coal Fired Power Plant as the Energy Source							
Location in the "Food Chain"	Watt-hours at the point in the system	Conversion Loss					
		Device Efficiency	Loss at the Location		Accumulated Losses		
			watt-hours	%	watt-hours	%
End use - Provide a full charge for an iPhone SE Battery	6.17	End Use					
iPhone Charger	8.34	74.0%	2.17	26.0%	2.17	26.0%
Building Electical Distribution System Losses (wires, panels, terminations, etc.)	8.42	99.0%	0.08	1.0%	2.25	26.7%
Transformer Losses	8.50	99.1%	0.07	0.9%	2.33	27.4%
Transmission From the Power Plant to the Building Transformer	8.92	95.3%	0.42	4.7%	2.74	30.8%
Coal Fired Power Plant Efficiency	27.41	32.5%	18.49	67.5%	21.24	77.5%
Delivering Coal from the Coal Mine	28.85	95.0%	1.44	5.0%	22.68	78.6%
Bottom Lines						
Energy into the process - watt - hours	28.85					
Energy delivered - watt-hour	6.17					
Losses - watt-hours	22.68					
	78.6%					
Average price of electricity; $/kWh	Residential	Commercial				
(U.S. Average for May, 2017)	$0.1302	$0.1058				
Cost to charge an iPhone	$0.0008	$0.0007				
Annual charge cycles (1 per day)	365	365				
Annual cost to keep the iPhone charged	$0.2933	$0.2383				
Associated Emmissions, lb.						
CO_2 (Carbon Dioxide)	3.6500	Believed by some to be the primary greenhouse gas emitted by human activities; Respiratory problems occur at high concentrations.				
SO_2 (Sulfur Dioxide)	0.0039	Resiratory system harm and difficult breathing; Harms trees and plants by decreasing foliage and growth; Reacts to create haze.				
NOx (Nitrous Oxide)	0.0029	Reacts to form ozone, aerosols, and NO_2; Respiratory harm; Contributes to acid rain; Impacts water and air quality; Greenhouse				

The AHU Food Chain



Coal Fired Power Plant as the Energy Source						
Location in the "Food Chain"	kWh at the point in the system	Conversion Loss				
		Device Efficiency	Loss at the Location		Accumulated Losses	
			watt-hours	%	watt-hours	%
End use - Cool the Air Delivered to a Ball Room for 1 Hour on a Design Day in St. Louis,	334	End Use				
End use - Move Cool Air from the Equipment Room to the Ball Room for One Hour on a	7	End Use				
kW into the Cooling Plant (The device producing the cooling uses 1 unit of energy to	69	Energy Into the Electrical Panel Serving the Cooling Plant				
kW into the Air Handling Unit Fan and it's Drive System (Motor, Belts, and Motor Speed	12	60.2%	Energy Into the Electrical Panel Serving the Air Handling Unit			
Total kW into the Cooling Plant and the Air Handling Unit	81	This is the electricity that was delivered by the electrical panels in the chiller and air handling system mechanical rooms.				
Building Electical Distribution System Losses (wires, panels, terminations, etc.)	82	99.0%	12.71	15.5%	12.71	15.5%
Transformer Losses	83	99.1%	0.71	0.9%	13.42	16.2%
Transmission From the Power Plant to the Building Transformer	87	95.3%	4.08	4.7%	17.50	20.1%
Coal Fired Power Plant Efficiency	267	32.5%	180.18	67.5%	197.68	74.0%
Delivering Coal from the Coal Mine	281	95.0%	14.06	5.0%	211.74	75.3%
Bottom Lines						
Energy into the process - kWh	281					
Energy delivered to the cooling plant - kWh	81					
Losses - kWh	200					
	71.1%					
Average price of electricity; \$/kWh	Residential	Commercial				
(U.S. Average for May, 2017)	\$0.1302	\$0.1058				
Cost to cool a Ball Room on a Design Day in St. Louis, Missouri for an Hour (Note 3)	\$10.58	\$8.60				
Cost to Cool a Ball Room for a Typical Hot Day in St. Louis, Missouri (Note 3)	\$144.92	\$117.76				
Associated Emmissions for One Day, lb.						
CO_2 (Carbon Dioxide)	4.8191	Believed by some to be the primary greenhouse gas emitted by human activities; Respiratory problems occur at high concentrations.				
SO_2 (Sulfur Dioxide)	0.0051	Resiratory system harm and difficult breathing; Harms trees and plants by decreasing foliage and growth; Reacts to create haze.				
NOx (Nitrous Oxide)	0.0038	Reacts to form ozone, aerosols, and NO_2; Respiratory harm; Contributes to acid rain; Impacts water and air quality; Greenhouse gas.				

Using People Power

Say I wanted to charge my cell phone with some magic machine that was powered by the motion I use to walk. If I wanted to do it in an hour walk, I would need to provide the additional 6.17 watts of delivered energy to the cell phone battery along with the efficiency losses of the magic machine I was using along with the efficiency losses associated with my body working.

Delivered power -	6.17 watts
Magic machine efficiency -	74%
Power out of body into magic machine -	8.34 watts
Body efficiency -	22%
Additional power into body -	37.90 watts
Walking plus charging phone -	302.88 watts
Equivalent pace -	4.30 mph
	13.95 minutes per mile
Current walking power rate from above -	264.98 watts
Walking power if some of it went to charge an iPhone -	227.08
Equivalent pace -	2.90 mph

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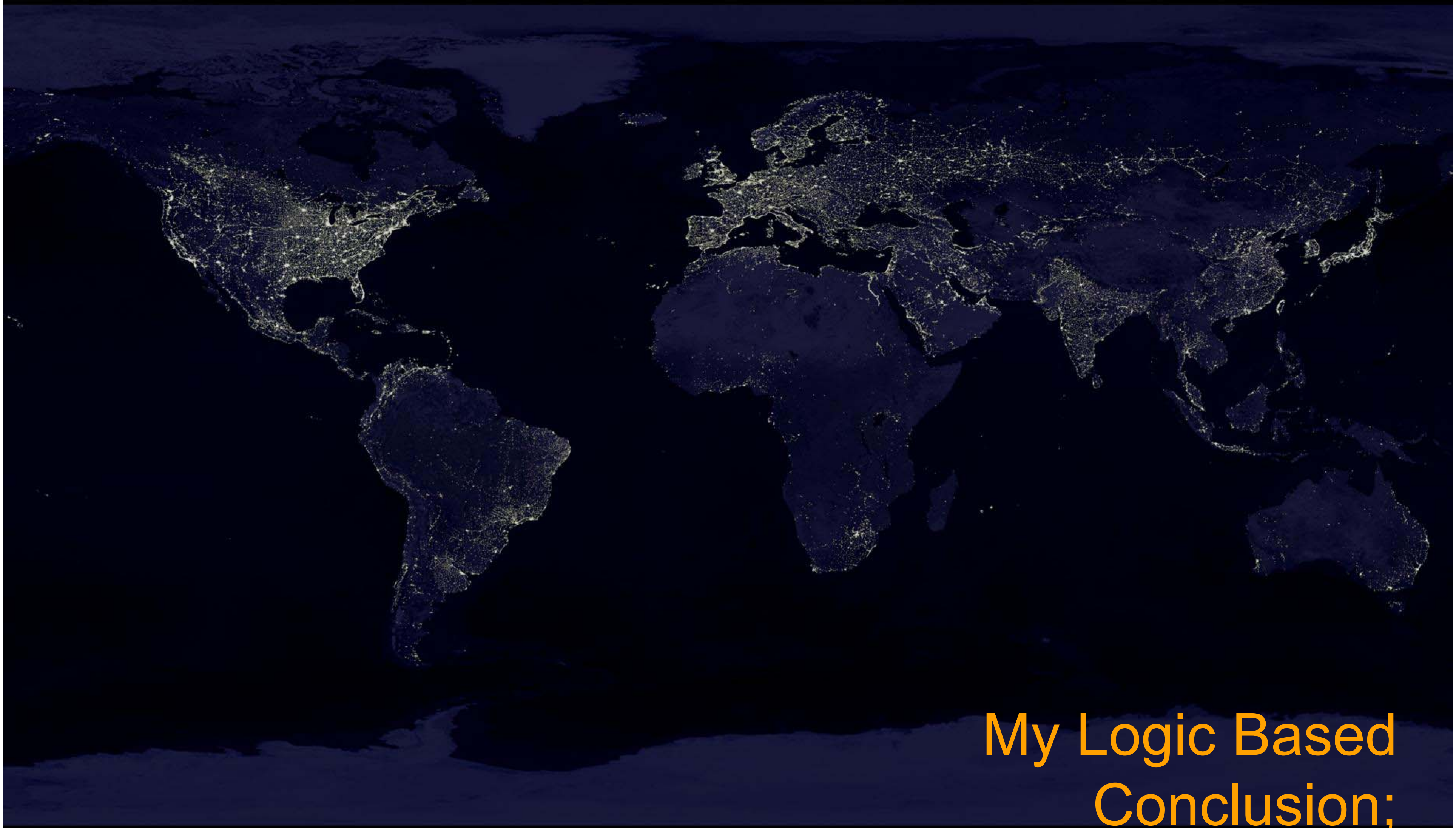
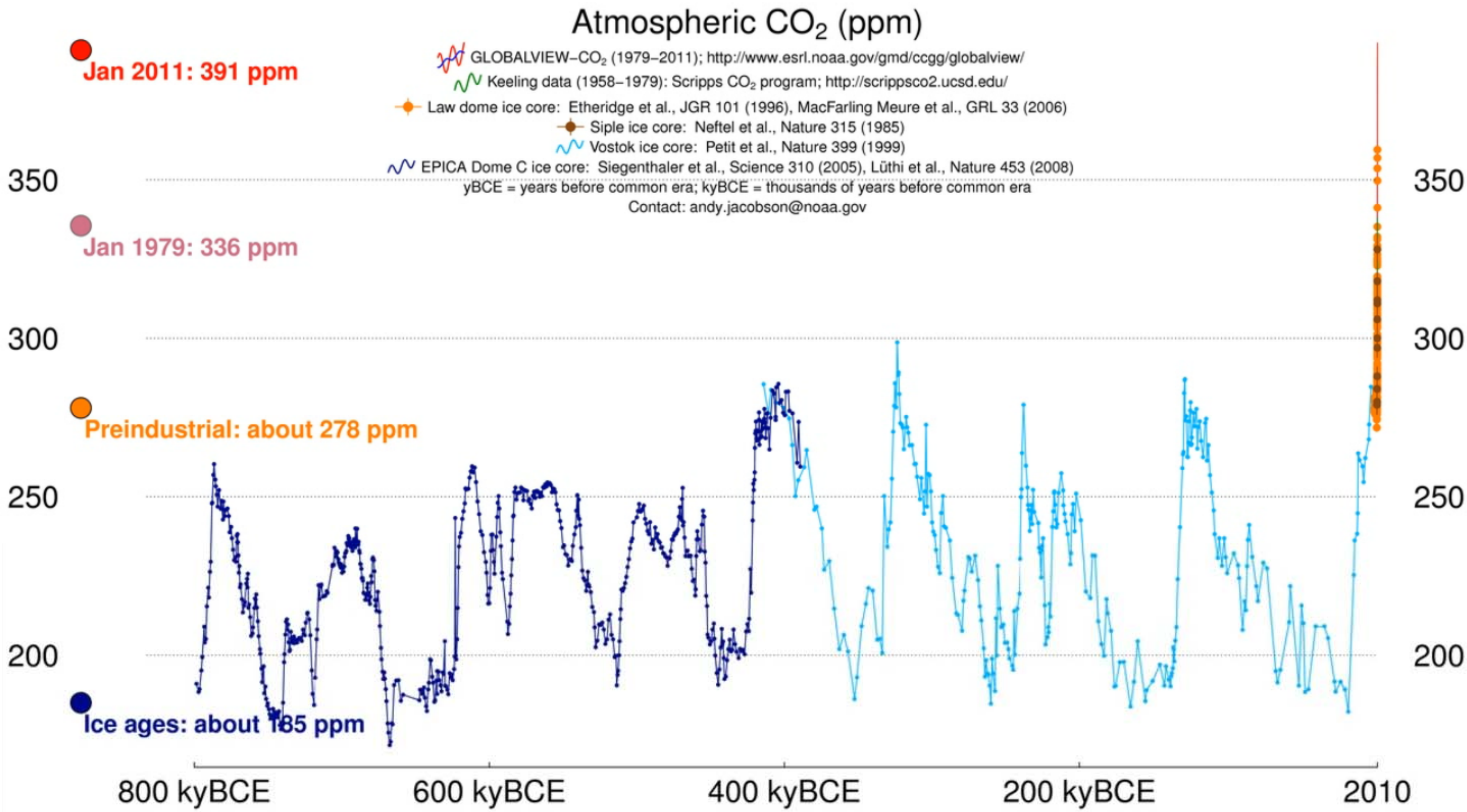
Equivalent pace -	4.30 mph
	13.95 minutes per mile
Current walking power rate from above -	264.98 watts
Walking power if some of it went to charge an iPhone -	227.08
Equivalent pace -	2.90 mph
Number of people with the magic machine required to keep the ball room cool for an hour	
	13,169

Public Domain Image Courtesy NASA Earth Observatory http://eoimages.gsfc.nasa.gov/images/imagerecords/47000/47687/ISS026-E-006255_lrg.jpg



My Logic Based Conclusion;

We Have to be Having Some Sort of Impact



Video downloaded from the Earth System Research Laboratory Global Monitoring Division at http://www.esrl.noaa.gov/gmd/ccgg/trends/history.html

Why I Want to Commission

Why I Want to Commission

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We Don’t Inherit the World from our Ancestors,
We Borrow it From Our Children
Unknown