Production of Sustainable aircraft grade Kerosene from water and air powered by Renewable Electricity, through the splitting of $CO_2$, syngas formation and Fischer - Tropsch synthesis

# *The KEROGREEN $CO_2$ plasma route to CO and alternative fuels*

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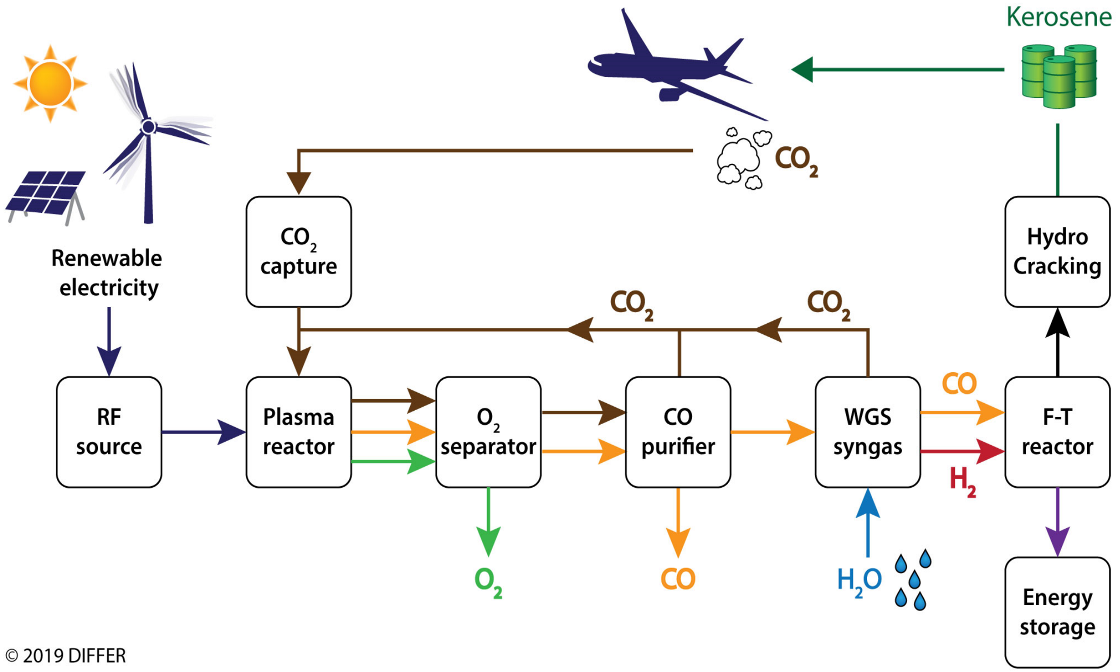
DUTCH INSTITUTE FOR FUNDAMENTAL ENERGY RESEARCH, EINDHOVEN, THE NETHERLANDS

Heat-to-fuels workshop, 8-9 March 2021

This project has received funding from the European Union‘s Horizon 2020 Research and Innovation Programme under GA-Nr. 763909

# Kerogreen project









INERATEC

**Kerogreen aim:** Demonstration of the full chain process from renewable, electricity, $CO_2$ (captured) and $H_2O$ to kerosene.

- Research and optimization of individual process steps **TRL (1-3) → 4**
- Integration phase at Karlsruhe Institute of Technology → **3 L per day**
- Duration 2018-2022

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# Kerogreen project

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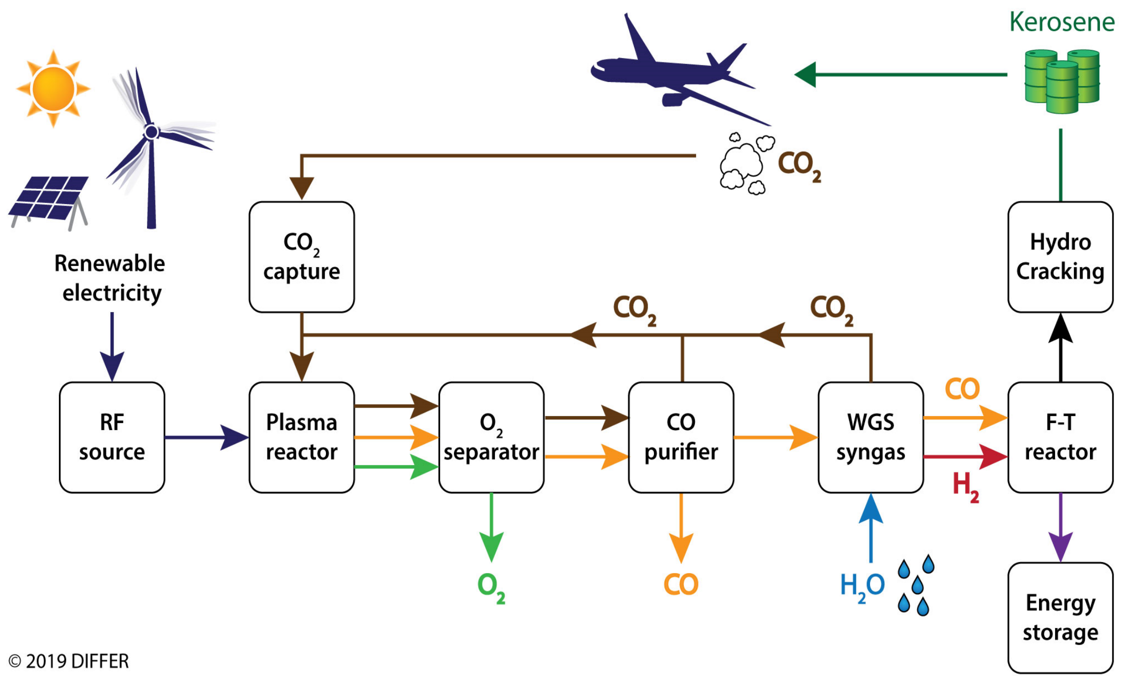




**KEROGREEN** offers an innovative conversion route based on **plasma driven dissociation** of $CO_2$, separation of oxygen by means of solid oxide electrolyte cells and Fischer-Tropsch (F-T) synthesis of kerosene.

- $CO_2$ plasmolysis (DIFFER)
- $O_2$ separation (DIFFER, VITO, Cerpotech, Hygear)
- CO purification (HYGEAR)
- Water gas shift reaction reaction (KIT)
- F-T synthesis (INERATEC)
- Heavy HC hydrocracking (KIY)

**Main challenges**

- Plasma dissociation efficiency of $CO_2$
- Oxygen separation after plasmolysis by SOEC
- System integration of different technologies into one container sized assembly
- Maximization of the energy and carbon efficiency of the full chain

KEROGREEN

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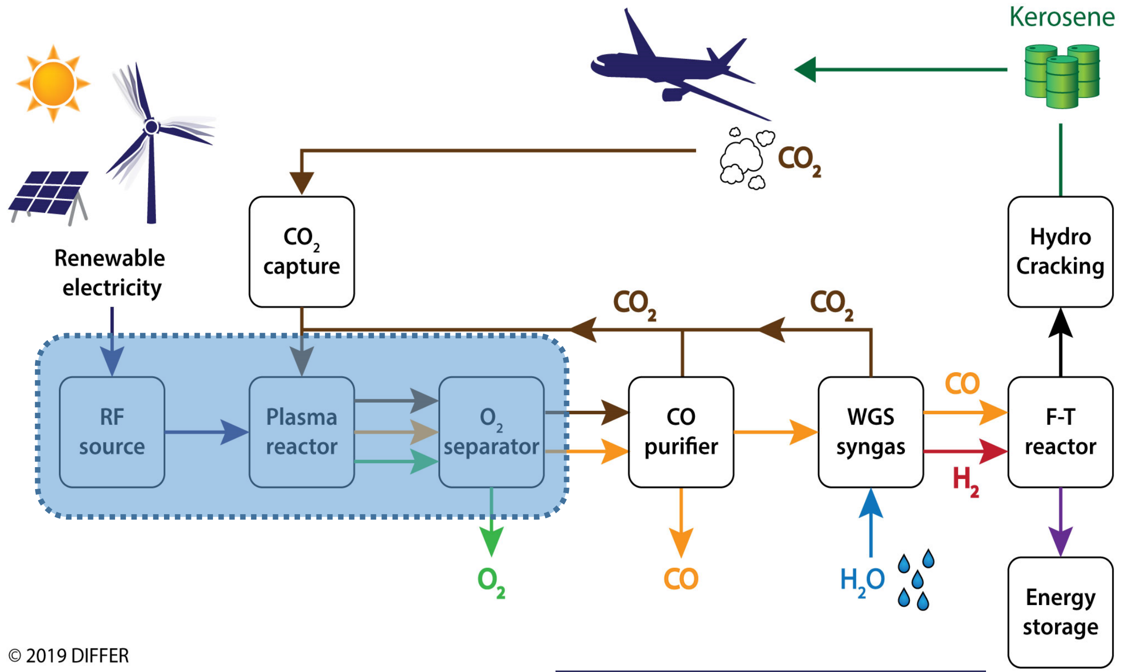
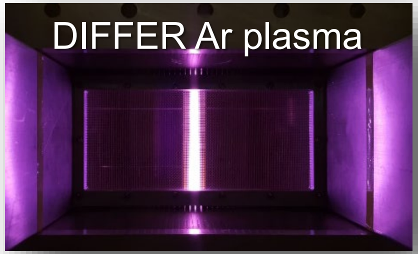
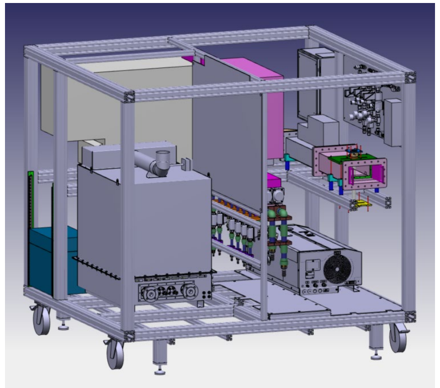


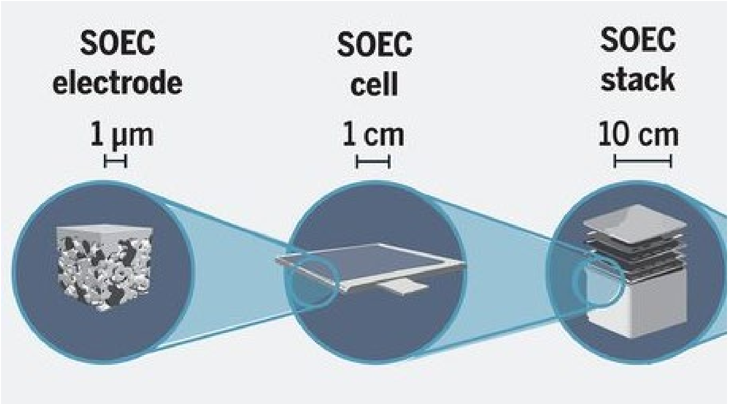

© 2019 DIFFER



## DIFFER involvement

- <u>**Plasma modeling and optimization**</u>
- Plasma upscaling from 1 to 6 kW
- Material requiements for using SOEC as oxygen separator
- SOEC upscaling from 1W to 1.5 kW

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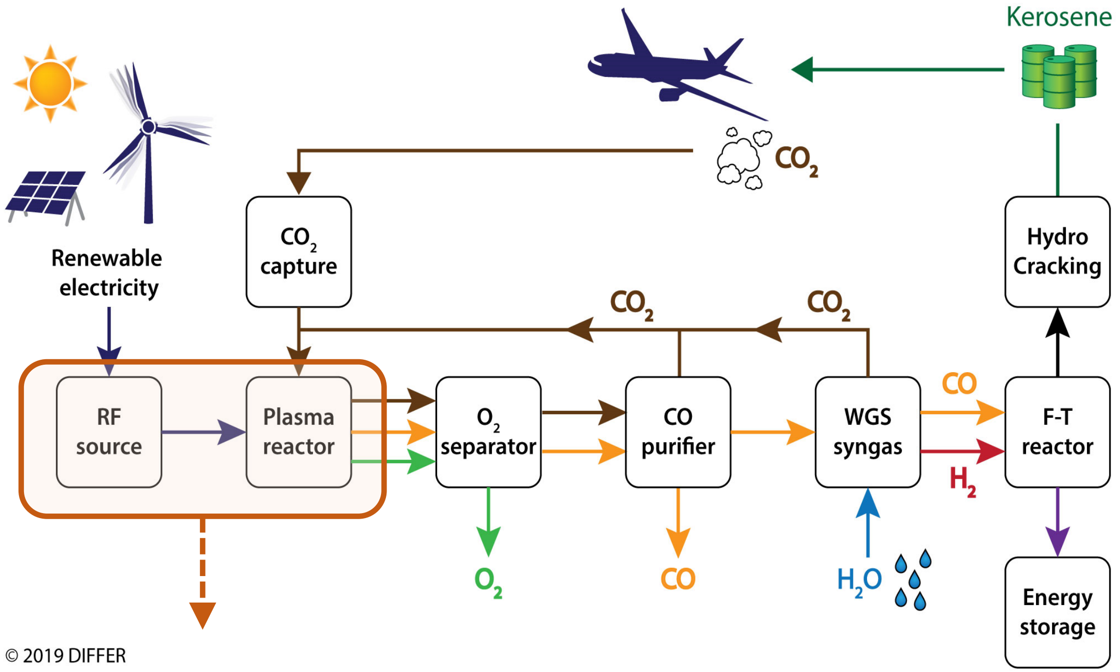
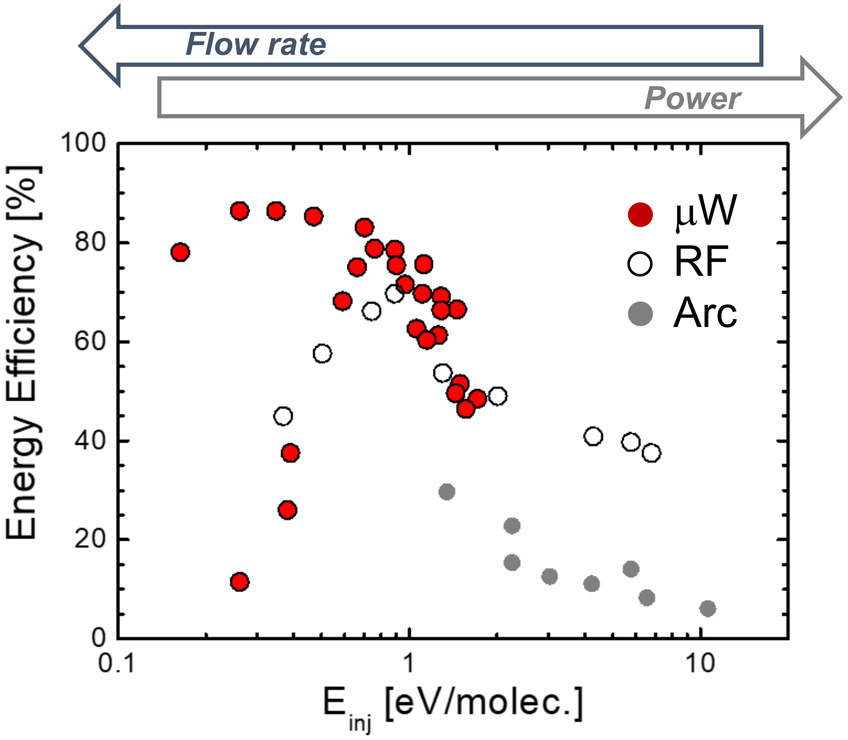
# Why $CO_2$ plasmolysis?

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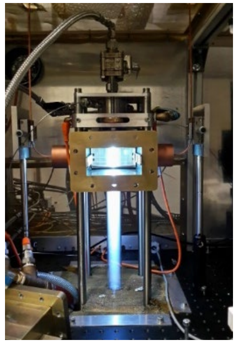
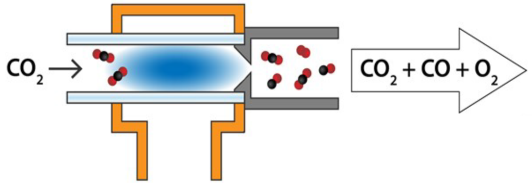


**$CO_2$ plasmolysis: $2CO_2 \rightarrow 2CO + O_2$**

- Input: $CO_2$ + renewable electricity
- Output: $CO_2$, CO and $O_2$
- High energy efficiency, …




Microwave generated plasma so far most efficient

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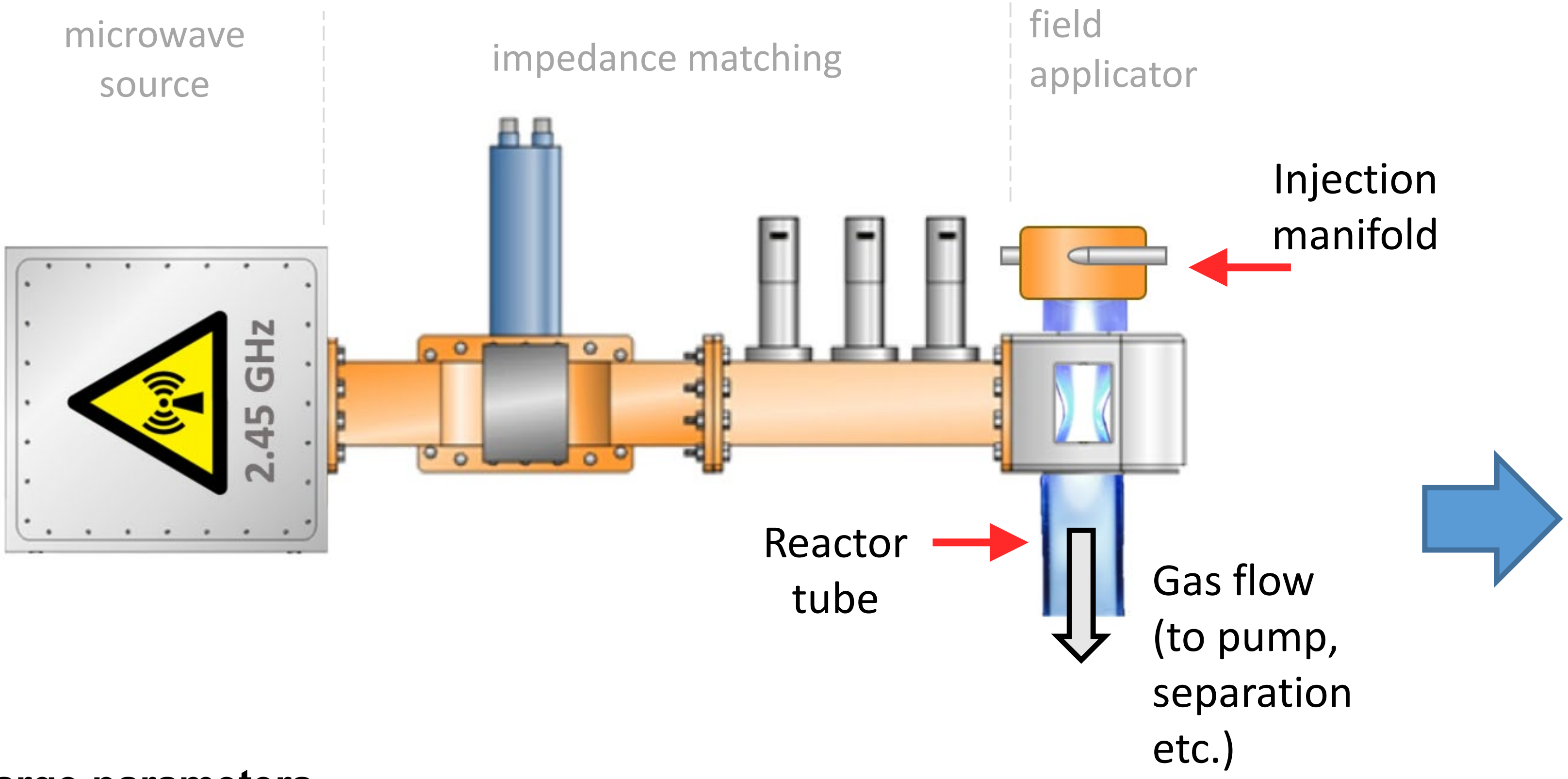
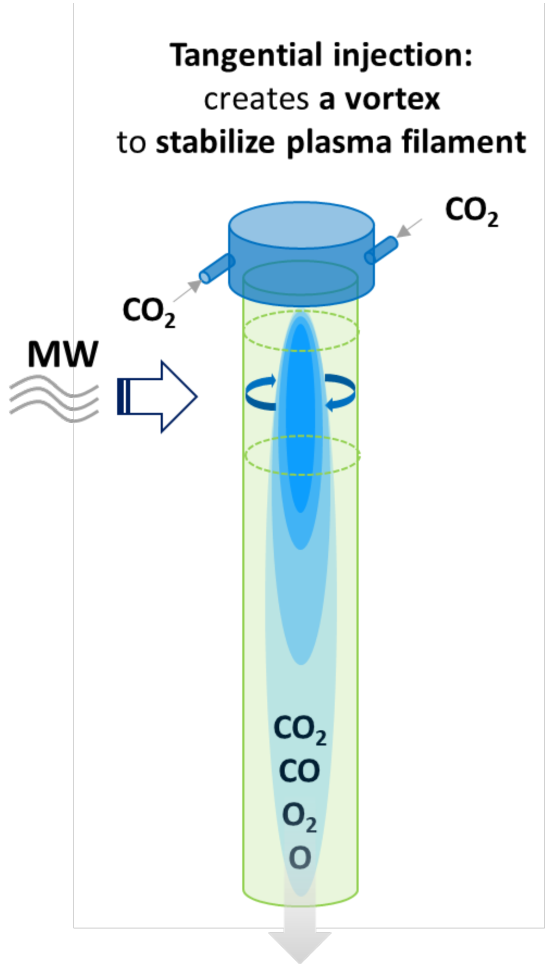
# Set up - $CO_2$ conversion in a microwave plasma flow reactor




**Discharge parameters**

- Power (P): 400-1500 W
- Pressure (p): 50-1000 mbar
- $CO_2$ input ($\phi$): 1-28 slm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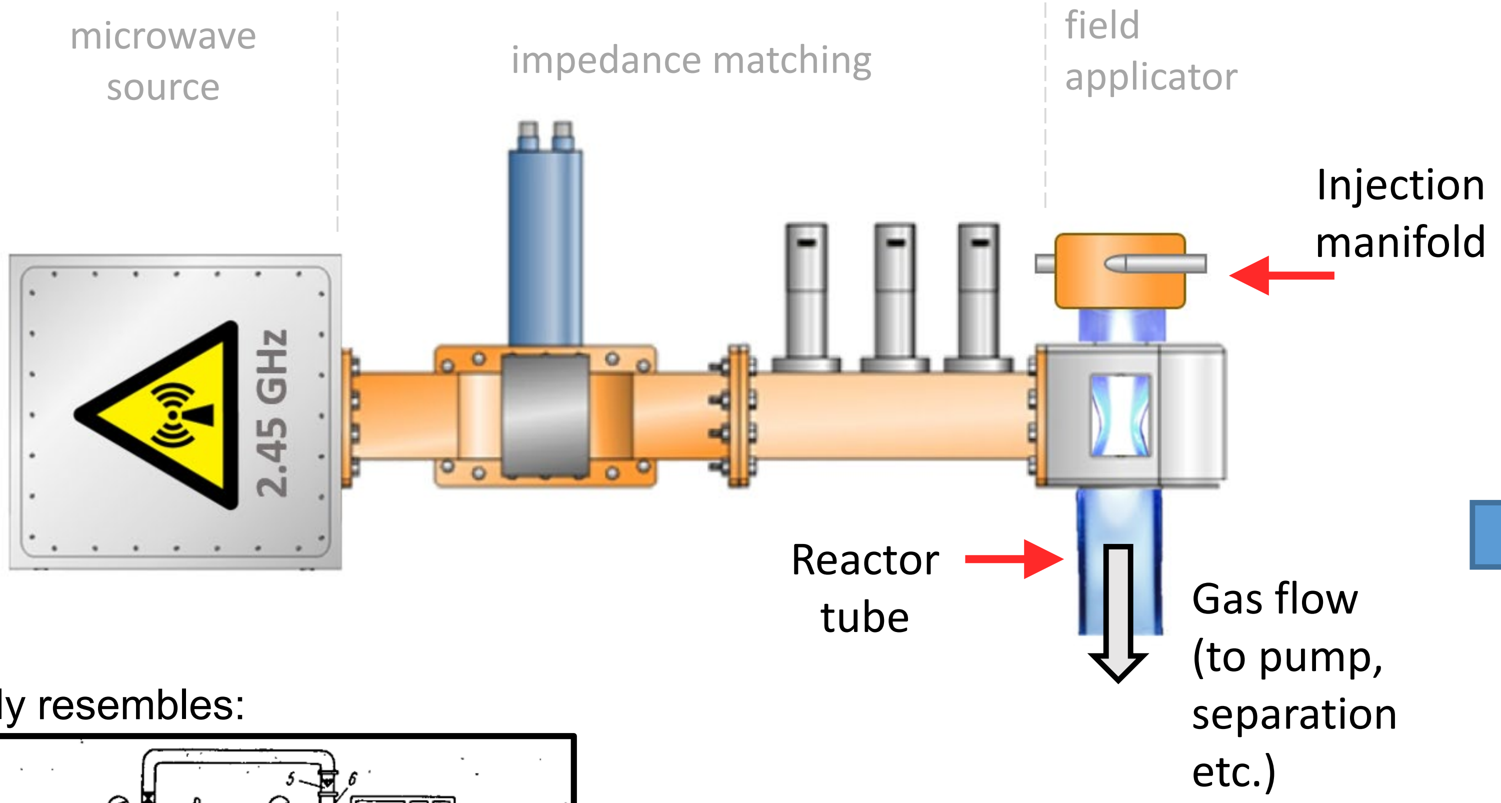


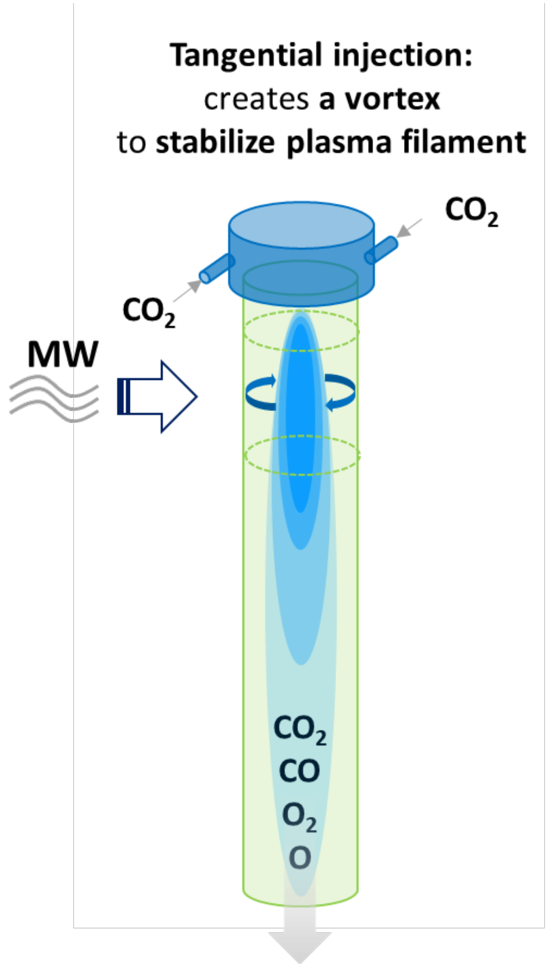


Closely resembles:

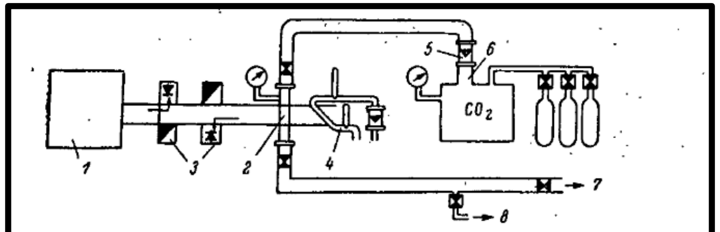


FIG. 1. Schematic diagram of the apparatus; 1) microwave generator; 2) reactor; 3) system of directional couplers; 4) calorimetric load; 5) rotameter; 6) buffer tank; 7) pump; 8) sample of the gas for analysis.

Givotov et al., J. Hydrogen Energy **6** 441 (1981)
**80% energy efficiency reported**

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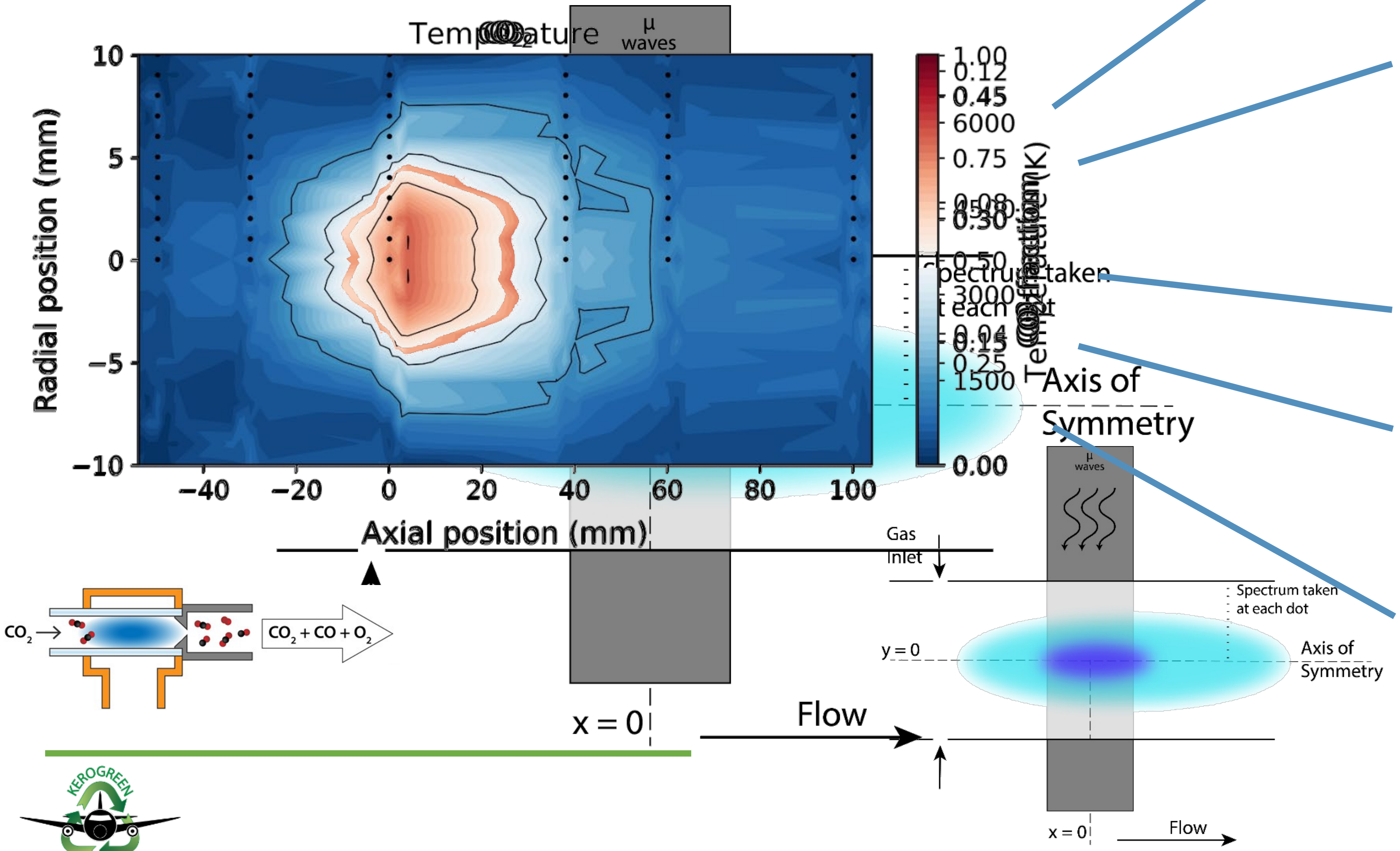
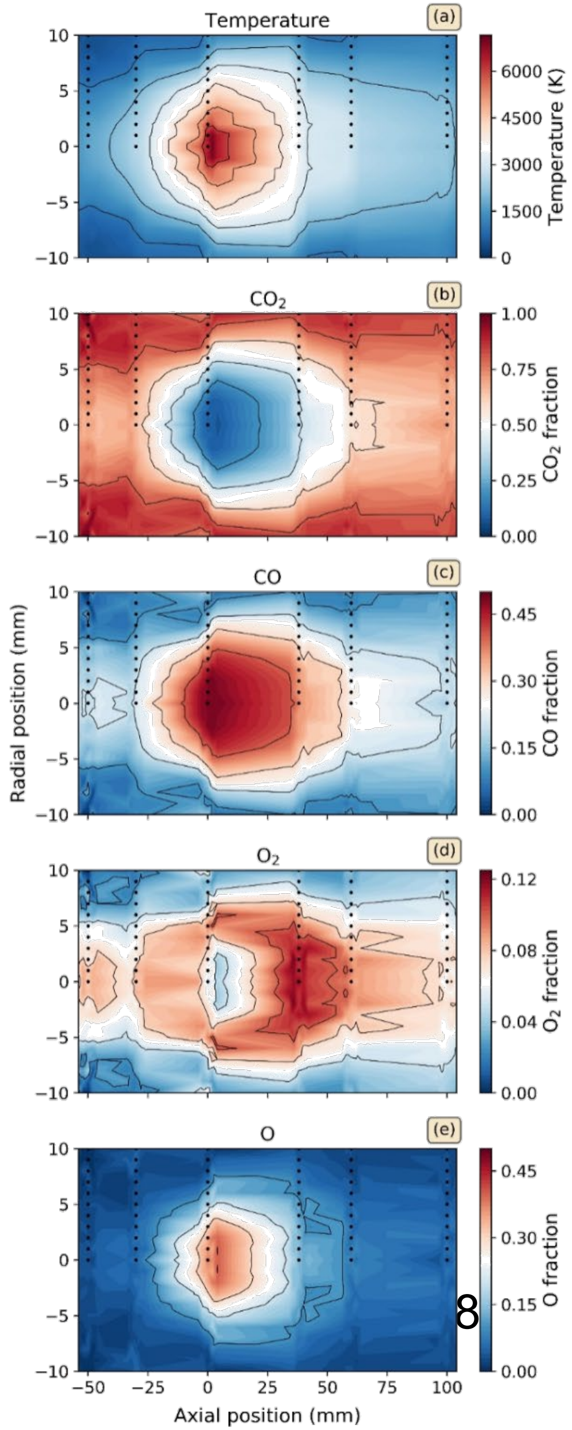
# 2D maps T & $CO_2$, CO, $O_2$ and O fractions



# Gas temperature and CO output are correlated

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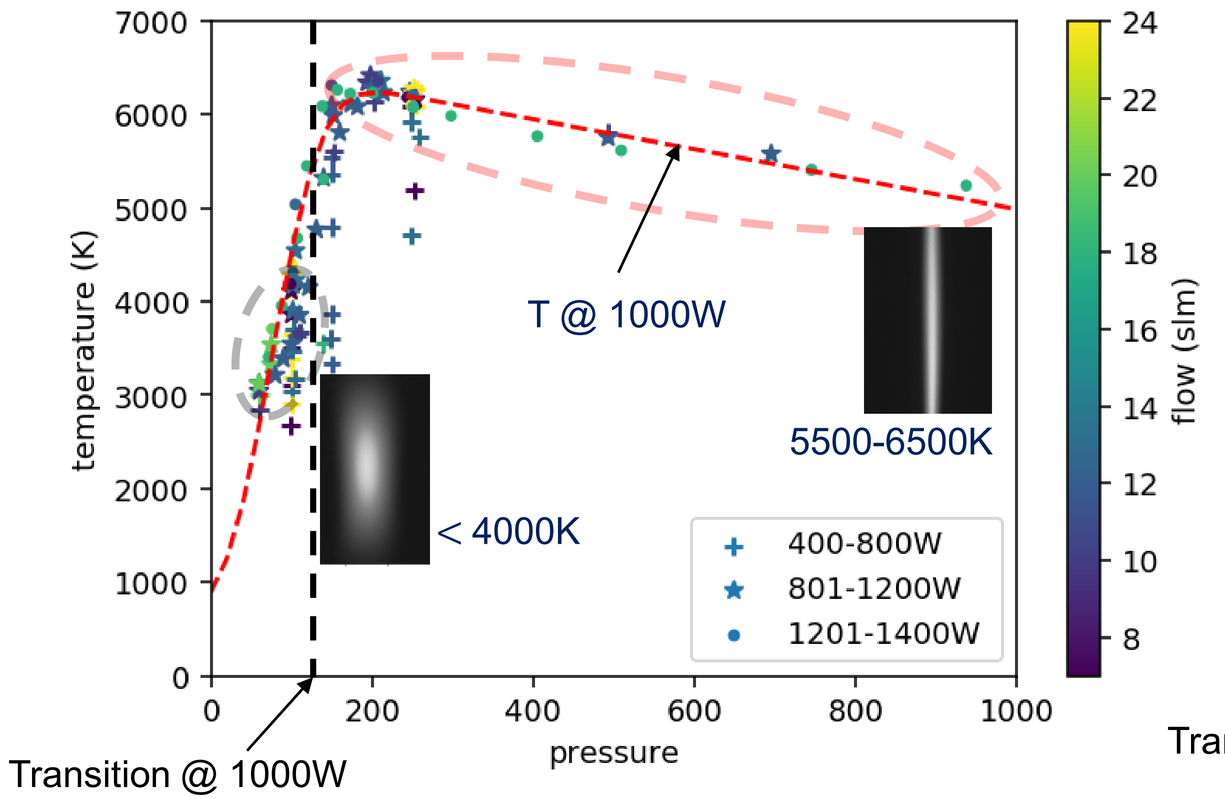


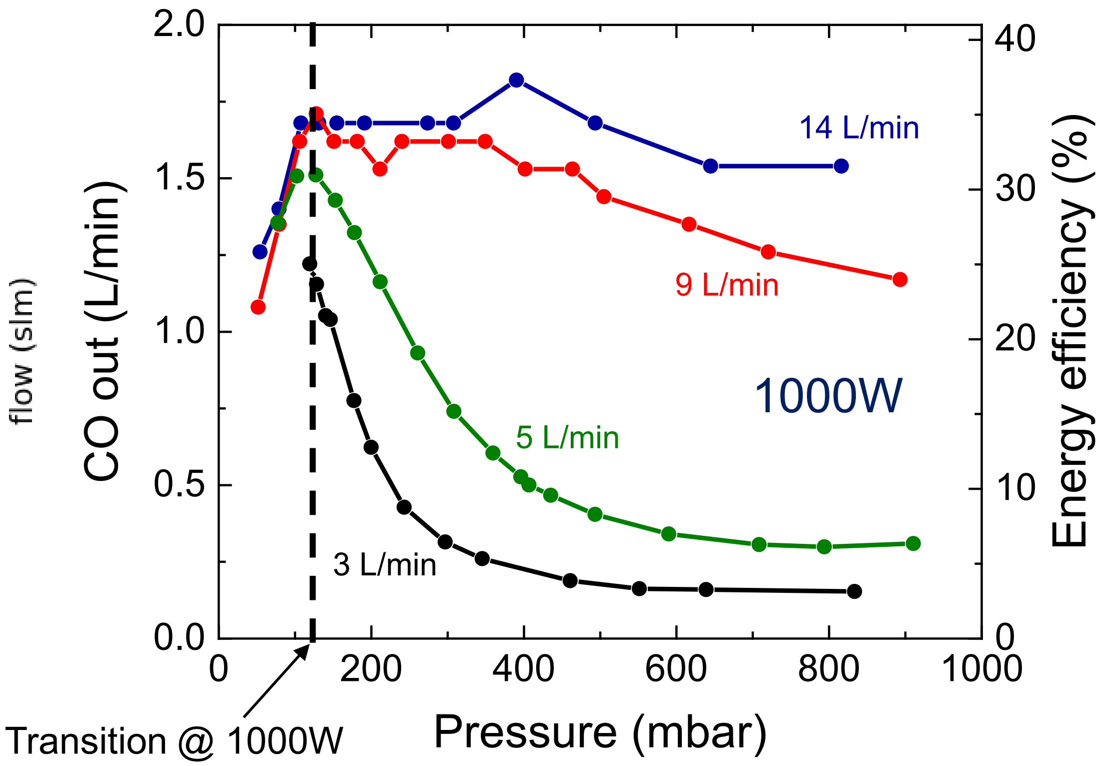


T and plasma shape independent of flow rate…
… yet, strong flow dependence at high pressure → Transport effect!

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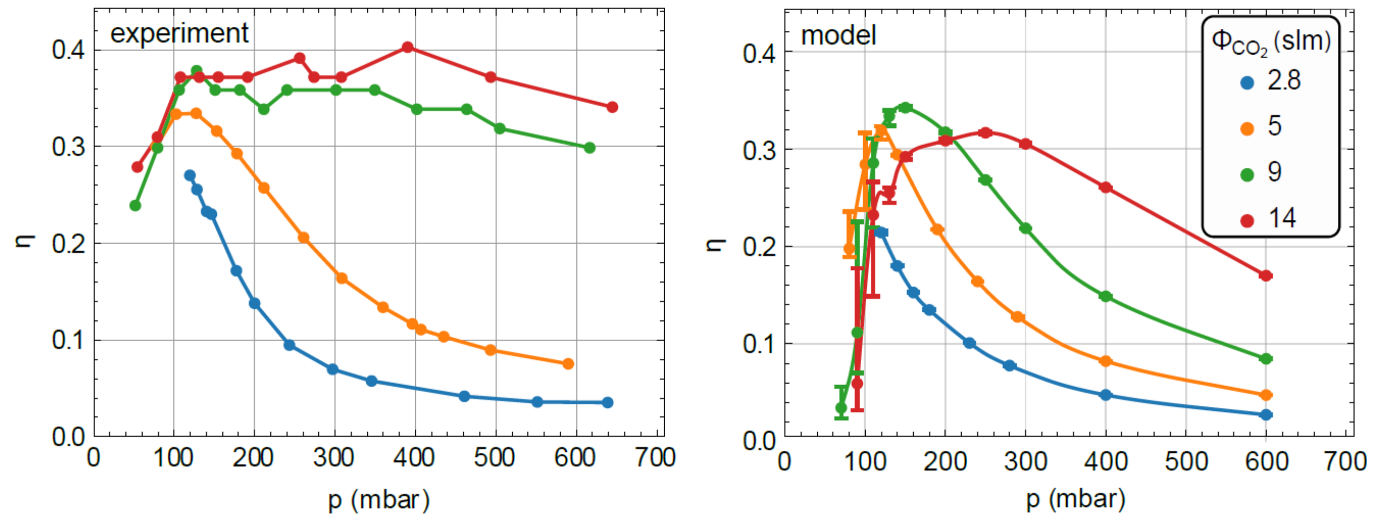
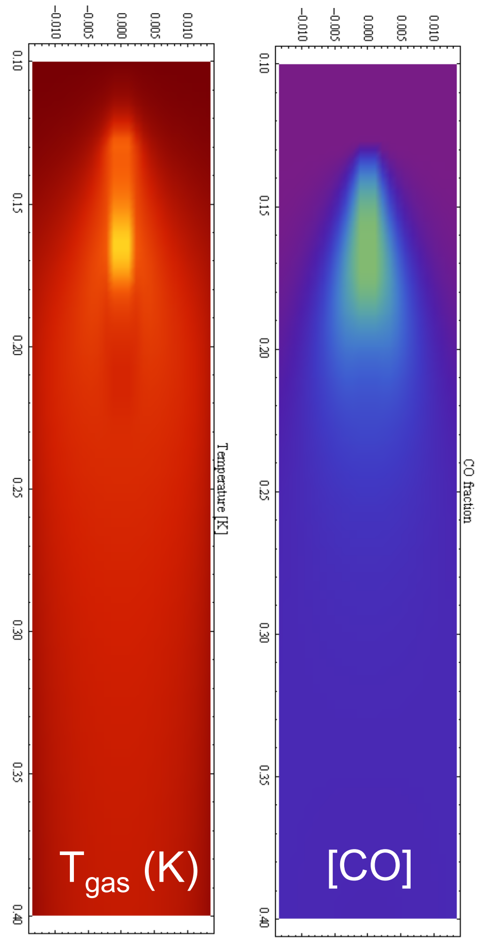
# Simulation results: energy efficiency for several flow rates @ 1kW




- Both pressure and flow dependence of $\eta$ roughly captured despite substantial simplifications in flow implementation
- Simple thermal chemistry adequate to describe reactor performance

Wolf, A. J. and Peeters, F. J. J., et al. (2020) J. Phys. Chem. C 2020, 124, 31, 16806–16819

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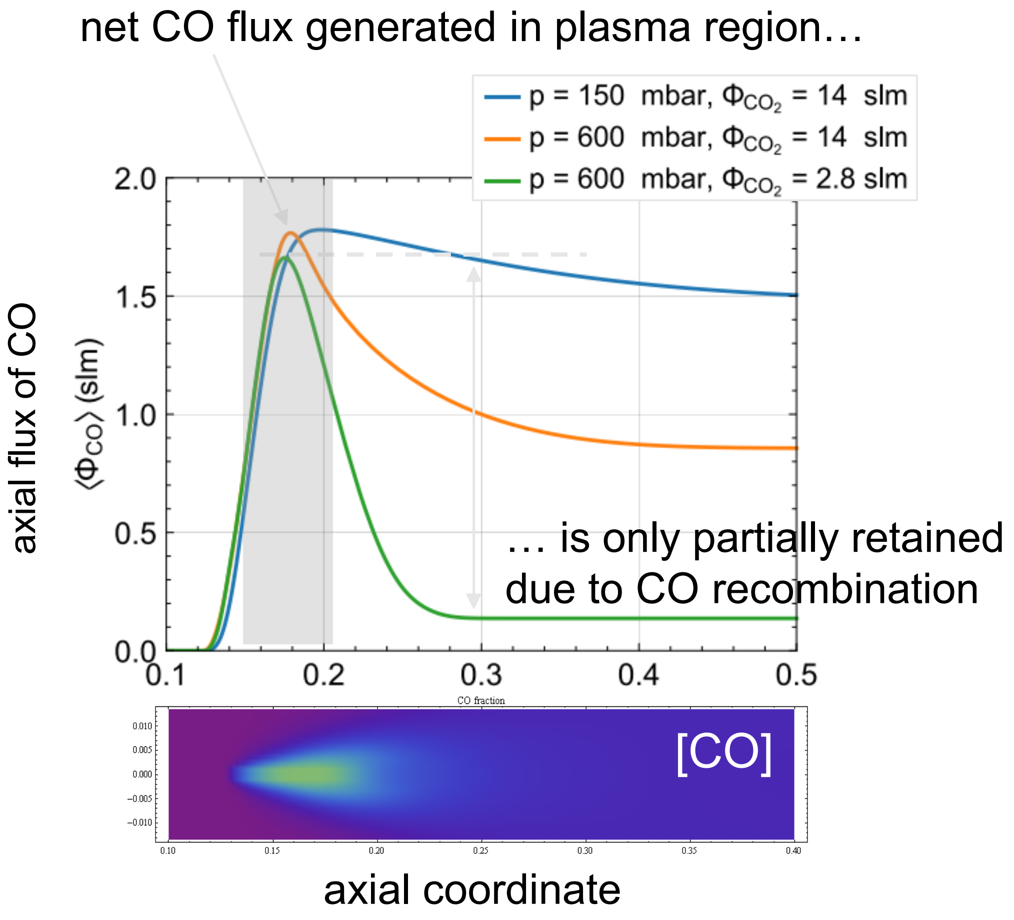
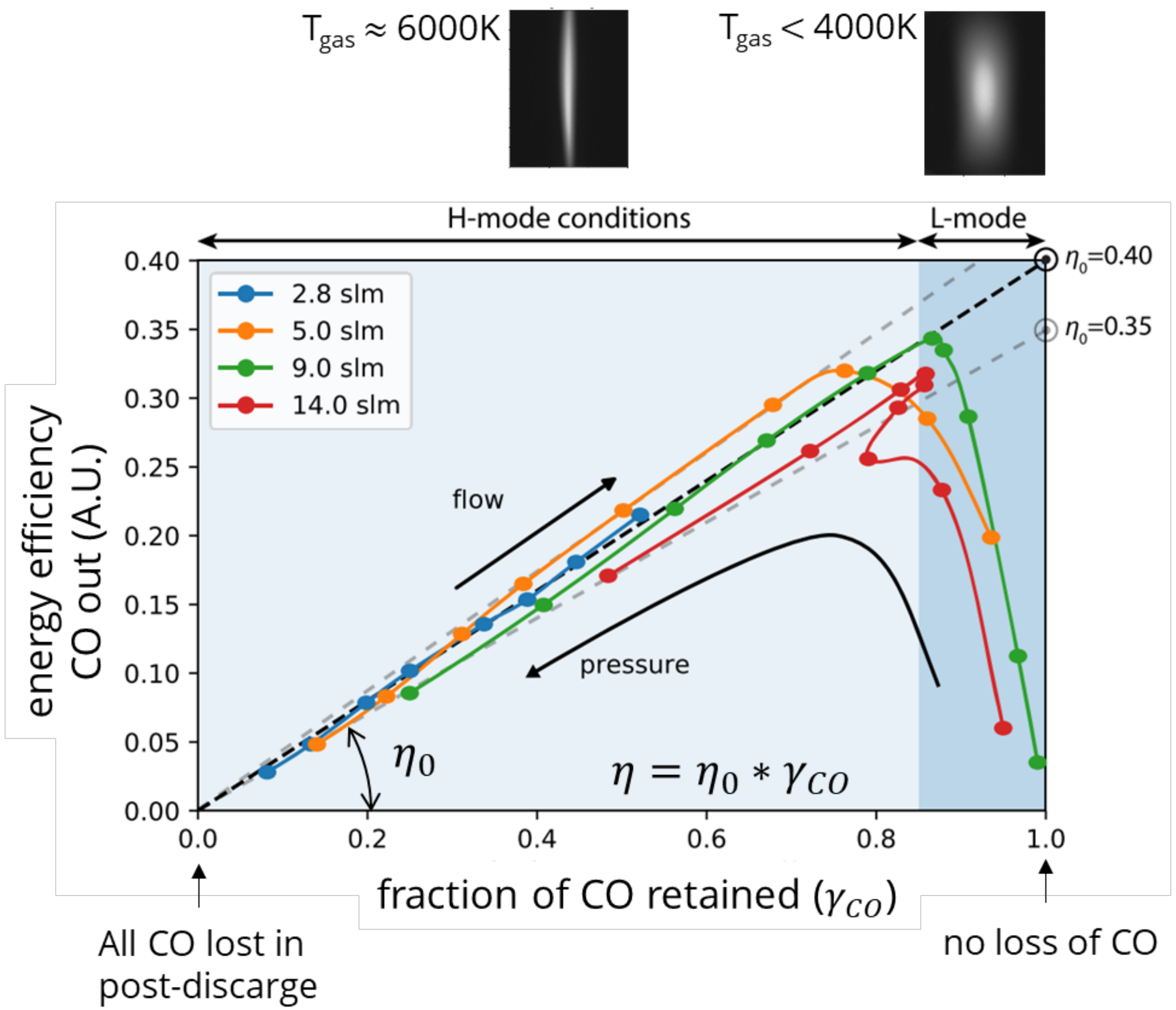
# Simulation results: Disentangling production and losses

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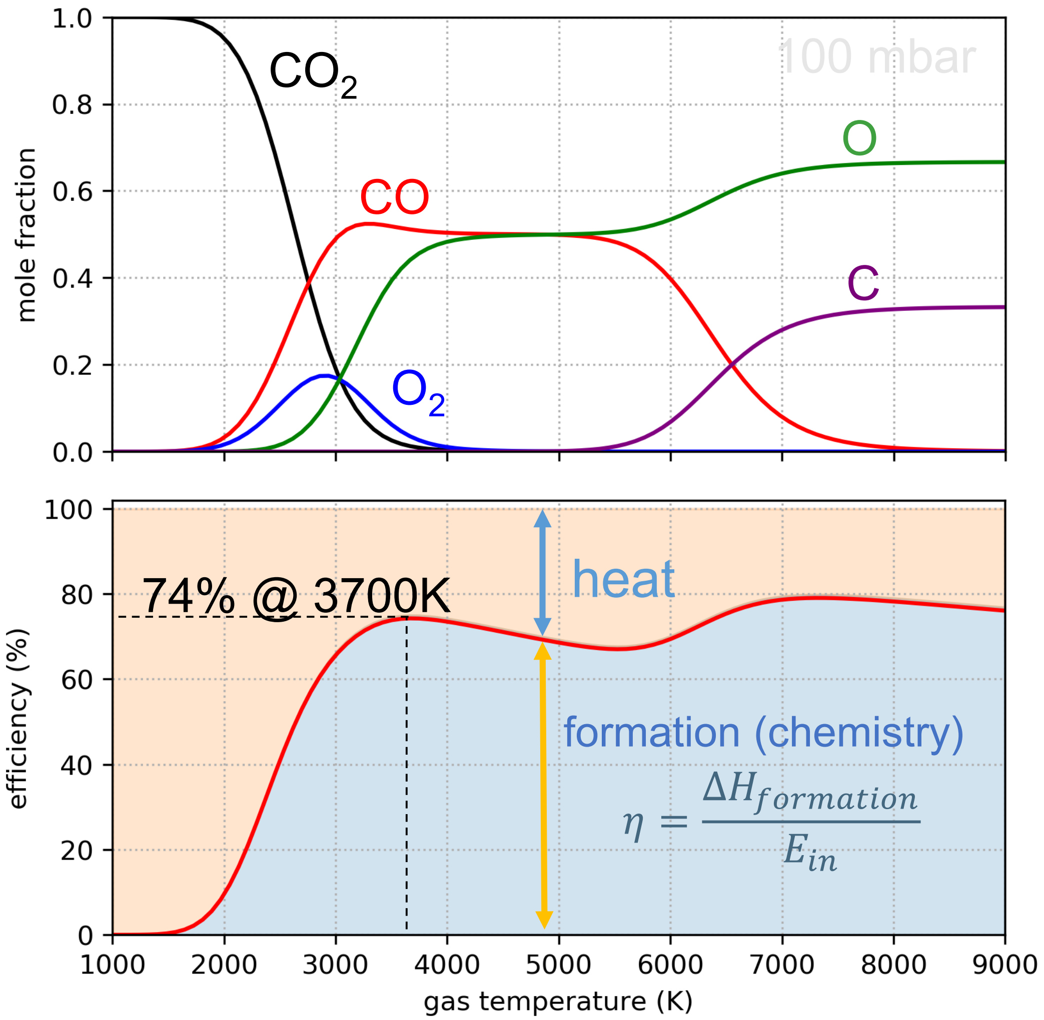
# Thermal $CO_2$ conversion in a closed system




Thermodynamic equilibrium composition: minimization of Gibbs free energy

The **fraction of energy invested in formation** depends on the **temperature**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# The ‘quenching’ trajectory largely determines the efficiency

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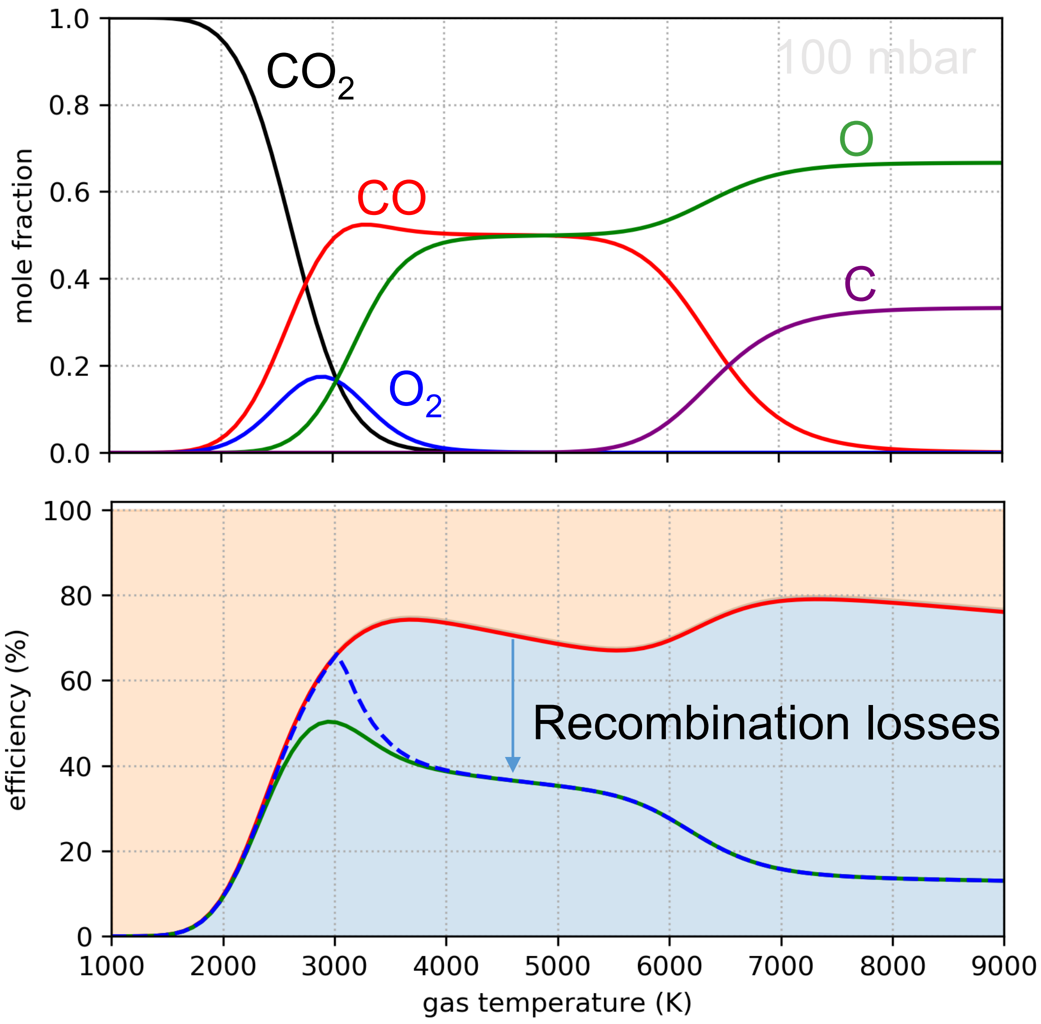


## 3 quenching scenarios

### without CO back-reactions

**“Ideal” quenching**

- $O + O \; + (M) \rightarrow \; O_2 + (M)$
- 52% efficiency @ 3000 K

**“Super-ideal” quenching**

- $O + CO_2 \rightarrow CO + O_2$
- 65% efficiency @ 3000 K

**Super-ideal quenching (open system)**

- Admixture of extra $CO_2$
- > 70% efficiency

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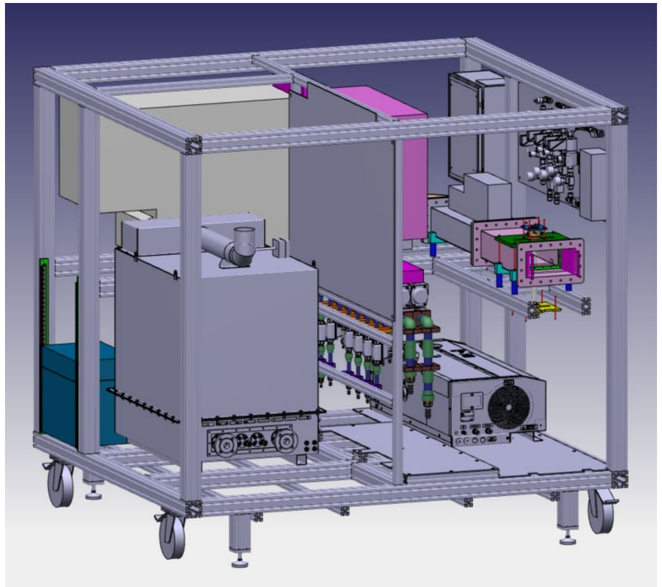
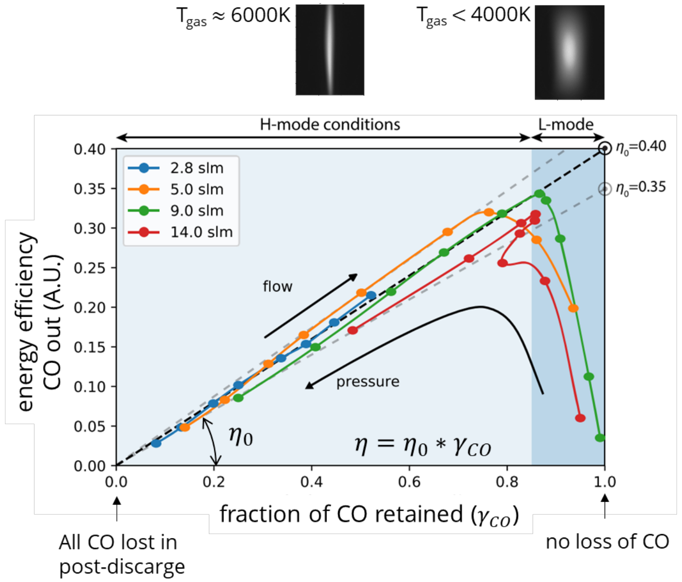
# Summary and outlook

## Summary

- Energy efficiencies for plasmolysis obtained sofar are in the range 40-60%
- Plasma conversion of $CO_2$ using microwave plasma well understood
- Reactor engineering is essential to optimize performance further:
  - decrease the losses by controling quenching trajectory
  - increase the utilization of atomic oxygen to react with inflowing $CO_{2:}$ **super-ideal quenching**
  - recuperate the thermal energy in the exhaust to enhance the power spend for conversion






## Outlook

- Uposcaled 6 kW reactor is made ready for integration @ KIT
- Advance SOEC architectures will decrease ohmic losses:
  - allow operation at lower T (less CO losses),
  - while preserving high oxygen pumping rates.
- Integrated phase: Commercial vendor → 1.5 kW unit
- DIFFER studies: $CO_2$ plasma-integrated SOEC.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**Thank you for your attention!**

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