REBURNING: AN HISTORICAL PERSPECTIVE

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Historically, the “green” record of combustion is mixed

- 1287 Plantagenet, Edward I, King, (aka Edw, Hammer of the Scots)
  –Forbade use of sea coal in kilns of Southwark *“under pain of heavy forfeiture”*
- 1578 Tudor, Elizabeth I, Queen
  –Coal burning forbidden in vicinity of Westminster Palace
- 1661 Evelyn, Sir John,
  –“*Fumufugium or the Inconvenience of Air and Smoke of London Dissipated”*
- 1948 Air pollution disaster in Donora, Pa
- 1952 Air pollution disaster in London
- 1963 U.S. Clean Air Acts (CAA)
- 1970 CAA amendments
- 1990 CAA amendments
- 1990 Costner, P and Thornton, J.
  – “*Playing with Fire, a Greenpeace Report*”
- 1992 Ginsburg, R
  –“*Beyond the Rush to Burn” National Toxics Campaign Fund*

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United States NO_x Regulation History

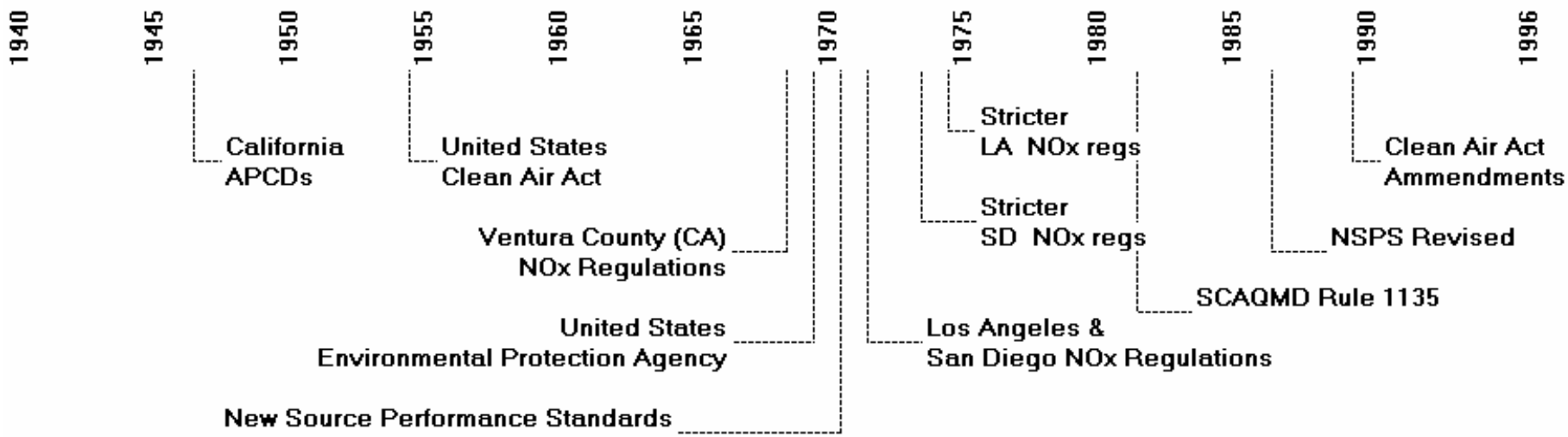

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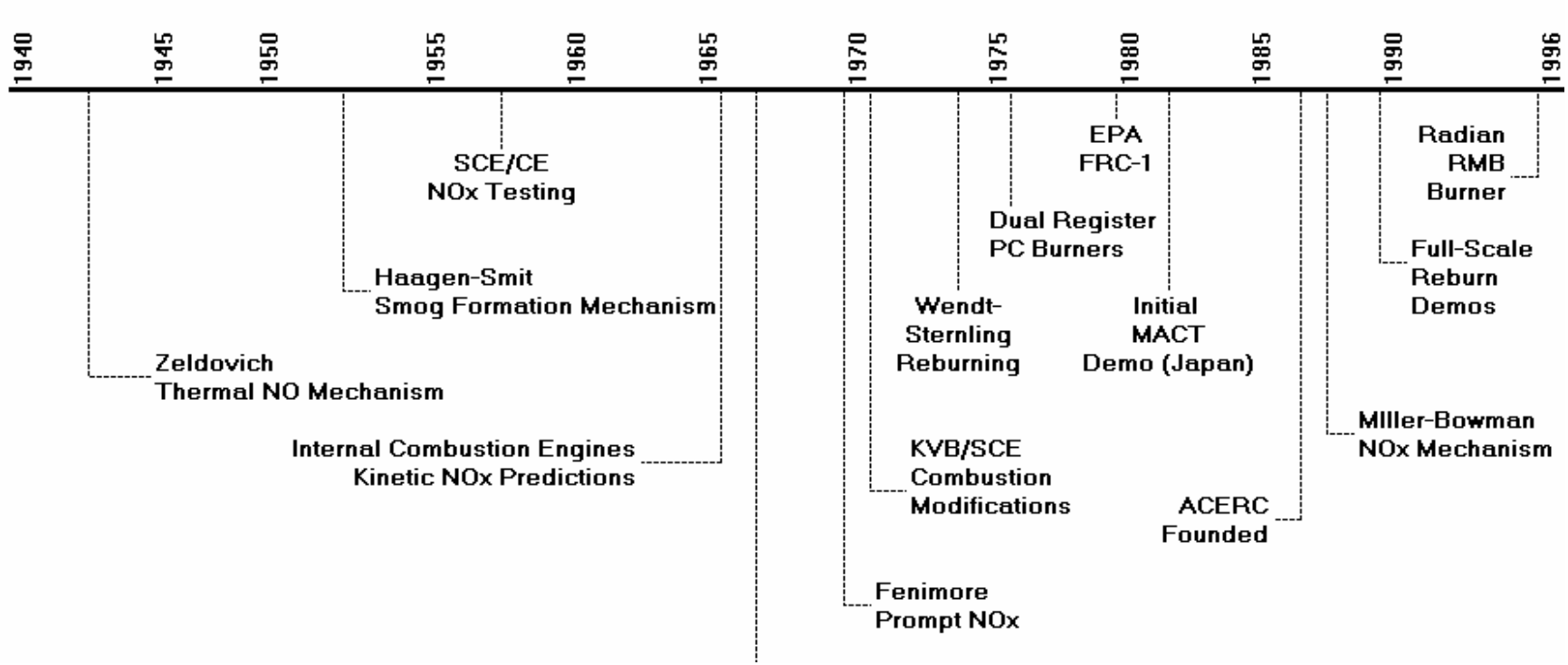
Figure 2. Overview of Combustion NO_x Applications



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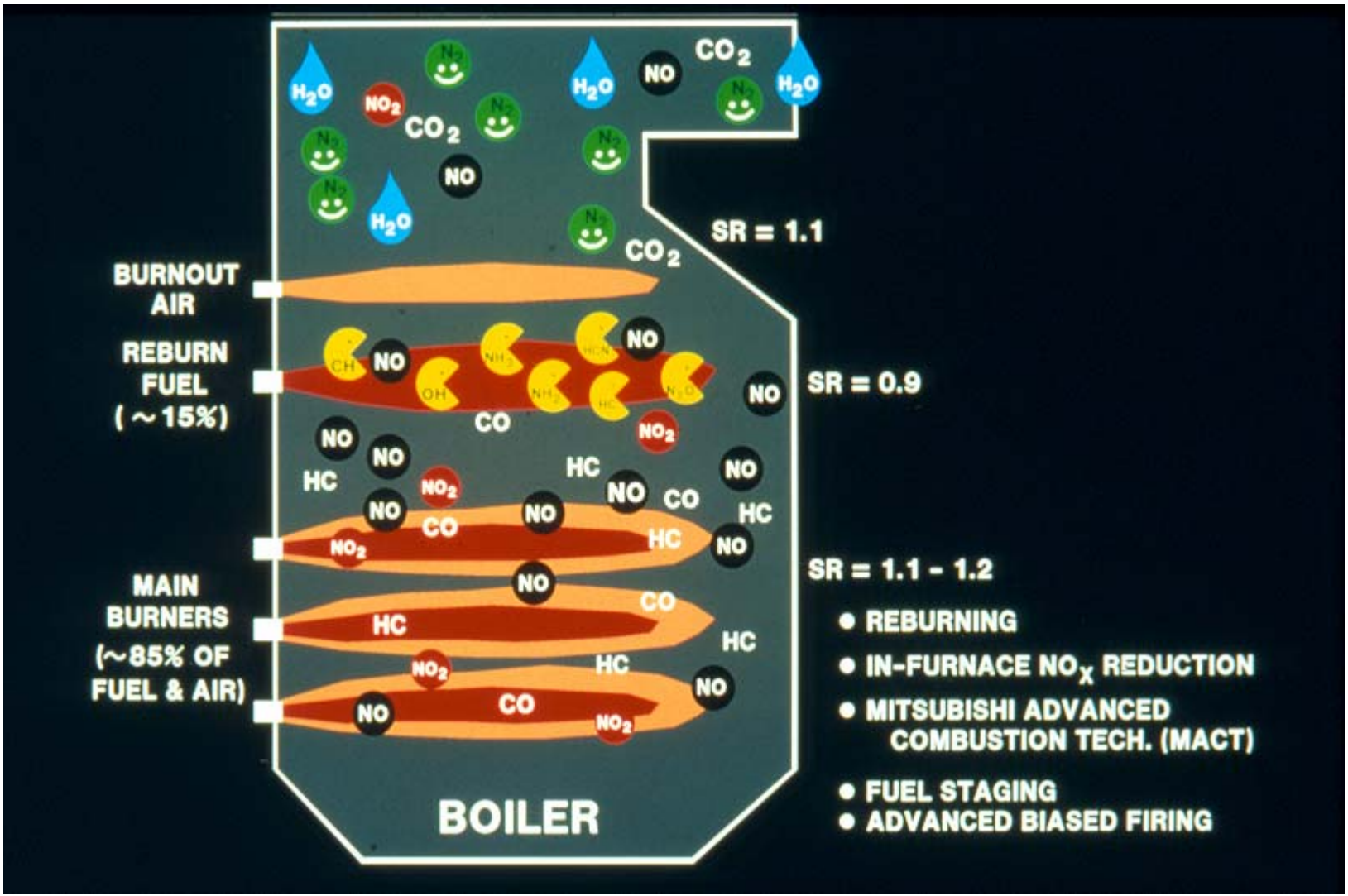
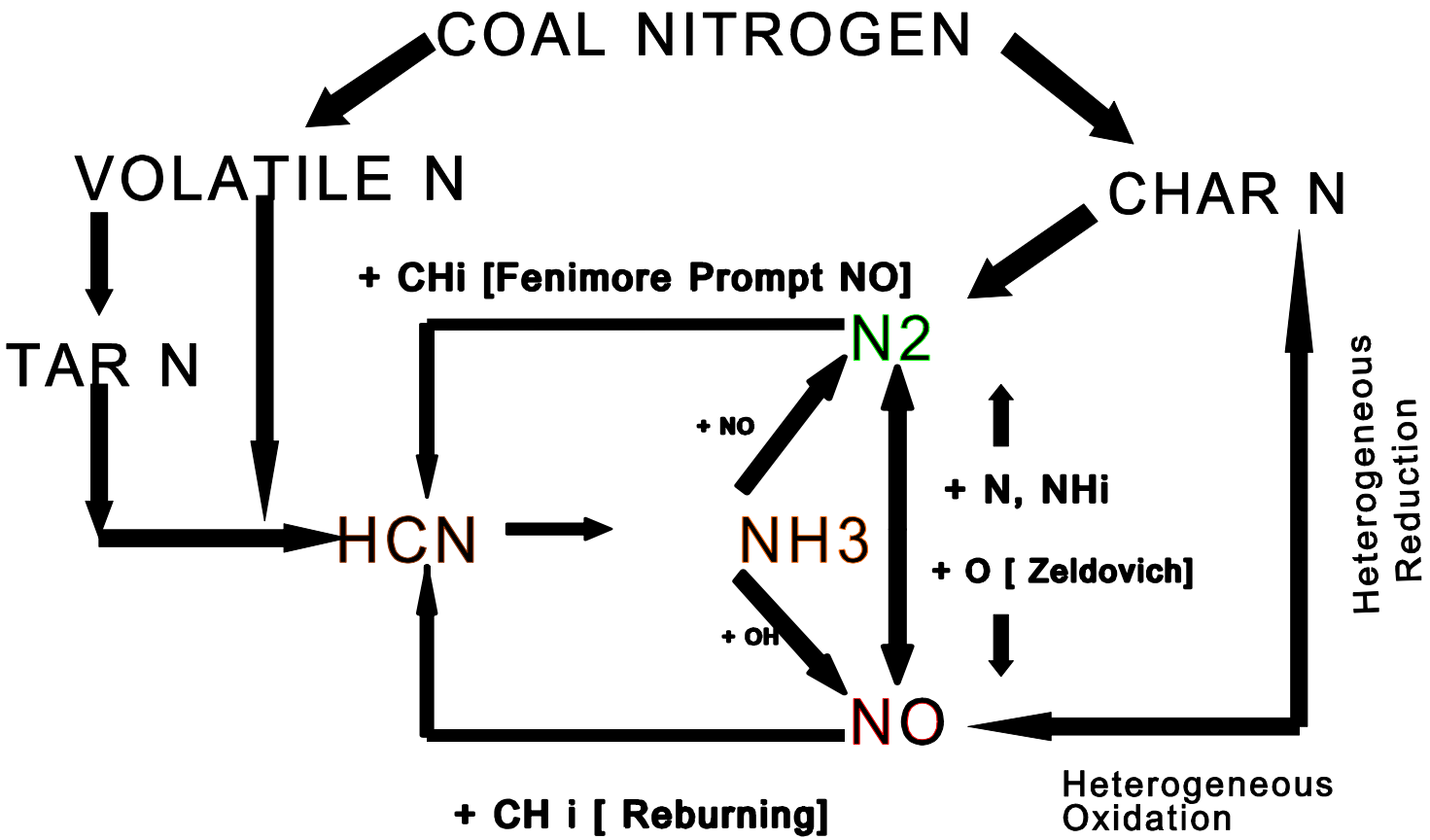
Reburning


BURNOUT AIR
REBURN FUEL (~15%)
MAIN BURNERS (~85% OF FUEL & AIR)
BOILER
SR = 1.1
SR = 0.9
SR = 1.1 - 1.2
• REBURNING
• IN-FURNACE NO_X REDUCTION
• MITSUBISHI ADVANCED COMBUSTION TECH. (MACT)
• FUEL STAGING
• ADVANCED BIASED FIRING

NO_x formation and destruction mechanisms



Prior work

- Myerson, Taylor and Faunce *"Ignition limits and products of the multistage flames of propane-nitrogen dioxide mixtures"* Sixth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA p154 (1957)
  - Showed that NO reacts with hydrocarbons via free radical reactions and is thereby destroyed.
- Reed, R.D. "Process for the disposal of nitrogen dioxide", John Zink Company, U.S. Patent 1,274,637 (1969)
  - Led to the John Zink Thermal Oxidizer (for nitric acid waste gases, NO_2)
    - Separate, external, unit for incinerating NO_2
    - Could be operated in the "decolorizing mode" (forming NO) or "oxidizing (actually, total reduction) mode" (forming N_2).
- Reburning
  - *In-situ, post-flame,* incineration of pollutants formed in the primary zone. The flue gas is "burned again".

REDUCTION OF SULFUR TRIOXIDE AND NITROGEN OXIDES BY SECONDARY FUEL INJECTION

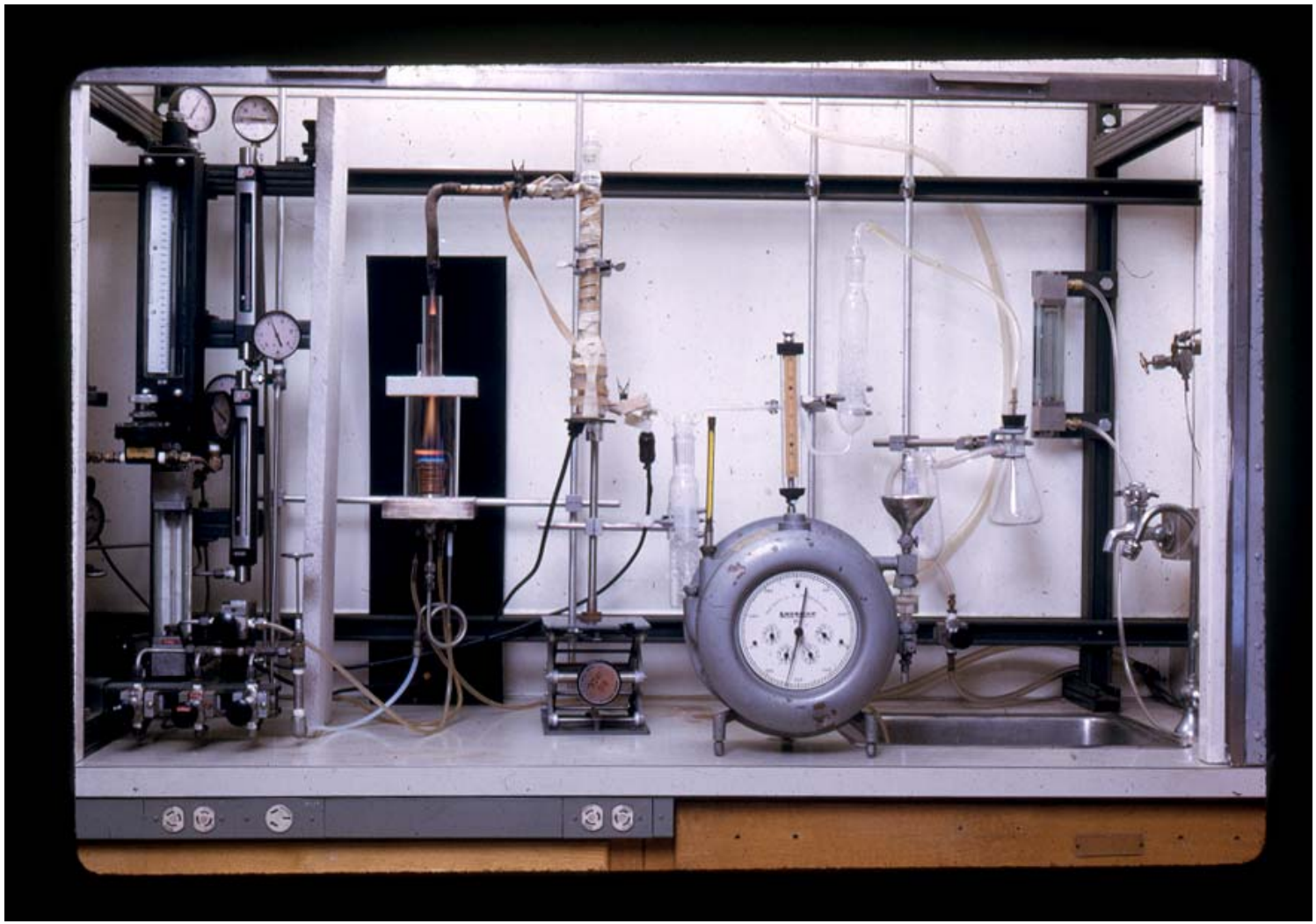
J. O. L. WENDT,* C. V. STERNLING, AND M. A. MATOVICH

Shell Development Company, Emeryville, California

Tests with an experimental laboratory burner showed that sulfur trioxide can be reduced to SO_2, and nitrogen oxides to nitrogen, by the injection and combustion of a clean secondary fuel downstream of the primary combustion zone. Sulfur trioxide and nitrogen oxides from fuels containing sulfur or nitrogen are formed in the primary flame by free radical reactions involving such species as the O atom. These reactions can apparently be reversed by a secondary combustion, which lowers the O_2 concentration. Our results suggest that this method of pollution abatement, which, for brevity, we call "reburning," may, with further development, be applicable for the reduction of SO_3 and NO_x emissions from coal- or oil-fired furnaces, boilers, and incinerators, wherever the primary flame must be operated at excess air.

Fourteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA p897 (1973). *Presented at Penn State University Symposium, August 20-25, 1972*

Reburning for SO_3 destruction.



SO_3 reduction by reburning

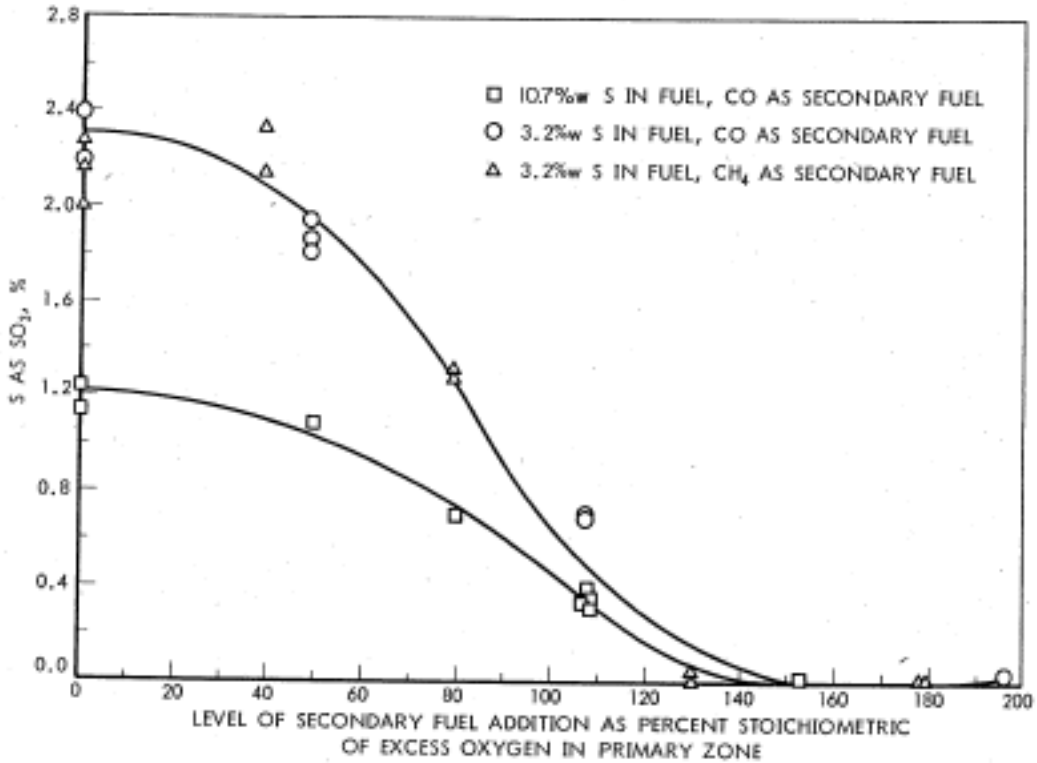
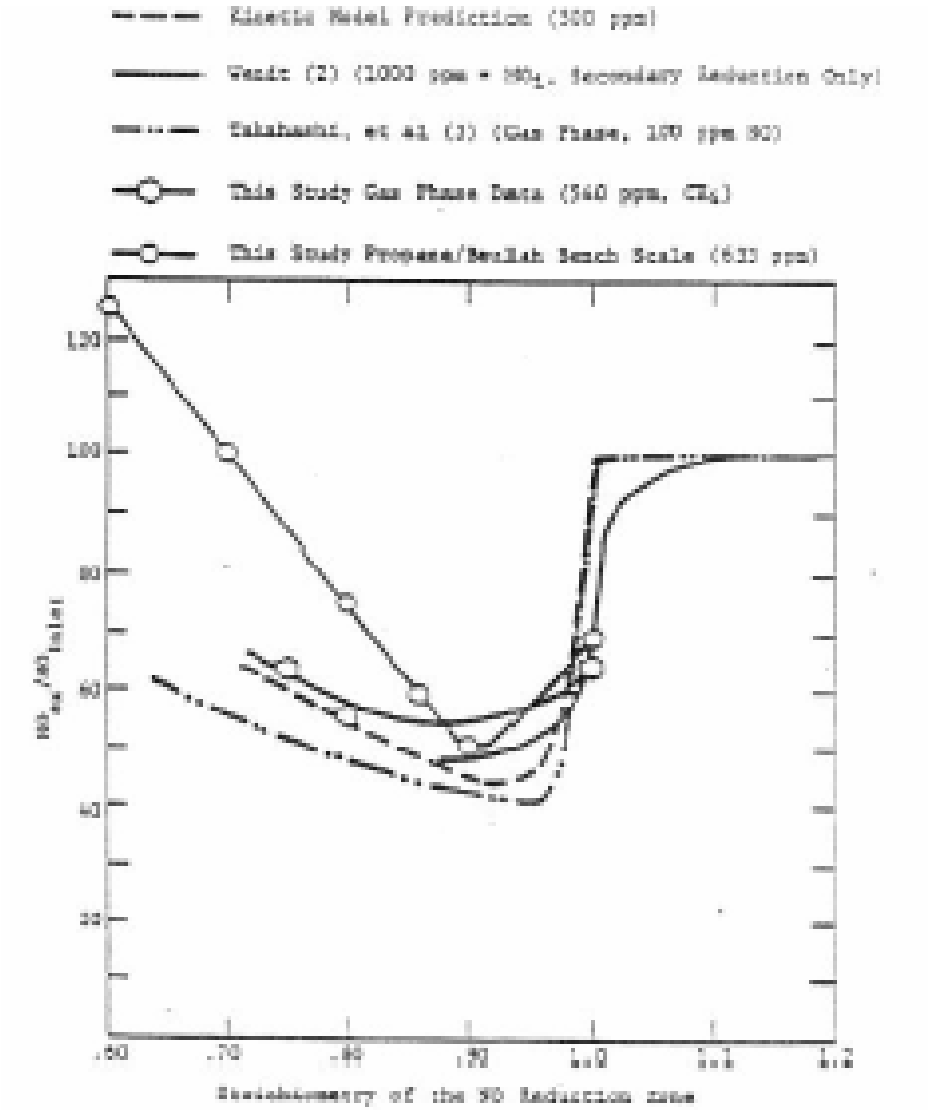


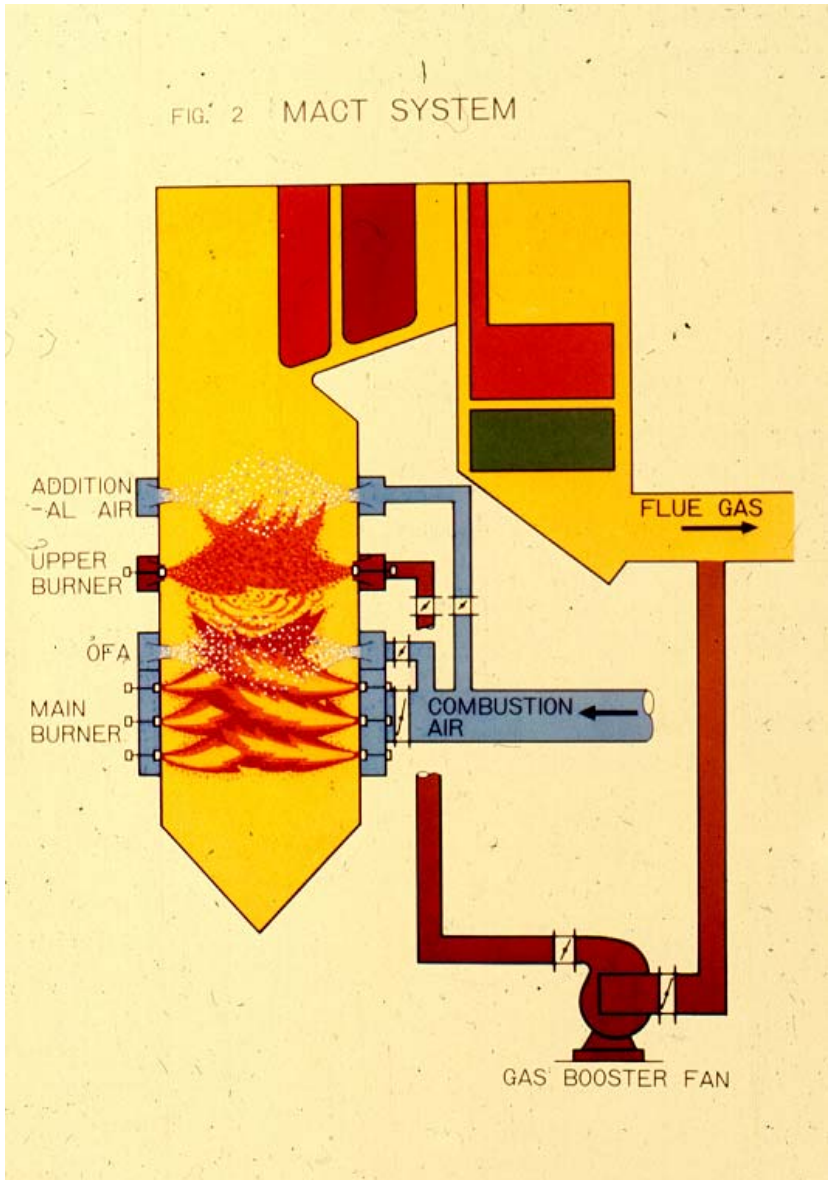
Figure 4. SO_3 REDUCTION BY "REBURNING"

NO reduction by reburning



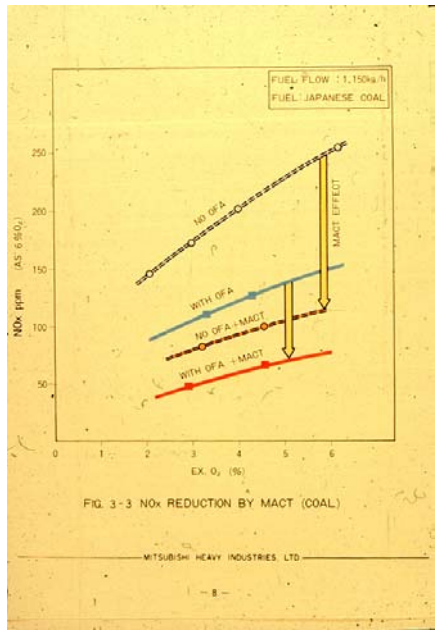
Why no reburning patents?

- “There is no money in pollution control”.
- “This company is not in the business of making burners”.
- Therefore, publication in the open literature was allowed.

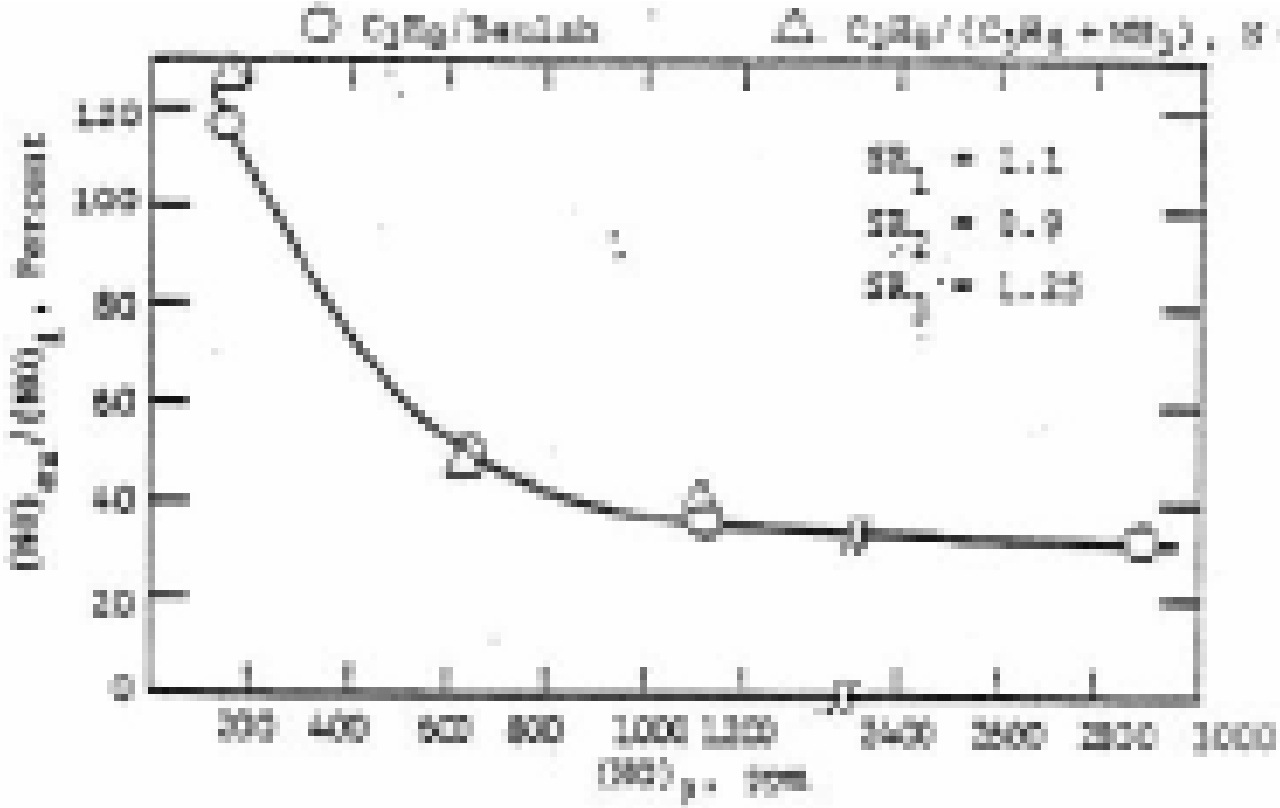


Mitsubishi Advanced Combustion Technolgy (MACT In-Furnace NOx Removal Process.

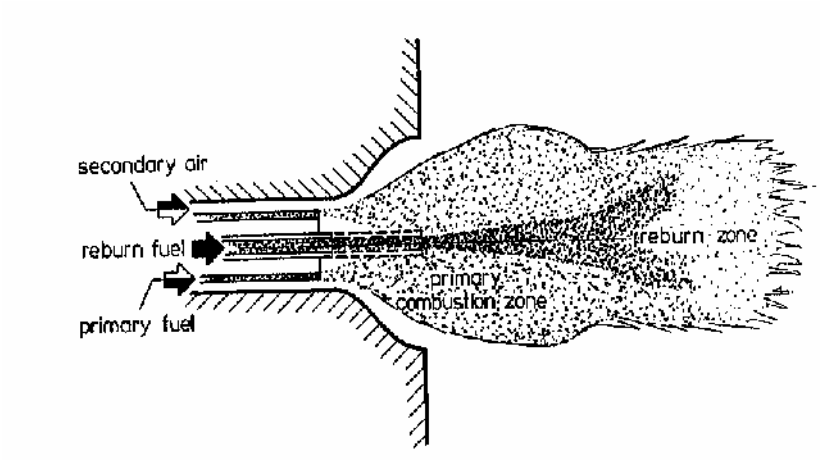
Takahashi et al., US-Japan NOx Information Exchange, Tokyo, Japan, May 1981.

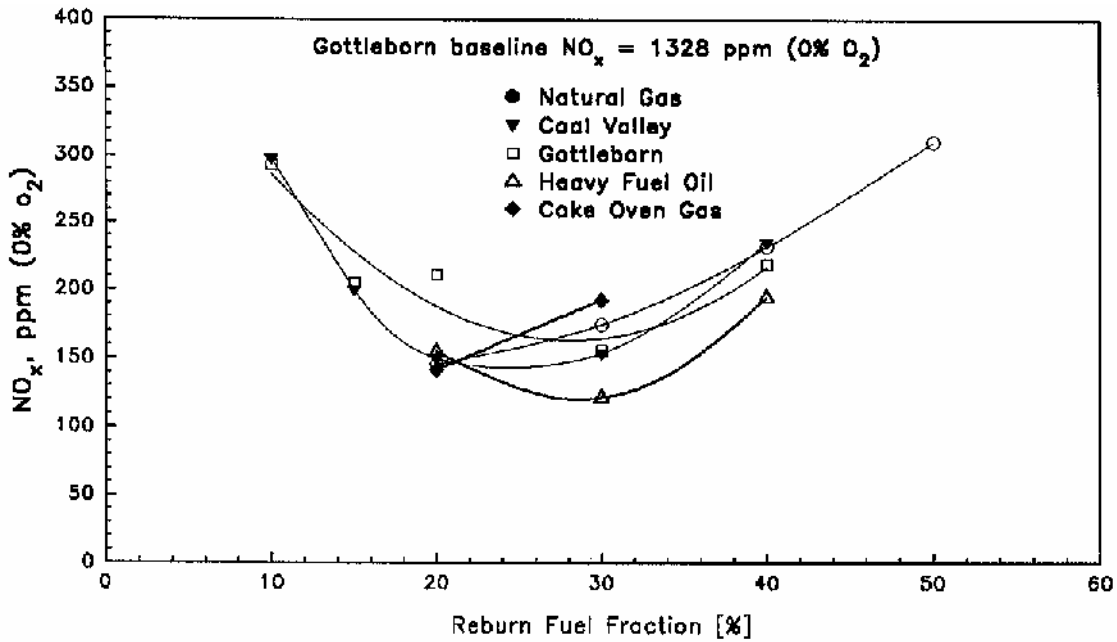


NO reduction by reburning: effect of primary NO level



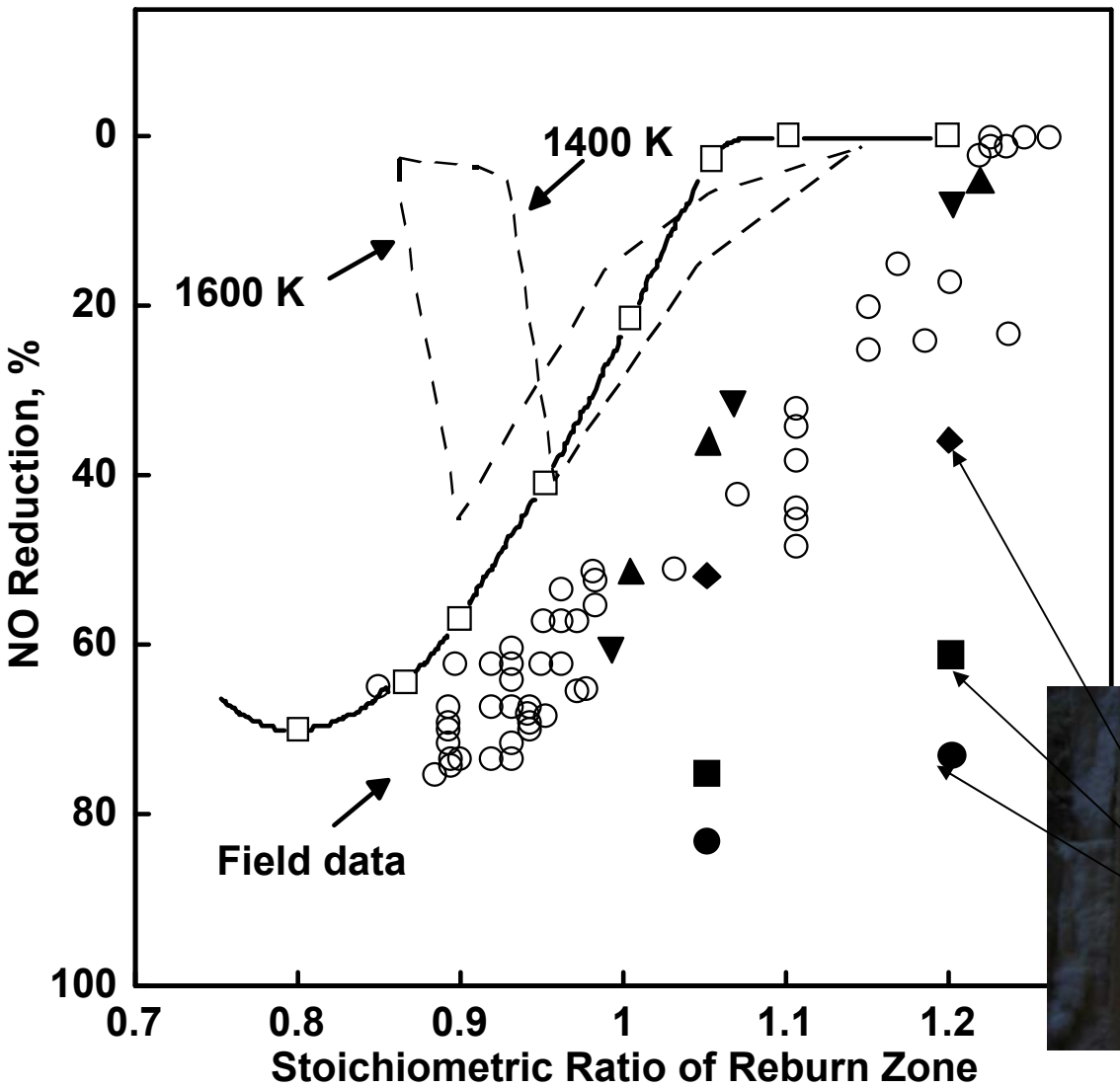
Application of reburning for lower NOx in practical coal burners (IFRF)

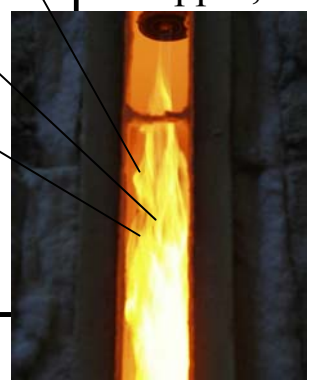




Fuel lean reburning

(Miller, Touti, Becker and Wendt, Proc. Combust Inst, 27, 3189,1998)





Decrease of NO emissions by natural gas reburning. Comparison of: field data, ○ [11]; laboratory data under rapidly mixed conditions, □ [8]; and premixed kinetic modeling, ----- [5]. Shaded symbols denote data from this work: 17 kW laboratory combustor diffusion flame; ◆ Re_{gas} = 3000, ■ Re_{gas} = 1000, ● Re_{gas} = 500. 0.9MW package boiler simulator; ▲ NO_{in} 1700 ppm, ▼ NO_{in} 680 ppm

Conclusions

- Reburning (i.e. *in-furnace* NO reduction) was conceived through fundamental research 1969-1972
- Was vigorously pursued by MHI 1970's on.
- Picked up by EPA and DOE 1980's
- Mechanisms, new applications of reburning developed 1980's-1990's
- Advanced to field demonstrations in US 1980's on
- Field applications in Europe 1990's
- Field applications in US (Clean Coal) 1990's to present.
- Future 2004 on
  - Promising?
  - Uncertain?