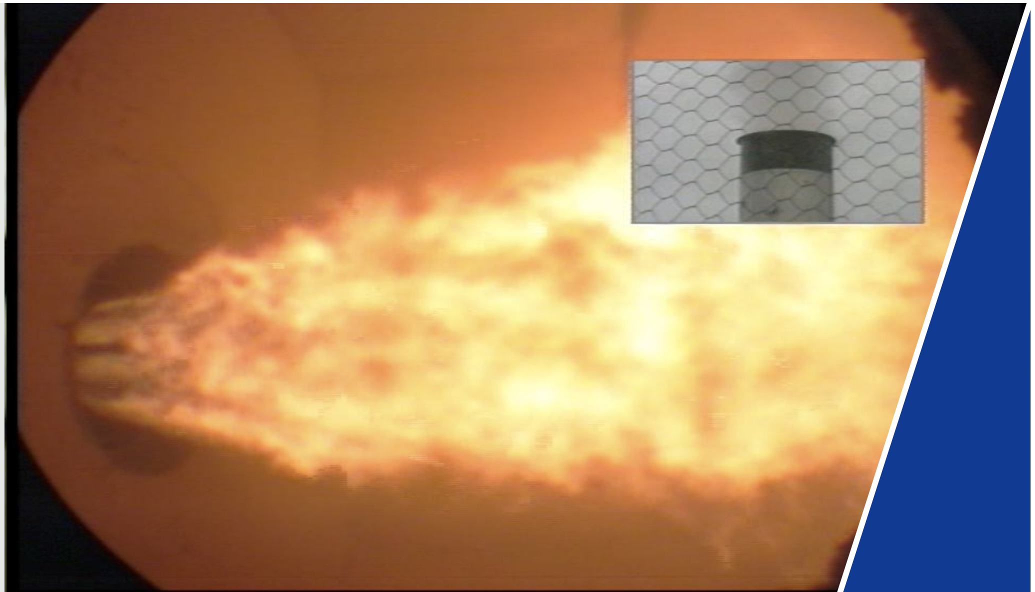
NOx Control & Technology for an Equipment Manufacturer

CRF, Cranfield, 10 April 2013



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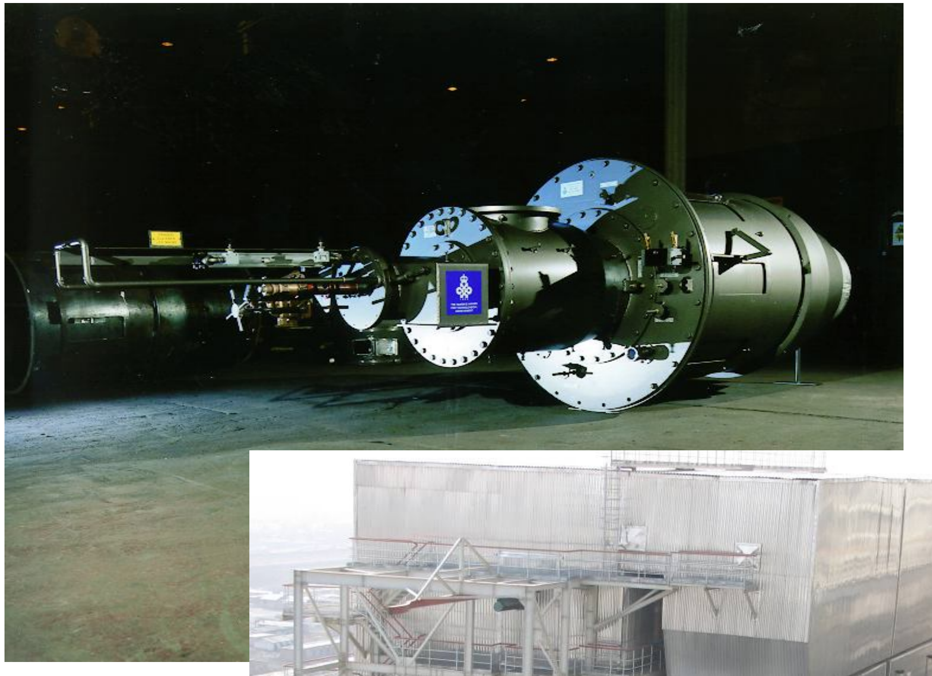
NOx Technologies

In-furnace combustion technologies:

- Low NO_x Burners (LNB's)
- Advanced LNB's (aLNB's)
- Overfire Air (OFA)
- Boosted Overfire Air (BOFA)
- Reburn

Post-combustion technologies:

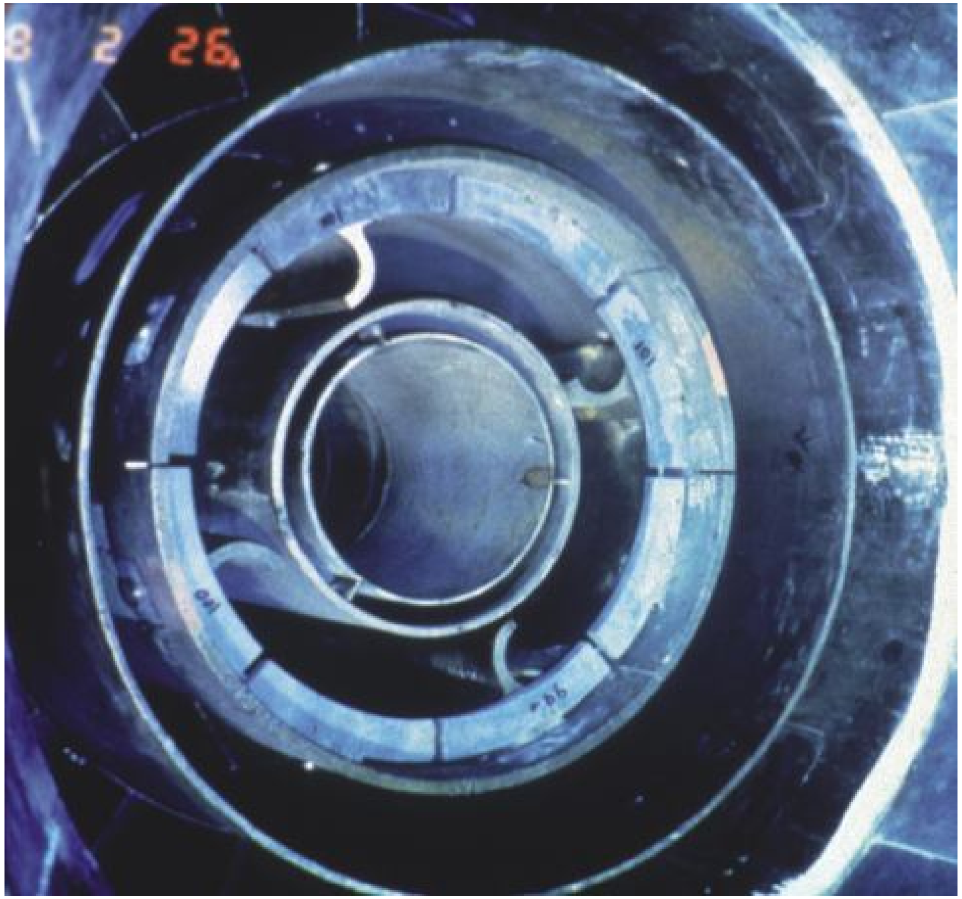
- Selective Non-Catalytic Reduction (SNCR)
- Selective Catalytic Reduction (SCR)
  - Full SCR
  - Optimised SCR

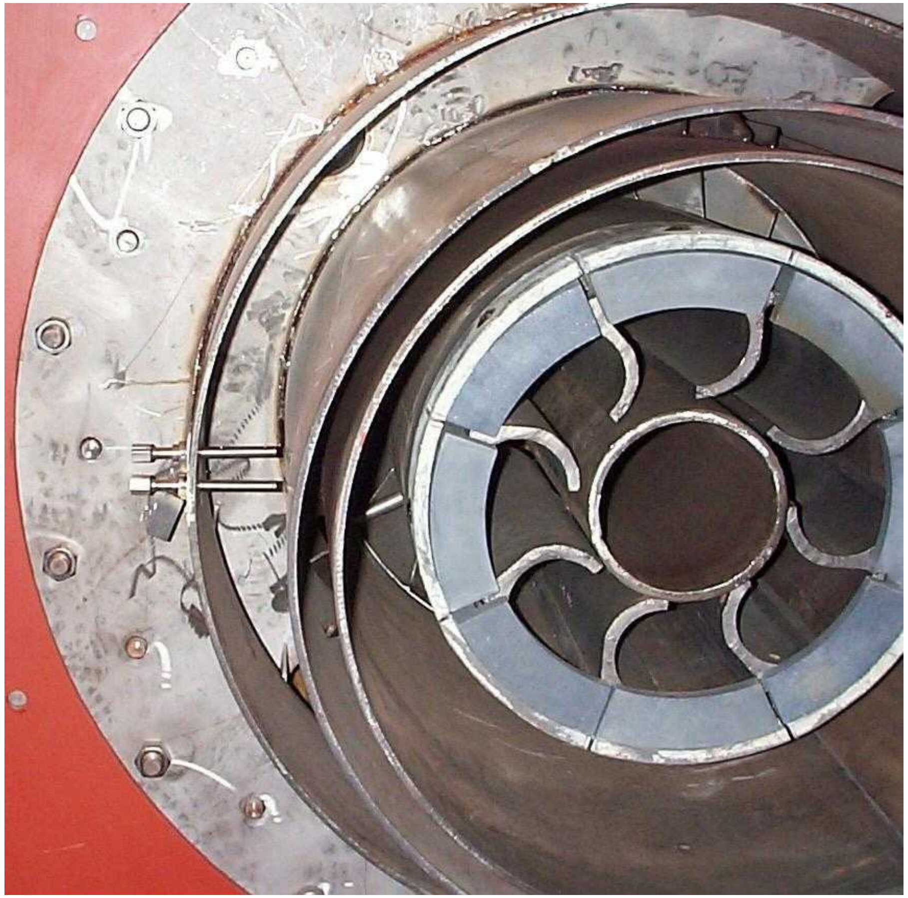


In-furnace Technologies - Burner & OFA Development

- Low NOx burners are a mature technology with over two decades of experience and competitive NOx control
- OFA enhancement used to achieve lower NOx levels
- Subsequent development of boosted OFA (BOFA) systems –
  - Ideally suited to the retrofit market
  - Maximises utilisation of available furnace volume for maximum NOx control
  - Used also as a means of carbon in ash control
  - Not normally considered for new build
- Burner development continuing in pursuit of the lowest NOx levels
- Biomass fuels present new challenges

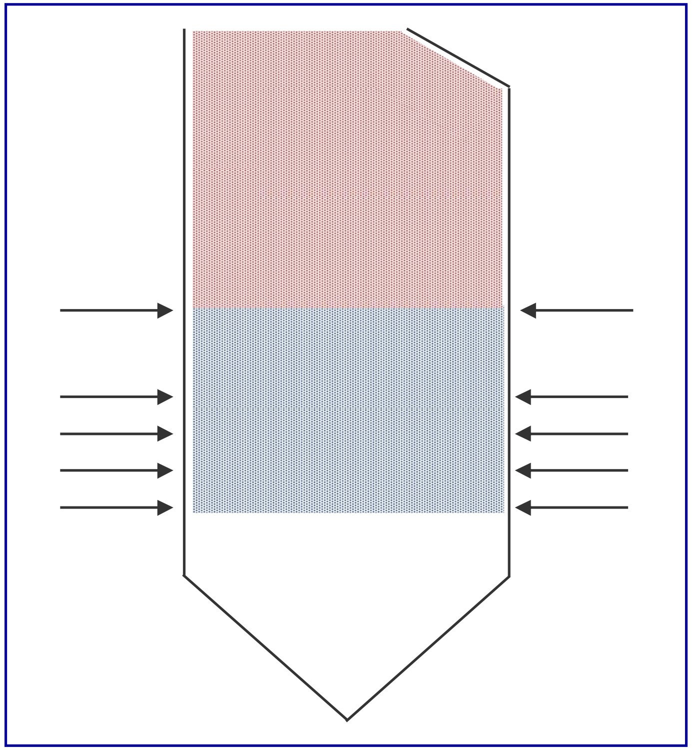
Low NOx Axial Swirl Burners – Mk.III & Mk.V



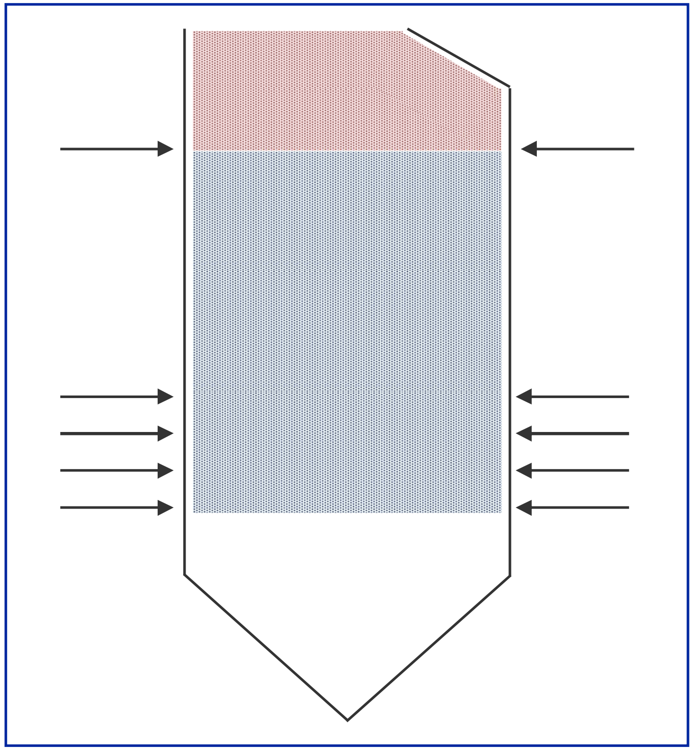


Installed throughout the UK and the world
Subbituminous and bituminous coals
40-80% NOx reduction without OFA depending on application

Two Stage Combustion – Low NOx Burners plus Overfire Air



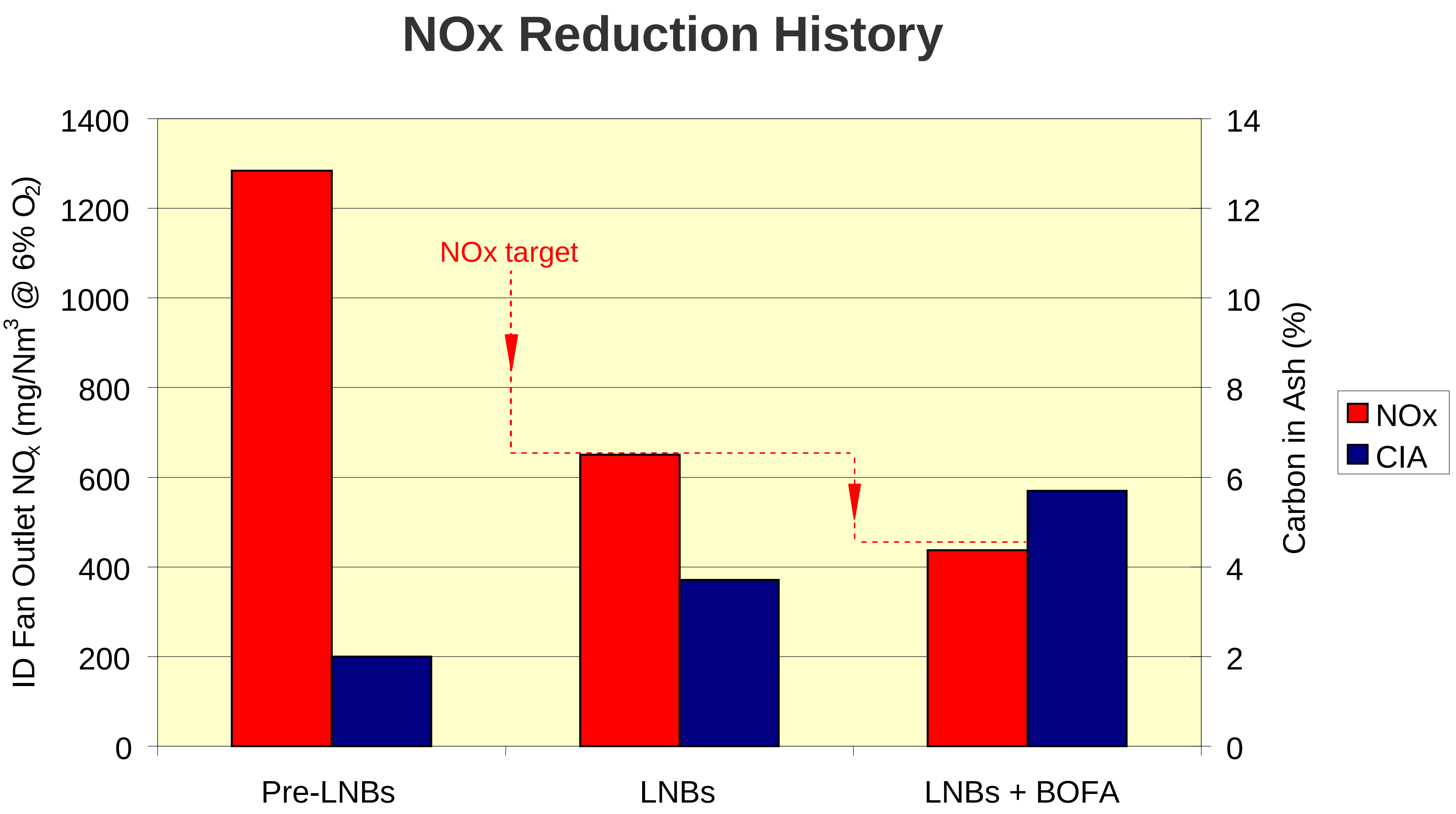
Normal OFA
NOx control is limited by burnout concerns, especially on retrofits



Boosted OFA
Provides longer residence time for NOx greater NOx control
Greater turbulence than normal OFA for rapid burnout

Project Profile – Drax Unit 1

Installation of BOFA technology to satisfy EU Large Combustion Plant Directive NOx requirement of 500 mg/Nm^3 for existing plant by 2008



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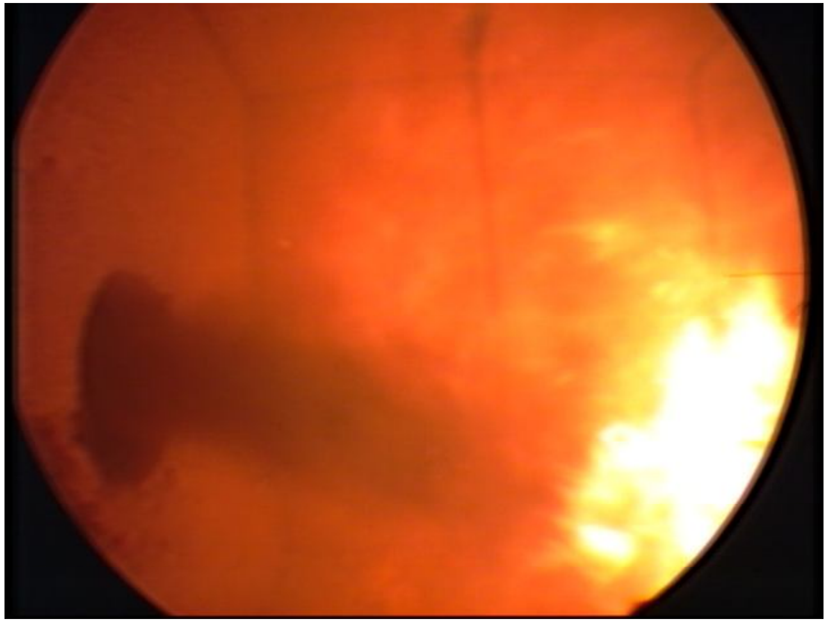
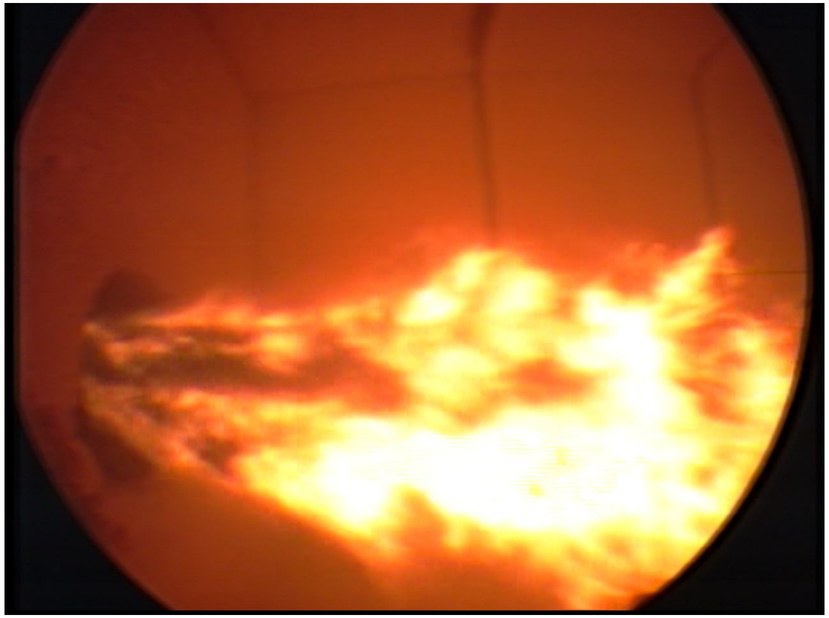
Mk.III Experience with Dried Lignite

In the large-scale test facility, changes to primary air velocity thro' PA tube annulus enlargement had a dramatic effect on flame front. This principle of PA velocity reduction was adopted for 100% biomass firing.



High Velocity



Low Velocity

Biomass Firing on Mk.III

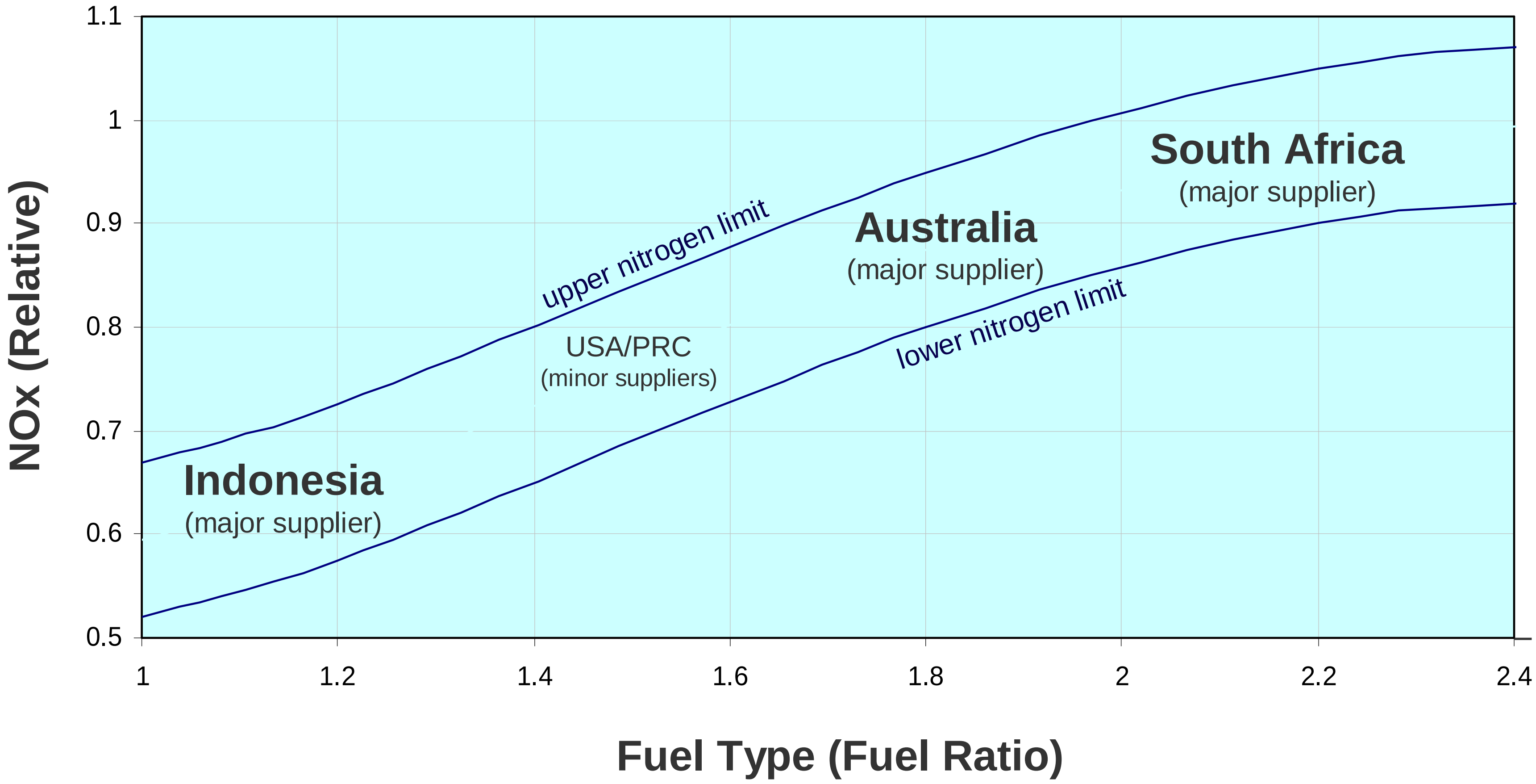
To promote early ignition and ensure flame stability on 100% biomass firing the following modifications have been successfully demonstrated on the Mk.III burner.

- Reduced PA velocity.
- Removal of fuel collectors to enable the swirling motion of the fuel jet generated by the inlet scroll to continue to the PA tube exit.

Combination of SA and TA streams into a single air stream (swirled) has also been proven to further enhance flame stability.

New Build NOx Targets - Dependency on Coal Type

New furnace and burner designs are targetting lower and lower NOx levels, <300 mg/Nm^3 over the internationally traded coal range & <200 mg/Nm^3 on higher quality fuels



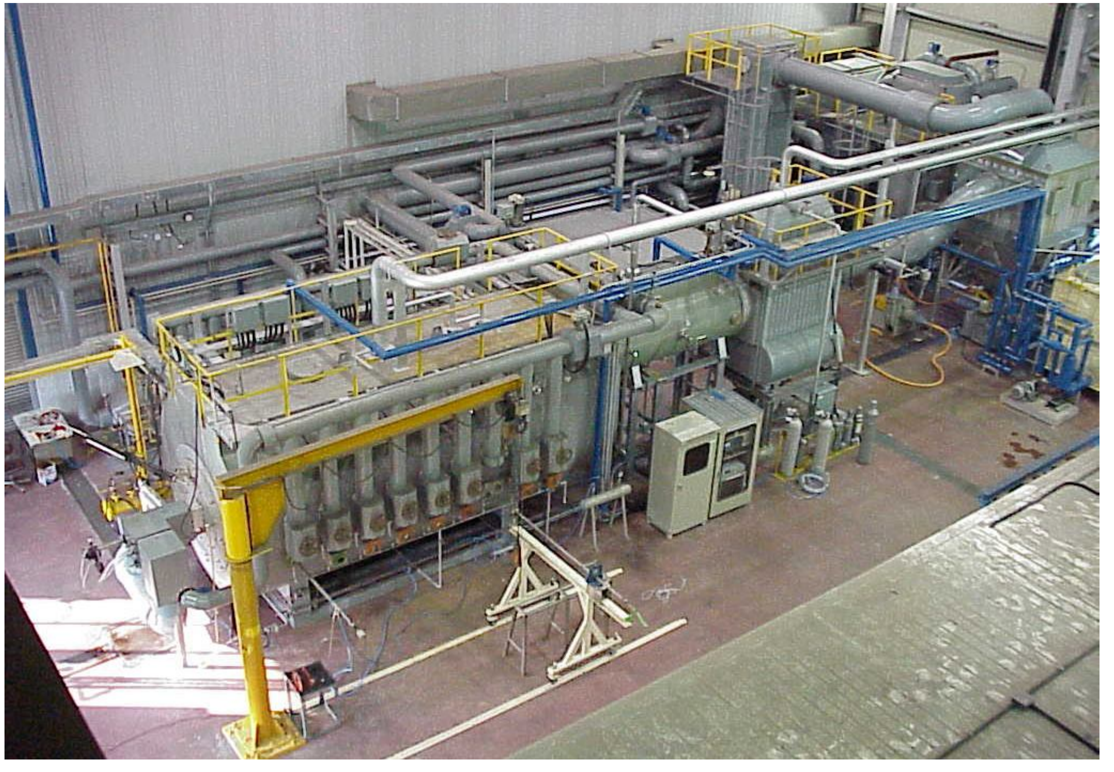
D-NOx Burner – The Next Generation

- Developed 2007 to 2011
  - Stage 1: Pilot scale 2.2MW_t Burner Testing (Mar –Apr 2008)
  - Stage 2: Full scale 63MW_t Burner Testing (Oct – Dec 2008)
  - Stage 3: Full scale 40 MW_t D-NOx™ / Mk.III Comparison (Sept – Nov 2009)
  - Stage 4: Drax Integrity Demonstration (Jun 2010)
  - Stage 5: Castle Peak B installation (Jun 2011)

- Design features
  - Axial flow PA with reduced number of high wear components
  - CFD-designed PA tube
  - New flameholder
- Performance
  - Up to 25% NOx improvement over Mk.III two-stage performance
  - No change to carbon in ash

D-NOx – Development Stage 1

2.2 MW_t Burner Testing (March - April '08)



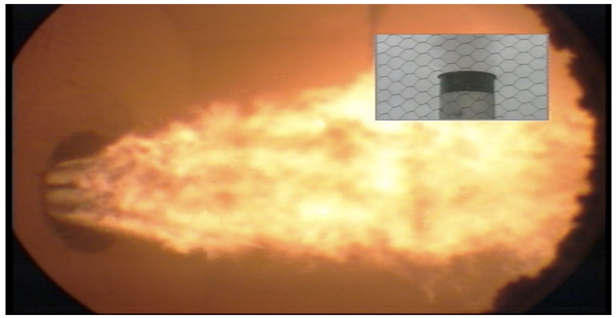
Changwon 3MW_t Test Facility

Selection of swirl, flameholder, coal distributor and air split configurations

D-NOx – Development Stage 2

63MW$_t$ Burner Testing (October ‘08 – April ‘09)

Testing on the Clean Combustion Test Facility carried out at λ 0.8.



D-NO_X – Development Stage 3

40MW_t Burner Testing (September – November '09)

Performance benchmarking tests

Identical tests conducted on Mk.III and D-NOx burners
15-25% improvement in NOx performance
without any loss of combustion efficiency

Mk.III Single Stage Combustion
NOx baseline
GCV loss 0.5%

Mk.III Two Stage Combustion
OFA port 5 λ 1.0
NOx 15-20% reduction on singe stage figure
Less residence time on test rig than on plant
GCV loss <1%

D-NO_X Two Stage Combustion
OFA port 5 λ 1.0
NOx 15-25% reduction on Mk.III figure
GCV loss no change

D-NO_X – Development Stage 4

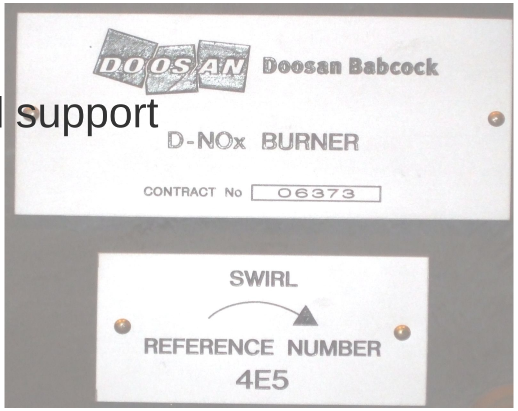
41MW_t Burner Installation (Jun ’10 to present) Integrity Demonstration

- Two burners installed on lower and top rear rows of 660 MWe unit
- Burners operational from June 2010
- Aims:
  - Investigate burner integrity and wear
  - Demonstrate oil ignition system
  - Verify CRAC3D modelling
- Progress:
  - Remote IR flame monitor successfully trialled
  - Permanent IR flame monitoring system successfully installed
  - Measured component temperatures within modelling range
- Plan:
  - Remove PA cartridge to allow inspection against wear and deformation

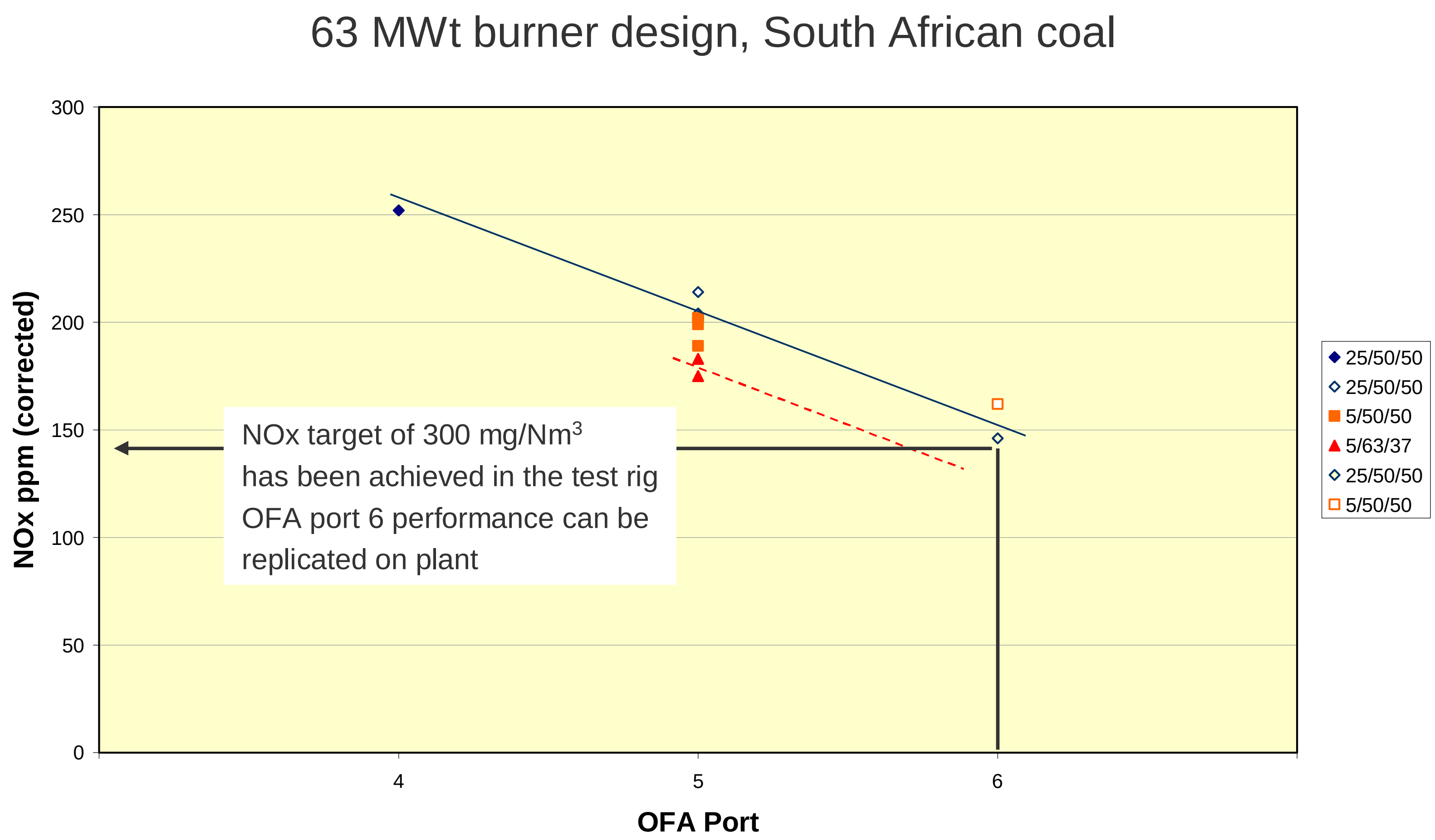
D-NO_X – Development Stage 5

42MW_t Burner Installation (March/April 2011) Plant Installation

- Project Scope
  - 18 D-NOx Burners installed on 680MWe unit during March / April 2011 outage
  - Partial retrofit, top 2 rows front and top row rear
  - Designed for two stage combustion and a stoichiometry of 0.9
  - Additional BOFA ports opened up to allow for the deeper staging
- Performance
  - Indonesian coal 188 mg/Nm^3, Australian coal 298 mg/Nm^3
  - Back-to-back NOx reduction of 19-22%
  - Carbon in ash <1-2% (no change), CO negligible
  - Burner turndown demonstrated at 45 % load without oil support



D-NOx Burner – Continuing Development Test Rig Performance



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Performance – Furnace Design Influence

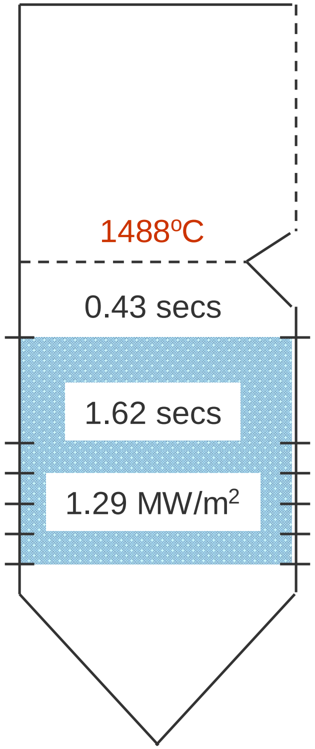
UK 1970s
660 MWe

NOx 450 mg/Nm3
6% carbon in ash

UK coal

Mk.III burners
60 x 41 MWt

Boosted OFA for retrofit application



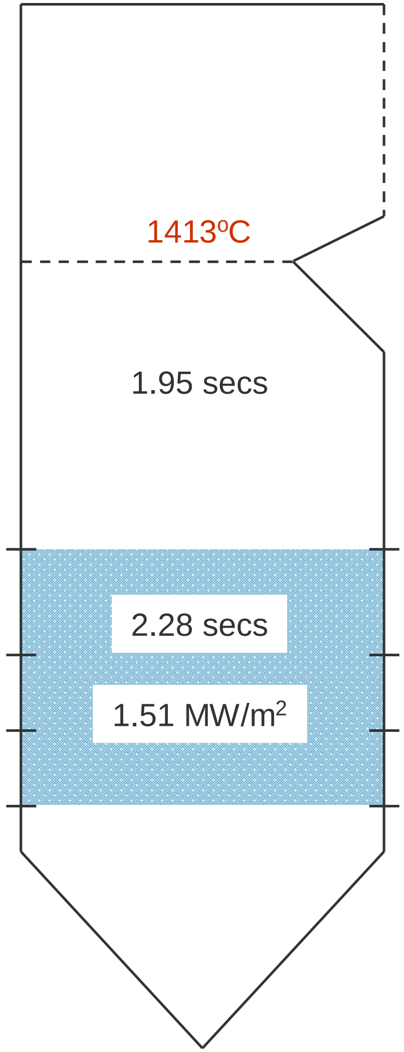
Korea 2013
870 MWe

NOx 310 mg/Nm3
3.5% carbon in ash

Internationally traded coal

D-NOx burners
42 x 66 MWt

Dual OFA for new build application



Unit size and burner size have increased over the years

Furnace designs now dominated by NOx control

Much lower NOx levels are achievable new build

Conclusions

- Mk.III low NOx burners are fitted throughout the UK and the world, reducing uncontrolled NOx levels by 40-80% depending on coal quality
- OFA or BOFA retrofits addressed the 2008 EU requirement for 500 mg/Nm^3 on existing plant
- Biomass interest has called for modifications to the existing burners to address ignition issues
- New plant required NOx levels worldwide continue to fall to below 300 mg/Nm^3 over the range of internationally traded coals, demanding continuing burner developments
- D-NOx burner has achieved target levels in the test rig and is being installed in all current new build units
- D-NOx^2 burner targetting even lower NOx levels is already being tested