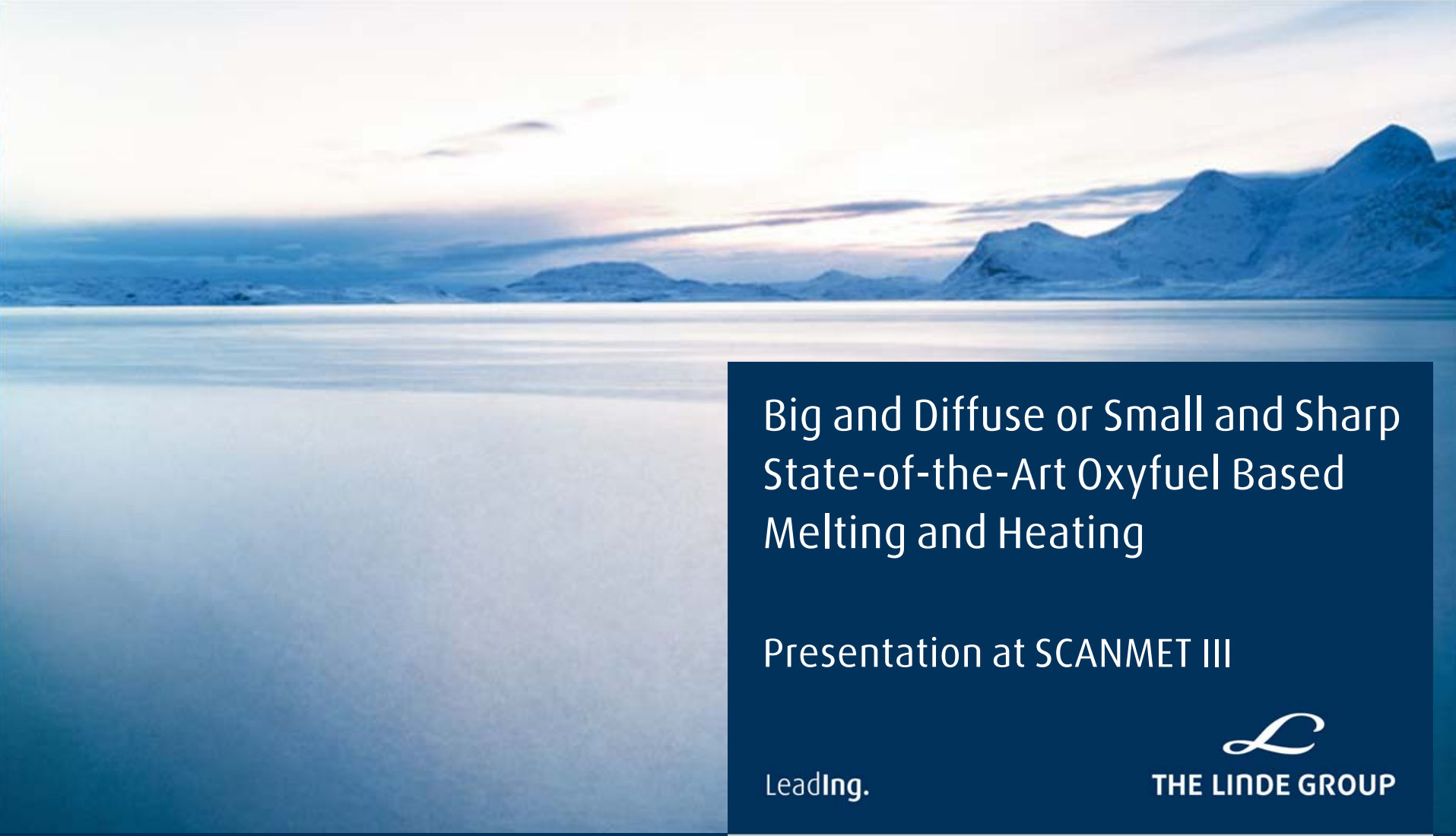


Big and Diffuse or Small and Sharp State-of-the-Art Oxyfuel Based Melting and Heating

Presentation at SCANMET III

LeadIng.

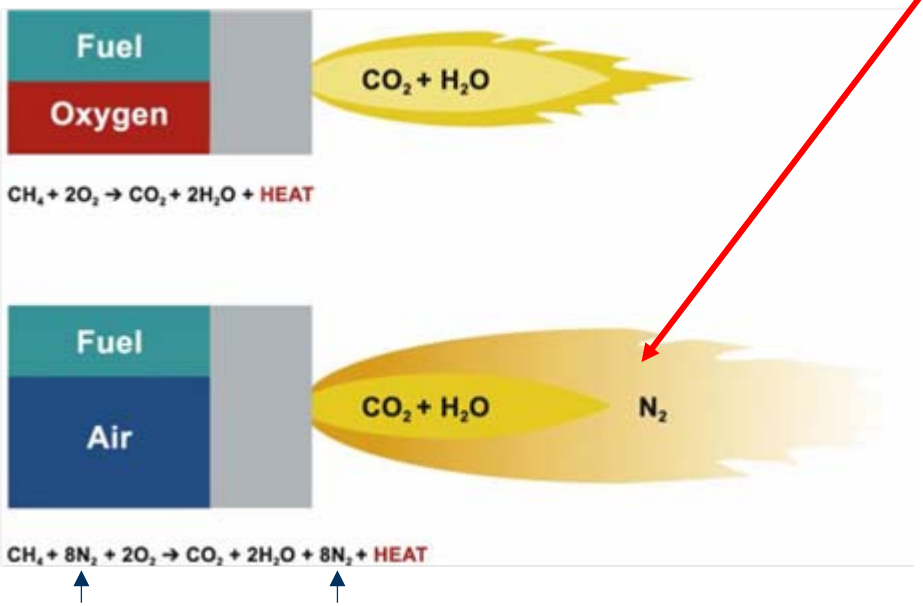
THE LINDE GROUP

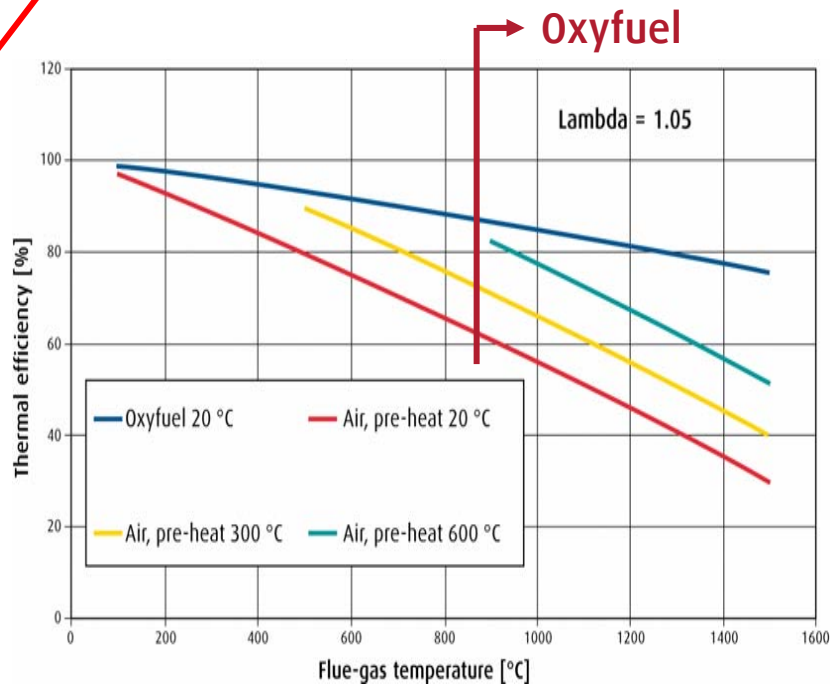
Joachim von Schéele
June 10, 2008

Oxyfuel Solutions
Energy Efficiency

- Low flue-gas losses due to low flue-gas volume
- Possible to use high flue-gas temp
- Radiating compounds, H_2O & CO_2
- Possible to use high power input
- Possible to use Low Calorific Fuels

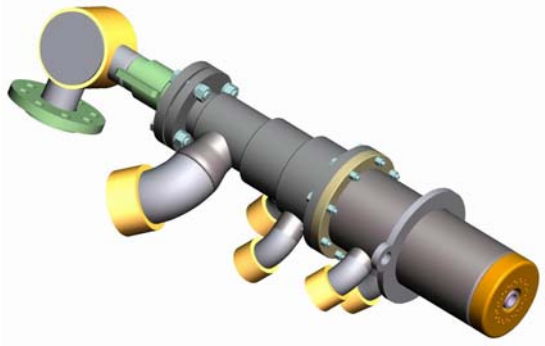
8 Molecules of Nitrogen Ballast!



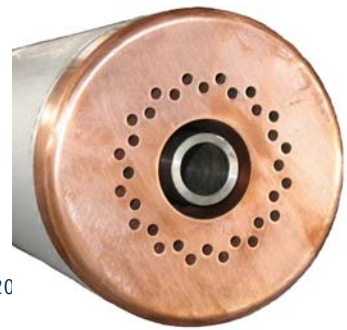


THE LINDE GROUP

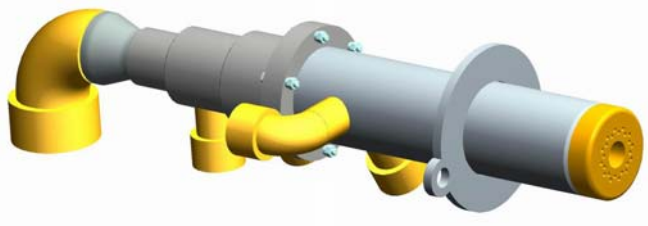
Hi JET



- UP TO 5 MW BURNER WITH INNOVATIVE MIXED SWIRL FLAME TECHNOLOGY.
- 'DEEP' CARBON INJECTION INTO THE LIQUID STEEL.
- OXYGEN AND NATURAL GAS CONSUMPTION SAVINGS DUE TO THE SHUT-OFF OF THE OXYGEN AND NATURAL GAS DURING INJECTION MODE

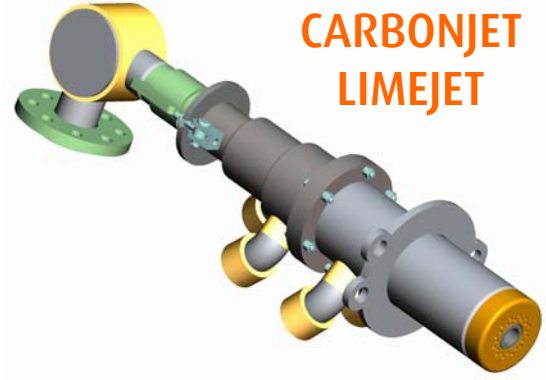


OXYGENJET



- UP TO 5 MW BURNER WITH INNOVATIVE MIXED SWIRL FLAME TECHNOLOGY.
- SUPERSONIC/COHERENT OXYGEN INJECTION.
- OXYGEN AND NATURAL GAS CONSUMPTION SAVINGS DUE TO THE SHUT-OFF OF THE OXYGEN AND NATURAL GAS DURING INJECTION MODE

CARBONJET LIMEJET



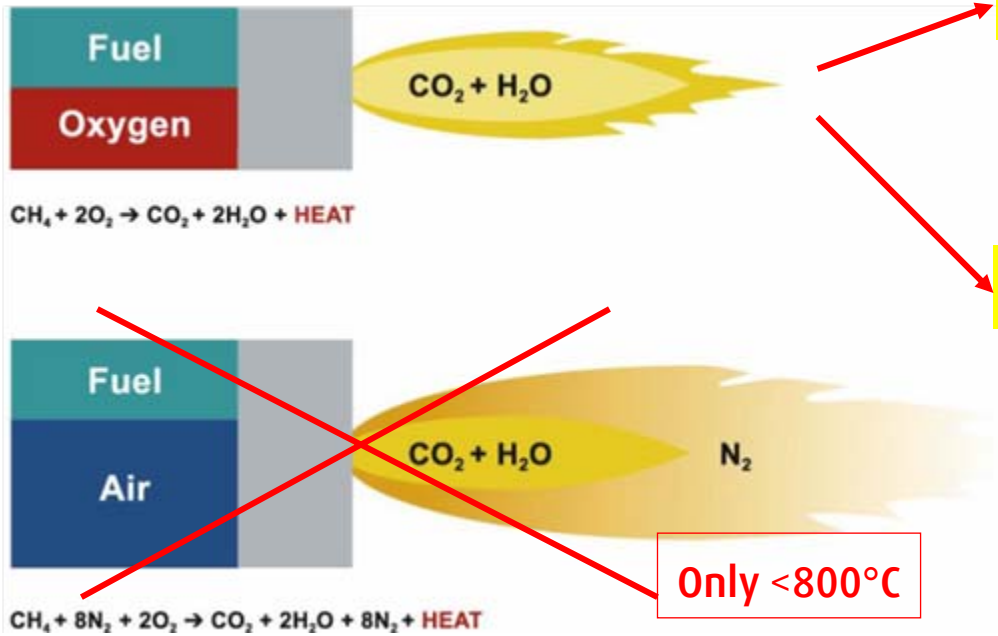
- UP TO 5 MW BURNER
- WITH INNOVATIVE MIXED SWIRL FLAME TECHNOLOGY.
- CARBON/LIME/DOLO-LIME INJECTION.
- OXYGEN AND NATURAL GAS CONSUMPTION SAVINGS DUE TO THE SHUT-OFF OF THE OXYGEN AND NATURAL GAS DURING INJECTION MODE

REBOX® Oxyfuel Solutions
Combustion Technologies

THE LINDE GROUP

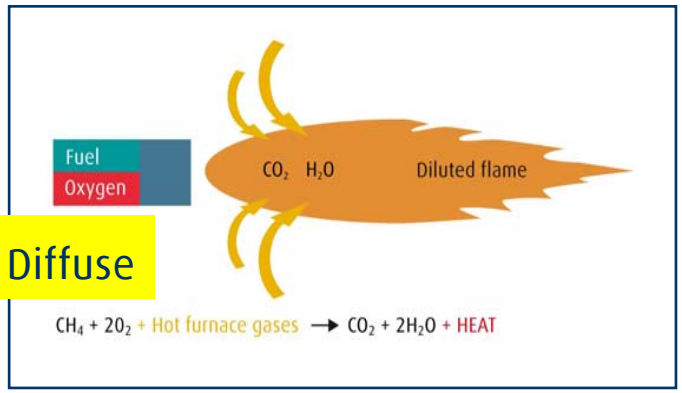
Oxyfuel Combustion Technology

- Energy savings
- Increased production
- Lowered emission



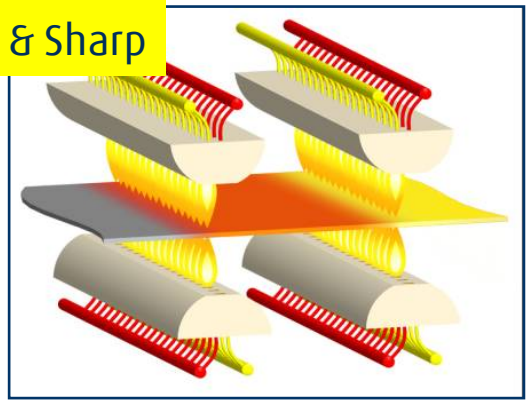
Flameless – low NO_X, high uniformity

Big & Diffuse



DFI – for ultra fast heating

Small & Sharp



And the Newest: REBOX® HLL!

Flameless Oxyfuel
Uniform Heating and Reduced NO_X

THE LINDE GROUP

Combustion extended in time and space

- Volume combustion
- Spontaneous reaction above self ignition temp. (>750°C from safety point of view)

Dilution of flame reduces flame temperature

- Flame temperature is even with no peaks which minimizes thermal NO_x

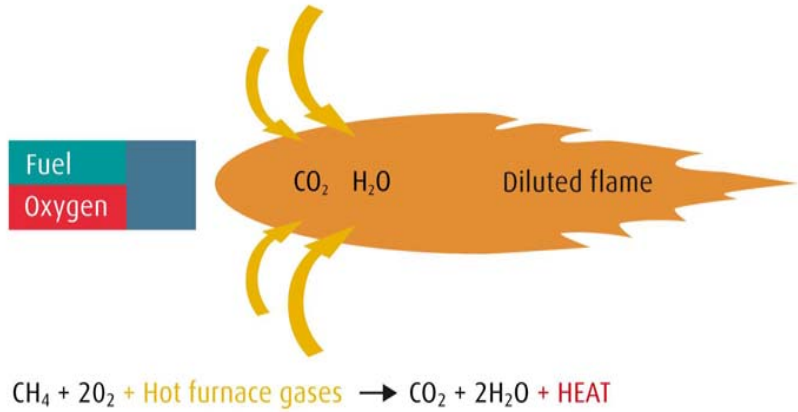
Minimized temperature difference between flame and furnace walls

- Uniform heating of object

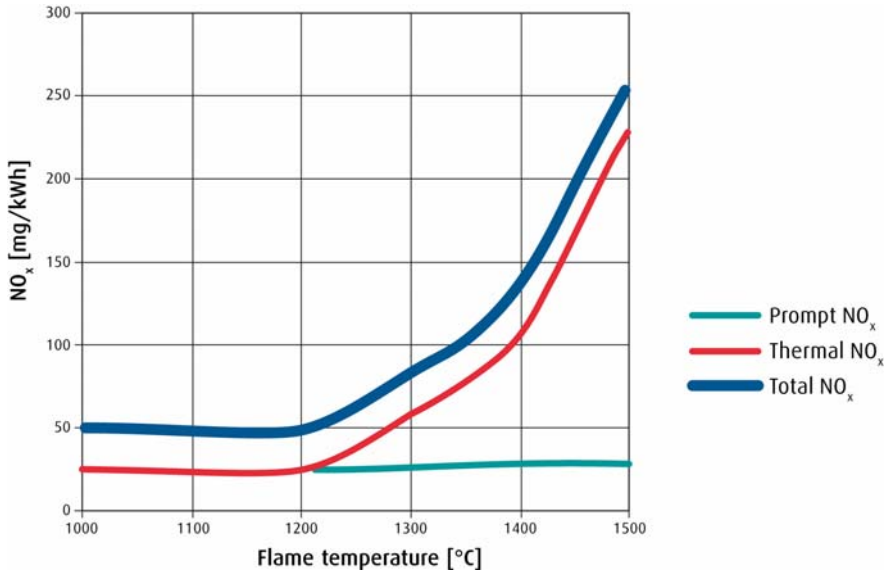
Dilution results in good stirring of the highly radiating CO_2 and H_2O gases in furnace

- More even furnace temperature
- Convection transfer to object

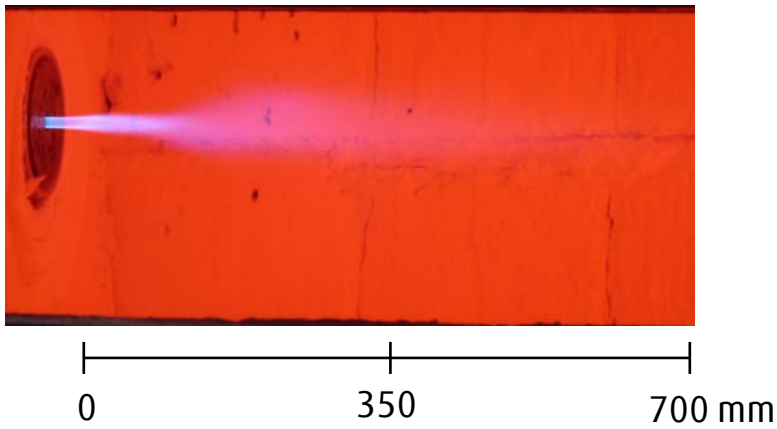
Compact and powerful burner technology



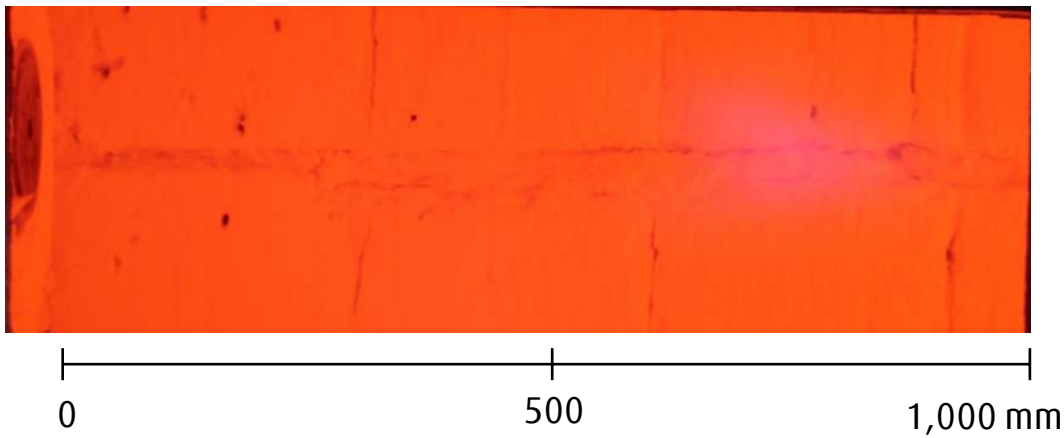
$CH_4 + 2O_2$ + Hot furnace gases → $CO_2 + 2H_2O$ + HEAT



Flameless Oxyfuel



Oxyfuel Staged Combustion
with 5% Primary Oxygen

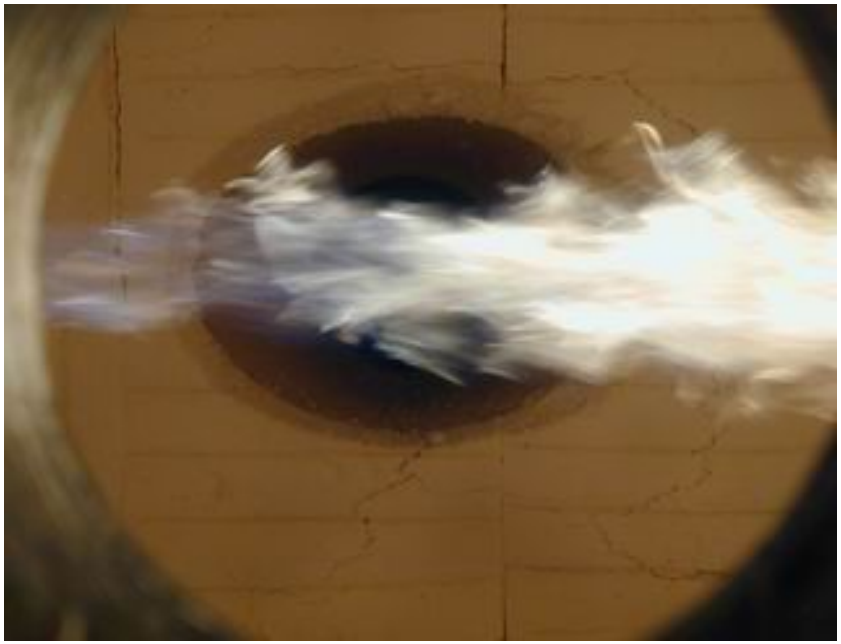


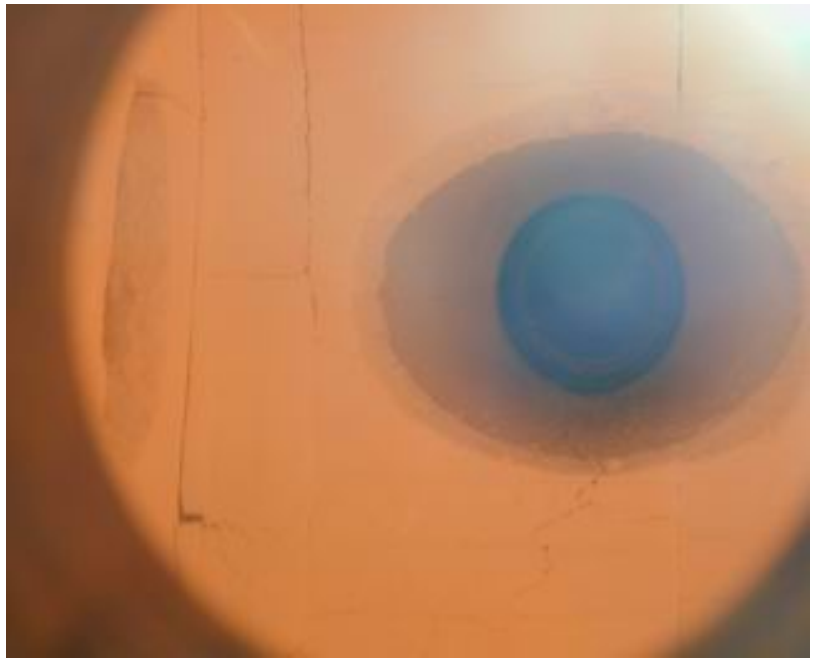
Flameless Oxyfuel

Flameless Oxyfuel
Ultra Low NO_X Levels

	NO_X mg/MJ
Standard Oxyfuel	~100-200
Staged Oxyfuel	70-100
Flameless Oxyfuel	<25

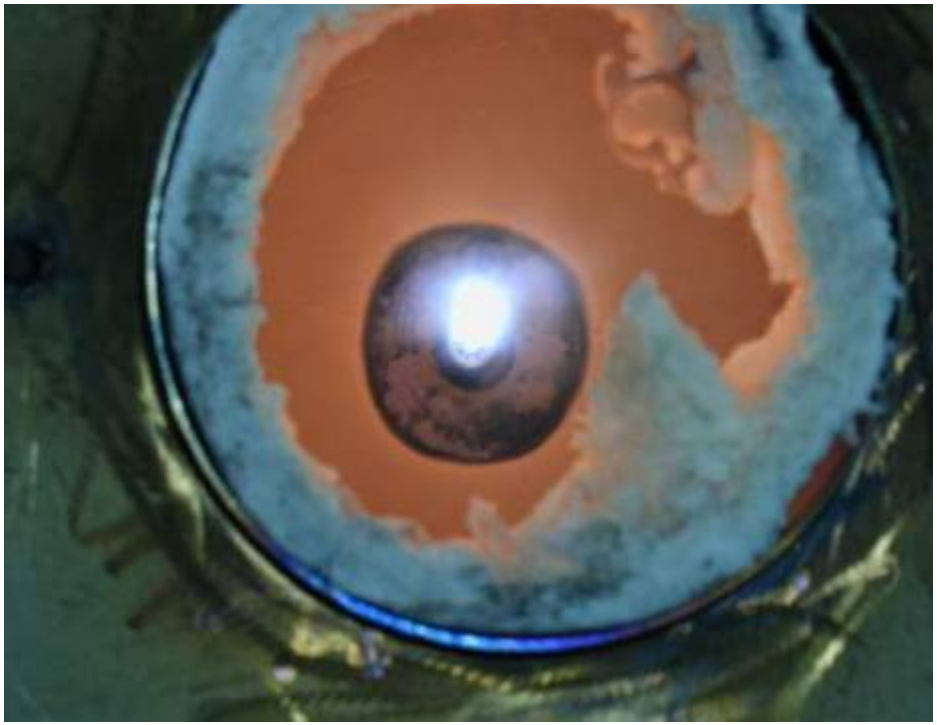
Dilution reduces flame temperature and provides effective stirring of the highly radiating CO_2 and H_2O gases





Flameless Oxyfuel has Lower Flame Temperature, but Same Energy Content

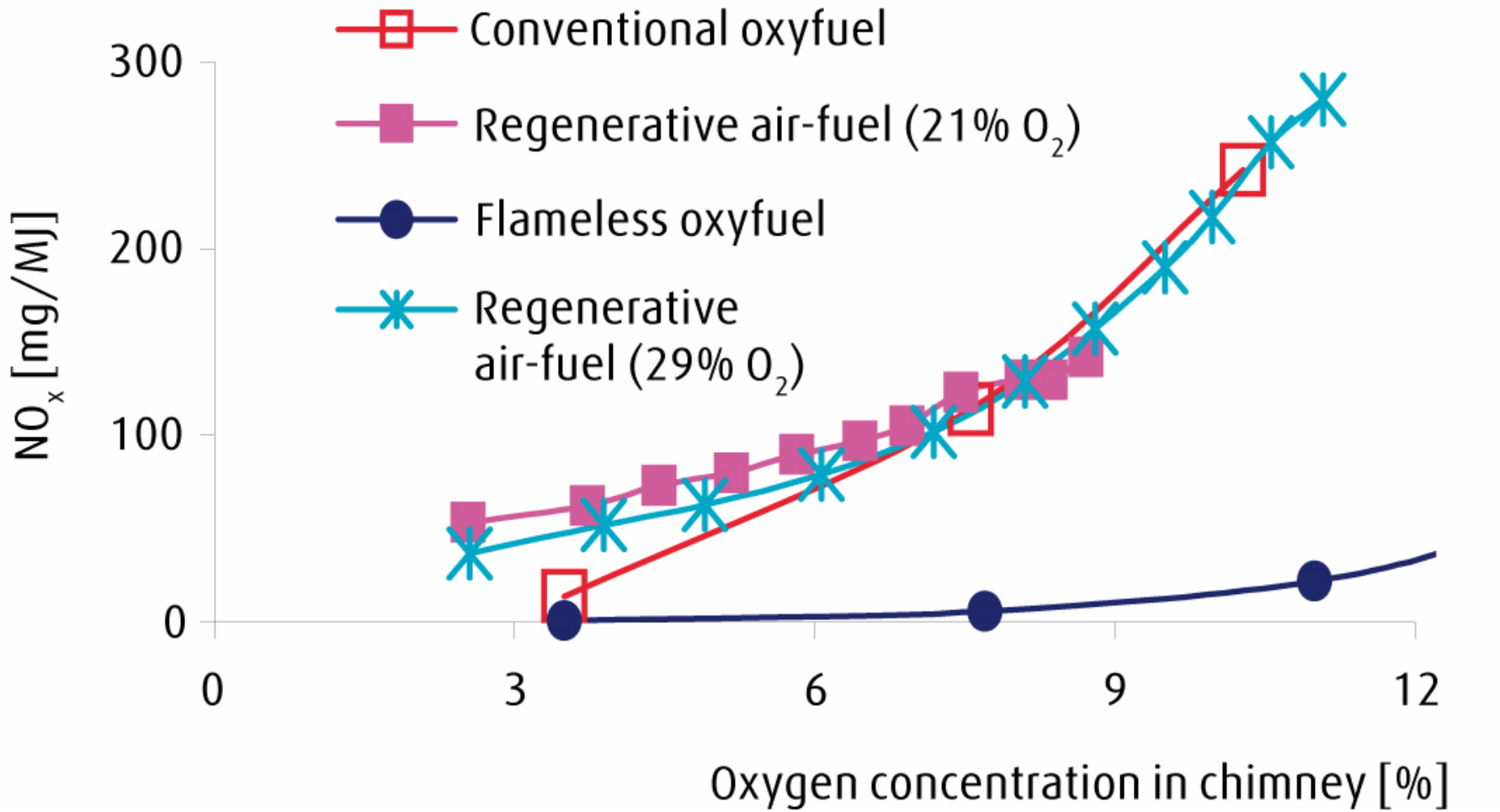
THE LINDE GROUP



Flame mode

Flameless mode

Flameless Oxyfuel
Ultra Low NO_X Despite Ingress Air



Benefits of Oxyfuel in Vessel Preheating

THE LINDE GROUP

Benefits from higher heating temperature of a steel-making vessel:

- No need to have too high tapping temperature from the EAF/BOF
- Shorter heating cycles for less number of vessels needed
- Only 75-80% flue gases due to less fuel and no nitrogen in combustion – smaller flue-gas system
- 50-55% lower fuel consumption compared to cold air fuel system

Simple, compact and low weight installation as compared to air-fuel system with recuperator or regenerative solution

<u>Additional Benefits from Flameless oxyfuel:</u>

- **Further improved heat distribution in the vessel**
- **Ultra low NO_x emissions**
- **Extended refractory lifetime due to a more even temperature distribution in vessel**

Vessel Preheating with Flameless Oxyfuel

THE LINDE GROUP

Vessel preheating using oxyfuel is common technology – using
Flameless Oxyfuel is a Milestone in Preheating!

- Increased temperature uniformity in ladle
- Decreased fuel consumption
- Lower NO_X formation
- Increased heating capacity

Ladle preheating at ACERINOX

Cases of flameless oxyfuel

Sandvik	90 t converters	1.4 MW
Outokumpu	90 t ladles	1.5 MW
Acerinox	90 t ladles	2.0 MW
OVAKO	90 t ladles	1.4 MW
Kanthal (1500°C)	5 t ladles	0.2 MW
Outokumpu	90 t converters	2.5 MW

REBOX® Oxyfuel Solutions
General Results from Installations

THE LINDE GROUP

Fuel and CO_2 savings
Up to 50% reduction

Low NO_X emission
Levels continuously below 70 mg/MJ

Less Scaling
Up to 0.4%-units reduction

Increased production capacity/flexibility
Up to 50% higher throughput

Car bottom furnace at SCANA Steel, all equipped with flameless oxyfuel

THE LINDE GROUP

Lower Fuel Consumption in a Reheating Furnace

		Air fuel	AF w recu	REBOX®
Enthalpy in steel	kWh/t	200	200	200
Transmission losses	kWh/t	10	10	10
Flue-gas enthalpy	kWh/t	290	140*	50
Flue-gas temperature	°C	1200	850	1200
Air preheating	°C	20	450	20
Thermal efficiency	%	42	70	80
Energy need	**kWh/t**	**500**	**350**	**260**
Energy need	**GJ/t**	**1,8**	**1.26**	**0.936**
Oxygen production	kWh/t			25

*after recuperation

Flameless Oxyfuel burners, Water-cooled & Ceramic

THE LINDE GROUP

Ultra low NO_X & Uniform heating

- —High flue gas circulation and lower flame temperature

Dual mode burner – standard and flameless

Separated jets – Supersonic

Powerful: 0.5-5 MW

- —Oil, coal or gaseous fuels

Easy retrofit & Compact rugged design

- —Quick release fittings
- —Simple dismounting
- —Integrated UV and pilot burner
- —Burner diameter 105 mm (w-c), 300 mm (ceramic)
- —Weight 10-20 kg (w-c)

REBOX® Oxyfuel Solutions
Retrofit Replacing Air-fuel

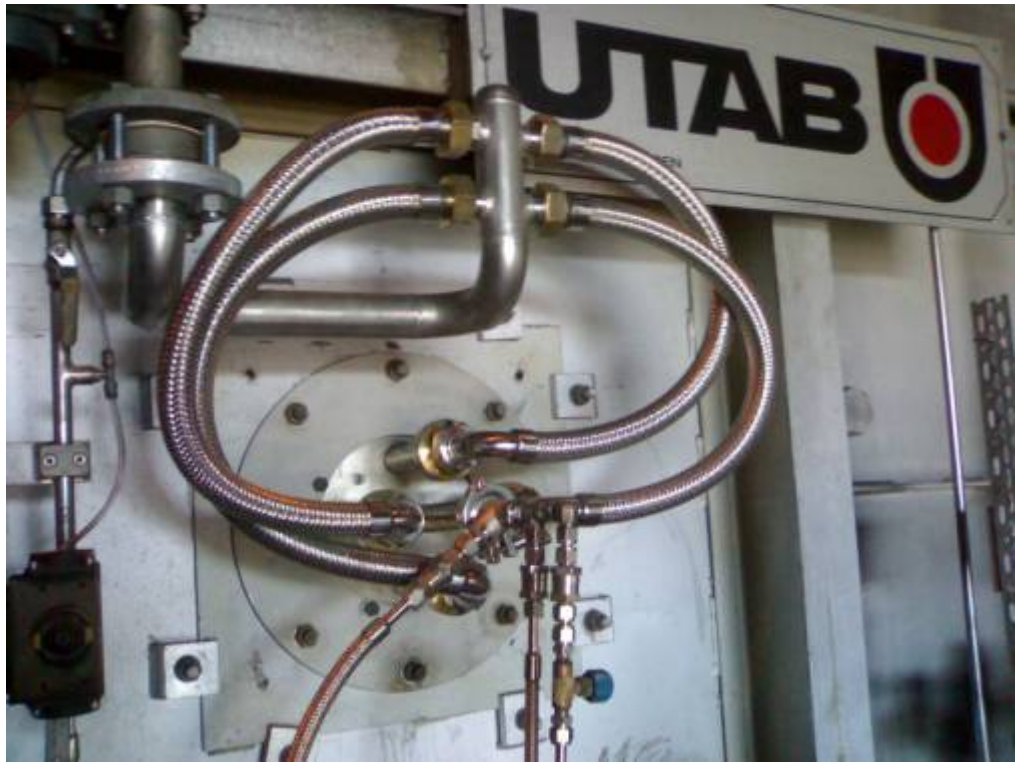
4 MW air-fuel installed, before REBOX®

2.5 MW Flameless Oxyfuel Installed

REBOX® Oxyfuel Solutions
Typical Installation

THE LINDE GROUP

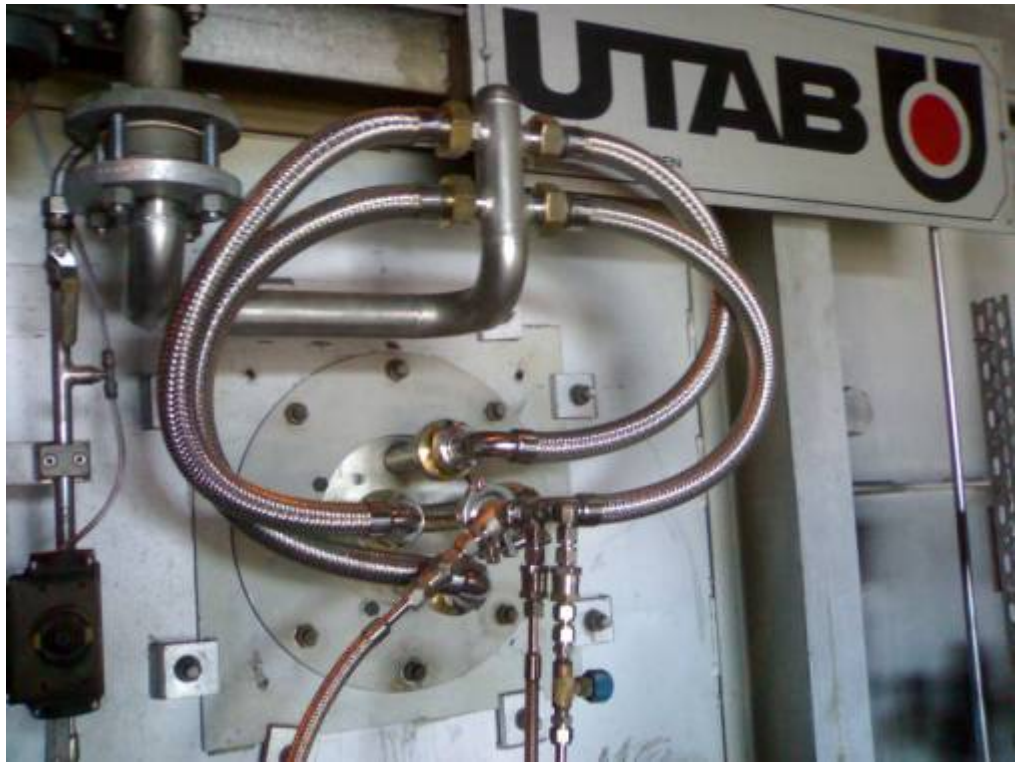
Flameless Oxyfuel Burner



REBOX® Oxyfuel Solutions
Typical Installation

THE LINDE GROUP

Flameless Oxyfuel Burner



REBOX® Oxyfuel Solutions
Use of a Low Calorific Fuel

THE LINDE GROUP

For Coke Oven Gas, Blast Furnace Top Gas, BOF Gas, and other in-house gases. Used individually or in different combinations.

Combusting Low Calorific in-house gases with oxygen provides the flame temperature needed in reheating and annealing operations.

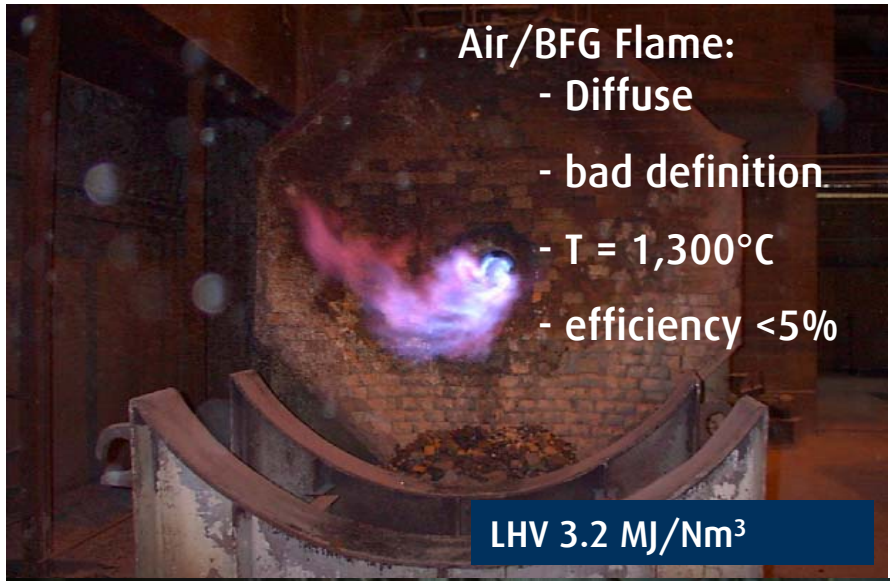
With oxygen a fuel of

3.3 MJ/Nm³ (0.9 kWh/Nm³)

is “upgraded” to be like a

7.7 MJ/Nm³ (2.1 kWh/Nm³)

fuel combusted with air (i.e., roughly like conventional air-fuel combustion)

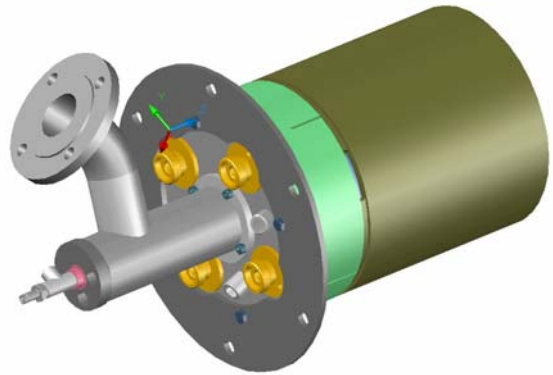


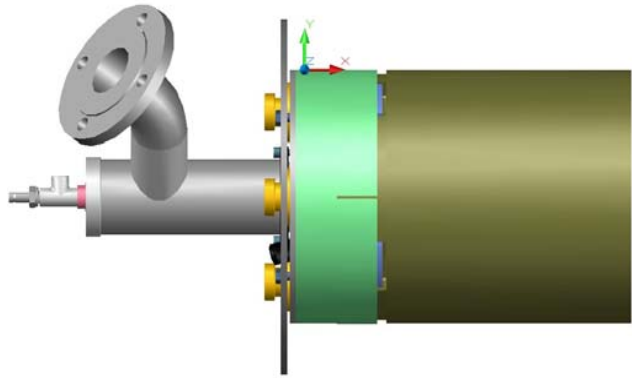
REBOX® Oxyfuel Solutions
Use of a Low Calorific Fuel

THE LINDE GROUP

Burner design – Flameless Oxyfuel using a Low Calorific Fuel

- Separate Jet Flameless technology
- Ceramic self-cooled design
- Dual-fuel and mixed fuel capability
- Flame and Flameless mode for cold and hot furnace operation



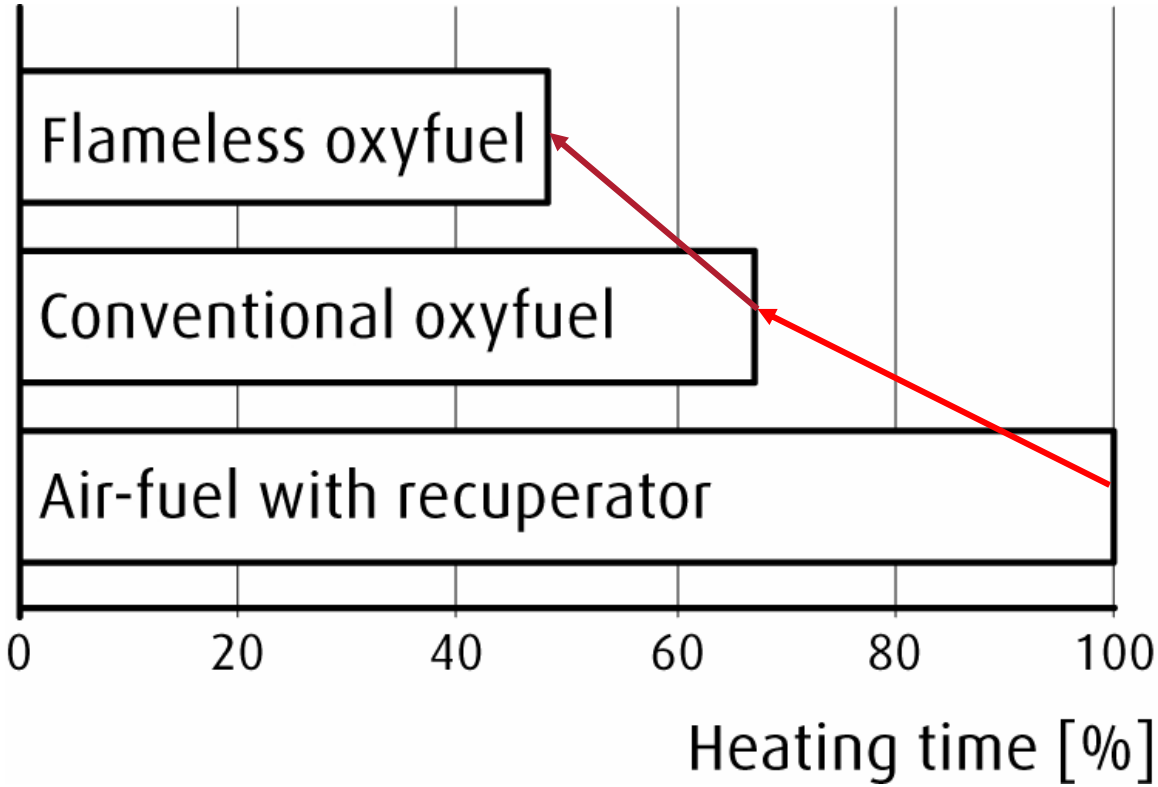


Ø 300mm stone
For 400-600mm Wall

325 kW at 15 mBar BFG

LPG/NG injection possible

REBOX® Oxyfuel Solutions
Flameless vs. Conventional



Total Heating Time at Ovako Hofors Works using different combustion technologies

Rotary hearth furnace at ArcelorMittal Shelby, all equipped with flameless oxyfuel

REBOX® Oxyfuel Solutions
Example of Installation

THE LINDE GROUP

Walking Beam Furnace at Outokumpu, Degerfors. Conversion into all flameless oxyfuel operation.

Linde Turn-key delivery in 2003

Combustion system with flameless burners, furnace upgrade, new flue gas system, flow train, control system

Furnace data

Dimensions: 27 m length, 5 m wide

Fuel: LPG

Stainless steel: all grades, 1,550 mm wide 140-300 mm thickness

Performance Guarantee

35% more through put

30% fuel savings (down to 0.97 GJ/ton cold charged)

NO_X emission <70mg/MJ (350 mg/m3)

Revamped in 25 days

REBOX® Oxyfuel Solutions
Example of Installation

THE LINDE GROUP

13 Soaking pit furnaces at Ascométal, Fos-sur-Mer and Les Dunes. Conversion into all flameless oxyfuel.

Linde Turn-key delivery in 2005-2008

Combustion system with flameless burners, furnace upgrade, new flue gas system, flow train, control system

Furnace data

Dimensions: 80-120 ton/furnace

Fuel: Natural gas

Bearing steel

Performance

50% more heating capacity

40% fuel savings (down to 1.15 GJ/ton cold charged)

NO_X emission reduced by 40%

Scale formation reduced with 3 ton/1000 ton heated (0.3%)

REBOX® Oxyfuel Solutions
Example of Installation

THE LINDE GROUP

Rotary hearth furnace at ArcelorMittal Shelby. Conversion into all flameless oxyfuel.

Linde Turn-key delivery in 2007

Combustion system with flameless burners, furnace upgrade, new flue gas system, flow train, control system

Furnace data

Dimension: 15 m diameter

Billet diameter: 76-222 mm

Fuel: natural Gas

Carbon steel:

Performance Guarantee

>33% more through put

50% fuel savings (from enrichment; 65% from air-fuel)

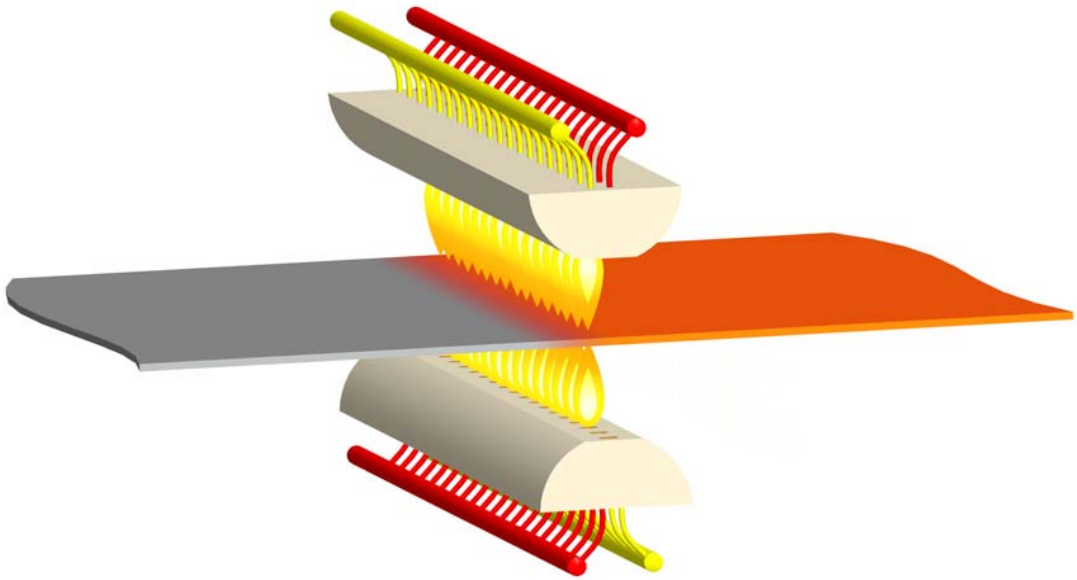
NO_x emission <70 mg/MJ

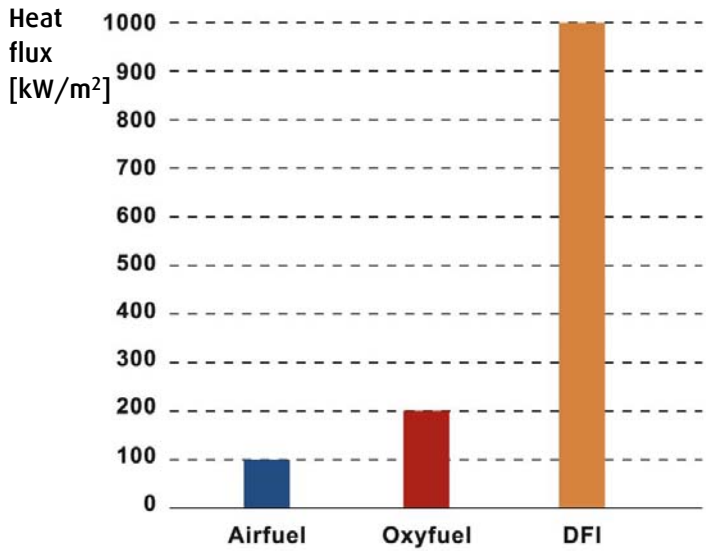
Direct Flame Impingement (DFI) Technology

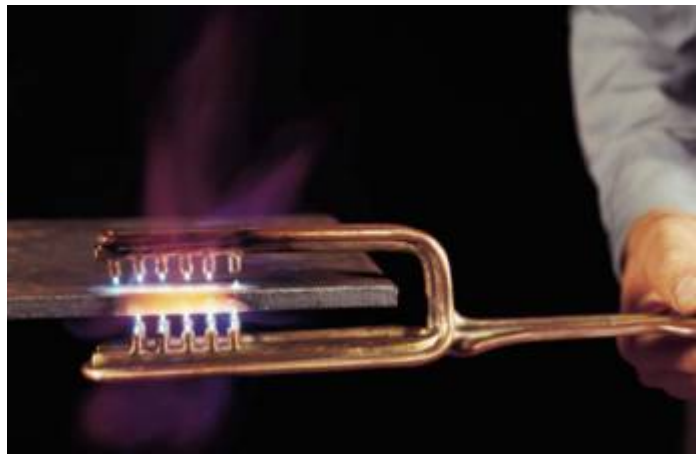
THE LINDE GROUP

Firing Directly Onto a Moving Material

DFI Oxyfuel the local heat flux could be as high as 800-1000 kW/m²







DFI Oxyfuel in a Stainless Strip Annealing & Pickling Line at Outokumpu

THE LINDE GROUP

Outokumpu Nyby Works, Sweden

DFI Oxyfuel installation in 2002 by Linde

4 MW installed power

120 oxyfuel flames, four burner rows

2 meter long unit at entry of strip annealing furnace

Furnace throughput capacity increased 50%, from 23 to 35 t/h

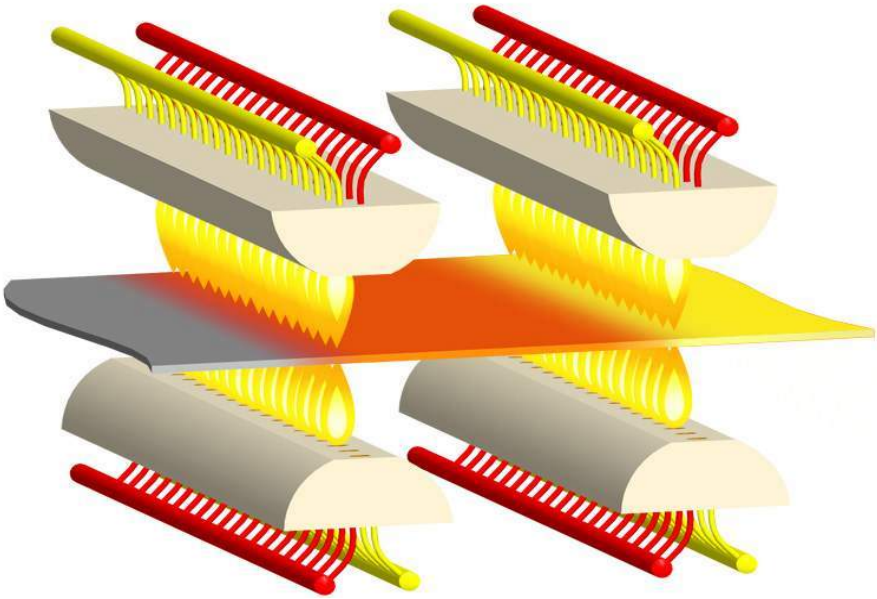
DFI Oxyfuel in Metal Coating Lines
ThyssenKrupp Steel at Finnentrop and Bruckhausen

THE LINDE GROUP

3 m of recuperative zone removed to fit DFI

Compact DFI unit: L 2.8 x W 2.8 x H 1.2 meter

12 days line stop

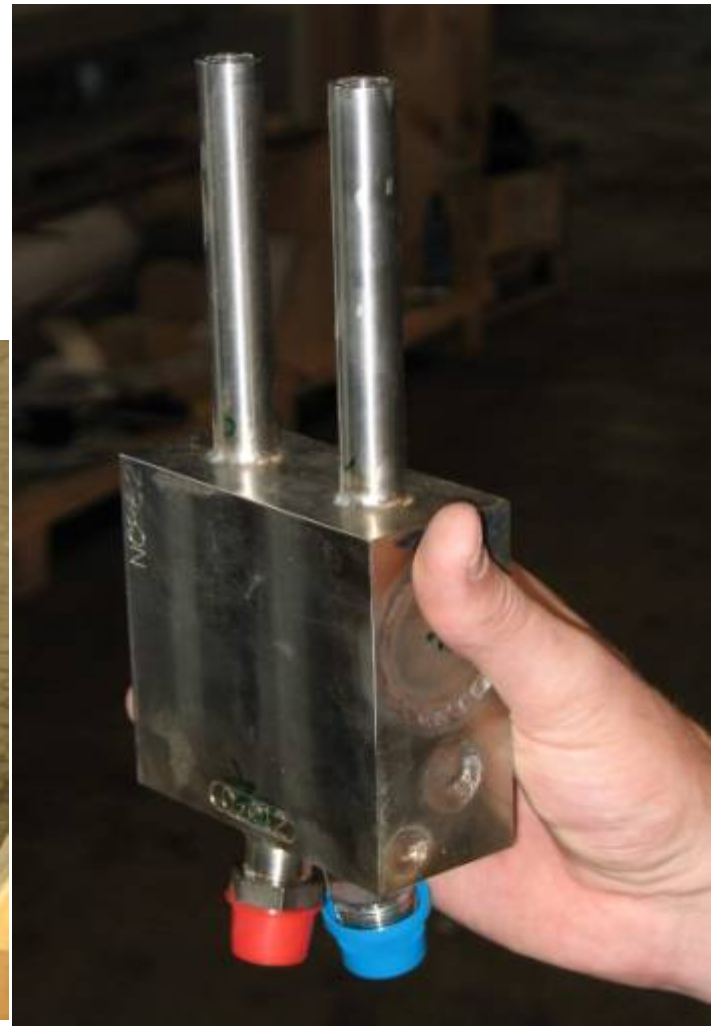


DFI Oxyfuel in Metal Coating Lines
ThyssenKrupp Steel at Finnentrop and Bruckhausen

THE LINDE GROUP

5 MW power input

- 80-90% thermal efficiency
- Totally 120 oxyfuel flames, in 4 burner rows
- Option for 2 more burner rows (+ 2 MW)



REBOX® DFI Oxyfuel
Example of Installation

THE LINDE GROUP

Galvanizing lines at ThyssenKrupp Steel, Finnentrop and Bruckhausen. DFI boosting.

Linde Turn-key deliveries in 2006 and 2007

Combustion system with Direct Flame Impingement in 4 Burner Row Units, flow train, control system

Furnace data

Dimensions: 2.8 m long

Fuel: Natural Gas

Carbon steel strip: all grades, 1,550 mm wide

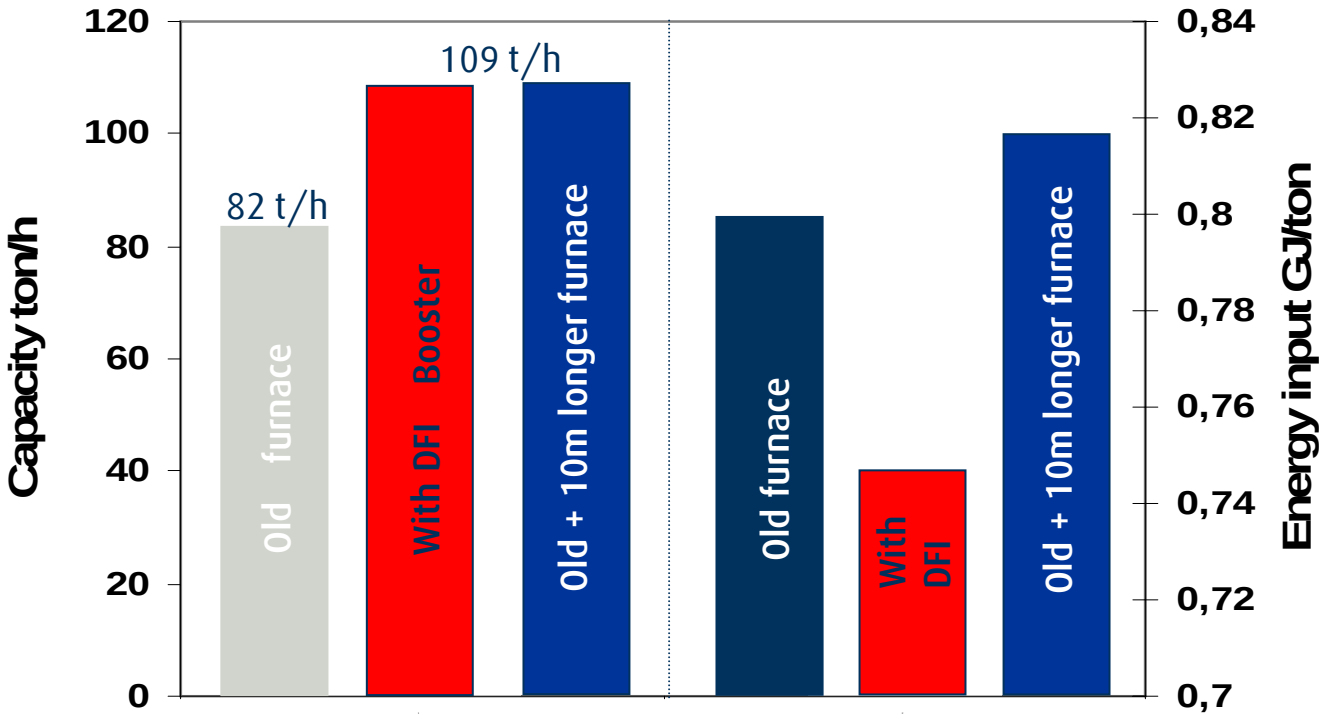
Performance Guarantee

30% more through put

10% fuel savings

Revamped in 4 days/furnace

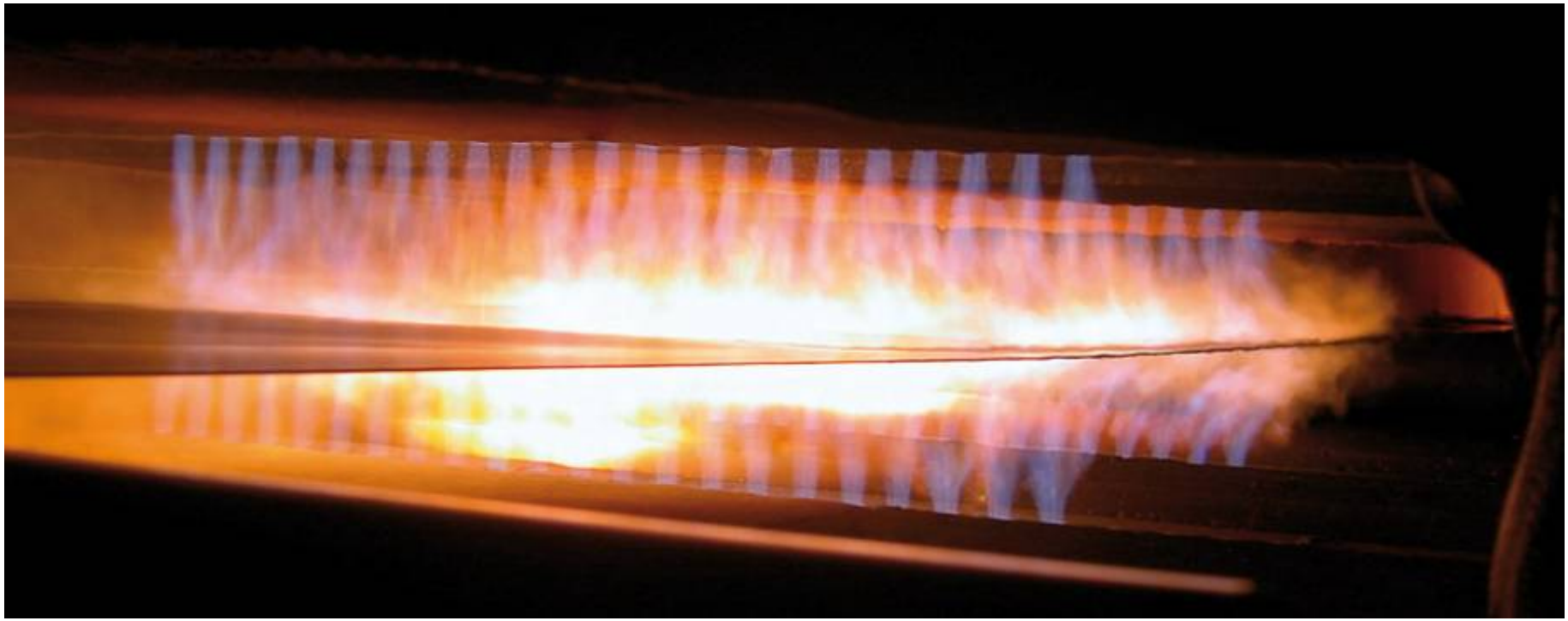
"DFI is 3 solutions in one – more capacity, clean strip and no extension of line"



The alternative to DFI Oxyfuel at ThyssenKrupp Steel at Finnentrop was a 10-m extension of the furnace, but that would not have provided decreased fuel consumption and elimination of the cleaning section.

Direct Flame Impingement (DFI) Technology

THE LINDE GROUP



Here DFI for ΔT 200°C at max production rate (ton/h), but can be used for much higher ΔT, for example 500°C

Direct Flame Impingement (DFI) Technology

THE LINDE GROUP

DFI oxyfuel could be used not only for strip heating relating to annealing and coating of different kinds.

- Agglomeration – for example, ignition of sinter beds and agglomeration of briquettes
- Iron-making
- To change material properties
- Press hardening
- Edge-heating
- Skid-marks removal
- … ?

A technology that has 10 times the heat transfer than the one in use is waiting to be fully exploited!

THE LINDE GROUP

Summary:

In the steel industry, flameless oxyfuel should be applied for heating in all types of furnaces and vessels, with temperatures above 800-900°C.

Flameless oxyfuel leads to great benefits in terms of lower fuel consumption, decreased CO_2 and NO_X, and increased production capacity.

The benefits of flameless oxyfuel have already been demonstrated in 30 installations.

In general air-fuel is only viable below 800°C.

There are only two exceptions where flameless oxyfuel should not be used:

- Conventional oxyfuel in Electric Arc Furnaces
- DFI Oxyfuel applications

In addition to strip processing lines, where DFI Oxyfuel has shown great success, where else in the iron and steel making process chains could DFI Oxyfuel be applied?