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SoA Highlights

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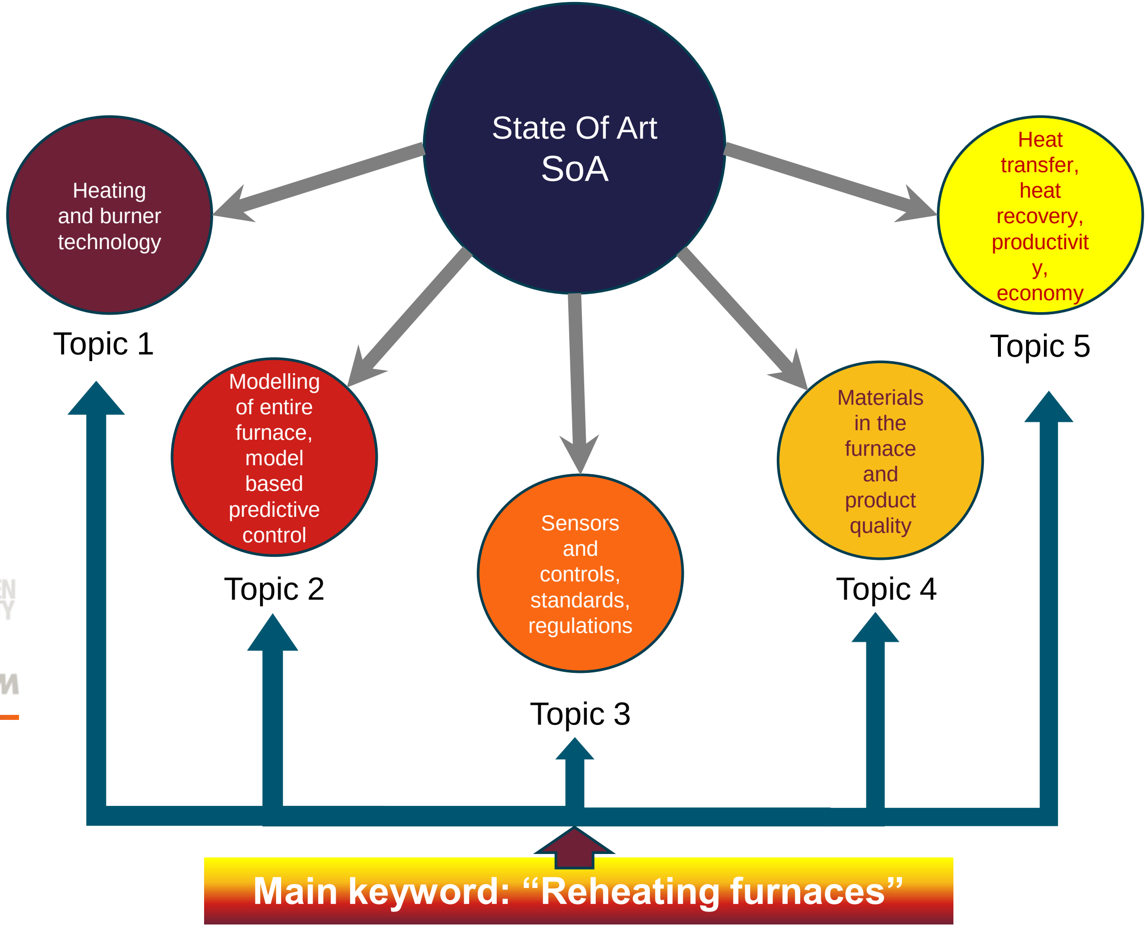


- RFCS projects, HEU projects and intl literature performed over the last 25 years
- Classification into 5 main topics or subgroups

Heating and burner technology

Modeling of the entire furnace, level 2 control

Materials in the furnace and product quality

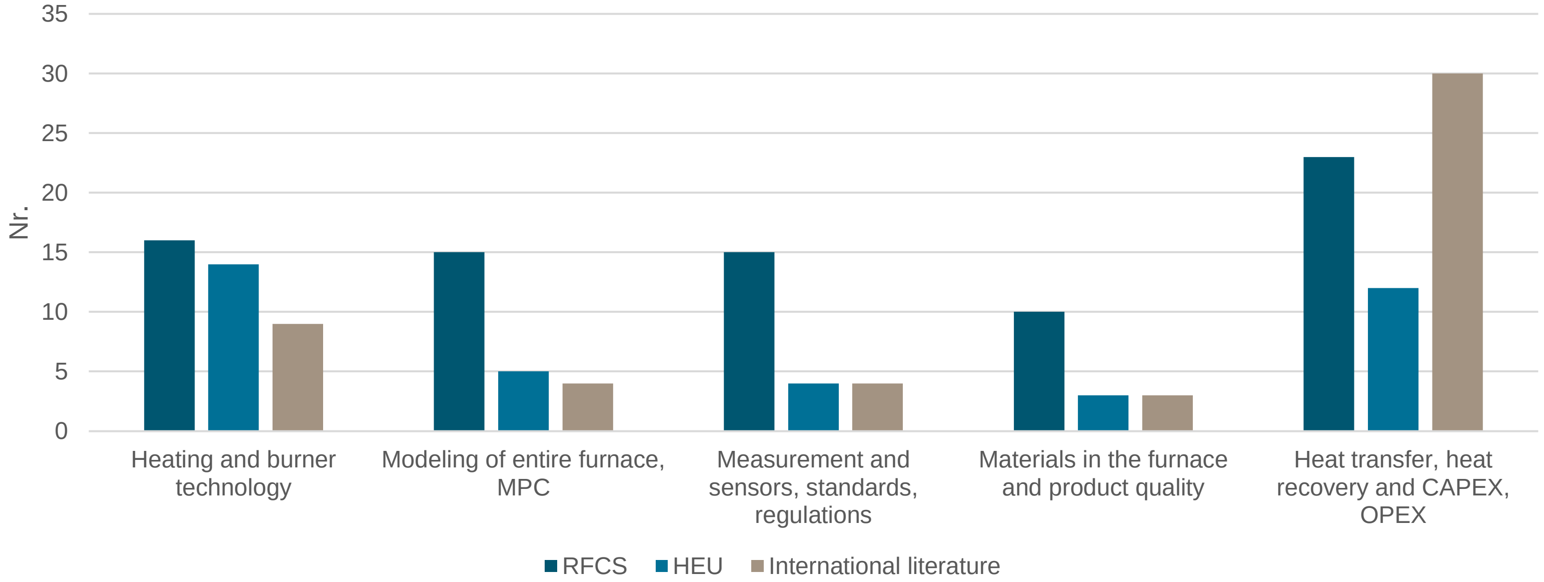
Sensors and control, standards, regulations

Heat transfer, Heat recovery, CAPEX, OPEX

SoA - Relevant literature per topic

RFCS	37
HEU	25
Journals	50

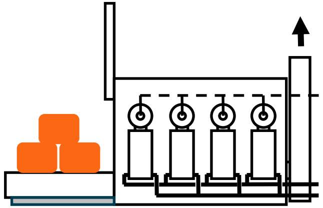
Projects and literature on reheating furnaces per topic



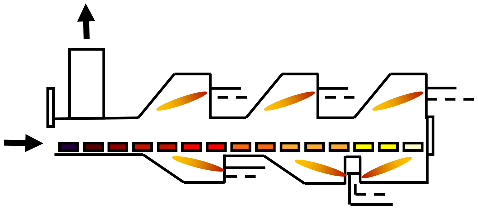
SoA - Heating and burner technology

Key technologys to decrease **CO_2** and **NO_X emissions** of heating and burner technology for **reheating furnaces**:

batch furnace

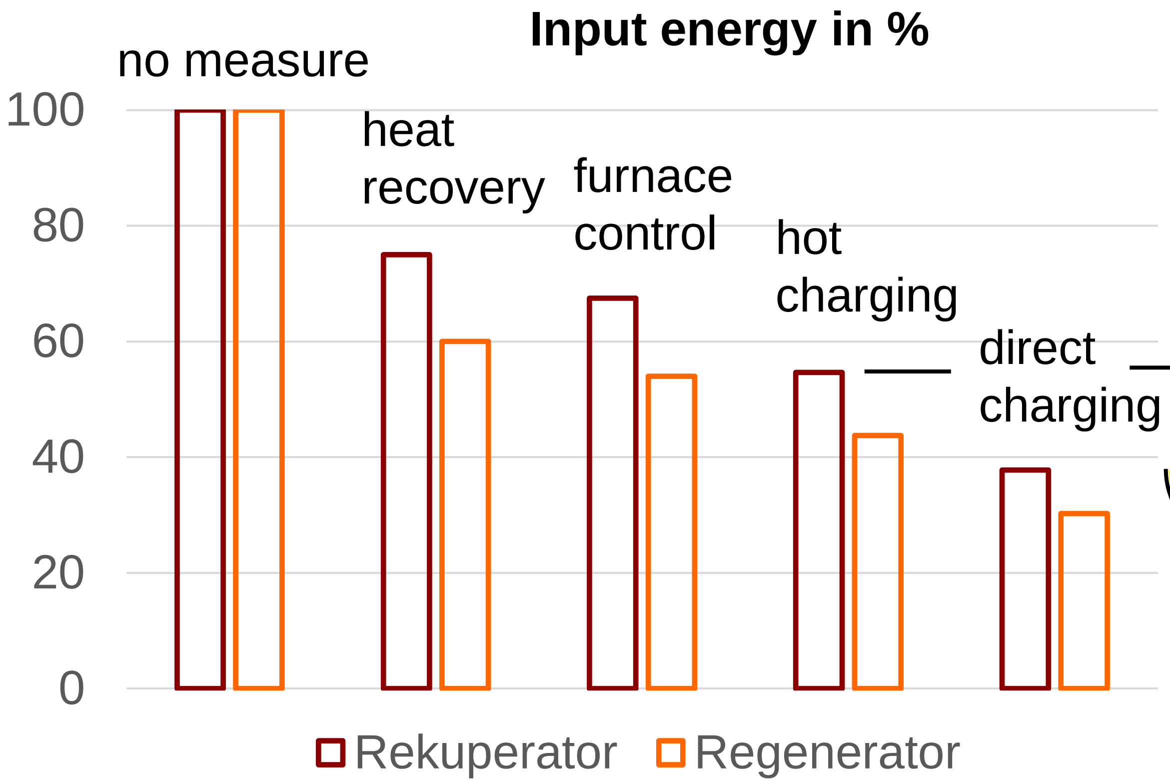


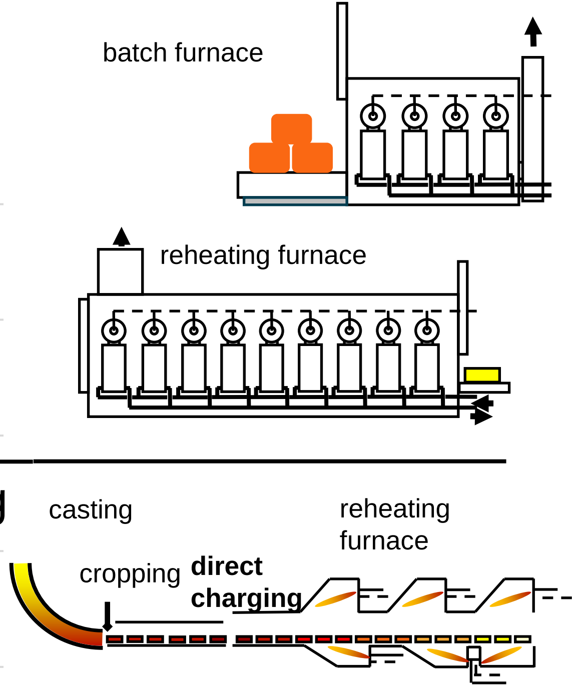
continuously operating furnace



Burner technology	Process gases	Efficiency by Heat recovery	Efficiency by process combination
NOx reduction - Flameless combustion - Ultra Low-NOx combustion	Substitution of natural gas in reheating furnace 100% or mixture with NG, oxidizer: air or OEC	Heat recovery form off gas by Combustion air preheating - recuperative - regenerative	Continuous casting not coupled rolling: warm charging Continuous casting coupled with rolling: direct charging

SoA - Heating and burner technology

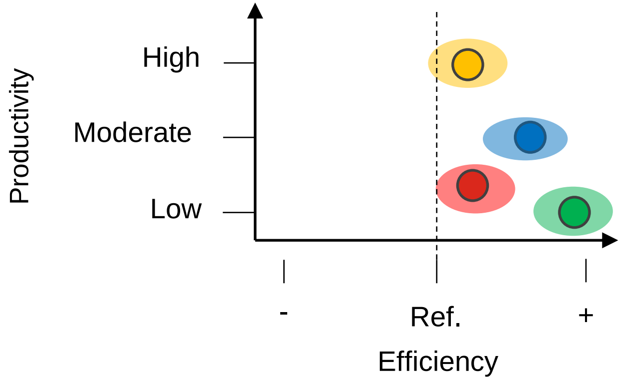




State of the art 2023

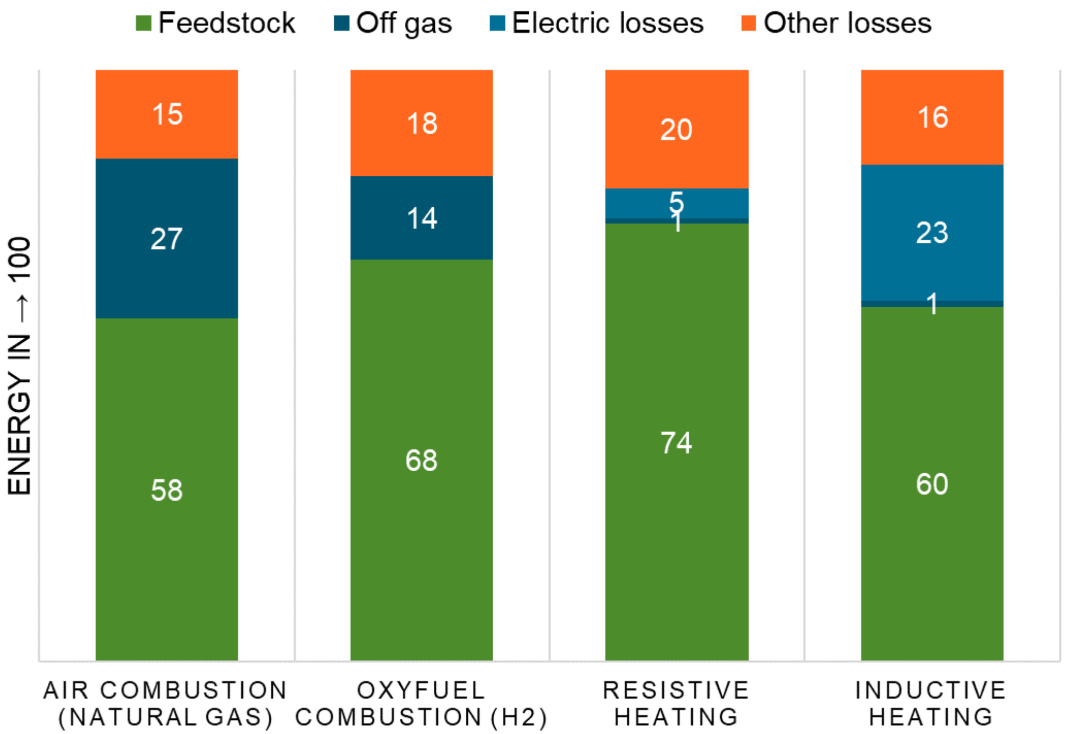
Ref. Refers to a natural gas fired furnace with SoA recuperators

- Flameless regenerative burners 🔴
- Flameless oxyfuel combustion 🔵
- Electrical heating
  - Resistive radiative heating 🟢
  - Inductive heating 🟡



	Flameless regenerative burners	Flameless oxyfuel combustion	Resistive radiative heating	Inductive heating
CAPEX	Higher investment cost for burners	Higher investment cost for burners, need of oxygen infrastructure	Need new investment of entire furnace	Need new investment of entire furnace
OPEX	Lower specific fuel cost	Lower specific fuel cost, additional cost for oxygen	• Lower specific energy cost (highly dependent on elec. cost) • Uncertainties regarding longevity of heating elements	Slightly lowered energy cost (highly dependent on elec. cost)

Energy performance - example



~397 kWh/t ~338 kWh/t ~310 kWh/t ~382 kWh/t

SoA - Sensors/controls, standards, regulations

The key technologies reviewed in topic 3 focus on **improving the energy efficiency of furnaces** and **enhancing product quality** using advanced measurement and control technologies.

Main parameters recorded in a furnace:

Furnace and charge temperature

- IR (gas) pyrometers
- Thermal Imaging
- Suction pyrometer
- Optimized control of temperature

Furnace atm. measurement and control (O_2, CO)

- Measurement of air and gas flow
- ZrO2 probes for O_2 content measurement
- Pneumatical/electronical gas/air ratio controllers

Air and fuel flows

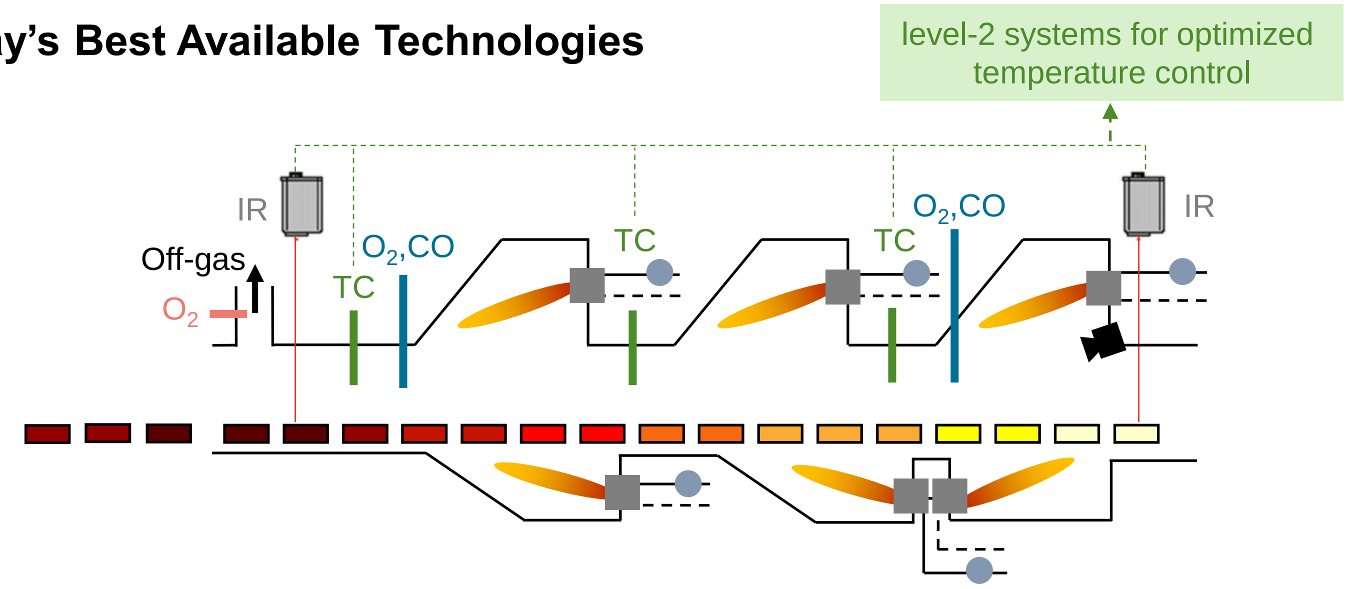
- Vortex, ultrasonic, thermal flow meters, vane wheel anemometer
- Orifice meters still typically used

Off-gas composition

- Continuous and portable off-gas analysis equipment according to SRM (Standard Reference Method)

SoA - Sensors/controls, standards, regulations

Today's Best Available Technologies



- Air-gas ratio control
- O_2, CO measurement in the furnace
- O_2 measurement in the off-gas
- IR Pyrometer
- Thermocouple
- Thermal imaging

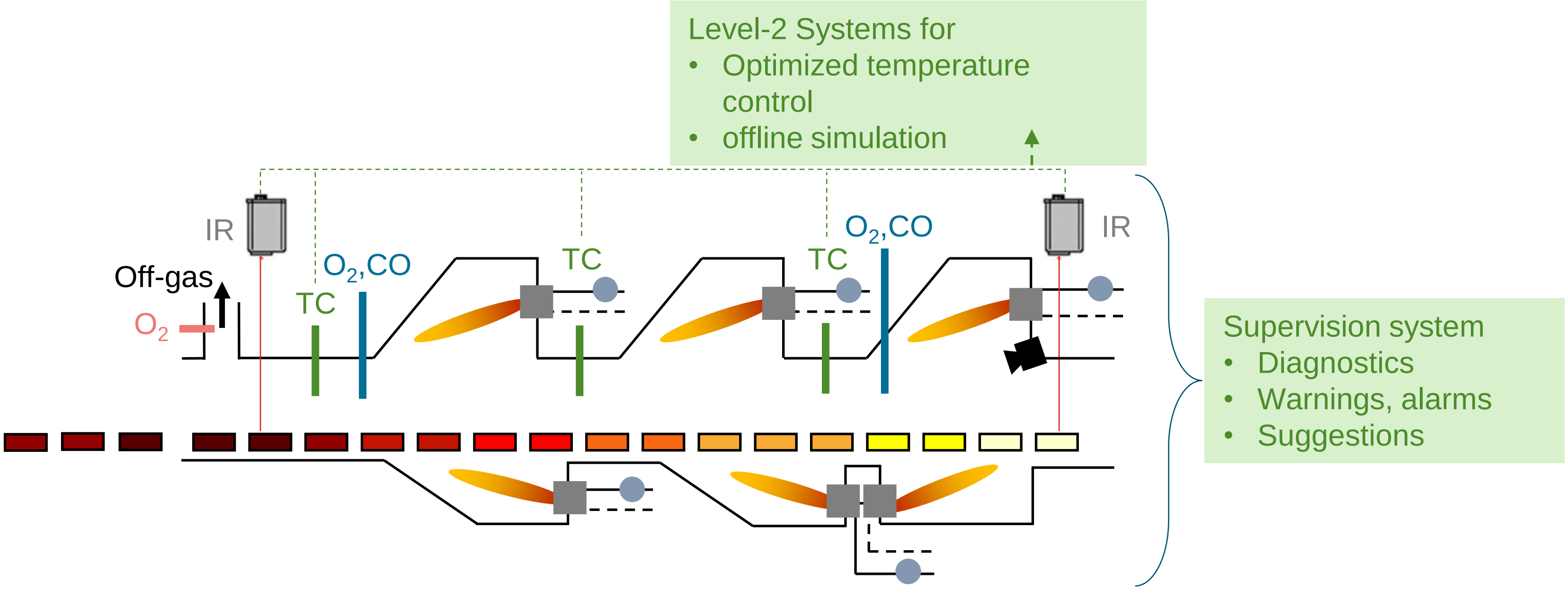
SoA - Modelling of entire furnace, model based predictive control (Level 2)

The key technologies reviewed in topic 2 focus on **modelling of furnace** and **model based predictive control (level 2)** in order to:

- **improve energy efficiency** of the furnace
- **minimize stop due to accidents**
- **enhance product quality**

Product profile temperature	Product microstructure	Furnace management
▪ Optimized control of temperature ▪ Offline simulation operative practice ▪ Model based predictive control	▪ Attention to optimum operation at rolling mill	▪ Diagnostics, Warning and Suggestion system (DWS)

SoA - Modelling of entire furnace, model based predictive control (Level 2)



- No technologies, but *methods* → No BAT available for the modeling technologies
- IT Technologies for data storage/management

SoA - Materials in the furnace and product quality

- Focus of investigations in reviewing *Materials in the furnace and product quality :* Surface properties: decarbonization + scale + interface + Defects
- Success-story:
  - Definition of critical parameters (e.g. atmoshere, chemistry)
  - Interaction with descaling
  - Possible application of coatings

Scale growth	Descaling	Application of coatings
▪ Constox ▪ Oxmapro ▪ ScaleControl	▪ Hides ▪ ReduHeatLoss	▪ Hiperscale

SoA - Materials in the furnace and product quality

BAT

- Limit alloying elements (e.g. Al, Si, P, B, Cr, Mo, Ti, Nb, Cu, Ni, Sn, As, Sb)
- Limit reheating temperature
- Limit duration in the furnace, especially at high temperature
- Limit oxygen content
- Limit humidity
- Limit transfer time between furnace and descaler
- Assure an optimum descaler performance related to the rolled grade
- Apply coating to avoid decarbonisation depending on product and grade. Higher scale formation rates are beneficial for reducing decarburization, as decarburised regions are removed by the oxide layer. For some materials decarburization was not detectable when Stopoxy was used.