PLASMA-BASED HEATING TECHNOLOGIES FOR HIGH TEMPERATURE INDUSTRIAL PROCESSES

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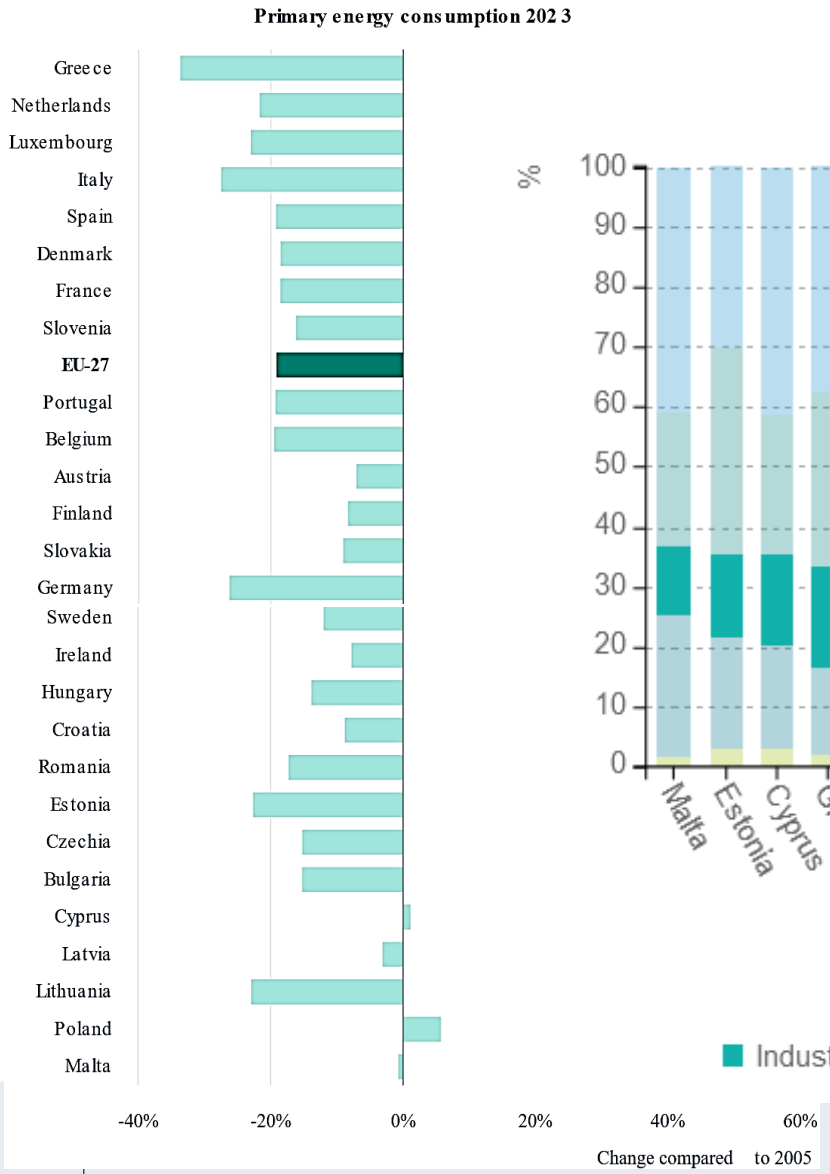
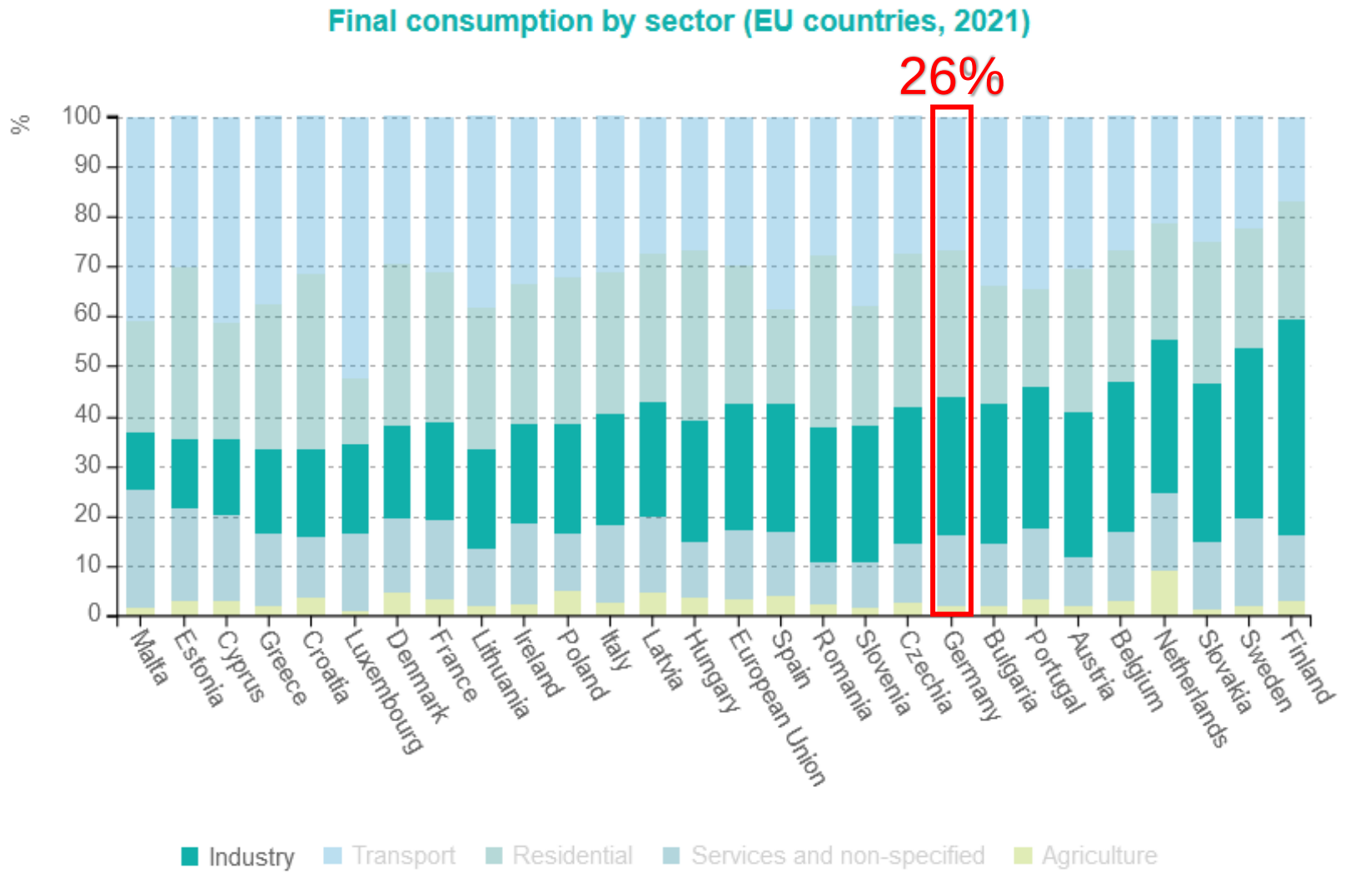
A view of Europe with European Environment Agency (EEA)





11-43% industry

Source : European Environment Agency (EEA)
Enerdata

Sven Eckart, September 2025
Chair of Gas- And Heat Technology, TUBAF

Which industry do we need to free from CO2?

metal

~6 % of global CO_2 emission from steel and aluminium
~2 % Non-ferrous metals industry

glass

0,5 % to 1 % of global CO_2 emission

ceramic

0,3 % to 0,5 % of global CO_2 emission

cement

~8% of global CO_2 emission

… but also paper, textile, food, and energy production

Source : **WWF 2019,** Klimaschutz in der Beton und Zementindustrie Hintergrund und Handlungsoptionen
energiezukunft.eu

What methods do we have for this

Fossil fuels

Combined heat and power

Improving energy efficiency

Oxyfuel

Material Substitution and Recycling

Biogas

Biomass

Hydrogen

Cracking gas

Ammonia

others

Induction

Resistive heating

Electrical energy

DC

Plasma

MW

High Volt

DME/OME

Methanol

- **Today we are mainly focussing on the plasma but all of them have to be consider for the high temperature industry**

CCS/CCU

Motivation for the Use of Plasma in Thermal Process Technology

Reduction of greenhouse gas emissions from fossil energy sources

- Lowering the CO_2 footprint
- Minimization of pollutant emissions (focus on nitrogen oxides)
- Alternative to gaseous energy carriers
- Flexible use of electrical energy
- Preservation of combustion-like technologies through
  - injection of reactive gases, and
  - intensive gas recirculation analogous to combustion technology
- No need for a complete redesign of the thermal process plant

Challenges:

- Achieving very high temperatures (> 1100 °C)
- High energy input and transfer rates to product

Motivation for the Use of Plasma in Thermal Process Technology

Advantages of Plasma Use

- Energy transfer to a gas stream beyond the chemical energy content of the gas
- Heating of even inert gases
- Ability to reach high to extremely high temperatures

Disadvantages or Challenges

- Possible occurrence of reactions leading to pollutant formation
- High temperatures require special material and flow design concepts

Key Questions

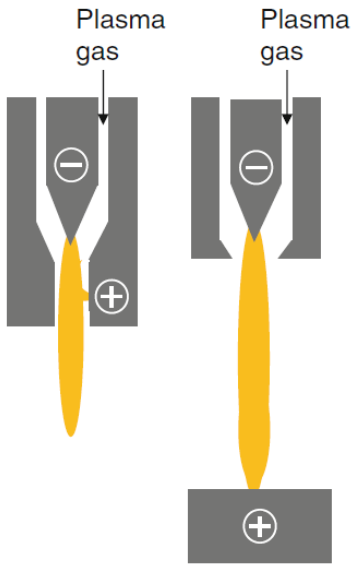
- **How can plasma be generated efficiently and stably?**
- **Which gases are suitable, and which pollutants may form?**
- **Can a plasma torch replace a burner?**

Introduction to Plasma Generation

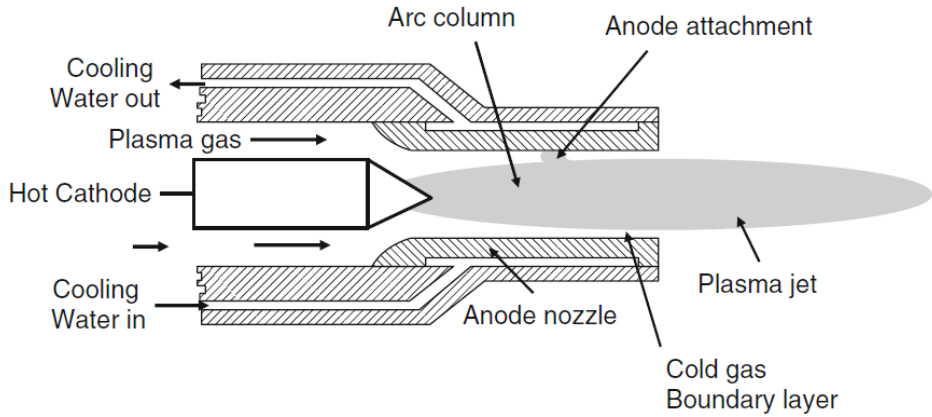
- Plasma generation for heating gas jets a burner replacement

Arc plasma

Arc discharge between two electrodes as direct or alternating current plasma

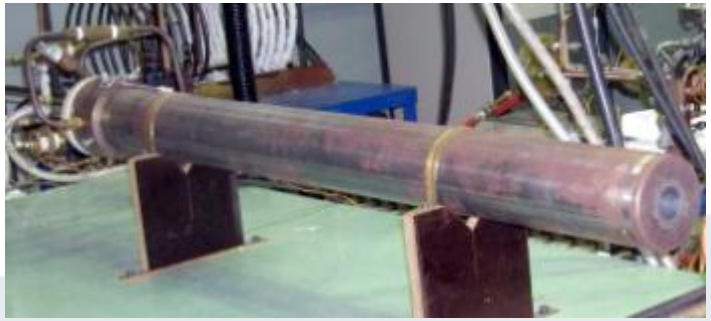


DC Plasma Torch



Electrodes/ cathode from Tungsten and Copper
Types of gases: Argon (Ar), Nitrogen (N2), Oxygen (O2)

High Temperature Technologies Inc.
BC Canada



Up to 600 kW DC Plasma , Steam+Argon

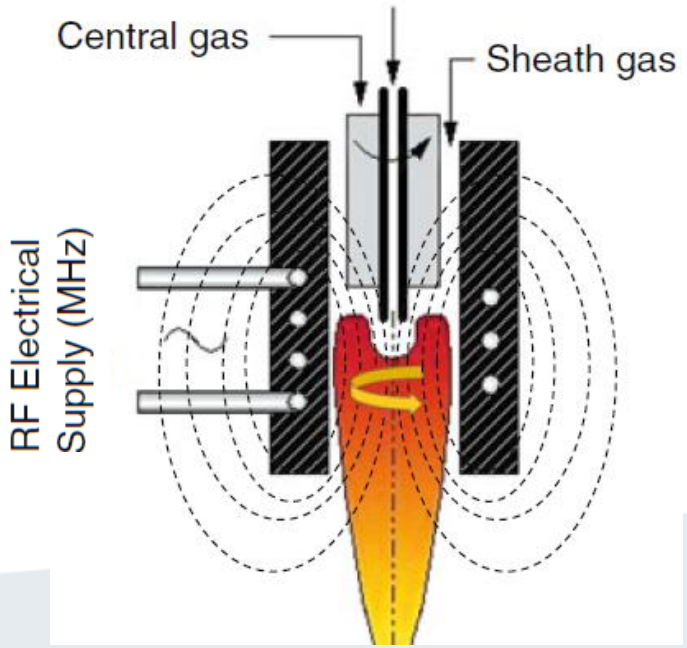
Plasmageneratoren
Quelle: M.I. Boulos et al. 2016, Handbook of Thermal Plasmas

Introduction to Plasma Generation

- Plasma generation for heating gas jets a burner replacement

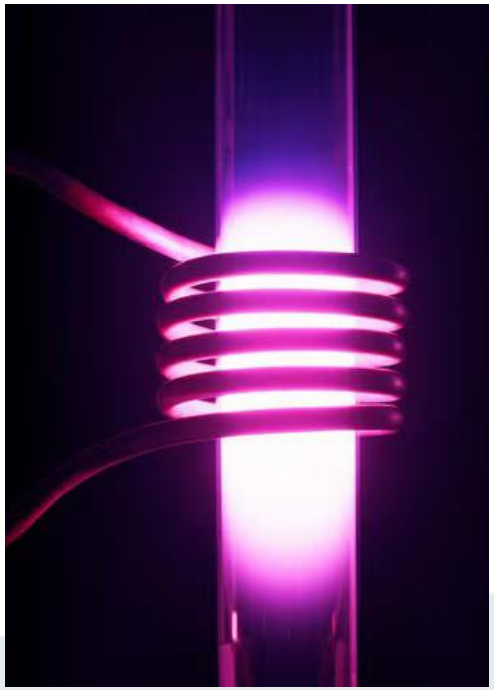
ICP-Systems (Inductively Coupled Plasma)

generated by a high-frequency electromagnetic field in an gas stream



Frequencies up to 3000 kHz
Types of gases: Argon (Ar), Nitrogen (N2), Oxygen (O2)

TRUMPF, Germany



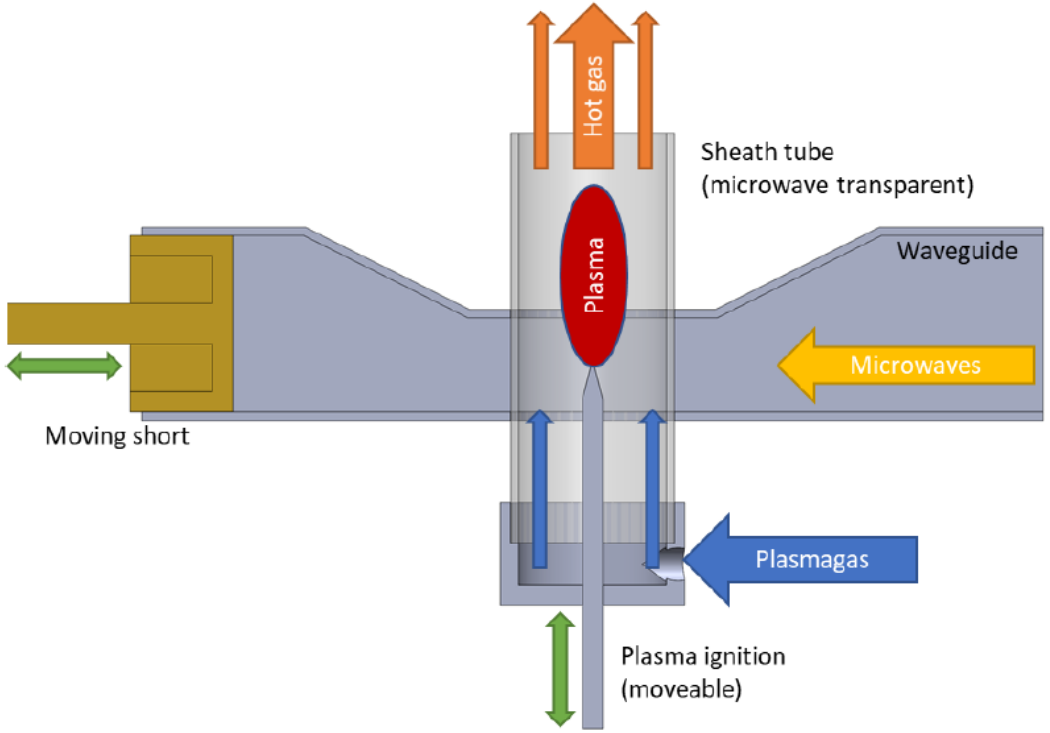
High-performance generator up to 500 kW ICP Plasma

Introduction to Plasma Generation

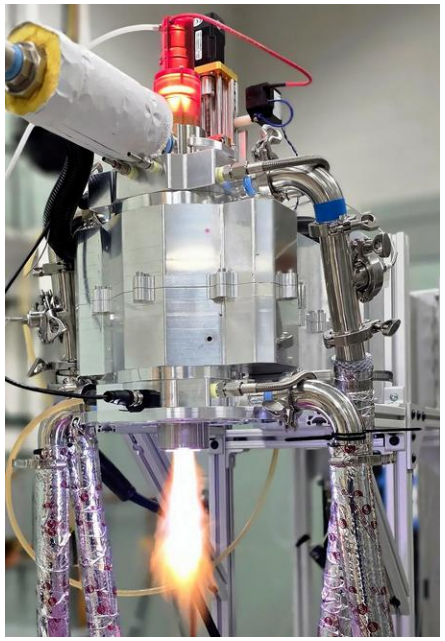
- Plasma generation for heating gas jets a burner replacement

MIP – (Microwave Induced Plasma)

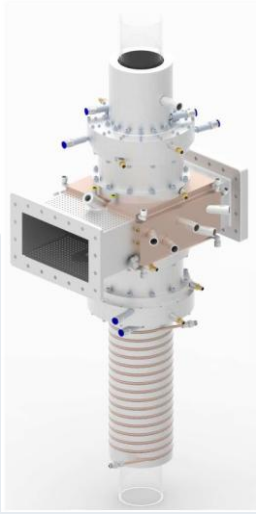
Plasma formation in local electric field peaks



Applied Plasma Technologies, US 100kW



Radom, US 100kW



Muegge,
Ger 100kW

:fm,
Ger 100kW

Safety considerations

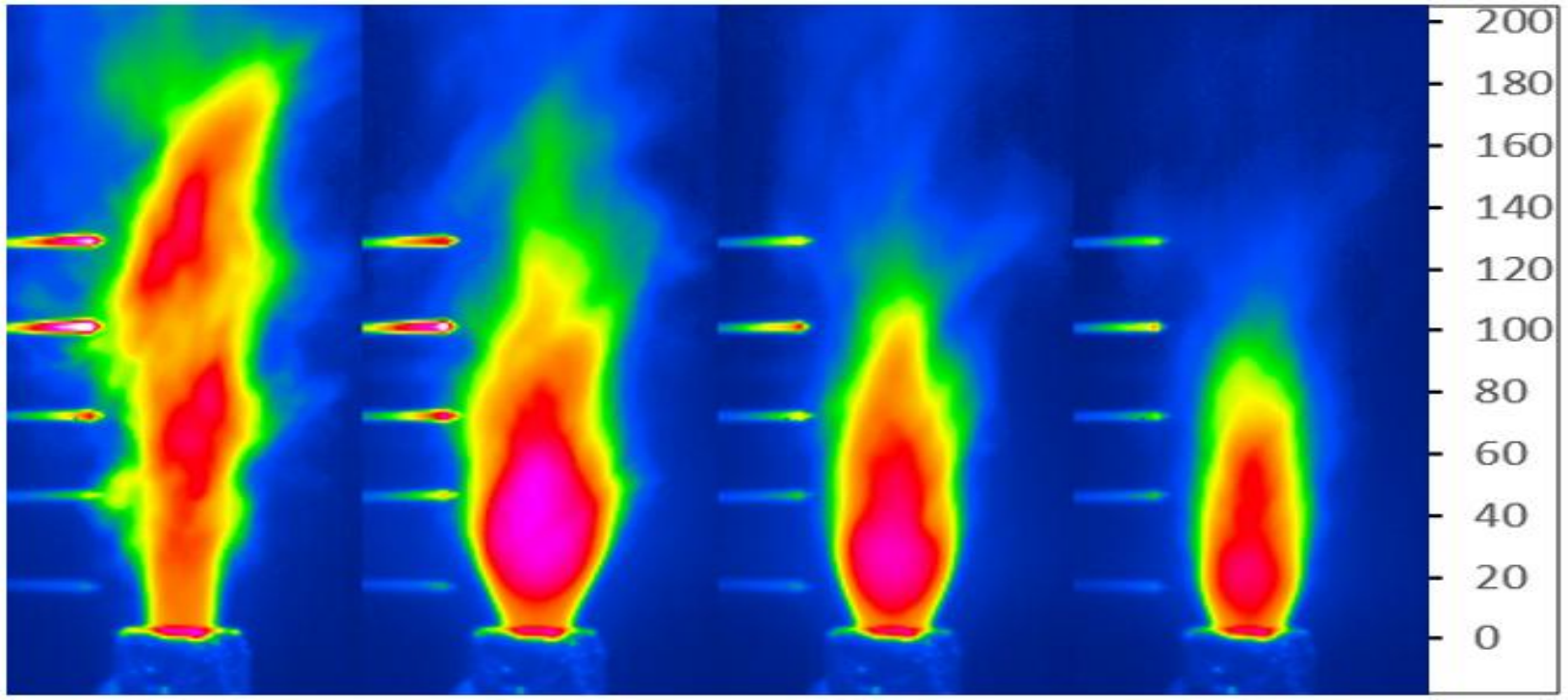
MICROWAVE Plasma

- Depending on the used gas there are harmful emissions like CO, NO_x and O_3
  - Usage of a exhaust gas system to prevent damage to health and environment
- Emission of a small amount of microwave radiation (interference with electrical installations)
- Appropriate metallic shielding will mitigate the problem
- Emission of electromagnetic radiation in a wide frequency range
  - Measurement for a 10 kW plasma torch with 150 l/min air
  - The field reaches several meters
- Metallic enclosure can contain the effects

Torch length and width

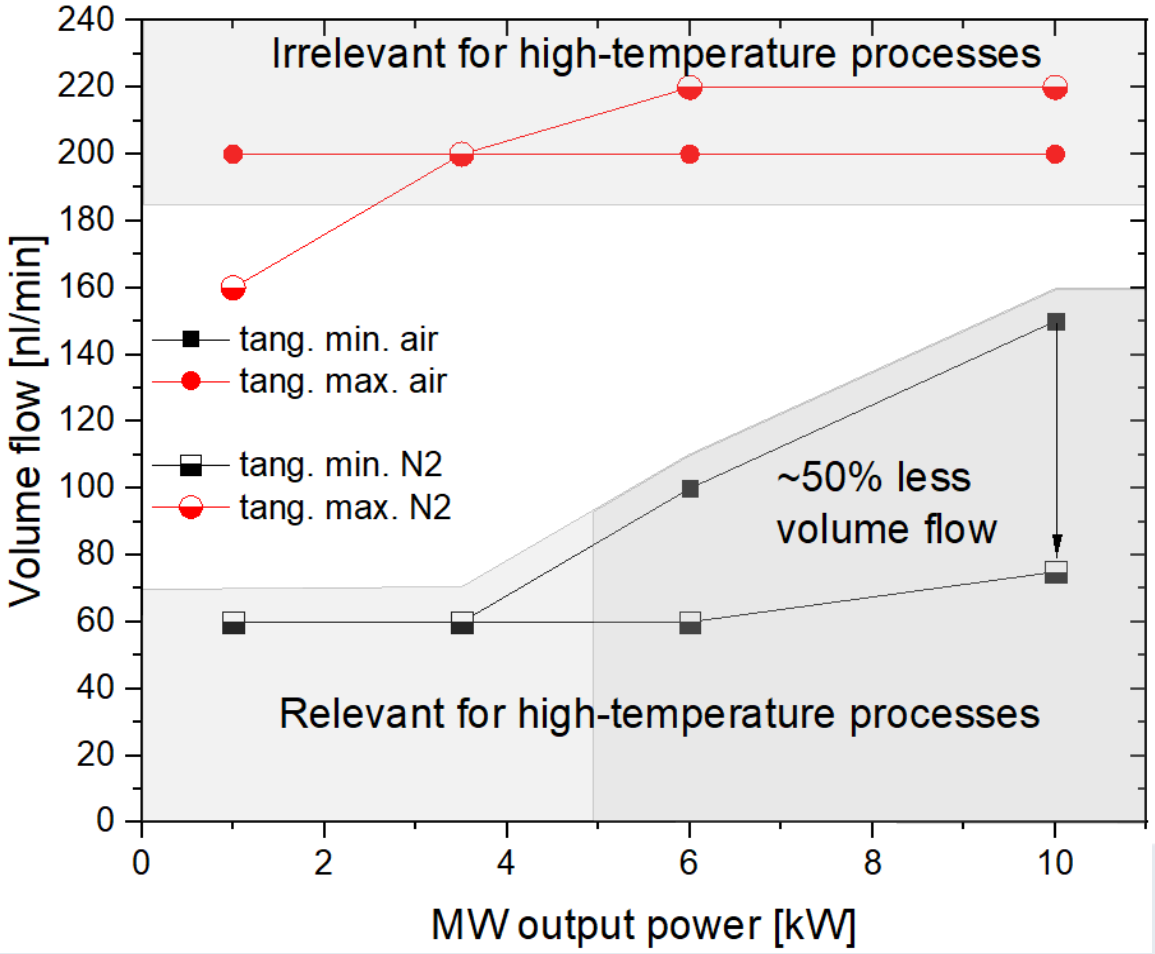
MICROWAVE Plasma 10kW - Air

Volume flows	torch shape			
Power P	Long	Mushroom	Torpedo	Fan
[kW]	[l/min]	[l/min]	[l/min]	[l/min]
10	290	345	440	500

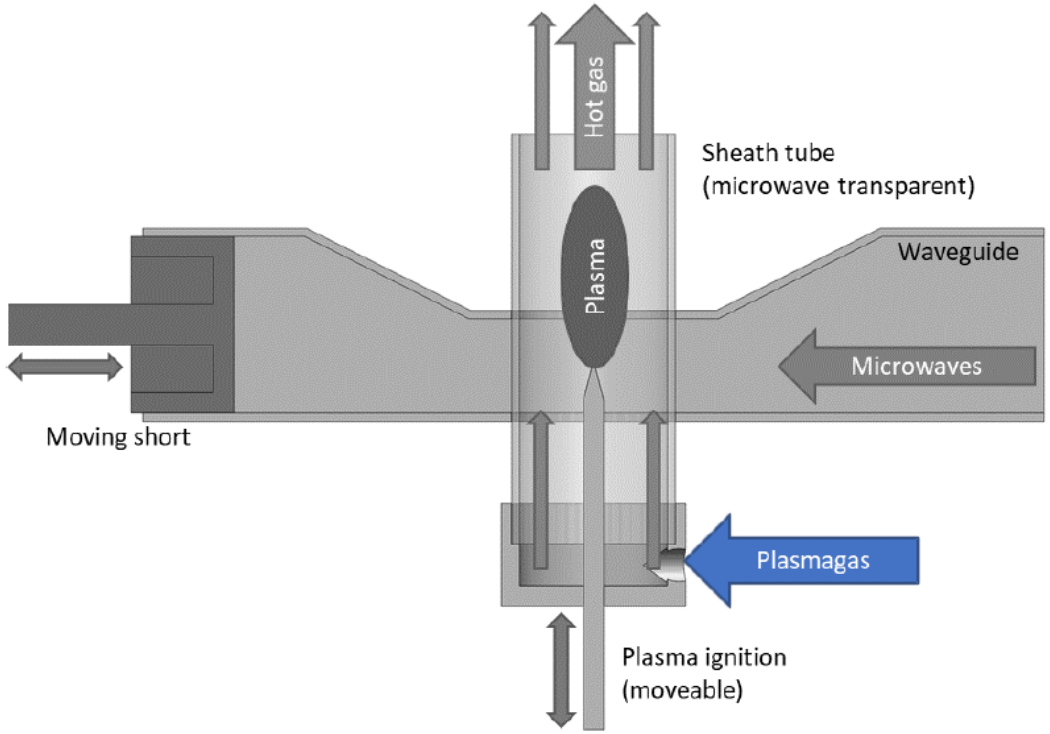


Torch length and width

MICROWAVE Plasma 1-10kW – Air / Nitrogen

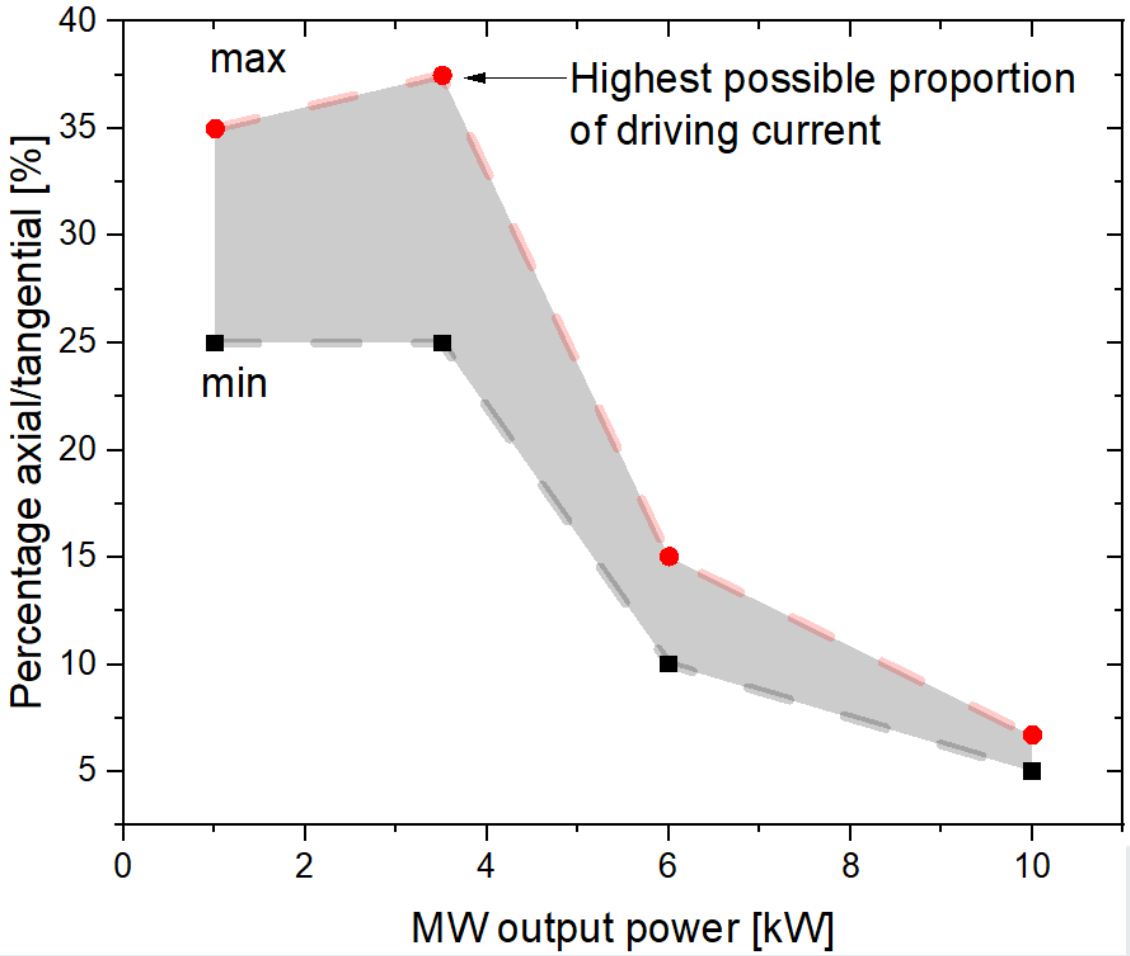


Stability map and min/max flow of the gas supply in the MW plasma generator

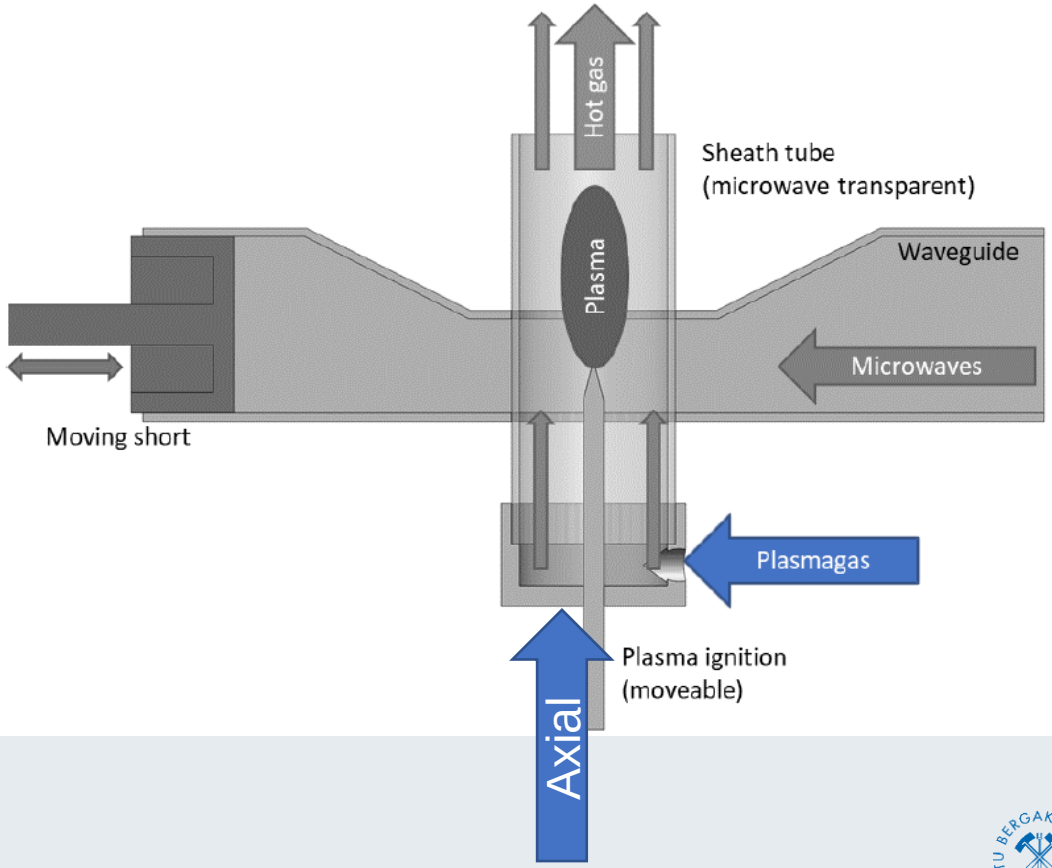


Torch length and width

MICROWAVE Plasma 1-10kW – Air / Nitrogen

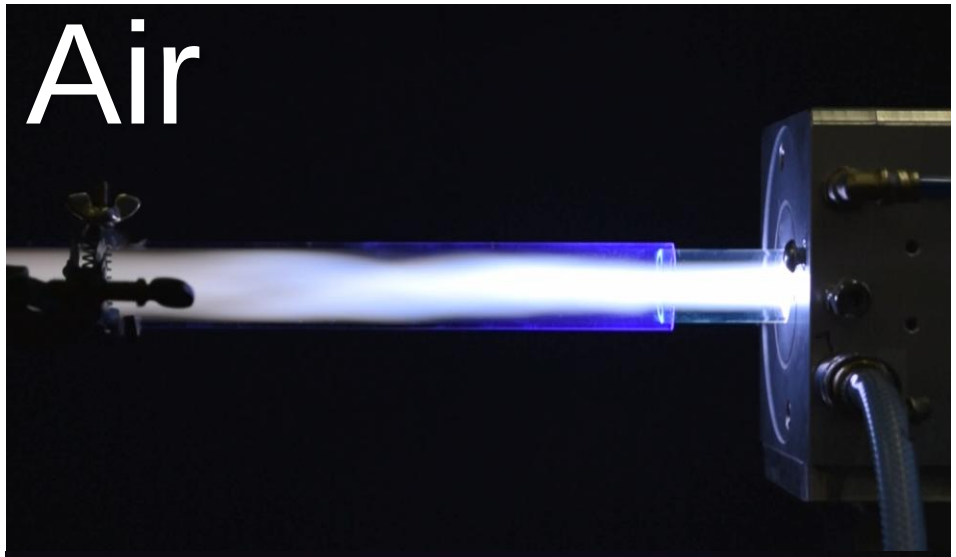


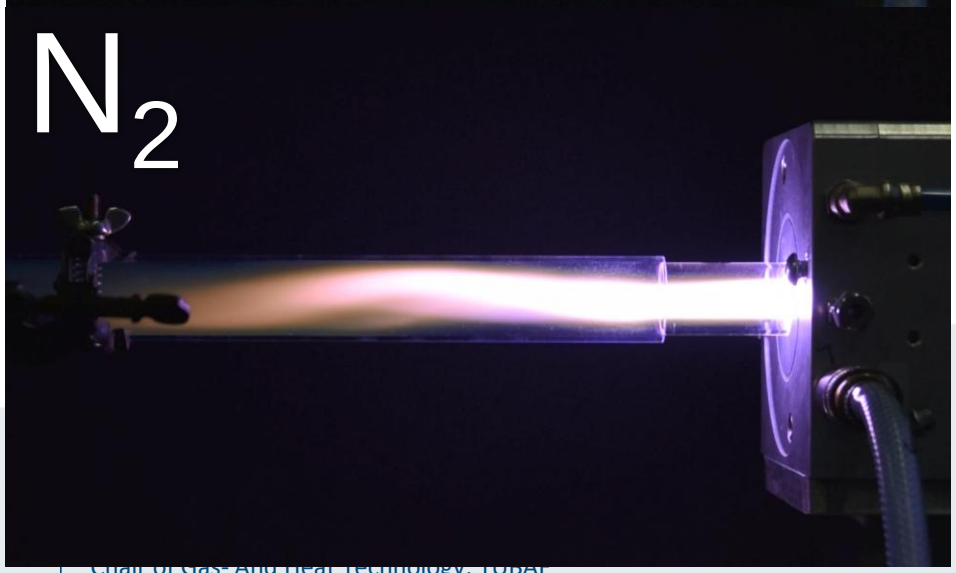
Statement on the mixing rate of axial flow into tangential envelope flow



Torch length and width

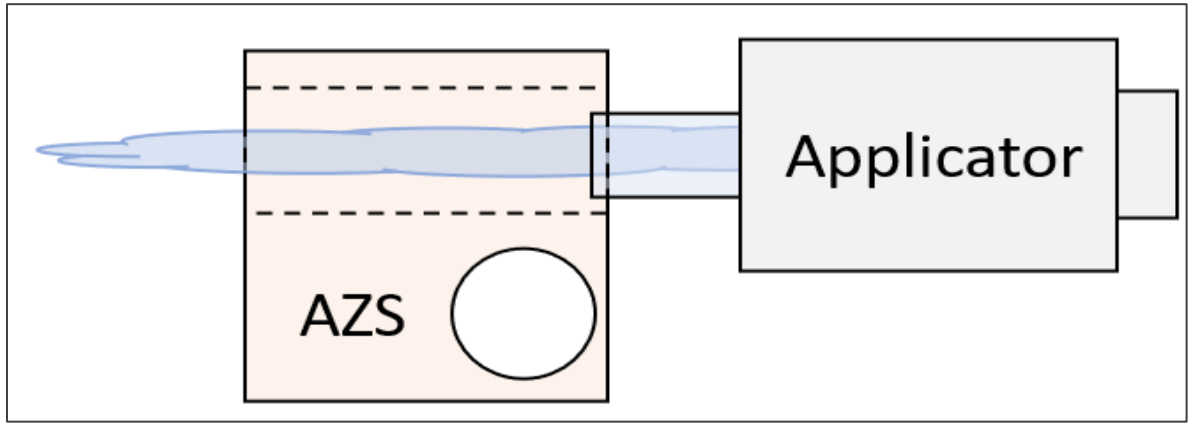
MICROWAVE Plasma 10kW



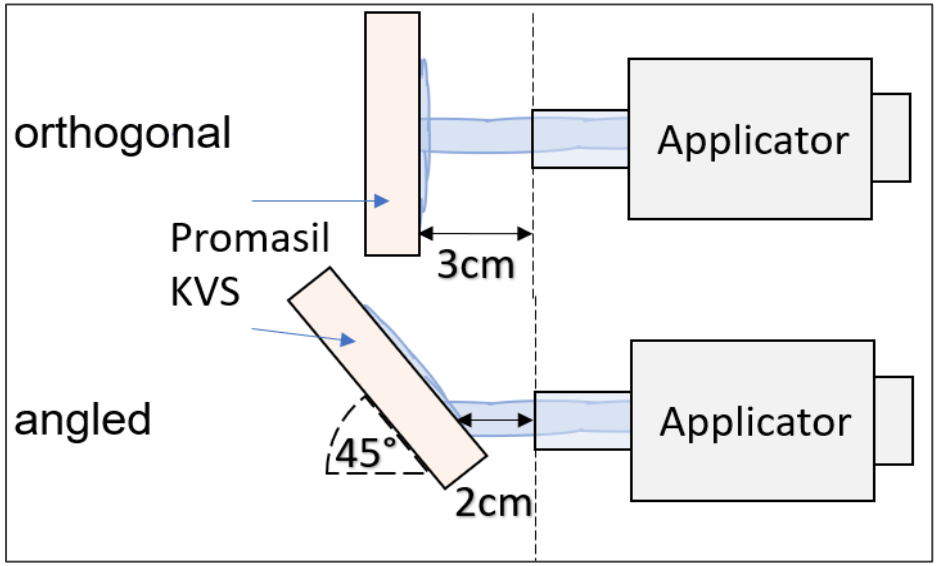


The behavior of quartz glass needs to be better understood ands seems highly to interact with the flow profile as well as the gas.

Plasma Material interaction



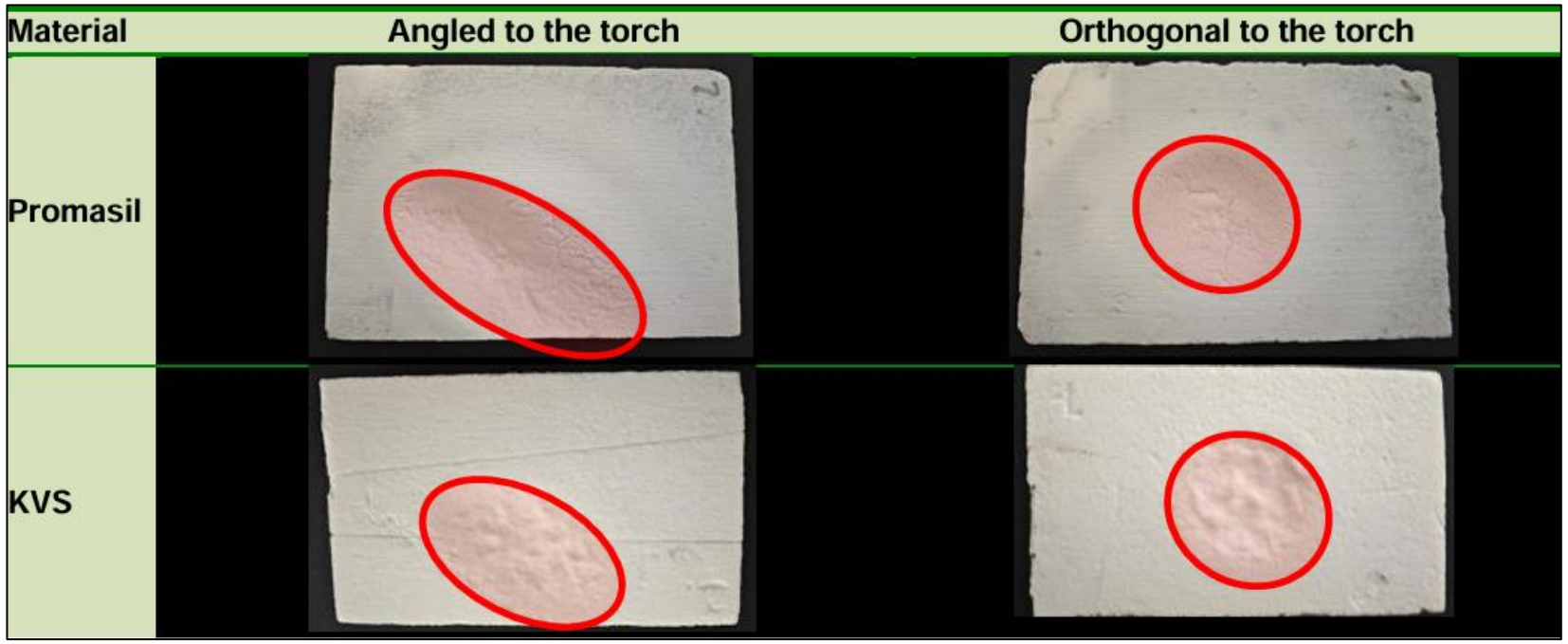
Scheme of the the “Burn-through” test



Scheme of the the “scorch test” test

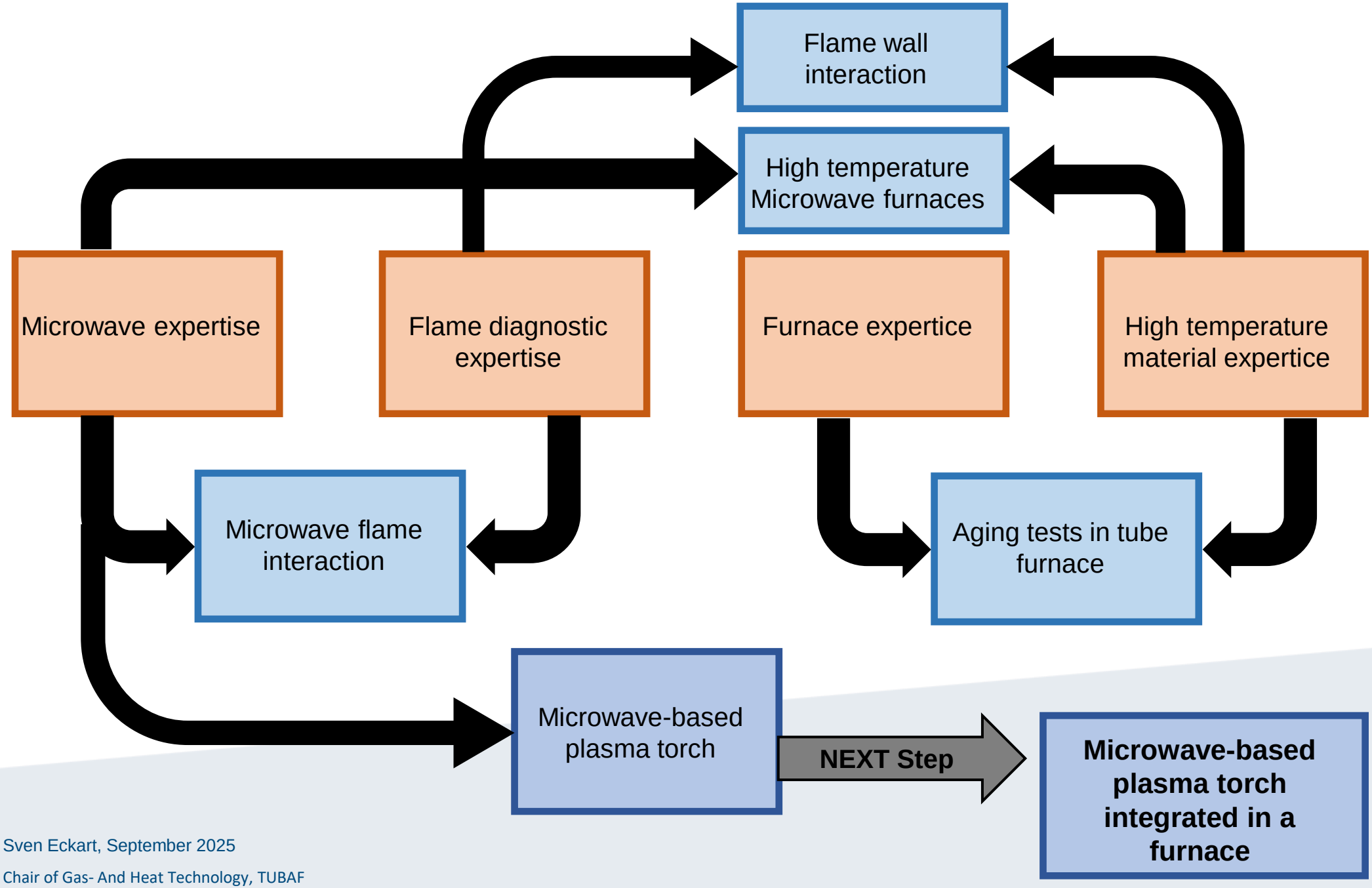
- Investigation of the interaction of Plasma with different materials by two test series: “”Burn-through test” and “scorch-test”
- Burn-through test: Integration of the plasma torch into a wall (simulating a burner scenario)
- Scorch test: Examination of material interactions with direct plasma contact

Plasma Material interaction



Pictures of the materials after the microwave „scorch test“, damaged and deformed areas in red

- Burn-through: no damage!
- Scorch: deformations on both materials, but only slight surface damage was observed for KVS (has higher temperature resistance)


Flame wall interaction
High temperature Microwave furnaces
Microwave expertise
Flame diagnostic expertise
Furnace expertice
High temperature material expertice
Microwave flame interaction
Aging tests in tube furnace
Microwave-based plasma torch
NEXT Step
Microwave-based plasma torch integrated in a furnace

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ZENTRUM FÜR EFFIZIENTE
HOCHTEMPERATUR-STOFFWANDLUNG

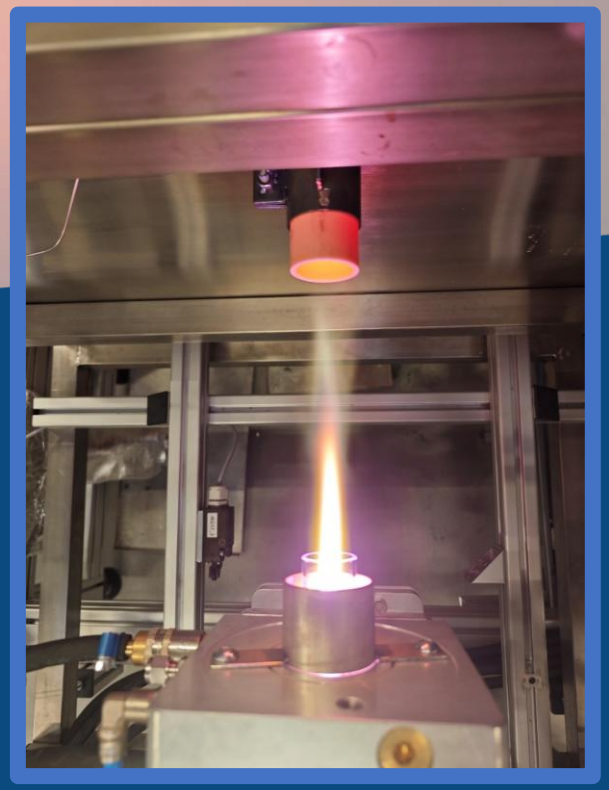
MyGlass Microwave-hybrid heated Glass melting

Andreas Pestel, Ralph Behrend, Sven Eckart, Sindy Fuhrmann, Hartmut Krause

24. September

14.10 Uhr

Saal Lissabon



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CONCLUTIONS

- Microwaves plasma torches are a promising technology for high temperature processes

- For the usage of microwave plasma torches a suitable encasement should be considered, furthermore attention should be given to the pollutant emissions of NOx and O_3 if the torch is operated with air or oxygen-rich atmospheres

- Future research areas are Improvement of energy efficiency, material processing, optimizing plasma formation , forming and different process integration

Outlook

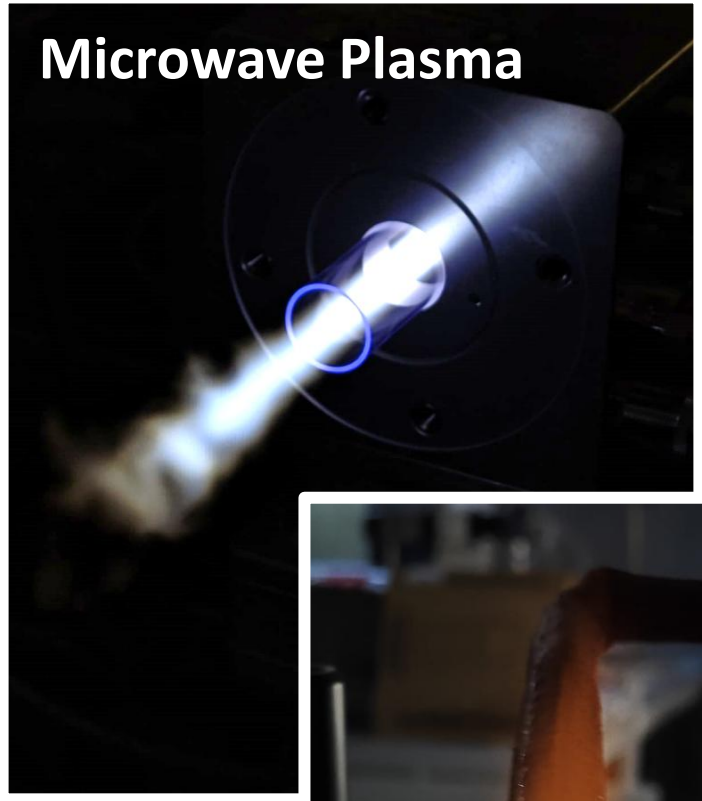
Comparison of plasma torches **to:**

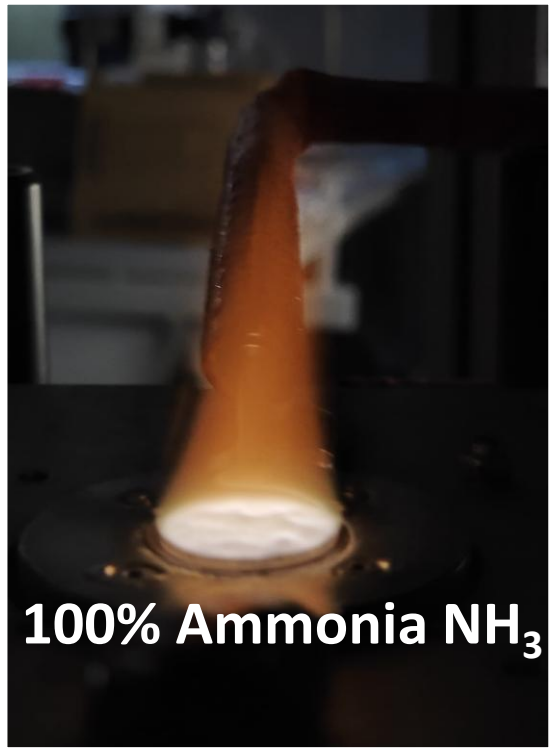
- Hybrid (electric/chemical) systems
- Electric alternatives such as flow heater
- **Natural gas-oxygen flames**
- **Hydrogen-oxygen flames**
- **Ammonia-oxyfuel flames**

Topics of interest:

- Material effects
- Effectivity of comparable systems
- Radiation and heat transfer effects

→ New oven and furnace designs for specific products





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