# U.S. EPA MARKAL:

## Representing $SO_X$ and $NO_X$ control technologies in MARKAL using an engineering-cost model.

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## *ISA Workgroup's Role in the EPA*

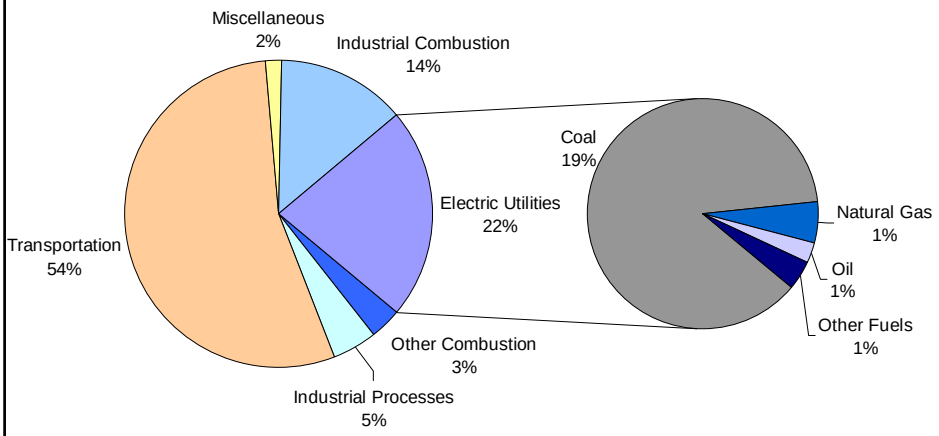
- Support ORD Global Change Program (MARKAL modeling)
  - Develop and assess scenarios of future technologies over 50 year time horizon
  - Focus on transportation and electricity sector
  - Improve understanding of how technological change can impact future air pollutant and greenhouse gas emissions
- Perform energy technology assessments with a focus on environmental impacts
- Provide useful analyses and tools to states and regions that are trying to make energy decisions

## Motivation

- U.S. electric sector emissions of $SO_X$ and $NO_X$ are constrained by both the Clean Air Act and CAIR (Clean Air Interstate Rule)
- Coal is responsible for most of the electric sector emissions
- Several retrofits to existing coal plants can be made to significantly reduce $SO_X$ and $NO_X$ emissions
- **Critical to include these retrofits in MARKAL; otherwise existing coal capacity is replaced too quickly with cleaner technology in order to meet emissions constraints**

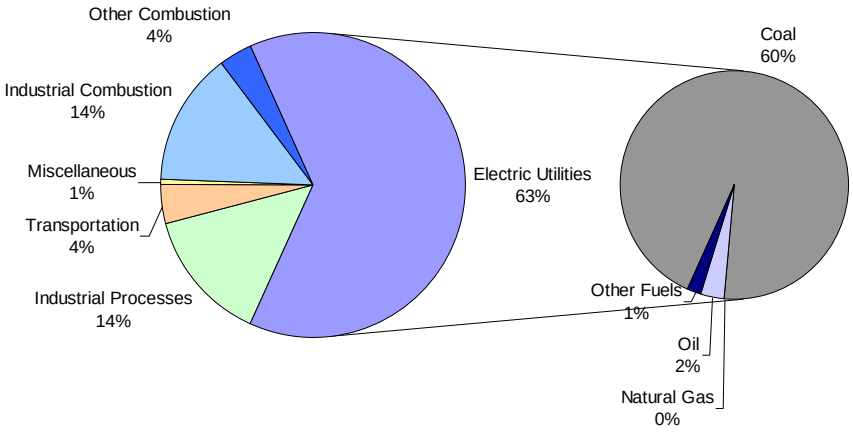


## Profile of U.S. $NO_X$ Emissions




Source: EPA, 2005 (National Emission Trends)

## Profile of U.S. $SO_X$ Emissions

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## Coal in EPA U.S. National MARKAL Database

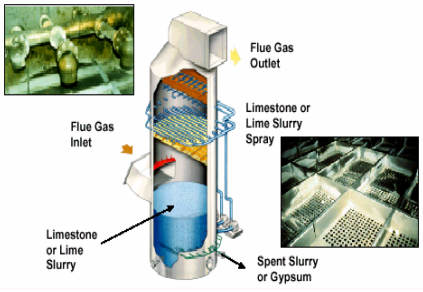
**General coal representation**

- Both surface and underground mine types
- Coal supply curves specified by region: Dakotas, Gulf, Interior, Northwest, Powder River, Rocky Mountains, Southwest

**Coal characteristics affecting emissions**

- 3 coal types: bituminous, sub-bituminous, and lignite
- 3 sulfur levels:
  - High (≥ 1.68 lbs $SO_X$ / MBTU)
  - Medium (>0.6 and <1.68 lbs $SO_X$ / MBTU)
  - Low (≤ 0.6 lbs $SO_X$ / MBTU)

# $SO_X$ Control: FGD (Wet Scrubbers)




- Most widely-used process is limestone forced oxidation (LSFO)

$CaCO_3 + SO_2 + 1/2\ H_2O \rightarrow CaSO_3.1/2\ H_2O + CO_2$

$CaSO_3.1/2H_2O + 1/2\ O_2 + 3/2H_2O \rightarrow CaSO_4.2H_2O$

- LSFO operating parameters: reagent ratio = 1.05-1.1, L/G = 70-120, auxiliary power = 1.2-2%
- State-of-the-art is 95% $SO_2$ removal
- Capital intensive, space requirements
- Over 200 GW of wet scrubbers installed on coal-fired boilers worldwide (~30%)



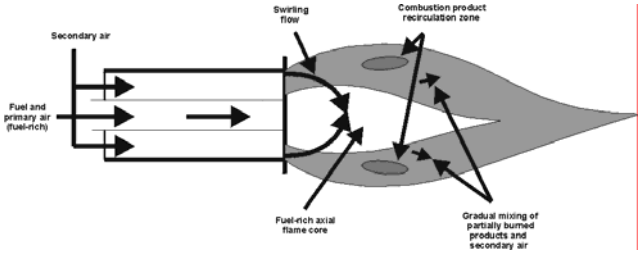
# NOx Control Technologies

## (Commercially Established)

- Primary – reduce the NOx produced in the primary combustion zone
  - Low $NO_X$ burners (LNBs)
  - Overfire air (OFA)
- Secondary - reduce the NOx already present in the flue gas
  - Reburning
  - Selective non-catalytic reduction (SNCR)
  - Selective catalytic reduction (SCR)

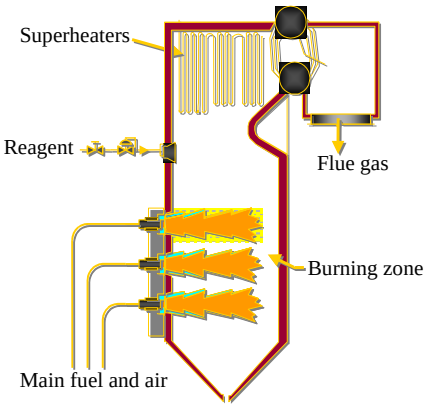
## Low NOx Burners (LNB)

- Limit NOx formation by delaying complete mixing of fuel and air
  - Reduced oxygen in primary flame zone
  - Reduced flame temperature
  - Reduced residence time at peak temperature
- Can provide reductions in excess of 50% from uncontrolled level






## Selective Non-Catalytic Reduction (SNCR)

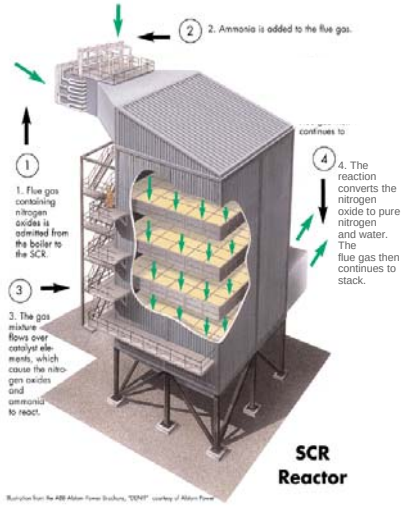



- Urea or $NH_3$ injection, generally between 980 to 1150 °C
- 30 to 60% $NO_X$ reduction
- Low capital costs
- Load following, $NH_3$ slip, performance on larger boilers
- Applications: cyclone, wall, tangential boilers 50-620 MW

**Source:** Srivastava et al. (2005)

## Selective Catalytic Reduction (SCR)

- $2NH_3 + 2NO + 1/2\ O_2 \rightarrow 2N_2 + 3H_2O$
  $4NH_3 + 2NO_2 + O_2 \rightarrow 3N_2 + 6H_2O$
- Configuration alternatives
  - "High-dust" SCR-APH-PM-FGD – most used
  - "Low-dust" PM-SCR-APH-FGD
  - "Tail-end" APH-PM-FGD-SCR
- $NH_3$ injection, generally between 350-400 °C
- More than 90 percent reduction is possible
- Capital intensive, space requirements
- Over 120 GW of SCR systems installed on coal-fired boilers worldwide (~20%)

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## Data Sources

- DOE EIA 767 – Plant technical data, no fuel characteristics
- DOE EIA 860 – Plant specific fuel characteristics and consumption data
- EPA CAMD – Emissions data

- Plant characteristics, fuel type, plant factor, S content, ash content, heat content, bottom type, firing type, etc.

## Tools

- CUECost (EPA/ORD model)
  - Engineering-economic cost model
  - $NO_x$ retrofit cost for each plant in population
- Script in VBA to automate calculations
  - Cost estimation based on most important parameters (i.e., boiler size, coal type, ash content, PLF, heat rate)
  - Individual plant and fuel characteristics taken into account (i.e., firing type, bottom type, S content, ash content)



## Method (Part 1)

- VBA script ran CUECost for all U.S. coal boilers listed in EPA's Clean Air Markets database.
- Result is a spreadsheet containing the following estimates for each boiler:
  - Input sulfur level (lbs/MBTU)
  - Boiler capacity (MBTU/yr)
  - Heat Input (MBTU/hr)
  - Retrofit costs: capital, O&M
  - $SO_X$ and $NO_X$ emissions (short tons / yr) assuming a given retrofit.
- The following retrofits were considered : FGD, LNB, SCR, SNCR, LNB-SCR, LNB-SNCR.

# Method (Part 2)

**Estimating $SO_X$ control parameters**

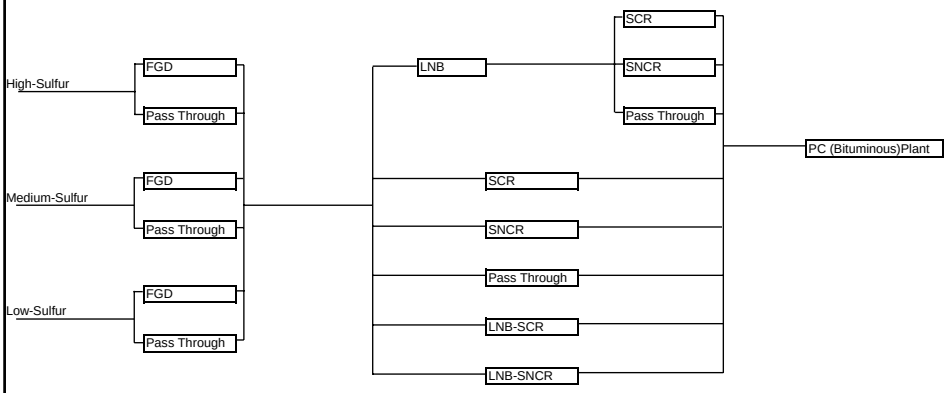
- Spreadsheet sorted by coal type and sulfur level to determine level of existing capacity with and without FGD.
- Calculate weighted average FGD retrofit costs and emissions assuming no pre-existing $SO_X$ control (by sulfur level and coal type).

**Estimating $NO_X$ control parameters**

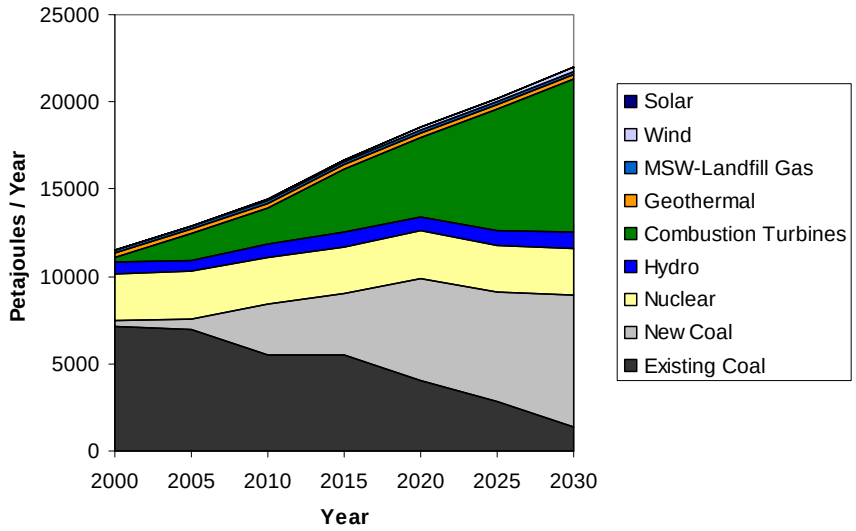
- Spreadsheet sorted by coal type to determine level of existing capacity with and without various $NO_X$ control retrofits.
- For each boiler, estimate cost and emissions for applicable $NO_X$ control retrofits.
- Calculate weighted average $NO_X$ retrofit costs and emissions by coal type.
  - Boilers with SCR or SNCR are assumed to be fully retrofitted.



# MARKAL RES for Coal Retrofits



# MARKAL Results with Old Retrofits




- "New Coal" includes new pulverized coal with advanced $SO_x/NO_x$ controls (FGD+LNB+SCR) and IGCC.
- "Combustion Turbines" include simple- and combined-cycle gas turbines as well as distillate oil turbines.



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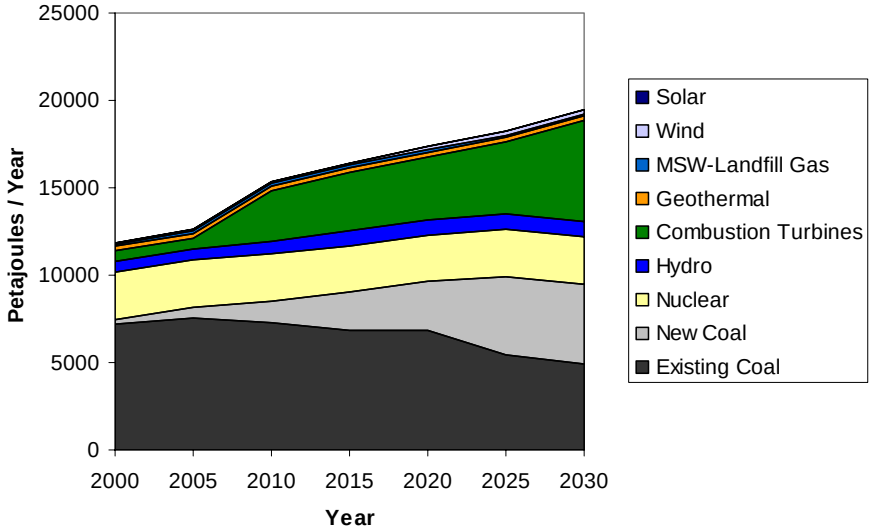


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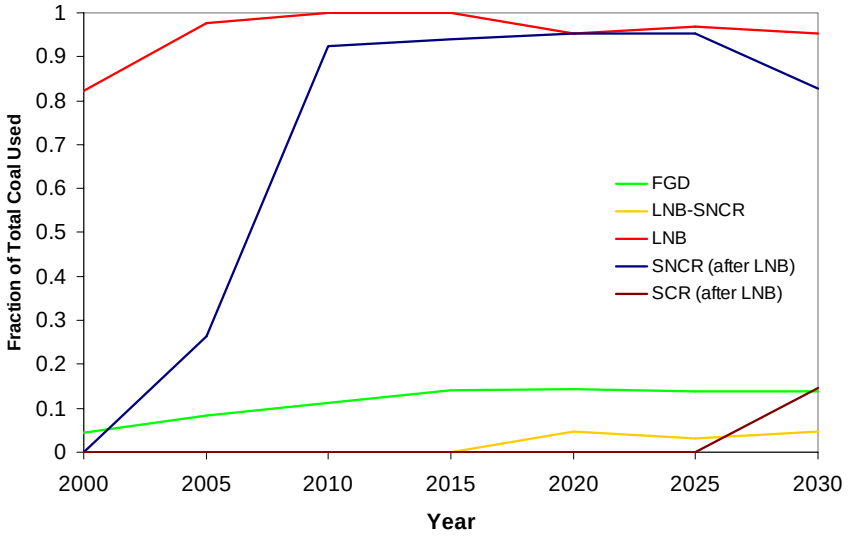
## Utilization of New Retrofits






## Summary

- Boiler-level engineering-economic model (CUECost) used to estimate average emissions and retrofit costs associated with $SO_X$ and $NO_X$ control.
- $SO_X$ and $NO_X$ retrofits added to U.S. EPA MARKAL, including all appropriate combinations of primary and secondary controls.
- With Clean Air Act and CAIR constraints, accurate results from the U.S. EPA MARKAL electric sector depend on accurate representation of $SO_X$/$NO_X$ control retrofits for coal.