REINHOLD ENVIRONMENTAL Ltd.

2019 NOx-Combustion-CCR Round Table Presentation

February 11 & 12, 2019, in Salt Lake City, Utah / Hosted by PacifiCorp

London: Great Smog of 1952

NYC Circa 1970

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RJM International

- International arm of the old RJM Corporation
- Became independent 2005
- Acquired part-ownership of SAS 2010
- Home office in Winchester, UK
- International Presence

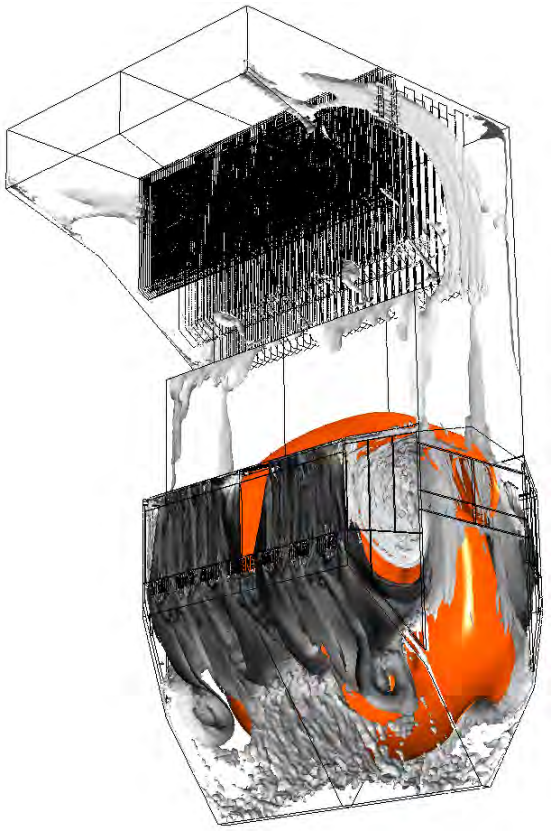
RJM worldwide presence

1. Field Service

- » Site Surveys
- » Air Distribution Analysis (ADA)
- » Fuel balancing
- » Operational improvements
- » Installation and Start-up assistance

2. Combustion Expertise

- » Computational Fluid Dynamics
- » Low NOx conversion
- » Fuel Switching (Coal-to-gas, etc.)
- » All fuels expertise
  - Coal
  - Oil
  - Natural Gas
  - Biomass
  - RDF (Refuse Derived Fuel)
  - Speciality
- » Firing Systems
  - Wall Fired
  - T-Fired
  - W-Fired or Turbo
  - Fluidized Beds
- » Combustion Controls



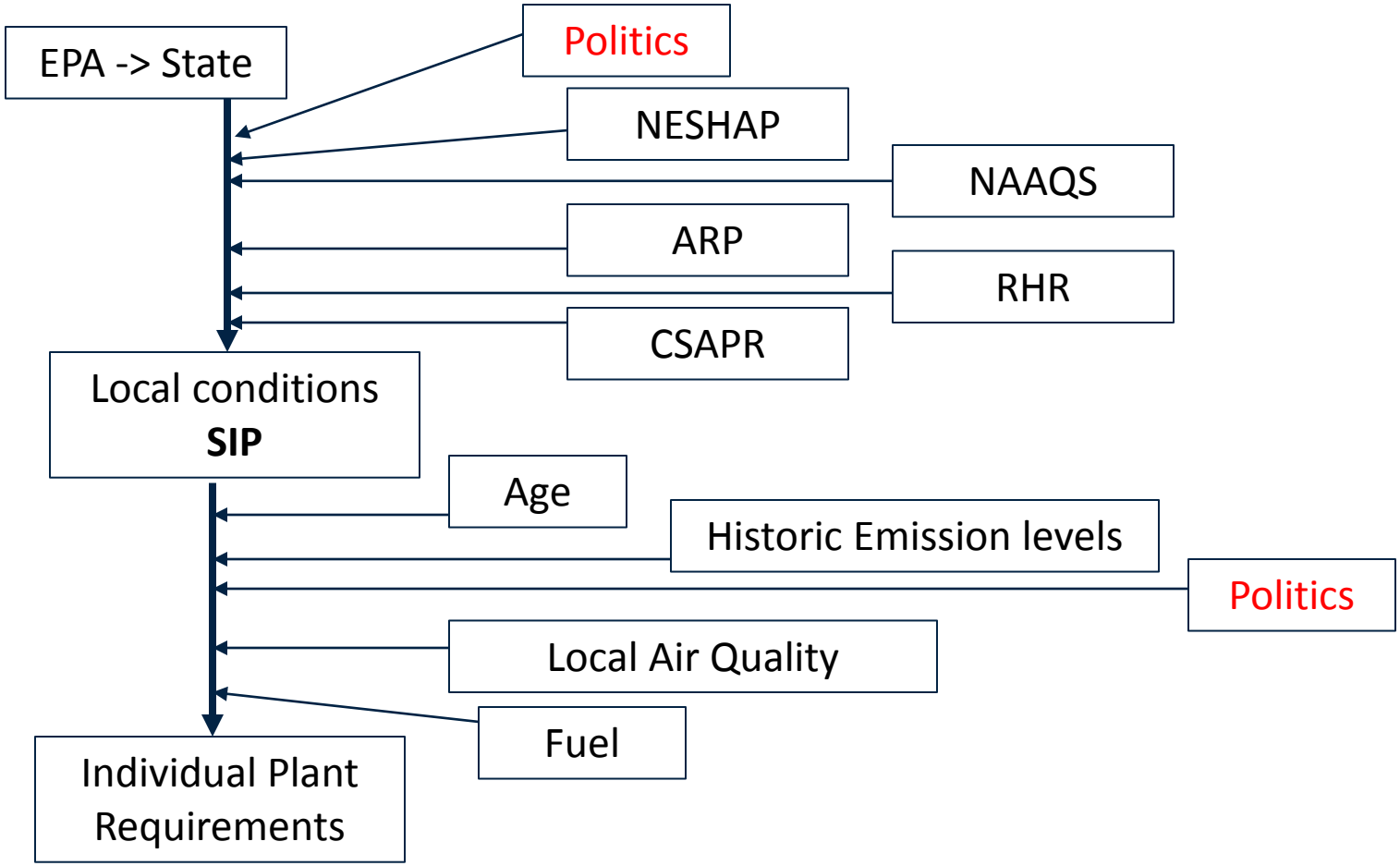
W-Fired Furnace
Local Source Anthracite

- History (https://www.epa.gov/clean-air-act-overview/evolution-clean-air-act)
  - Clean Air Act – 1963
    - The Clean Air Act of 1963 was the first federal legislation regarding air pollution *control*.
  - Amendments
    - 1970
      - The enactment of the Clean Air Act of 1970 (1970 CAA) resulted in a major shift in the federal government's role in air pollution control. This legislation authorized the development of comprehensive federal and state regulations to limit emissions from both stationary (industrial) sources and mobile sources. National Ambient Air Quality Standards (NAAQS) Established
    - 1977
      - The 1977 Amendments primarily concerned provisions for the Prevention of Significant Deterioration (PSD) of air quality in areas attaining the NAAQS.
    - 1990
      - New regulatory programs were authorized for control of acid deposition (acid rain) and for the issuance of stationary source operating permits. The NESHAPs were incorporated into a greatly expanded program for controlling toxic air pollutants. The provisions for attainment and maintenance of NAAQS were substantially modified and expanded.

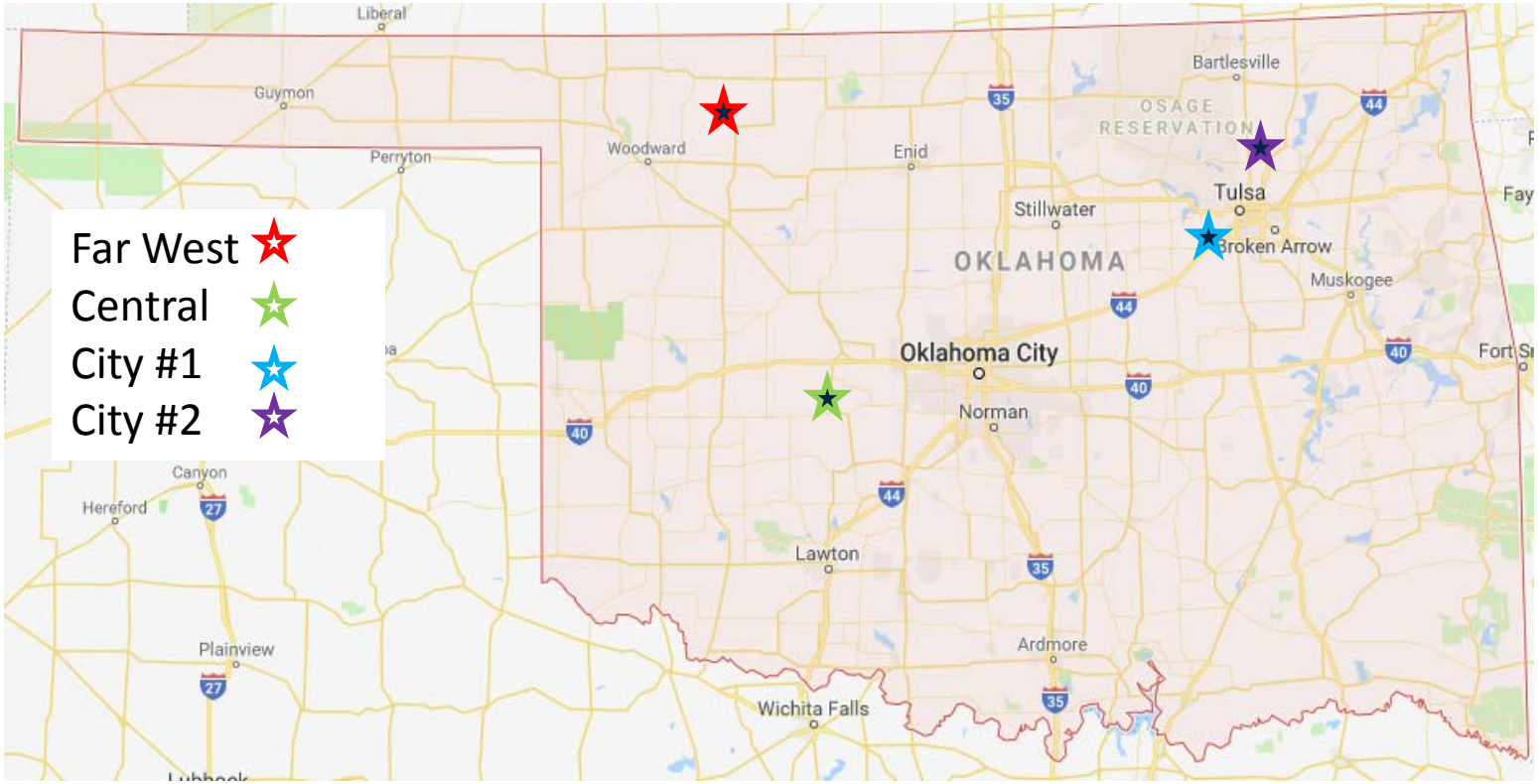
Some Acronyms

- **CAA** - Clean Air Act
- **MACT** - Maximum Achievable Control Technology
- **BACT** - Best Achievable Control Technology
- **RACT** - Reasonably Available Control Technology
- **NAAQS** - National Ambient Air Quality Standards
- **NESHAP** - National Emission Standards for Hazardous Air Pollutants
- **ARP** - Acid Rain Program
- **RHR** - Regional Haze Rule
- **SIP** - State Implementation Plan
- **CAIR** - Clean Air Interstate Regulation
- **CSAPR** - Cross State Air Pollution Rule
- **RGGI** - Regional Greenhouse Gas Initiative
- **CPP** - Clean Power Plan
- **ACE** - Affordable Clean Energy (Efficiency Rule – see Tony Licata)
- ***Etc.***

How to determine CAA attainment – AT AN INDIVIDUAL PLANT



- Oklahoma – A tale of four plants



Oklahoma NO_x – A tale of four plants

- Far West
  - Nothing is near
  - Several boilers, 70MW_e – 150 MW_e
  - Smallest boiler NO_x = no limit
  - Largest Boiler NO_x = 0.2 lbs/MMBtu (since 1999)
- Central
  - Reasonable distance from metro area
  - Boiler = 315 MW_e
  - NOx = 1.2 lbs/MMBtu till 2015 now 0.45 lbs/MMBtu
- City #1
  - Two boilers 175 MW_e
  - NOx = 0.44 lbs/MMbtu no emission limit except TPM
- City #2
  - Two boilers
  - 500 MW_e gas
    - 0.28 lbs/MMBtu
  - 500 MW_e coal
    - 0.15 lbs/MMBtu

What is the takeaway…

What is the takeaway…

- Need specialized training

Denver, CO

~ 1970

Pop ~ 500,000

Denver, CO

~ Today

Pop ~ 5,000,000

Some Acronyms

- **LCP** – Large Combustion Plant
- **LCPD** – Large Combustion Plant Directive
- **IED** – Industrial Emission Directive
- **NERP** – National Emission Reduction Plant (UK)
- **TNP** – Trans National Plan
- **ELV** - Emission Limit Values (concentration based)
- **SBG** – Stand-by Generator
- **SFA**- Supplementary Firing Apparatus
- **NERP** – National Emissions Reduction Plan
- **IPPC** – Integrated Pollution Prevention and Control
- **BAT** – Best Available Techniques
  - LCPD – Low NOx Burners and OFA
  - IED - SCR
- **WAG** - Welsh Assembly Government
- ***Etc.***

- NOx regulations are emission limits (EVL)
  - LCPD
    - Coal
      - 500 mg/Nm3 @ 6% O2
      - 0.40 lbs/MMBtu
    - Gas
      - 200 mg/Nm3 @ 3% O2
      - 0.123 lbs/MMBtu
  - IED
    - Coal
      - 200 mg/Nm3 @ 6% O2
      - 0.16 lbs/MMBtu
    - Gas
      - 100 mg/Nm3 @ 3% O2
      - 0.0615 lbs/MMBtu

Note that NOx for gas is always lower than NOx for coal

LCPD

– Superseded by IED 2016

3.16. LCPD plants are separated into three groups based on the date they were first permitted:

- "new-new" combustion plants: licensed after 27 November 2002 (if put into operation before 27 November 2003);
- "new" combustion plants: licensed between 1 July 1987 and 27 November 2002; and
- "existing" combustion plants: licensed prior to 1 July 1987

In these definitions "licensed" means the original construction licence or in the absence of such procedure, operating licence.

Rule Summary

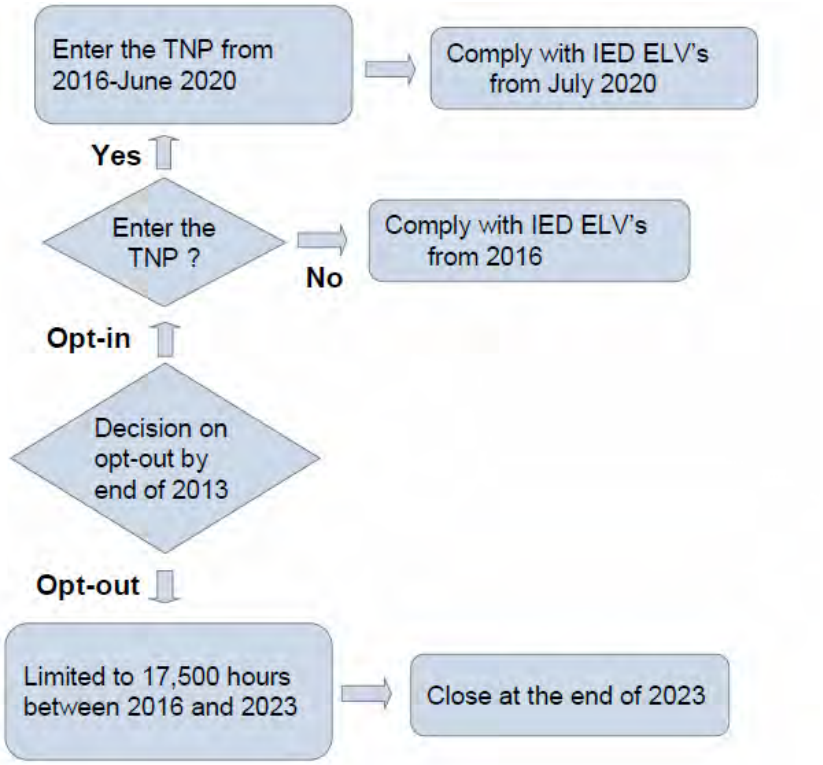
- Coal
  - NOx = 500 mg/Nm3 @ 6% O2
  - SOX = 200 mg/Nm3 @ 6% O2
    - 84 ppm @ 3% O2
    - 0.16 lbs/MMBtu
  - Particulate = 50 mg/Nm3 @6% O2
- Gas
  - NOx = 200 mg/Nm3 @ 3% O2
  - SOx = N/A
  - Particulate = 5 mg/Nm3 @3% O2

Two choices:

1. Opt in
   - Alert governing authority of intent to operate with mandates
   - Provide information on hardware and methods for achieving compliant operation
   - Be compliant by 2008
2. Opt out
   - Alert governing authority of intent to **NOT** operate with mandates by 2004
   - Can operate for maximum 20,000 total additional hours, from 2008 to 2015
   - Must shut down plant then

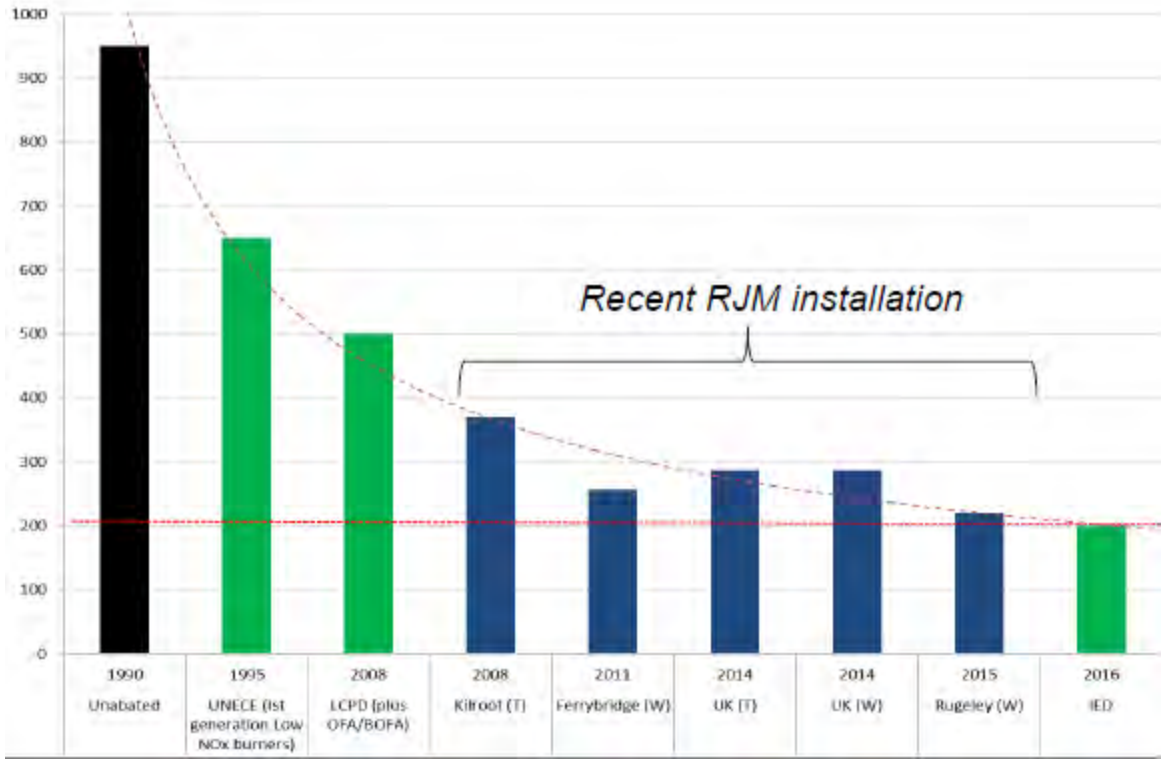
Rule Summary

- Coal
  - NOx = 200 mg/Nm3 @ 6% O2
  - SOX = 200 mg/Nm3 @ 6% O2
  - Particulate = 50 mg/Nm3 @6% O2
- Gas
  - NOx = 100 mg/Nm3 @ 3% O2
  - SOx = N/A
  - Particulate = 5 mg/Nm3 @3% O2



NOx vs. Time

Black = No controls
Green = Regulations
Blue = RJM Installations



London air quality

Today

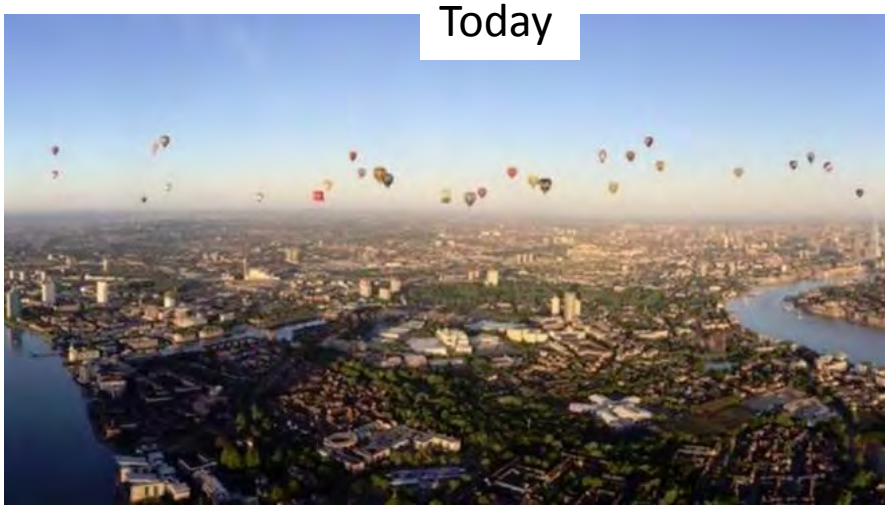
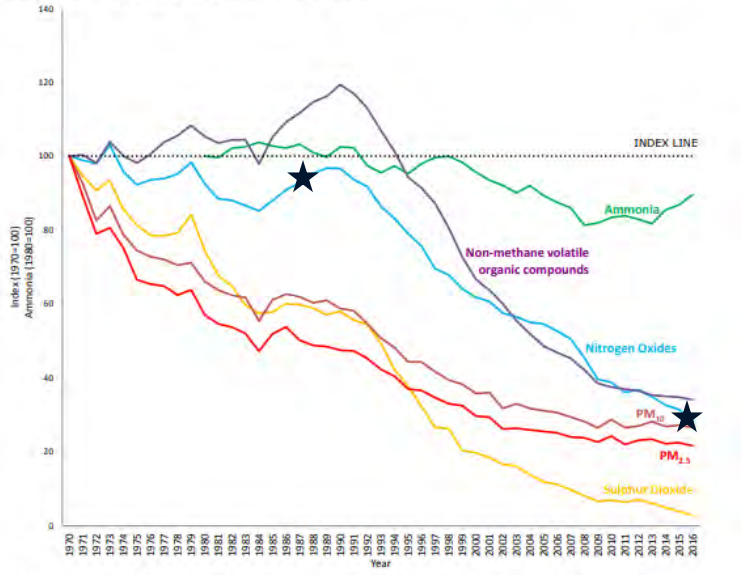
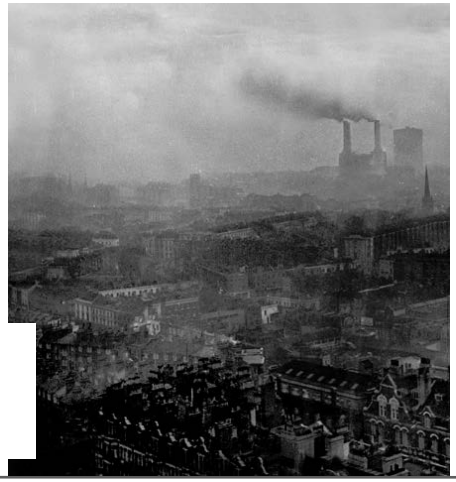


Figure 1: Trends in UK sulphur dioxide, nitrogen oxides, non-methane volatile organic compounds, ammonia and particulate matter (PM_{10}, $PM_{2.5}$) emissions 1970 – 2016



The index line is a comparator that shows the level of emissions if they had remained constant from the beginning of the time series.

★ = Personal visit to London



Great Smog of 1952
~ 12,000 died

- Both methods show dramatic air quality improvement
- US method has more complexity
- Both methods subject to rapid change
- Both EU and US have isolated coal for “special” treatment
  - US often has lowest NOx requirements for coal
  - EU has CO2 tax
  - UK several years ago
    - Max CO2 is 450 gCO2/kW-hr (thermal > 300 MW, ~ 100MW_e)
    - Typical CCGT number
    - Result => coal is illegal in UK after 2025

Plant description

- Early 1980's T-fired PC Unit
- Twin 500 MWe boilers
- Original NOx ~ 0.45 lbs/MMBtu
- Basic LNCF installed about 2012
  - ~ 0.2 lbs/MMBtu

- Require wet gas scrubber
  - Too much $'s
- Negotiated **"Deal"** with Fed & State & Environmental Special Interest group
  - Shut down one boiler – 2016
  - Shut down other boiler – 2026
  - No sulfur remediation required
  - Tons per month NOx, NTE specified
    - Rolling 30 average
    - Full load
    - 0.15 lbs/MMbtu

- Client had two choices
  - Reduce generation => lower TPM
  - Reduce emissions
    - Primary measures
    - Secondary measures
      - SNCR
      - SCR

- With plant already staged to close
  - Reduce emissions via primary measures

- Client approached RJM
  - Option #1 – tuning
  - Option #2 – modest hardware
  - Option #3 – Reduce load
- Decided to attempt tuning
  - Opt for hardware if unsuccessful

Primary Measures

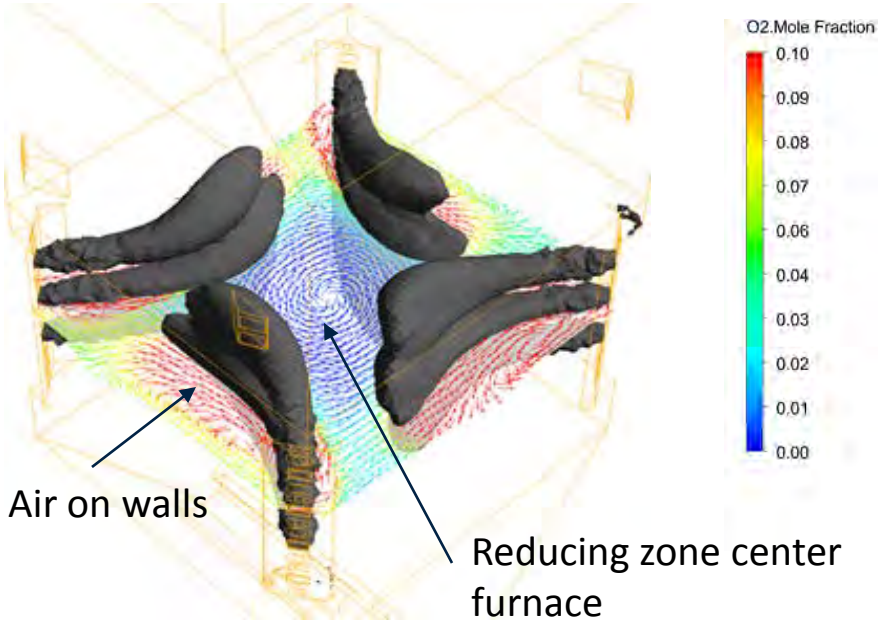
- MUST understand existing config.

Low NOx, Concentric Firing

- Introduced 1990's
- Std. methodology

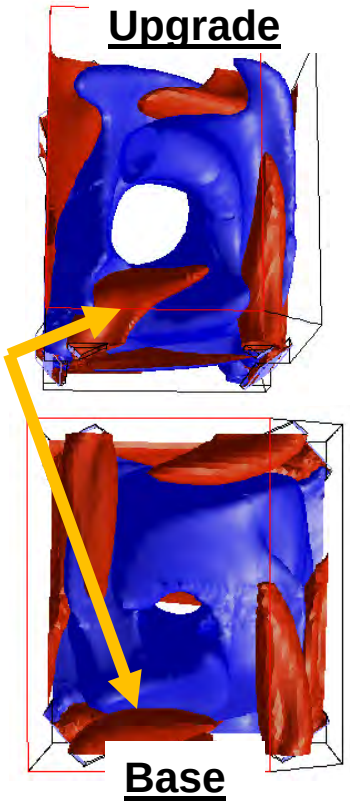
In general

- Lower furnace stoich = lower NOx
- Lowest NOx limit = function of:
  - Installed hardware
  - Type of coal
  - Final oxidation
    - SOFA ports



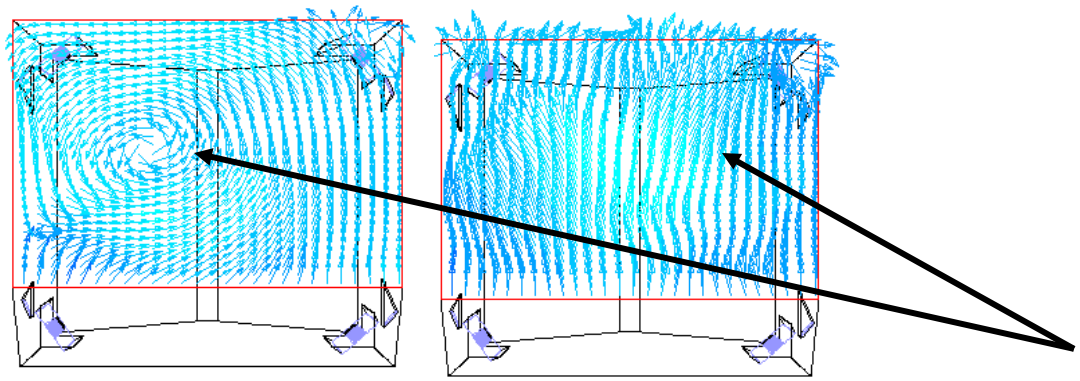
- Advice to client
  - Challenge will be final oxidation
  - Partially reviewed in paper
    - Berg, Goldring, Woodard, Smith,
    - Clearwater Coal Conf - 2007

CO = Blue
O2 = Red



Better SOFA penetration required as furnace stoichiometry is lowered

Baseline **Increased OFA**

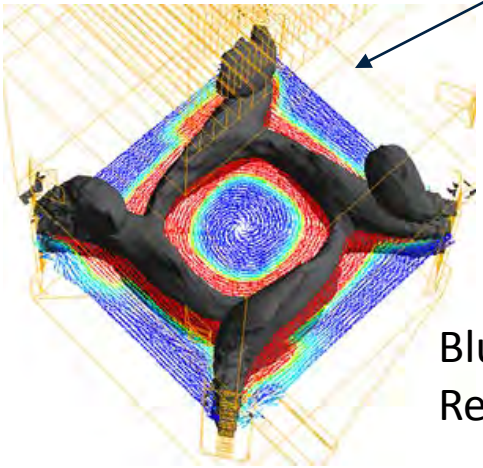


Outlet Vectors

Increased angle or velocity on SOFA
Can stall circulation

- Limitation can be removed with installation of center air

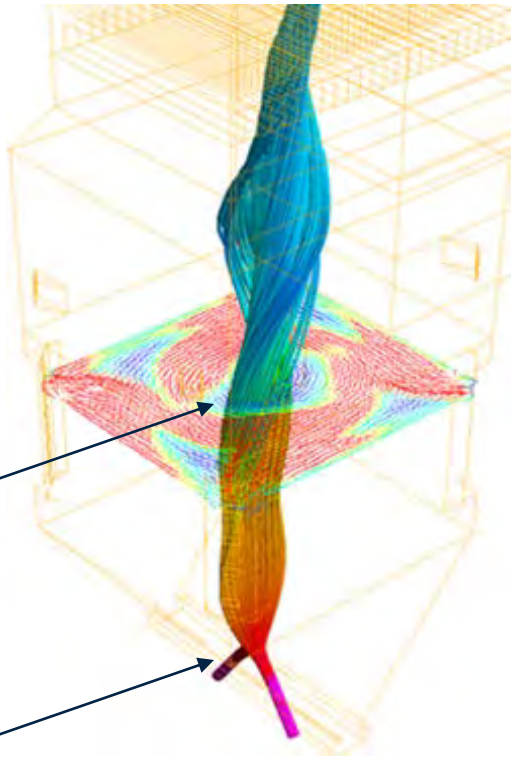
Requires careful optimization of fuel injection and air locations



Blue = Air
Red = CO

Removes CO middle furnace

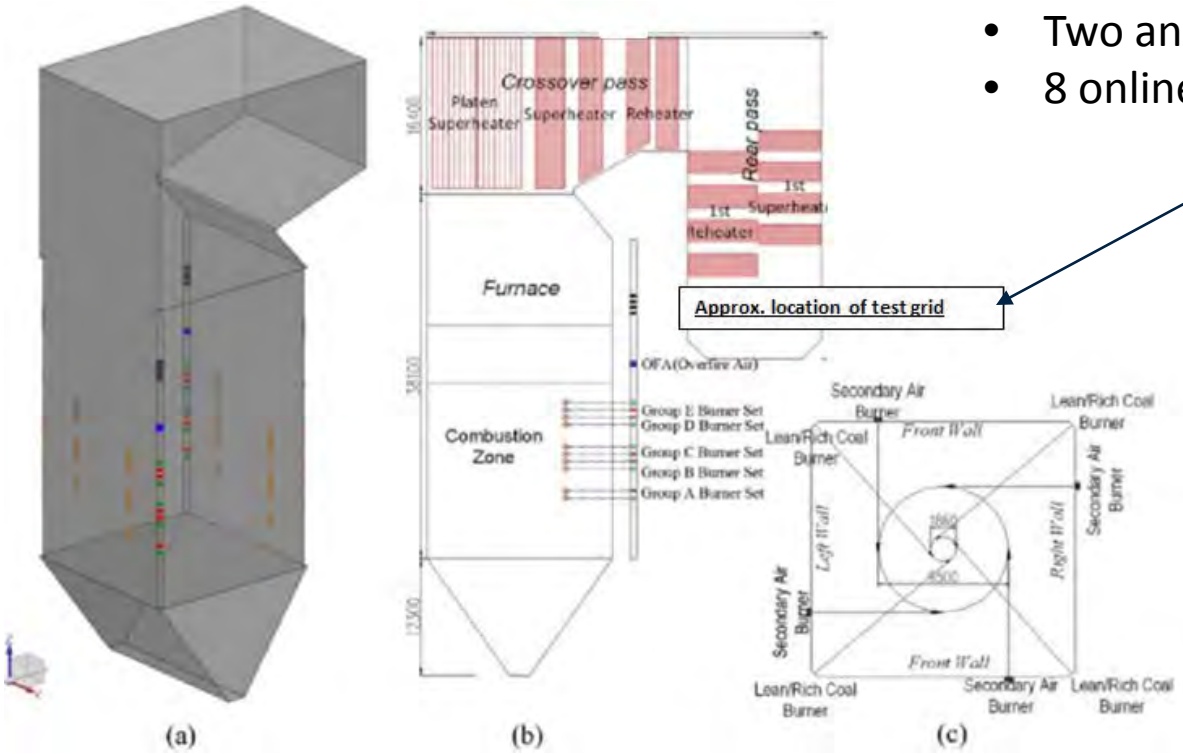
Air Injection Lower Furnace



Tuning

Set up Test Grid

- 3 x 8
- Two analyzers, change inputs
- 8 online O_2 analyzers



Tuning – Procedure

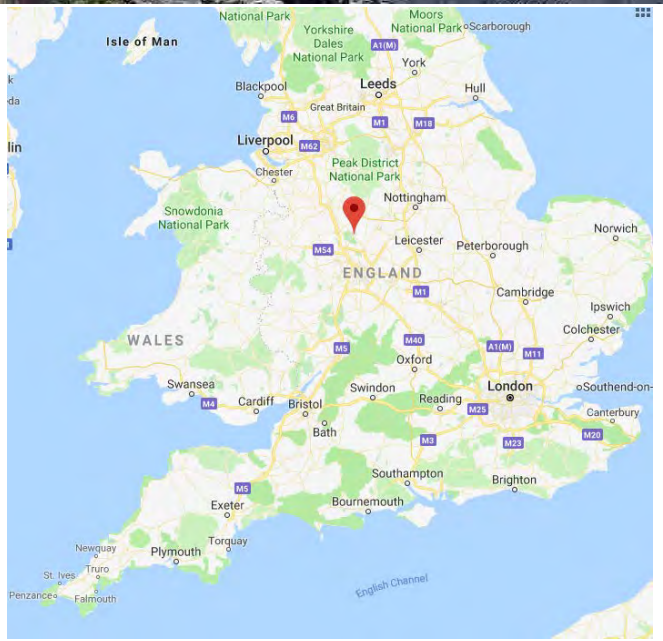
1. Reduce furnace stoichiometry
2. Consult O_2 or CO locations to adjust Yaw positions on SOFA ports
3. Check for instability with overnight operation
4. Repeat until stability cannot be maintained
5. Additional adjustments
    1. Three levels of SOFA ports
    2. Windbox to Furnace differential
    3. Variations on furnace dampers

Tuning – results

1. Client spent ~ 6 months
2. Original NOx ~ 0.18 – 0.19
3. Achieved ~ 0.16 fairly quickly
4. Furnace tended to instability below 0.15
5. Lowest 0.125
    1. Locations of CO would shift overnight
    2. One unit was stabilized
    3. Difference setting found for other unit
6. Client settled at 0.135
    1. Still some instability with CO
    2. Not considered a problem
    3. Remaining unit still in operation

Rugeley Power Station

- On river Trent, Staffordshire, UK
- Twin 500 MWe, Wall fired, PC units
-
- Subject of
  - Shields, et. al. ….
  - PowerGen Europe, 2016
  - "…IED NOx Compliance with Primary Measures only.."



- **LCPD Compliant**
- Owner (Engie) Concerned about volatility in coal markets and UK policy towards coal
- Following market analysis, opted for Primary measures only RJM retrofit
  - Total cost end of project ~ $7 million.
  - Unit 7 chosen for technology demonstration

Rugeley Power, Units 6 & 7

Project outline

See: 2018 Reinhold Conf, RJM-Method, Berg, et al

1. Combustion Audit and Baseline Testing
2. CFD Analysis
   - Comparison to Baseline data
   - New hardware
3. Custom Engineered (Bespoke) Hardware

Combustion Audit and Baseline Test

1. 450 mg NOx
2. Past retrofit left oversized burners
   - Poor aerodynamics caused thermal damage
3. High primary air flows
4. Larger than normal PF nozzles
5. High CO (~1,200 ppm) to achieve 450 mg NOx
   - At less than 100 ppm CO, NOx ~ 650 mg

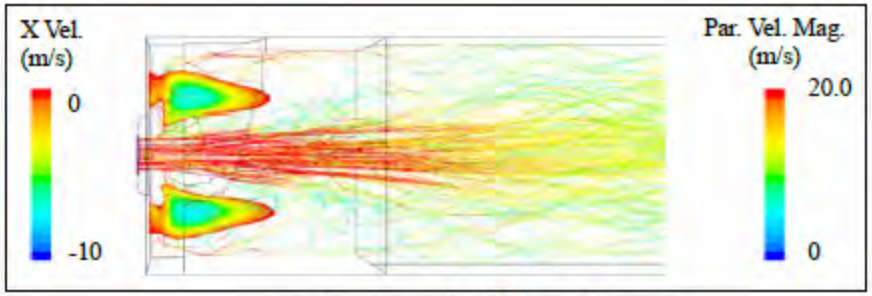


Figure 2: Example of PF punch-through

Figure 3: Rugeley existing burners showing extreme thermal damage and slagging

Courtesy RJM-International
2016 PowerGen, Milan Italy

Burner design had several challenges:

1. (1 - 200/650) ~ 70% NOx reduction
2. Thermal damage
3. Oversized openings
4. Large nozzles
5. Higher PA mass flow

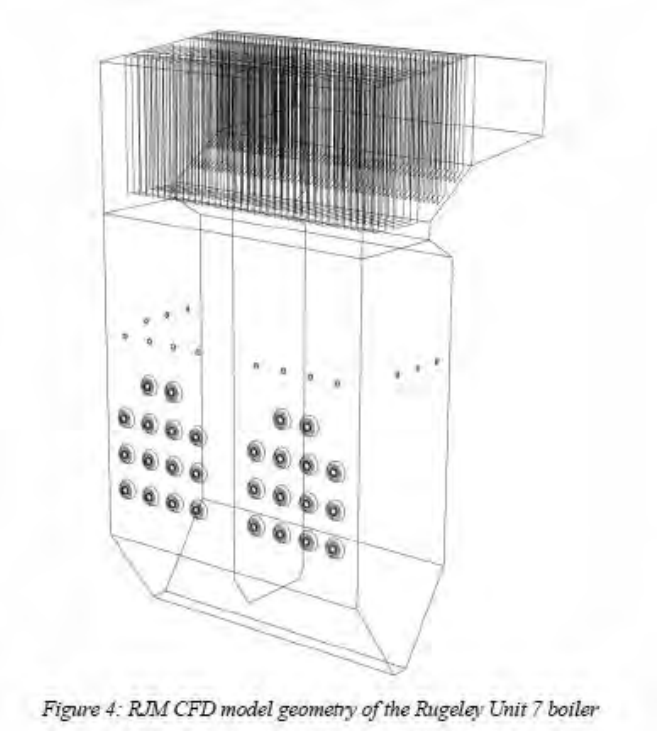
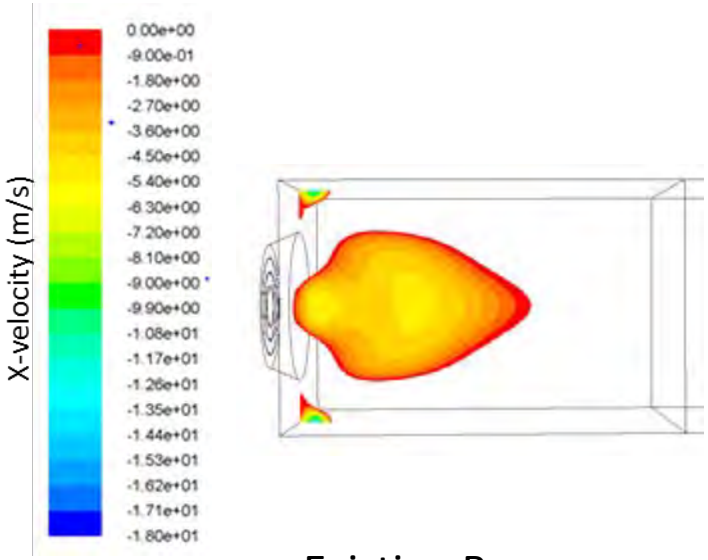
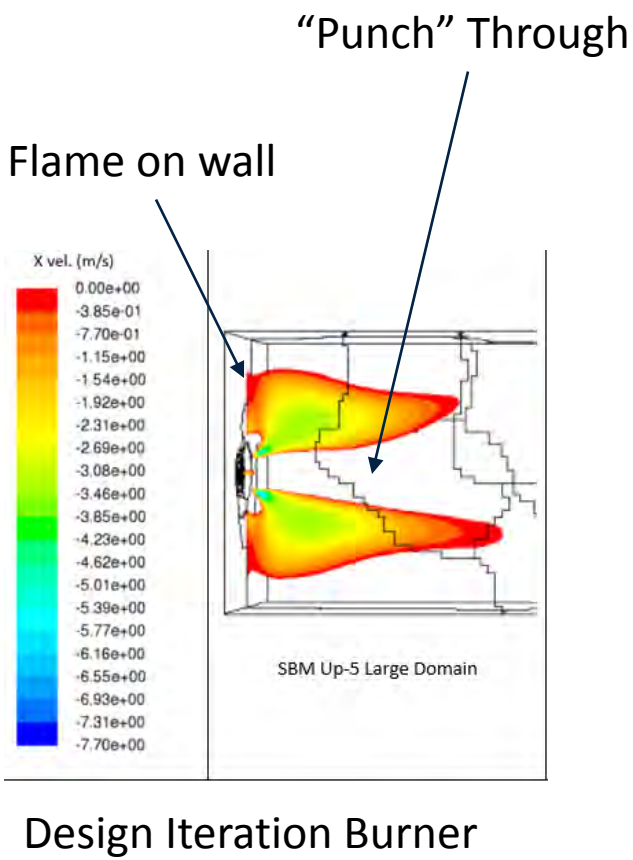


Figure 4: RJM CFD model geometry of the Rugeley Unit 7 boiler

CFD Analysis Burner Design

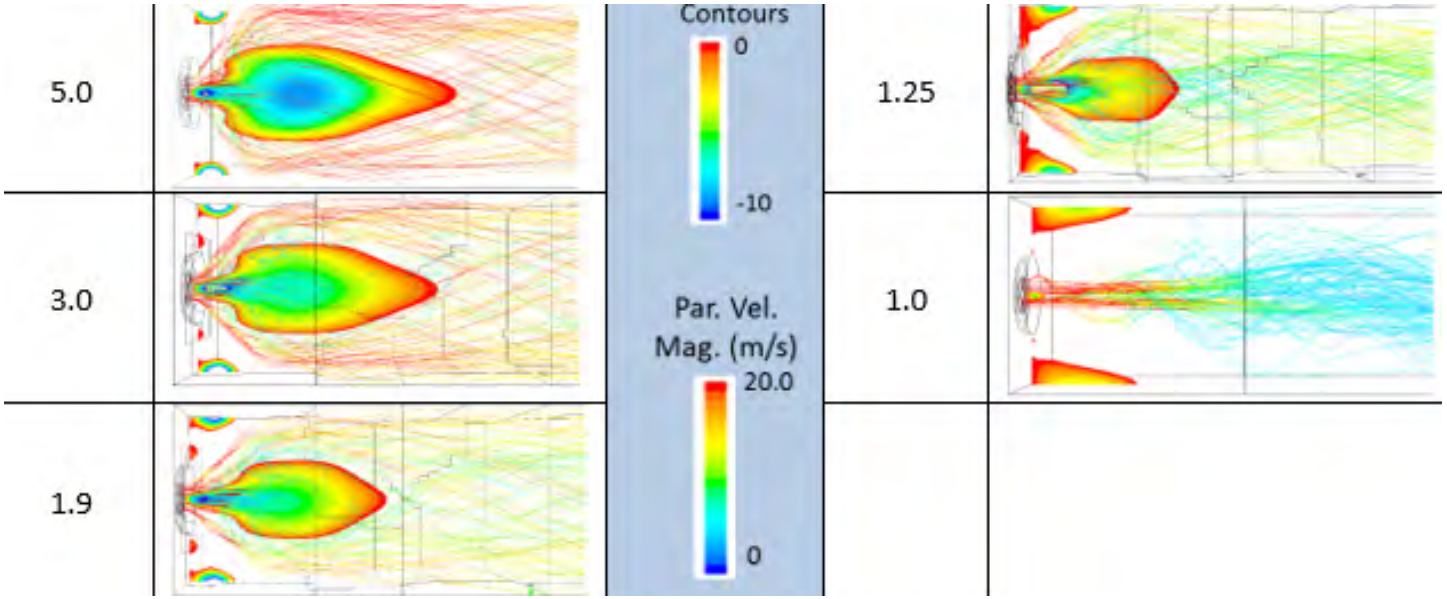


Existing Burner

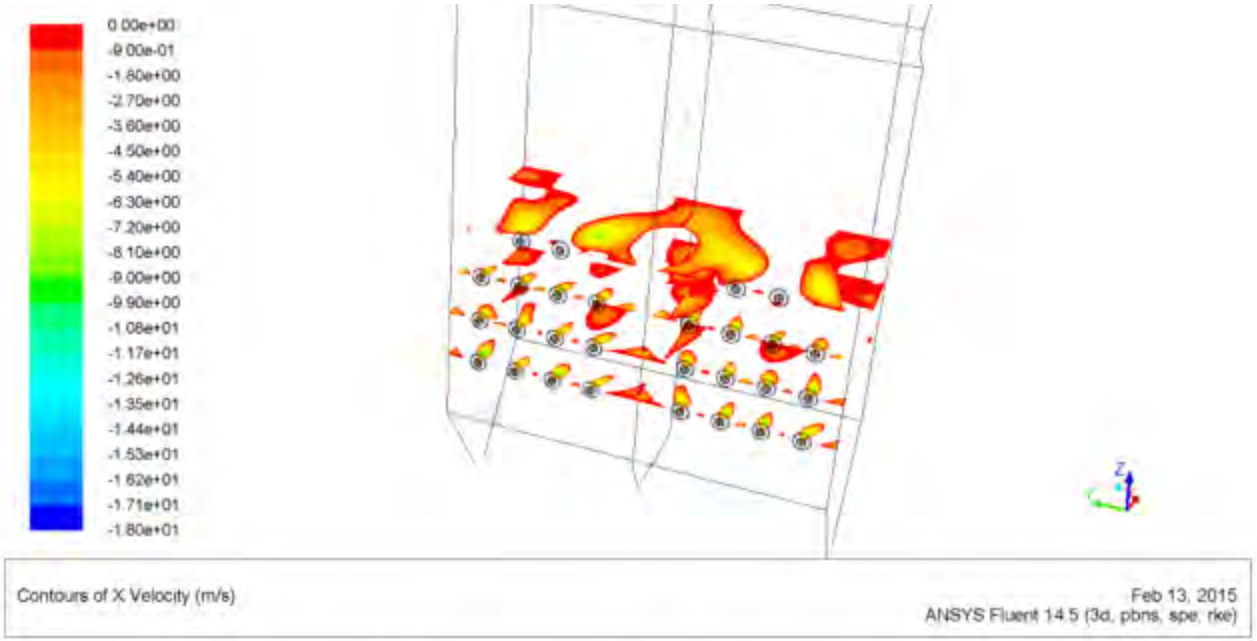


Design Iteration Burner

Burner Parametric Study



Burner Performance: In furnace



RJM Burner - Final Furnace Configuration (Up 14 – no Leakage)

Furnace modifications

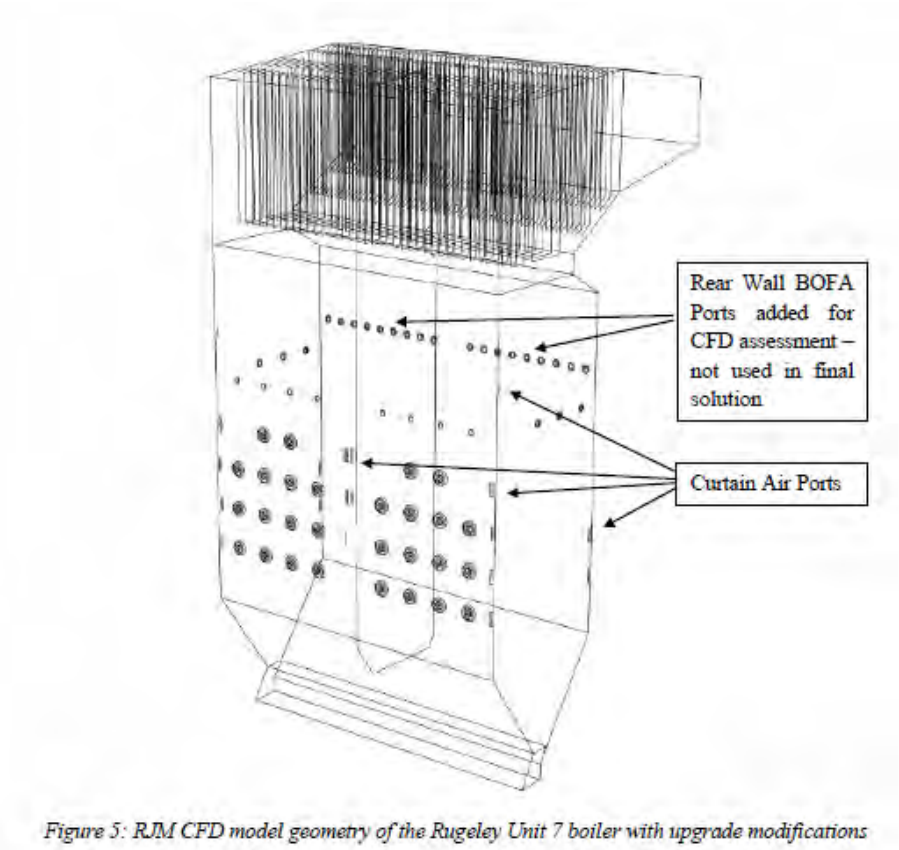
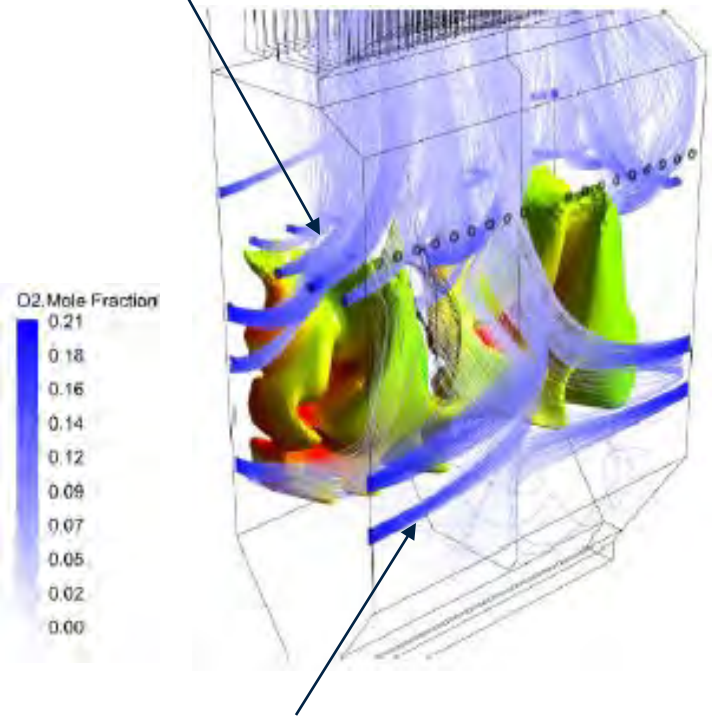


Figure 5: RJM CFD model geometry of the Rugeley Unit 7 boiler with upgrade modifications

Fire contained below BOFA ports



Wall Protection Air

Start-up

Load	100%	80%	50%
NOx	209*	198	178
CO ppm @ 3% O_2	140	170	79
CIA	6% - 8%	6% - 8%	6% - 8%
O2	3.0%	2.8%	2.8%

* IED allows for 10% above limit

Elimination of Flame – Burner interaction

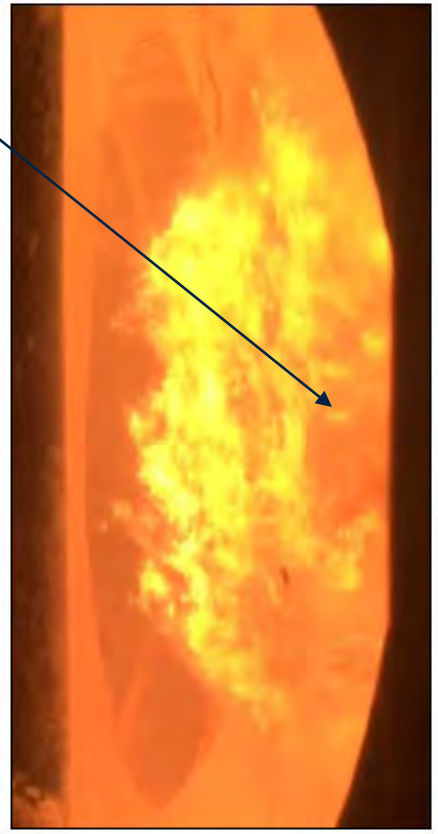


Figure 9: RJM burner suspended flame front at Rugeley Power Station

EPA vs. IED

- EPA method more complicated
- Both have achieved clean air
- Both subject to rapid change
- Coal limits in US similar to UK

US Implementation

- 500 MW, T-fired
- Achieved 0.125 lbs/Mmbtu
- Tuning only
- Hardware mod would be lower

UK Implementation

- 500 MW, wall fired
- Achieved 0.16 lb/MMBtu
- Burners and furnace mods (BOFA mod would be lower still)

1. Both units achieved NOx reduction with primary measures only
2. Both units are either shut down or scheduled to be shut down

Starry Night by V. van Gogh: Original CFD work?