

# The Electric Power System, Pollutant Emissions & Climate Change

Smith College, EGR 325  
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1

## Pollutant Emissions from Electric Power

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- Which are the pollutants from electric power generation?
- What is their source?
  - Fuel
  - Combustion
  - Other?
- How are the pollutants controlled?
  - Policy
  - Technology
- What is/can the power industry do?

3

## Overview

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- Impacts of power system on the environment: Pollutants from power generation
  - Sulfur
  - CO<sub>2</sub> and other GHGs
- Impacts of climate change on the power system

2

## Key problems related to Energy

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- Acid Rain
- Nuclear leakage
- Magnetic field radiation
- Fish/animal welfare
- Global warming
- Respiratory illness, human health

4

## Pollutants

- $\text{SO}_x$  – Sulfur oxides
- $\text{NO}_x$  – Nitrogen oxides, esp.  $\text{N}_2\text{O}$
- $\text{O}_3$  – Ozone
- Carbon, carbon dioxide
- Mercury
- VOC – Volatile organic compounds
- Particulates, ashes

5

## Sulfur: Acid Rain Damage



6

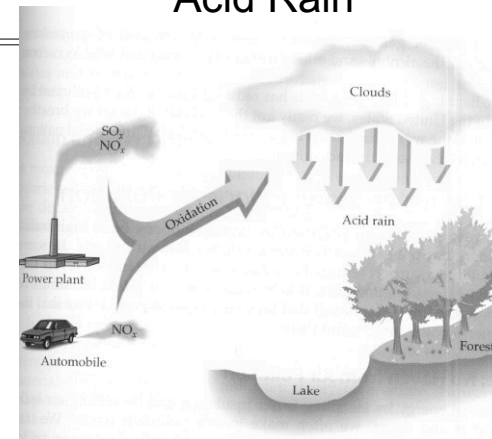
## Sulfur → Fuel → Coal

Coal types, hardest/least sulfur to softest/most sulfur  
– Anthracite → Bituminous → Lignite

1. Anthracite – Pittsburg
  - Hardest, oldest coal, most completely converted to coal (most carbon by weight)
  - Low/no sulfur → buried in fresh water
2. Bituminous – Appalachia
  - High sulfur → buried in salt water
3. Lignite – Montana, Wyoming
  - “Brown” soft coal → lower carbon content
  - A lot of sulfur
  - A lot of this coal

7

## Acid Rain

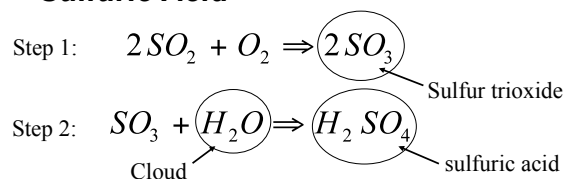


8

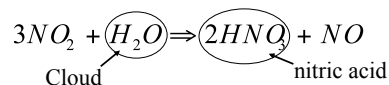
## Ingredients of Acid Rain

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- **Sulfuric Acid**



- **Nitric Acid**



9

## Control Technology

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- “BACT” and “RACT”
- Sulfur and acid rain
  - “Scrubbers” =
  - SCR – selective catalytic reduction
- Policy solutions
  - “Cap and trade” permit scheme
- A regional, not global, issue

10

## Nitrogen Oxides

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- Fuel NO<sub>x</sub>
  - *N in the fuel* reacts with O to form NO and NO<sub>x</sub>
- Thermal NO<sub>x</sub>
  - *N from air* mixes with O at high temperatures,
  - Rule of thumb: this will form at around 600 C°
- Prompt NO<sub>x</sub>
  - N from the air, (some from the fuel); not from processes above...
- Process NO<sub>x</sub>
  - Dependent upon the manufacturing process
  - In processing, agents may be added, there may be N in the agents and N in the process itself
  - e.g., KNO<sub>3</sub> – potassium nitrate is a refining agent in glass

11

## Greenhouse Effect

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- The earth temperature depends on
  - solar energy reaching the earth
  - radiated energy from earth back to space.
- Increased CO<sub>2</sub> concentration absorbs infrared radiations (7-12 μm).
- Part of this energy is reradiated back to earth, thus increasing the Earth’s temperature

12

## Greenhouse Gases, GHGs

- CO<sub>2</sub> is one of the greenhouse gases
- Other greenhouse gases
  - Water vapor
  - Methane
  - Nitrous oxide
  - Ozone

13

## Industrial Greenhouse Gases

- Carbon dioxide: burning fossil fuels, solid waste, and wood
- Methane
  - Emitted during the production of coal, natural gas, and oil
  - Also as a result from the decomposition of organic wastes in landfills, and the raising of livestock
- Methane traps over 21 times more heat per molecule than carbon dioxide

14

## Industrial Greenhouse Gases

- Nitrous oxide is emitted during
  - combustion of fossil fuels and solid waste
  - agricultural and industrial activities
- Nitrous oxide absorbs 270 times more heat per molecule than carbon dioxide
- (Ozone from CFCs and automobile exhaust )

15

## Pollutant Emissions (lb/MWh)

Pollutant	Fuel Type		Effect
	Coal	Natural Gas	
<b>Sulfur</b> Oxides (SO <sub>2</sub> )	14 lb/MWh	0.01 lb/MWh	Acid rain & respiratory

Pollutant	Fuel Type		Effect
	Coal	Natural Gas	
<b>Nitrogen</b> Oxides (NO <sub>x</sub> )	4.8 lb/MWh	4.3 lb/MWh	Acid rain & Smog

Pollutant	Fuel Type		Effect
	Coal	Natural Gas	
<b>Carbon</b> Dioxide (CO <sub>2</sub> )	2,100 lb/MWh	1,200 lb/MWh	Global warming Greenhouse Gas

16

## Control – Policy

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- Legislation: 1990 CAA – Clean Air Act
  - Defines “criteria pollutants,” “criteria species”
  - Based on threshold concentrations, which are ill-defined
  - Note that we regulate
    - NO<sub>2</sub>, not NO<sub>x</sub> in general, e.g. not N<sub>2</sub>O
    - SO<sub>2</sub> not SO<sub>x</sub>
    - CO not CO<sub>2</sub>

17

## Power Industry Response

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- The Electric Power Industry and Climate Change: Power System Research Possibilities
  - Research report from PSERC
  - 13 major power system universities
  - Regional power system operators
  - Transmission system owners
  - Power system equipment and software manufacturers

19

## Control – Policy

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- **1990 CAA Amendments**
  - National ambient air quality standards
  - New concept is that of a threshold – scientifically defined to be that level below which no harm is done
    - Two thresholds
    - One for humans
    - One for the environment
- **Note that the national legislation does not account for**
  - Storage/accumulation of the pollutants in the environment with/over time
  - Transport of pollutants to other geographic areas

18

## Discussion from PSERC Report

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- General power system topics
- Extreme weather
- Government policies
- Market mechanisms
- Industry planning

20

## Some CO<sub>2</sub> Reduction Options

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- Energy efficiency and conservation: Use less energy in total
- Biofuels: Convert all our corn to ethanol?!
- Nuclear: Build new reactors
- Coal: Practicality of sequestration is unknown
- Wind: A significant increase would require a lot of new transmission system capacity
- Pluggable Hybrids: Will transfer issues from transportation sector to electricity sector

21

## Extreme Weather

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- Slow increase in *average* global temperature not an issue.
- But increases in *extremes* of heat, rain, winds and changes in water runoff could be significant for power system design and operation.
- Key is the rate of change in extremes versus the rate of power system upgrade.

23

## Science & Technology Research Topics

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1. Develop and analyze methods to improve energy conservation and efficiency.
2. Analyze the effects on system load shape and transmission system expansion in response to an increased use of plug-in hybrid vehicles.
3. Analyze system impacts and control needs of a significant penetration of large, remote wind farms.
4. Analyze the impact of an expansion of nuclear energy, in terms of impacts on the transmission system and power system operation, and in GHG reductions.

22

## Extreme Weather Research Topics

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1. Use predictions of regional climate change to estimate the rate of change of power system design parameters.
2. Robust monitoring and control techniques for harsh weather and increased load demand.
3. Combine climate predictions of extreme weather with emerging blackout risk assessment.
4. Better system restoration in case of natural disasters.

24

## Government Policies

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- International
  - United Nations Kyoto Protocol, 1997
  - President Bush disengaged in 2001
  - US goal would have been to reduce CO<sub>2</sub> emissions to 7% below 1990 levels by 2008-2012
- Federal
  - 1990/92: CO<sub>2</sub> monitoring
  - Four mandatory limit bills now in Congress
- Carbon Capture and Sequestration
  - Probable technology for coal
    - Cost for retrofitting plants could affect dispatch
    - Issues with locating plants near sequestration site

25

## State Government Policies

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- RGGI – Regional Greenhouse Gas Initiative
  - Mandatory cap-and-trade beginning in 2009
  - Nine northeast and mid-Atlantic states
- WRCAI – Western Regional Climate Action Initiative
  - Regional emissions market and monitoring
  - To begin summer 2008
- California Assembly Bill 32
  - Reduce GHG to 1990 levels by 2020
  - Reduce to 80% below 1990 levels by 2050
  - Mandatory reduction beginning 2012

26

## Government Policies

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- Investigate how potential and actual government policies will affect power system operations and electricity market operations.

27

## Government Policies Research Topics

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1. Analyze the effect on system operations from changing the use of generators that result from production caps and emissions regulations.
2. Analyze the impact on both existing generating plants and the power system from possible government regulations constraining the use of specific types of generators.
3. Analyze the effect of bills such as AB32 on power system operations.
4. Analyze the effect of inconsistent/conflicting regional emissions policies (in conjunction with an analysis of inconsistent/conflicting regional permit markets) in contrast to uniform, national policies.

28

## Market Mechanisms

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- Responsive demand and conservation
  - Price-, Incentive-, Reliability-based
  - Manual and automatic response
- Carbon tax
  - Economist support for a carbon tax
  - Transparent mechanism
- Cap-and-trade emissions trading
  - Emissions limits; permits to produce pollutants; permits can be traded
  - Significant market design and permit allocation issues

29

## Market Mechanisms

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- Renewables portfolio standards, RPS
  - State based initiatives, with discussion on developing a federal RPS
  - Mandate MW, MWh or % energy from renewables
    - 4% by 2009 (MA) v. 30% by 2020 (MN)
  - Trading allowed via renewable energy certificates (RECs)
  - ‘Tier 1’ and ‘Tier 2’ resources
- Market design for issues for cap-and-trade, responsive demand and portfolio standards

30

## Market Mechanisms Research Topics

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1. Research the effect of conflicts and/or inconsistencies between regional cap-and-trade markets, and conflicts with renewable portfolio standards (RECs).
2. Analyze the effect on system and market operations if automated control systems are installed at customer locations.
3. Develop new planning and risk management tools, focusing on the risk introduced by uncertainty in climate change and government policies designed to address climate change issues.

31

## Industry Planning

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- Demand reduction and conservation
- Improved efficiency of the electricity infrastructure
- Increase emphasis on renewables (wind, solar, biomass, biofuel) and distributed generation
- Nuclear generation
- CO<sub>2</sub> reduction, capture, transformation and sequestration.
- Other industries are making long range plans.
  - (Market share, Anticipate Regs, Avoid \$ Loss, Avoid Litigation)

32

## Industry Planning Research Topics

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1. Analyze the efficiencies of market structures where carbon trading is allowed within the electric power industry and between the electric power industry and other GHG producing industries.
2. Evaluate the consequences on system stability and responsiveness that is lost by reducing hydro-generation.

33

## Conclusions

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- The power industry has mixed interest in addressing climate change issues
- Communication necessary between engineers and policy makers
- PSERC report at
  - [http://www.pserc.org/cgi-pserc/getbig/publicatio/reports/2007report/pserc\\_climate\\_change\\_final\\_rpt\\_june07.pdf](http://www.pserc.org/cgi-pserc/getbig/publicatio/reports/2007report/pserc_climate_change_final_rpt_june07.pdf)

34

## Summary

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- Early efforts
  - Acid rain, ozone hole
- Current issue
  - Climate change
- Continuing concerns
  - Mining
  - Heating of rivers, lakes, shoreline
  - All pollutant emissions

35