# The Hidden Costs of Energy: Coal Electricity Generation in the US and India

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# India v. the United States

- In the US, health damages from coal-fired power plants have greatly decreased since the 1990s
  - This partly reflects decreased use of coal to generate electricity
  - Mainly the result of lower damages per kWh due to controls on $SO_2$ and $NO_x$ emissions
  - Controls spurred by environmental regulations
- In India, health damages attributable to coal are rising
  - Coal generating capacity rose from 71 GW (2006) to 148 GW (2014) and is expected to double by 2030
  - A kWh of electricity in India generates more lives lost than a kWh in the US
  - Should $SO_2$, $NO_x$ from coal-fired power plants be controlled?

# Outline of the Talk

- Health damages from coal electricity generation in the US, 1999-2011
  - Why damages have fallen
  - How health damages compare with $CO_2$ damages
- Stylized facts about electricity generation in India
- Health damages from coal-fired power plants in India, 2011
- Cost-effectiveness of FGDs (scrubbers) at Indian power plants



FGD = flue gas desulfurization

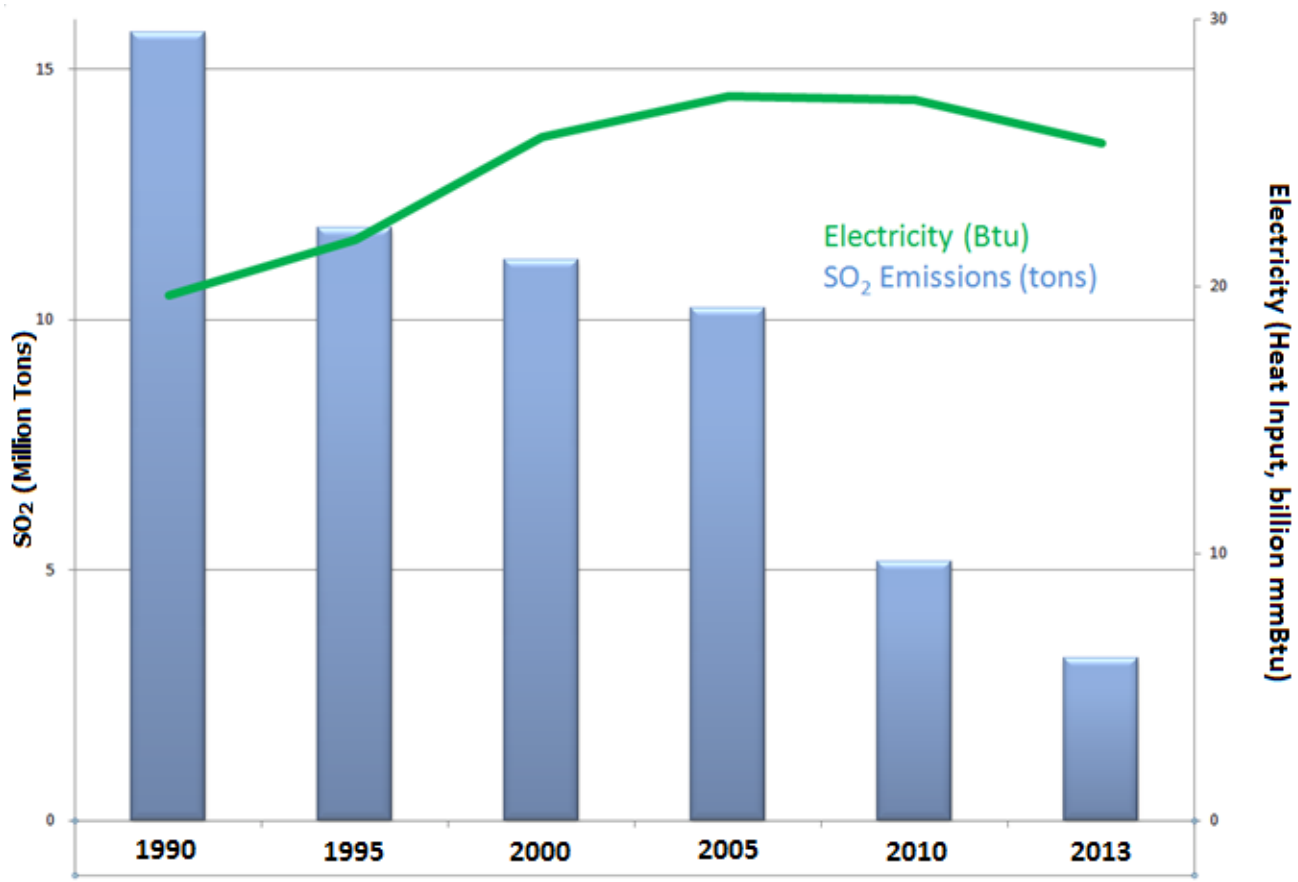
# Measuring Health Damages

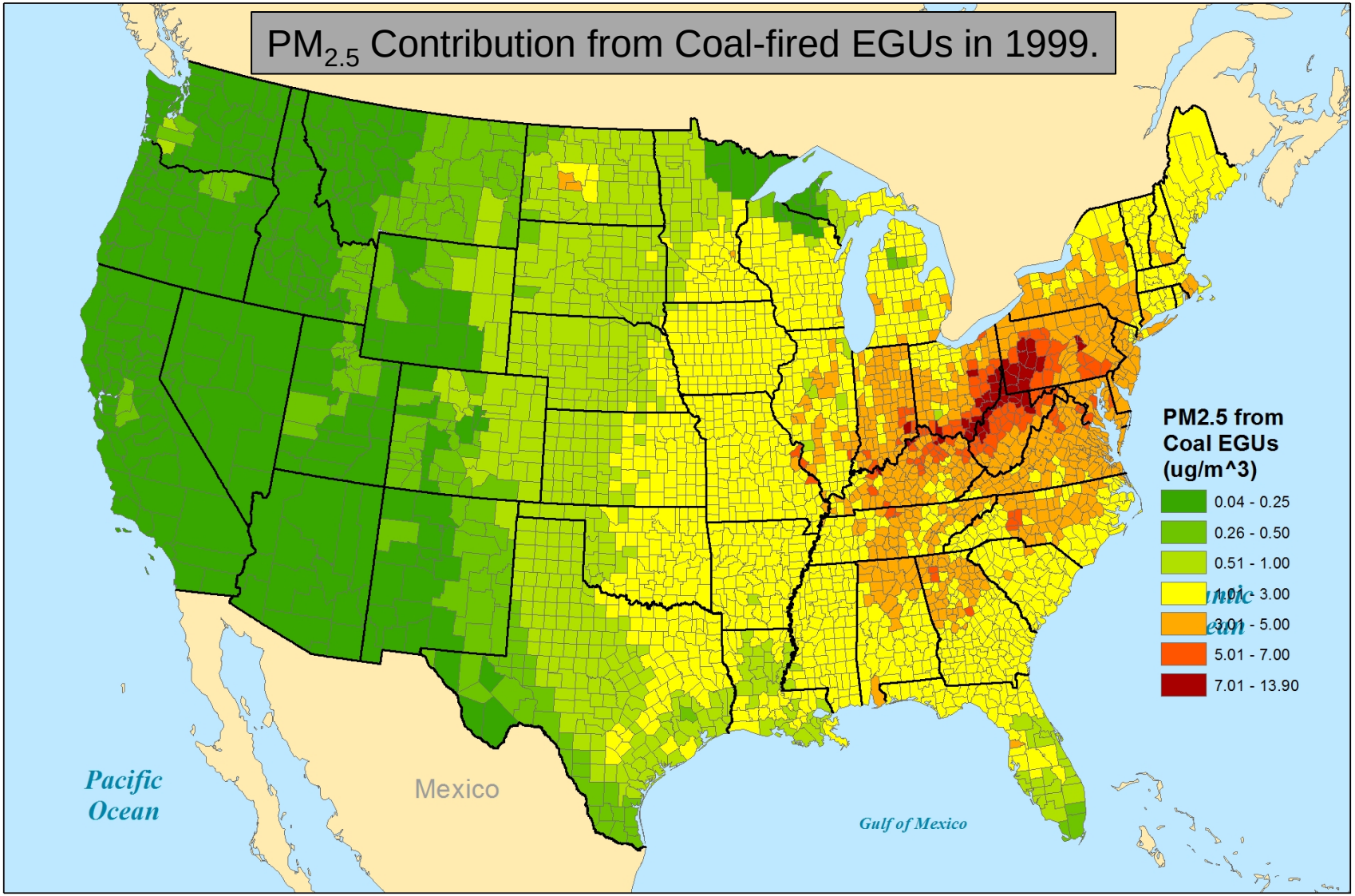
- Bottom-up approach using emissions by plant
  - Emissions of $PM_{2.5}$, $SO_2$, $NO_x$, VOC, $NH_3$
- Estimate impact of emissions on ambient $PM_{2.5}$
  - Allowing for secondary particle formation
- Dose-response functions translate change in ambient $PM_{2.5}$ into damages
  - Morbidity (chronic bronchitis), premature mortality
- Value health endpoints
  - Mortality typically dominates value of damages

# Measurement of Damages in US

- AP2 Model used (Muller, *Science* 2014)
- Source of emissions is National Emissions Inventory
- Source-receptor matrix allows conversion of $SO_2$, $NO_x$ to $PM_{2.5}$
- Premature mortality based on Pope et al. (2002)
- Lives valued using a $6 million Value of a Statistical Life (VSL)
- Change in damages primarily reflects change in emissions/kWh over time

# $SO_2$ Emissions from Coal in the US



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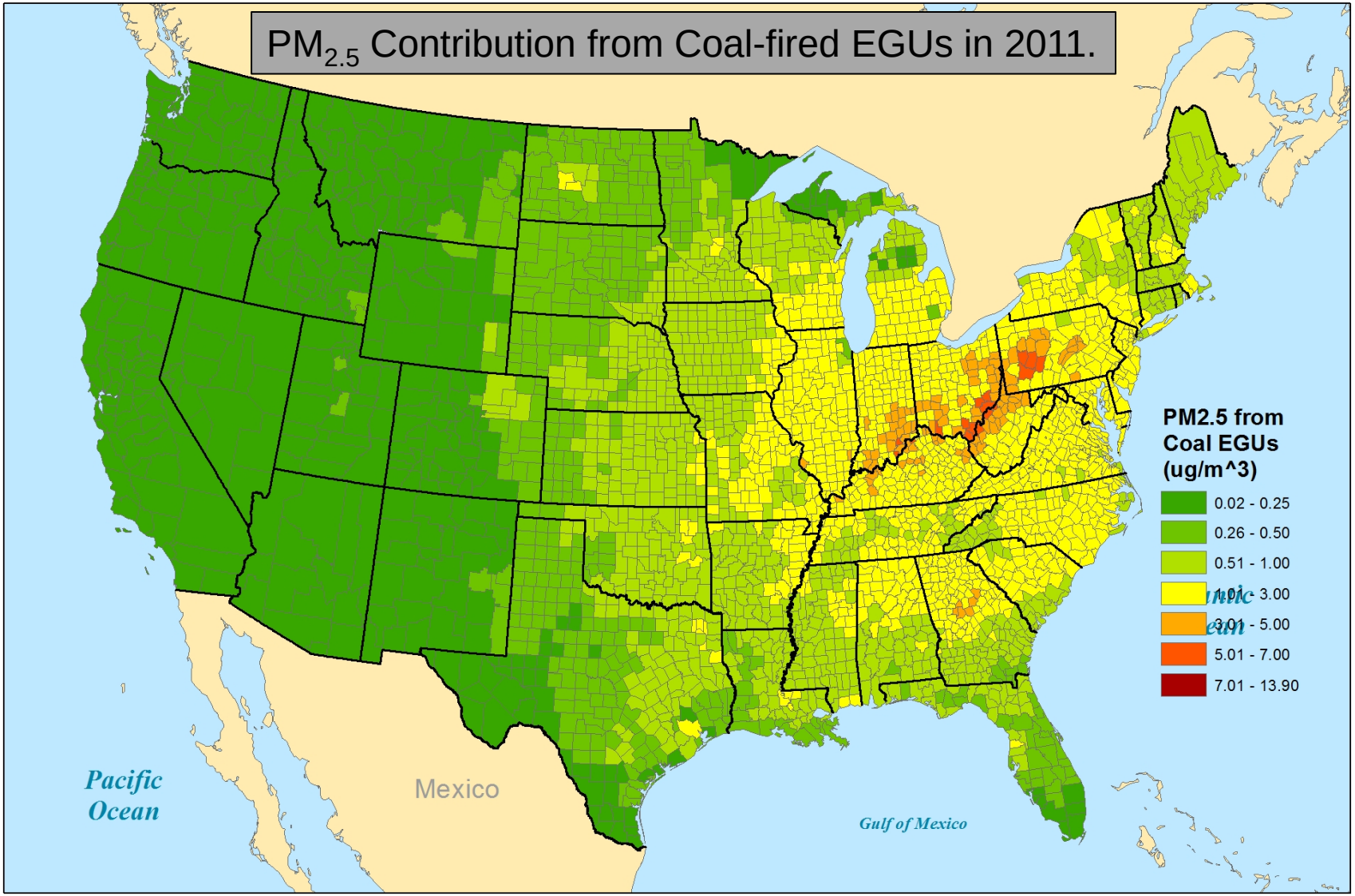


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EGU = energy generating unit

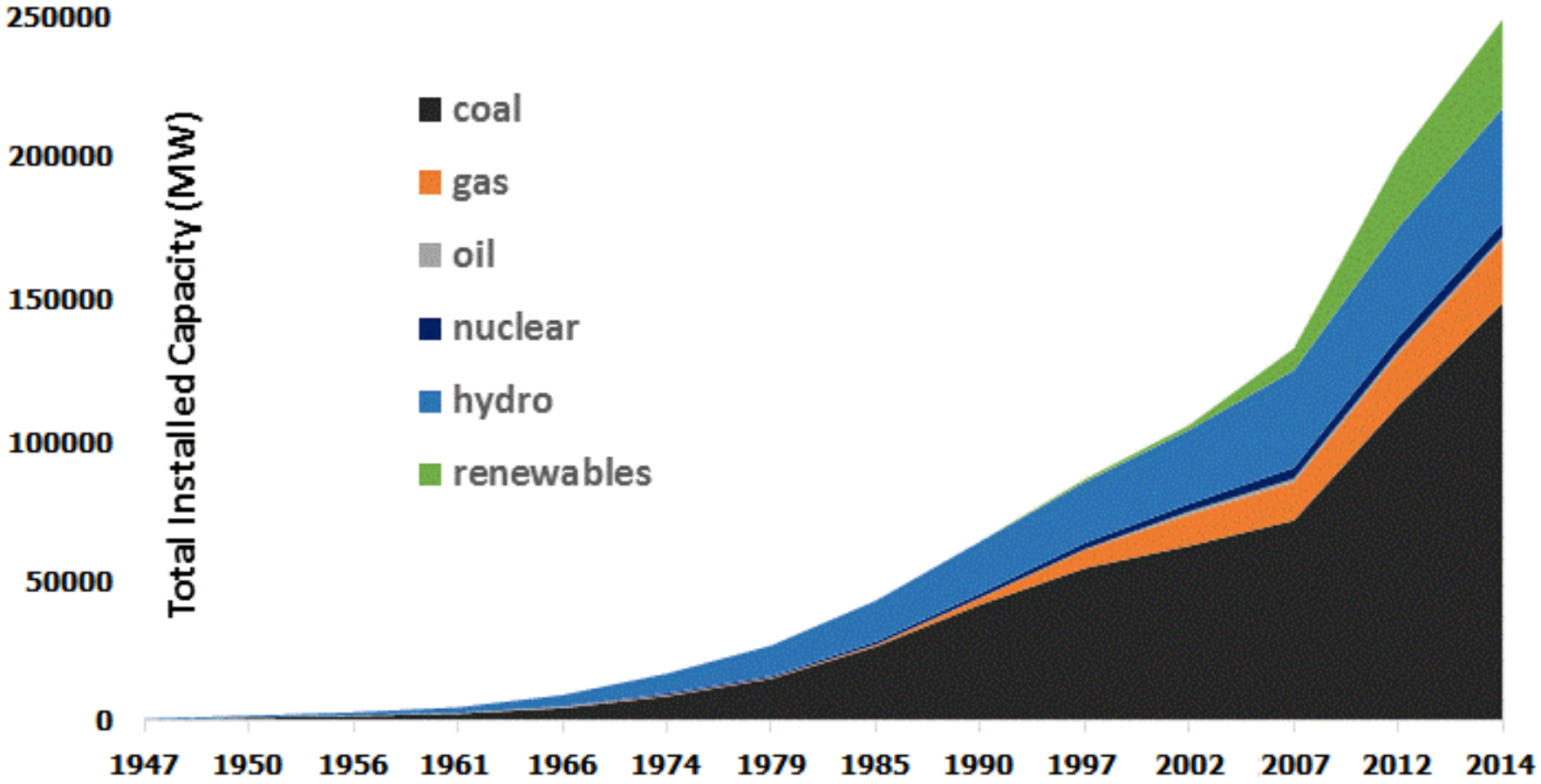
# Health Damages from Coal in the US 1999-2011

- Premature deaths attributable to coal plants fall from 27,000 (1999) to 9,470 (2011)
  - Reduction of 65%
- Deaths per kWh fall by 60%
- This due primarily to reductions in $SO_2$ emissions
  - $NO_x$ impacts 2 orders of magnitude smaller than $SO_2$
- Value of health damages 2011 = $68.4 billion (2007$) – 3.4 cents/kWh

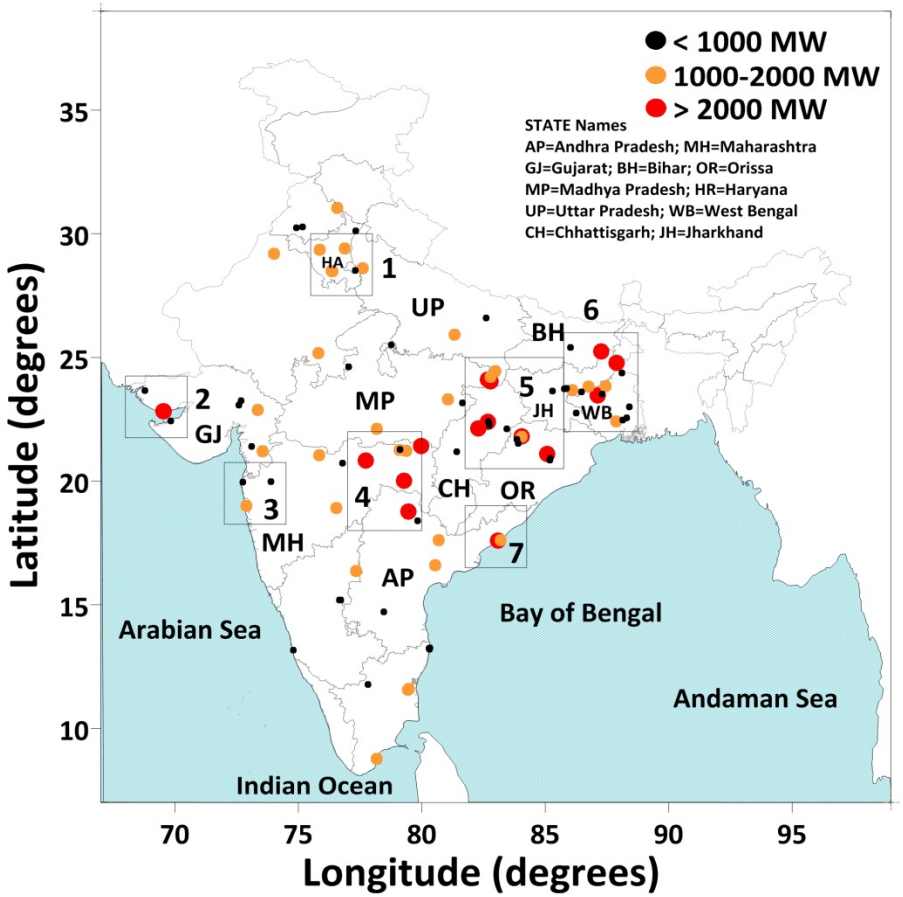
# How Do Health Damages Compare with $CO_2$ Damages?

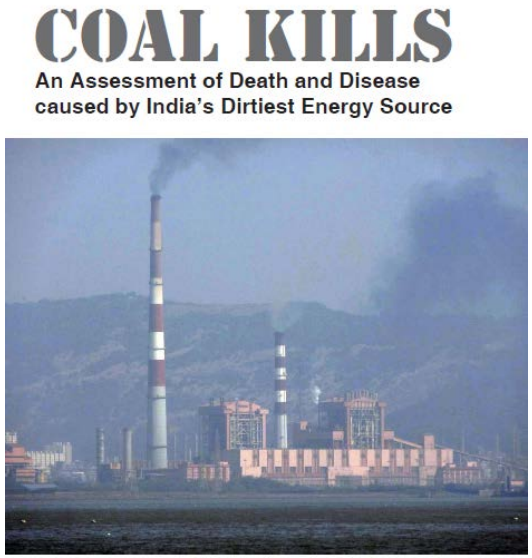
- $CO_2$ emissions fell from 1836 million metric tons (MMt) in 1999 to 1723 MMt in 2011
  - 6% decline reflects decreased electricity production from coal
- Using the Social Cost of Carbon estimate of $35/ton of $CO_2$
  - Total $CO_2$ damages = $60.3 bil. in 2011 (2007$)
  - Total heath damages from coal = $68.4 bil. (2007$) in same year

# Installed Capacity in India, 1947-2014



# Coal-fired thermal power plants




**2011-12**

**Operational 111 plants**

**80,000 to 115,000 premature deaths**

**GBD study estimate - 695,000 deaths from all sources in 2010**

Atmospheric Environment (2014)

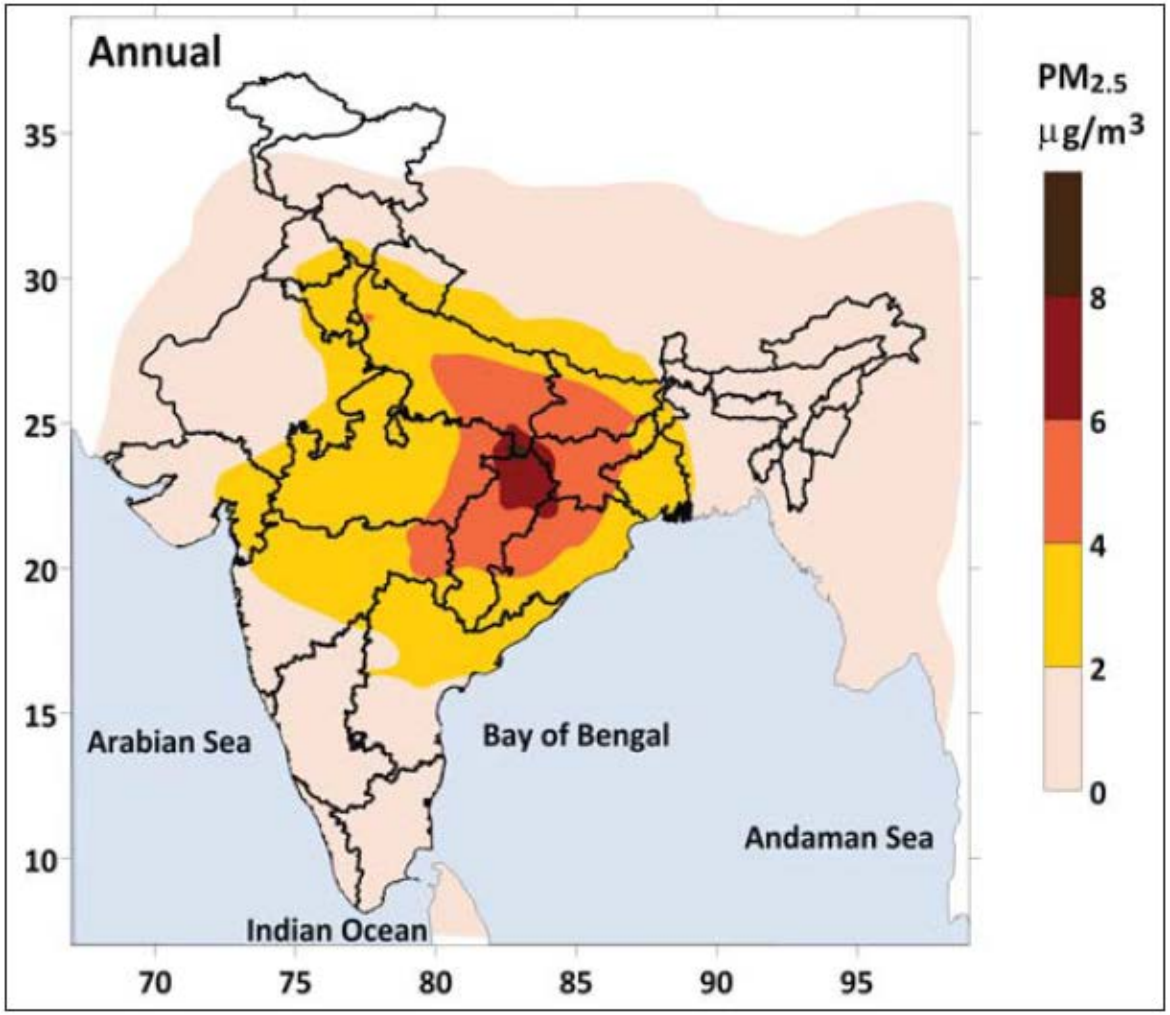
# Coal-Fired Power Plants in India

- Generate about 70% of electricity in India
- Coal burned per kWh 60% greater than in US
- Ash content of coal = 30-50%; Sulfur content = 0.5% by weight
- Plants have electrostatic precipitators (ESPs) to remove PM, although ash content affects their efficiency
- No limits on $SO_2$ emissions, but
  - Minimum stack height requirements
  - EGUs over 500 MW must leave space for a scrubber

# Impact of Coal Plant Emissions on Ambient Air Quality in India

- Coal-fired power plants in India emitted about 4.6 million tons of $SO_2$ in 2010-11
- Net generation about 0.620 Trillion kWh (cf. 1.733 Trillion kWh in the US in 2011, with ~ equal tons $SO_2$
  - Emission rate in India per kWh over twice as high as the US
  - Reflects lack of pollution controls; more coal burned per kWh
- $PM_{2.5}$ emissions/kWh also higher in India: 2 lbs/MWh v. 0.5 lbs/MWh in the US (2005)
- Applying CAMx to emissions from coal plants in India yields an estimated change in annual average $PM_{2.5}$ of 3.6 µg/m³ (population-weighted)

Modeled annual average $PM_{2.5}$ ambient concentrations due to the emissions from coal-fired thermal power plants in India



# Health Impacts of Coal-Fired Power Plants in India

- Power plant emissions associated with 80,000 deaths per year
  - Estimate based on transferring Pope et al. (2002) to India
  - Can be compared with 10,000 deaths associated with coal-fired power plants in the US in 2011
- What accounts for the difference?
  - Exposed population is much higher in India
  - Annual average change in $PM_{2.5}$ from coal-fired power plants is 4X greater than in the US (3.6 v. 0.85 μg/m³)
- Note that this ignores morbidity impacts, mortality under age 30

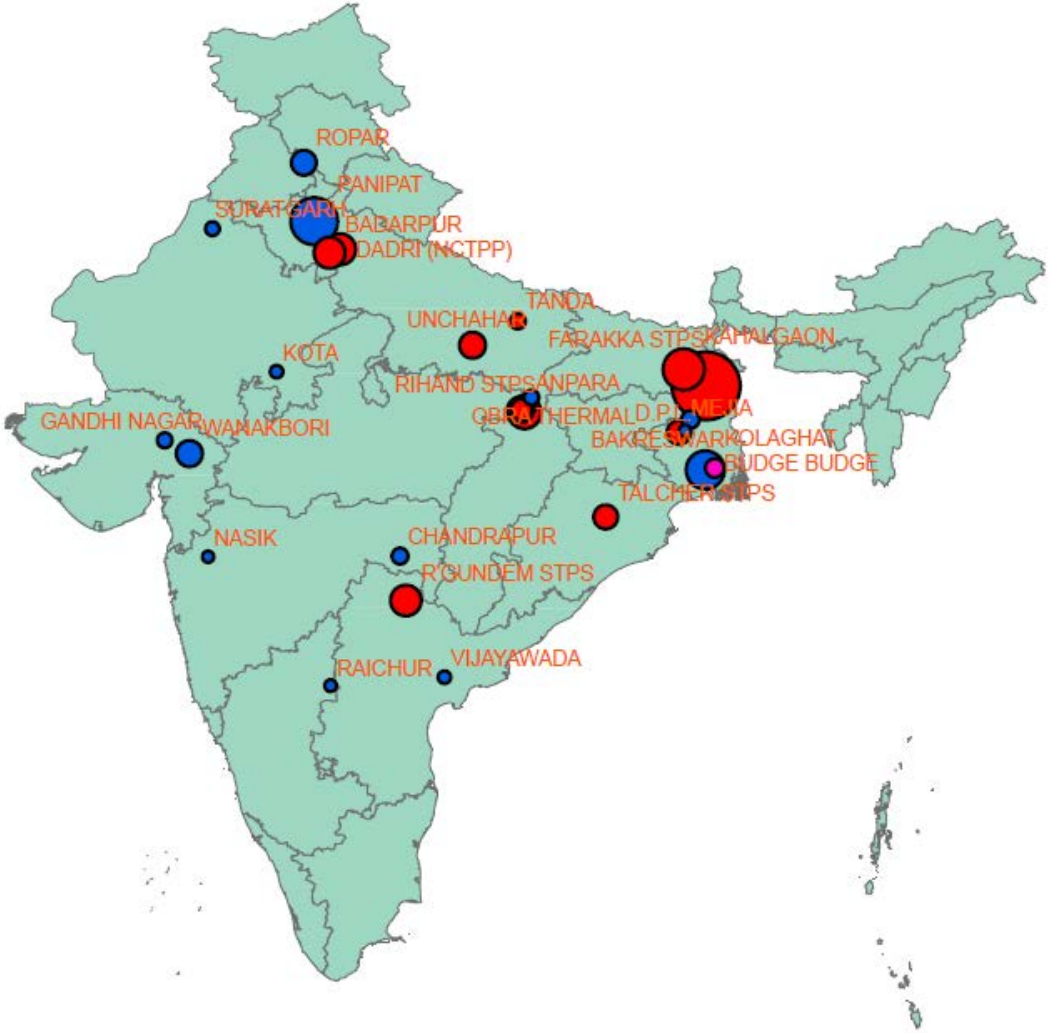
# Policy Issues

- Should India place more stringent controls on emissions from coal-fired power plants?
- Currently: No emissions limits on $SO_2$ or $NO_x$ from coal-fired power plants
- Should flue gas desulfurization units (FGDs) be required?
- Should regulations on coal washing be strengthened?
  - Ash content of coal must be ≤ 34% in sensitive and critically polluted areas
  - Only 5% of domestic coal was washed in 2007
  - 25% of plants violated PM standards in 2008 (self-reported)

# Is Retrofitting FGDs Cost-Effective?

- Malik (2013) investigates cost per life saved of retrofitting 72 coal-fired power plants with FGDs
  - Lagrangian plume model used to estimate impact on ambient air quality
  - Pope et al. (2002) used to estimate mortality impacts
- Cost per life saved by installing a scrubber
  - On average, 6 million Rs. (95,000 USD)
  - Cost ranges from 1.6 to 32 million Rs. per life saved
  - VSL for India (transferred from US) = 7.5 million Rs.
- Scrubber raises electricity costs per kWh by about 5%

# 30 Coal-fired Power Plants with Highest Sulfate Deaths



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# Concluding Remarks

- Health benefits of controlling emissions from coal-fired power plants are clear
  - In the US, controls on $SO_2$ clearly pass the benefit-cost test
  - In India they do at power plants with large exposed populations
- Strengthening environmental regulations in India likely to take time
  - Supreme Court has forced installation of 3 FGDs
  - But need greater appreciation of health impacts