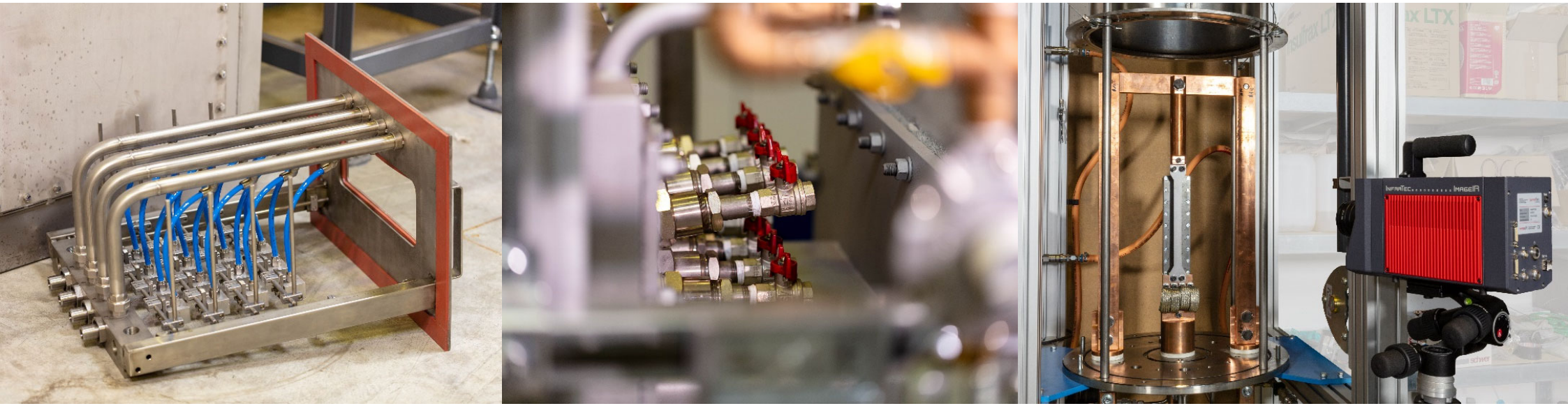


Department for Industrial Furnaces and Heat Engineering

Research activities in the field of sustainable thermo-processes for Aluminum production

88th AMAP Colloquium

Univ.-Prof. Dr.-Ing. Christian Wuppermann

19th of September 2024

IOB Institut für Industrieofenbau und Wärmetechnik | RWTH AACHEN UNIVERSITY

Introduction
IOB - Department for Industrial Furnaces and Heat Engineering

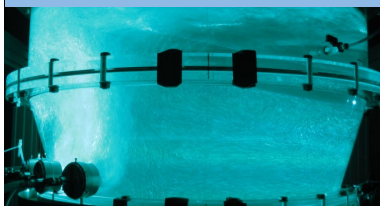
RWTH AACHEN UNIVERSITY

Students:	45,284
Staff:	10,365
Professors:	572
Total budget:	1,234 Billion €

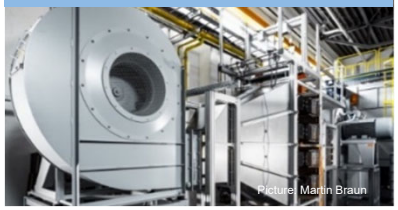
IOB Department for Industrial Furnaces and Heat Engineering | RWTH AACHEN UNIVERSITY

Professor:	Univ.-Prof. Dr.-Ing. C. Wuppermann
Scientific staff:	34
Non-scientific staff:	11 + 4
Third-party funding:	~ 3.3 Mio. €

High temperature flows
Dr.-Ing. Moritz Eickhoff



Industrial furnace Technology
Dr.-Ing. Dominik Büschgens



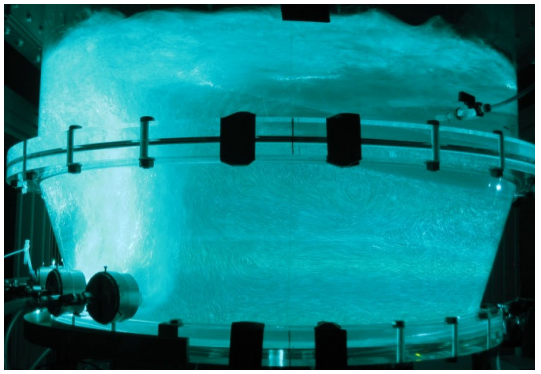
Combustion and burner technologies
Dr.-Ing. Nico Schmitz

Renewable energies and low-CO_2 process heating
Dr.-Ing. Christian Schwotzer

Energy and mass balances
Dr.-Ing. Thomas Echterhof

High temperature flows

- **CFD** simulations of metallurgical reactors (ESR, VAR, tundish, tandem furnace, …)
- **Physical modelling** and numerical investigation of **multiphase flows** (ladle, ISASMELT, ConArc, tundish, …)
- Application of self-learning algorithms (**AI**) for the identification of gas bubbles
- Metal crystallisation on rotating cooling cylinders (DFG – IME)
- **Process models** for furnace control and optimised operation (AiF – IEHK, …)
- Alternative recycling routes for PCB scrap and aluminium cans (BMWi)
- Development of a new type of hydrogen-fired glass melting tank (BMWK – GHI)



Cooperations: IME, GHI, IEHK, BFI, University of Oulu, TU Linz, MU Leoben, Rina CSM, Fraunhofer IOSB, Industry, …

Equipment: Water models of metallurgical plants (scales up to 1:1), Highspeed camera, LDA system, PIV systems shadowgraphy

Funding: DFG, BMWK, progress.nrw, Industry

Future potential: CFD modelling of metallurgical reactors to increase efficiency, Simulation and AI-based furnace models for process optimisation and energy reduction

Industrial furnace technology

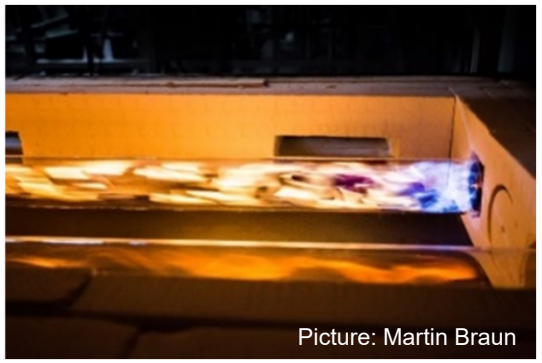
- **CFD-FEM, heat transfer**
- Convection-dominated thermal processes
  (Furnaces Al industry, high temperature ventilators)
- Quenching and cooling processes
  (High strength steels; Al 6xxx and 7xxx)
  High-resolution heat transfer - gas and liquid cooling
- Strip flatness
- Radiant heating tubes (Modelling, high temperature material properties, practical application, …)
- **Electric heating** (Resistive heating, new heating element designs, new heating concepts)


Picture: Martin Braun

Cooperations:	TU/MPA Darmstadt, LU Hannover, OvGU Magdeburg, B-TU Cottbus, Tile Research Institute Essen, industry, FOGI
Equipment:	High-speed thermocamera, modular heat treatment plant, Annealing simulator, test stand for heat transfer of nozzle arrays, test stand for water impingement density
Funding:	DFG, BMWK (IGF/ZIM), progress.nrw, Industry
Future potential:	Fundamentals of the production of metallic materials for automotive lightweight construction

Combustion and burner technologies

- Combustion technologies for lowest NO_x emissions
  → **Flameless oxidation** (FLOX, FLOX-2, …)
- Use of low-CO_2 fuels in the context of the energy transition
  → Pyrolysis gases, **hydrogen**, ammonia, …
- Radiant tube technology
  → Service life increase, pollutant minimisation, new concepts
- Special **combustion technologies**
  → **Oxyfuel**, Direct Flame Impingement, Low scale reheating
- Energy-efficient heating of thermoprocessing plants


Picture: Martin Braun

Cooperations:	TU Graz, Swerim, Rina CSM, TU Freiberg, Fraunhofer IKTS, TU Wien, …
Equipment:	Test rigs for burners/radiant tubes, Gas infrastructure for flexible mixing of eight gases, Membrane plant for O2 production, Off gas analytics, PLIF system
Funding:	EU, BMWK (Energieforschungsprogramm, IGF/ZIM), Industry
Future potential:	Hydrogen technology (combustion of H_2 and NH_3, H_2 infrastructure), primary and secondary measures for lowest NOx emissions

Renewable energies and low-CO_2 process heating

- **Renewable energies** in industrial furnace technology
- Substitution of fossil energy sources with **CO_2-neutral energy sources**
- Hybrid heating concepts (natural gas/electricity)
- Technical and economic **system analyses**

Cooperations: Fraunhofer ISI, IEE, IfU Hamburg, VDMA, BEE, …
Equipment: Interdisciplinary Staff Office, LCA software
Funding: BMBF, BMWK (ZIM), Industry
Future potential: Load-specific use of renewable energies, CO_2-neutral process heat

Energy and mass balances

- **Electric arc furnace technology**
- Mass, energy and exergy balances
- Reduction of CO_2 emissions
  → **Biomass** in the EAF with large-scale industrial trials
- Mathematical modelling and machine learning
  → EAF process model
- Circular Economy
  → LCA studies and use of residual materials in the EAF
- Development of measurement technology and methods

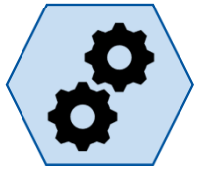
Cooperations: University of Oulu, Swerim, KTH, BFI, MU Leoben, Politecnico di Milano, Rina CSM, steeluniversity, RIST, University of Pretoria, CanmetENERGY

Equipment: Pilot EAF (600 kVA, up to 250 kg tapping weight), Off gas analytics, Agglomeration lab (Press, Mixer)

Funding: EU, BMBF, BMWK, DAAD

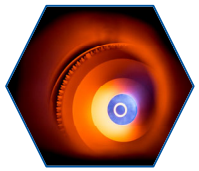
Future potential: Core aggregate/process of the future for the transformation to CO_2-neutral steel production (DRI, HBI) and for recycling

Focus Topics



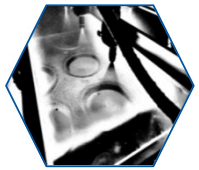
Process optimization and energy efficiency

- Productivity, product quality, emission reduction
- Installation/operation of non-permanent measurement systems
- Analytical and numerical calculations and modelling



Sustainable heating technologies

- Combustion of low-carbon fuels
- Electric heating
- Hybrid heating concepts
- Ultra-low NO_x combustion technologies
- Radiant tube technology

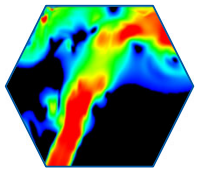


Efficient cooling processes

- Gas cooling and water quenching
- Flow induced by fans
- Heat transfer coefficient
- Customized heat treatments

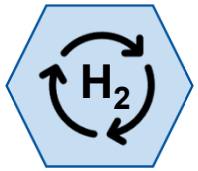
Defossilization strategies and Life Cycle Assessment

- Technical-economic analyses
- Transformation concepts
- CO_2 balancing, Product Carbon Footprint
- Multi-dimensional analyses of transformation pathways



Process modelling and simulation

- Physical Models (PIV, LDA, high-speed camera, IR camera)
- Flow, particle separation, mixing, degassing
- Computational Fluid Dynamics
- Melting, solidification, fluid flow, combustion
- multiphase flow, electro-magneto-hydrodynamics



Sustainable metallurgy and steelmaking

- Energy and resource efficiency
- Development of improved process control strategies
- Circular economy
- Substitution of fossil carbon carriers
- Pilot-scale EAF, dynamic EAF process model

Equipment

Technical Center 1, 500 m²

Technical Center 2, 300 m²

Technical Centers at IOB:
Electrical power 600 kW
Natural gas 3 MW
Metal and electric workshop
Water laboratory

Measurement techniques:

- Process analysis
  - Gas composition (CO, CO_2, H_2, O_2, …)
  - Air pollutants (CO, NO_x, SO_x, …)
  - Dust measurement (VDI 2066)
  - Volume flow, velocity, Temperature, Humidity
- Particle Image Velocimetry (PIV)
- Laser Doppler Anemometry (LDA)
- OH* spectroscopic imaging
- Infrared camera and pyrometers
- …

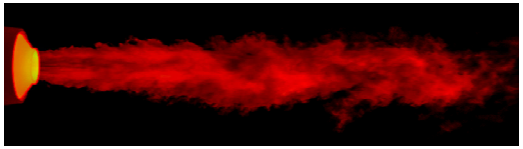
Equipment:

- 600 kW pilot electric arc furnace
- Vacuum heat treatment plant (1600 ºC)
- Annealing simulator (up to 100% H_2)
- Modular heat treatment plant
  - gas and water quenching unit
- Test furnaces for burner and radiant tube operation
  - Flexible gas infrastructure (NG, H_2, NH_3, …)
- Water models
  - Converter, Ladle, Tundish, Glass furnace
- Fluid flow test rigs
  - Tangetial fan
  - Heat transfer of industrial size nozzle fields
  - Water flow on stationary and moving surfaces

IOB: Research Projects

Decarbonization of steel downstream processes: HYINHEAT

HYINHEAT



Need:

- Gas-solid or gas-liquid interactions between furnace atmosphere and product | impact on refractory products and furnace materials | heat transfer to the product and temperature homogeneity | high-temperature chemistry for H2/O2 combustion | feed-forward and feed-back combustion control | NOx formation rates | NOx emission limit definition | emission measurement technology | safety and risk assessment | flame detection and monitoring

Objective:

- Redesign heating processes for H2 as fuel (*6 demonstrators in Aluminum applications*)
- Modify heating equipment, instrumentation, measurement equipment and infrastructure for use of H_2
- Develop O_2 combustion processes to improve energy efficiency
- Prove economic and environmental viability compared to other heating alternatives

Project:

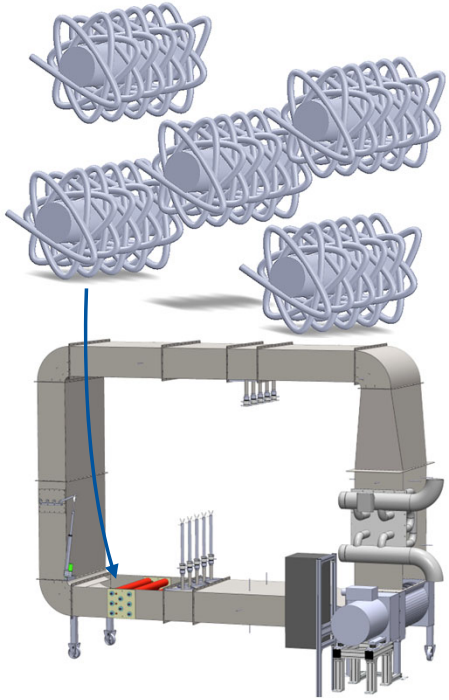
- Horizon Europe, Processes4Planet, coordination by RWTH-IOB
- 28 consortium members, 8 metal producers, 9 technology suppliers, 4 R&D organizations, 4 universities, 2 EU-Associations, 1 consultant & marketing expert
- 17.7 MEUR funding

Application sector:

- Steel Production (ladle preheater, walking beam furnace, tunnel furnace, radiant tubes)
- *Aluminum Production (reverberatory melting furnace, rotary melting furnace, …)*

HYINHEAT - partners

Industrial furnace technology: EnabEL (*IGF-Leittechnologie*)



Need:

- Reduction of CO2 emissions in thermal process technology through the transition to electrically powered heating systems for high power demands

Objective:

- Expansion of the application range of electric resistance heating systems in thermal process plants from <1 MW to up to 10 MW or more
- Improvement of the usability and performance of resistance heating systems

Project:

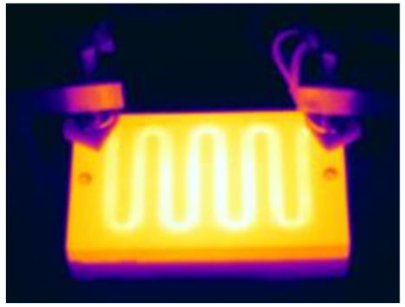
Three sub-projects:

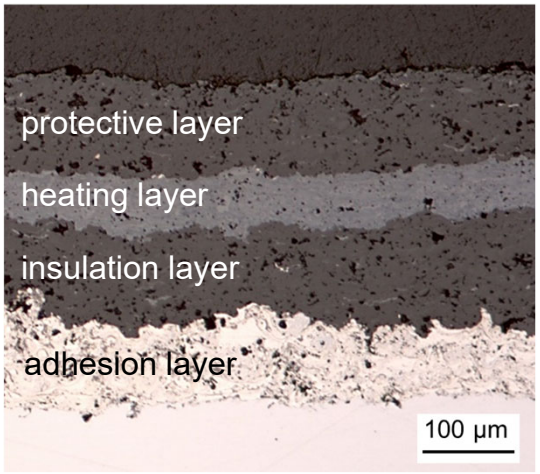
- **HighPowHeat:** Investigation of high electrical power connections, efficient conversion and transmission
- **OptiELHeat:** Optimization of the design of heating elements, investigation of heat transfer, and reduction of failure rates
- **MatELHeat:** Study of the corrosion and aging of heating element materials
- 6 consortium members from R&D, 36 advisory board members
- BMWK, IGF-project with 1,5 Mio. EUR funding

Application sector:

- Large-scale industrial thermal process plants with high power demands and operating times, as well as specific applications like flow heaters or electrically heated radiant tubes as replacements for burner applications

Industrial furnace technology: HT-Heiz





Need:
- Alternative heating methods required to replace fossil-fueled heating strategies
- Electric heating systems as an option in many scenarios
- Not applicable yet in harsh process environments
- E.g. steel production with the formation and flaking of scale or possible strip tears

Objective:
- Development of a new type of heating element system
  - Reliable and durable with high power density
- Production of the heating element using thermal spraying
- Development of electrical contacting
- Evaluation of chemical and mechanical durability

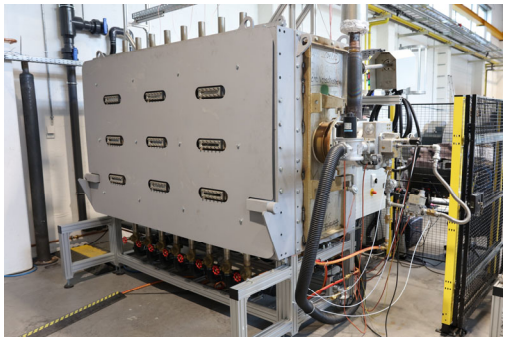
Project:
- BMWK, IGF-project
- 3 consortium members from R&D, 17 advisory board members
- 0,825 Mio. EUR funding

Application sector:
- Steel Production

Decarbonization of steel downstream processes: FlexHeat2Anneal

Federal Ministry for Economic Affairs and Climate Action

FlexHeat 2Anneal



Need:

- Decarbonization of radiant tube heating processes with a fuel flexibility from 0 to 100 vol-% hydrogen, ensuring stable and safe combustion, lowest NO_x emissions, constant line capacity and high energy efficiency in a cost effective and retrofittable way.

Objective:

- Investigate the limits of existing radiant tube systems (w-type, pp-type)
- Develop a new radiant tube systems fulfilling all needs (NOx < 100 mg/kWh for all temperatures)
- Demonstrate the new radiant tube systems in an industrial CAL
- Prove future environmental and economic viability

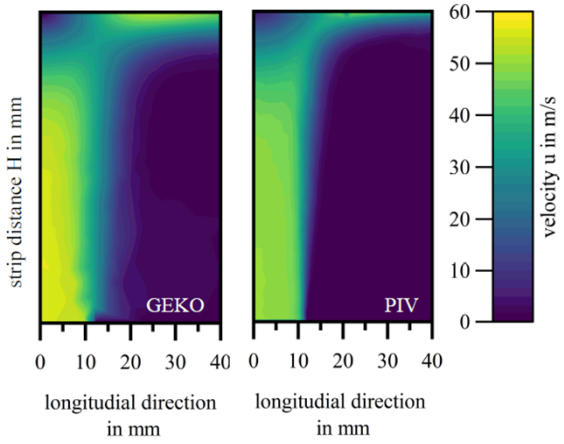
Project:

- 7^{th} Energy research framework programme
- 3 consortium members, 1 steel producer, 1 burner supplier
- 803 kEUR funding

Application sector:

- Steel Production (continuous annealing of packaging steel)

Industrial furnace technology: Prallstrahl-CFD



Need:

- Impact jets are used for cooling in continuous strip lines for fast and uniform cooling
- Pre-design with Nußelt-relations from literature
- Detailed design is based on measurements, simulations and experience
- Simulations and measurements are costly and time consuming
- No efficient and precise simulation of nozzle fields available

Objective:

- Construction of a test bench for the measurement of optical flow and heat transfer coefficients of impact jets
- Development of
  - a numerical model for the simulation of local Nu
  - a simplified numerical model for the simulation of mean Nu
- Validation and evaluation of the models

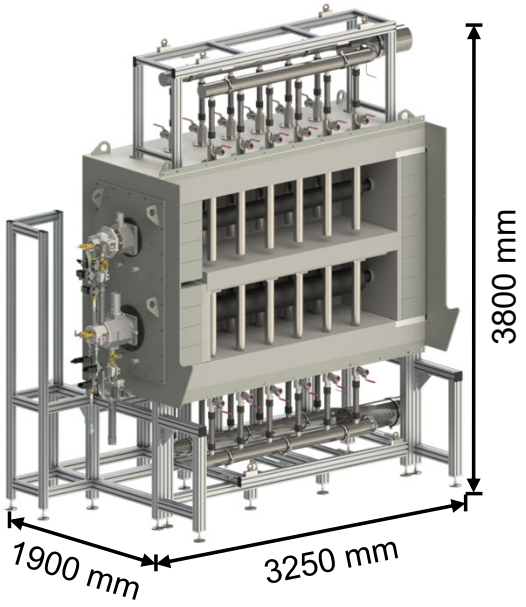
Project:

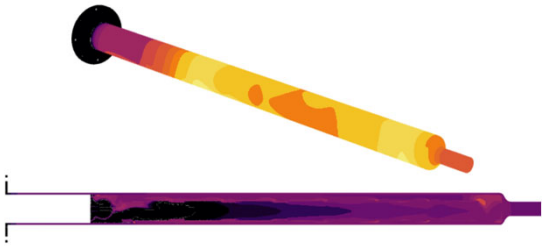
- BMWK, IGF-project
- Only IOB, 10 advisory board members
- 0,275 Mio. EUR funding

Application sector:

- Steel Production
- Aluminium Production

Flexible Furnace Operations





Need:

- Limited life-time of high-temperature components due to creep deformation and corrosion. Acceleration of creep under thermal cycling loads. Description of this effect offers potential for optimizing the service life by adapting the furnace operating mode.

Goals:

- Execution of uniaxial creep tests and long-term tests with rods and radiant heating pipes to create an experimental database
- Development of a material model to describe creep deformation and corrosion for selected materials
- Development of numerical models to calculate creep deformation
- Development of operational recommendations for optimizing the life-time of high-temperature components by adapting the furnace operating mode

Project:

- Industrielle Gemeinschaftsforschung (IGF)
- Participating research institutions: Center for Structural Materials, TU Darmstadt (IfW)
  OWI Science for Fuels gGmbH (OWI)
- 19 industry partners in the project committee (incl. SMS)

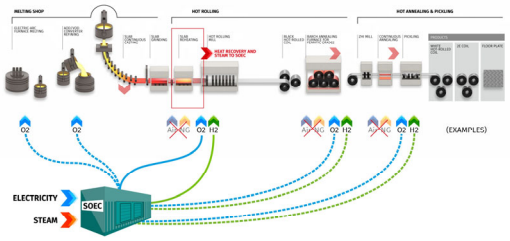
Application:

- High temperature processes > 900 ºC

Decarbonisation of steel downstream processes: SYRIUS (GA in progress)

SYRIUS

SOEC HYDROGEN INTEGRATION AND CIRCULAR USE IN STEELMAKING PROCESS



Need:

- Integration of hydrogen into sustainable steel processing routes necessary to achieve decarbonisation and to meet climate goals
- High-temperature Solid Oxide Electrolysis (SOEC) technology may offer high efficiency and low electricity consumption, but until now only at a small scale
- Testing of a large scale SOEC in an industrial environment needed to develop integration concepts and best possible synergy usage

Objective:

- Manufacture SOEC of 4.2 MW with heat recovery from process waste heat
- Test integrated system at TRL7 and certify renewable character of hydrogen long term
- Demonstrate efficient and safe management of integrated system
- Develop a business plan and demonstrate compliance circularity and sustainability objectives

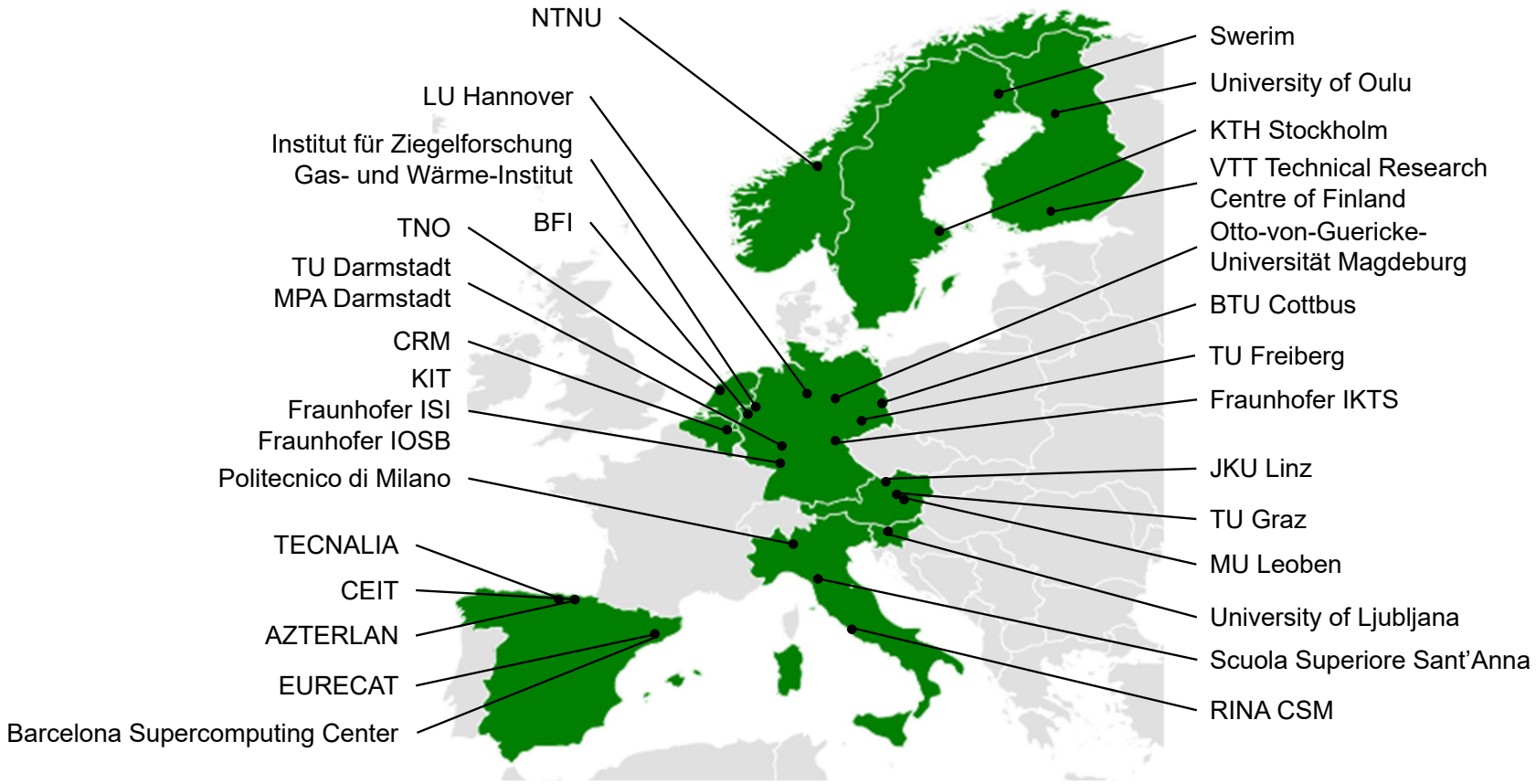
Project:

- EU Horizon
- 12 consortium members, 4 technology suppliers, 3 R&D organisations, 1 steel producer, 2 universities
- 10.0 MEUR funding

Application sector:

- Steel Production (reheating of slabs for flat products)

Network – Universities and Research and Technology Organizations



Memberships

- A.SPIRE association
- AMAP Advanced Metals and Processes – Open Innovation Research Cluster
- Center for Sustainable Hydrogen Systems
- Center for Circular Economy
- Combustion Institute
- ERCOFTAC - European Research Community On Flow, Turbulence and Combustion
- European Steel Technology Platform (ESTEP)
- Forschungsgemeinschaft Industrieofenbau e. V. (FOGI)
- VDI Technical Committee High Temperature Technology

Research Association of Industrial Furnace Manufactures

Events / Conferences

Training courses in cooperation with Stahlakademie des VDEh and VDMA

Aachener Ofenbau- und Thermoprozess-Kolloquium	since 2017 every two years
EASES *European Academic Symposium on EAF Steelmaking*	since 2015 every year / two years
Innovationsnetzwerk Hybrid-Heating	since 2018
Smelting Symposium	since 2021

Thinking the Future
Zukunft denken

Thank you for your attention

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