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

KEROGREEN - A plasma-based approach for CO_2 neutral fuel production

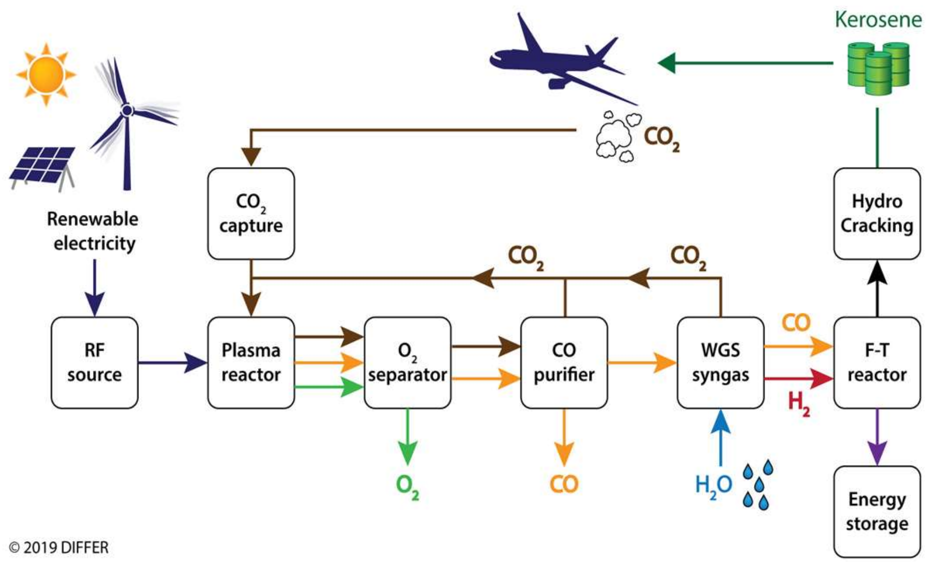
S. Welzel, A. Pandiyan, V. Kyriakou, D. Neagu, R. Sharma, F. Peeters, B. Wolf, W. Bongers, M.C.M. van de Sanden, A. Goede, M. Tsampas

DUTCH INSTITUTE FOR FUNDAMENTAL ENERGY RESEARCH, EINDHOVEN, THE NETHERLANDS

EERA AMPEA workshop on "Carbon Capture Utilisation and Storage", 10-11 March 2021

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

Kerogreen project



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

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

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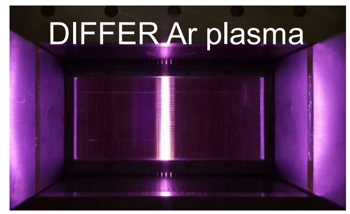
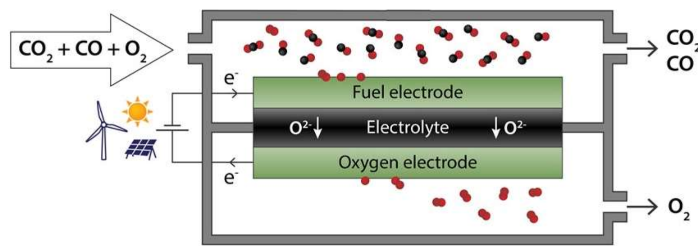
Outline

- Kerogreen project
- Plasmolysis of CO_2



- Oxygen separation by means of Solid oxide electrolyte cells (SOECs)



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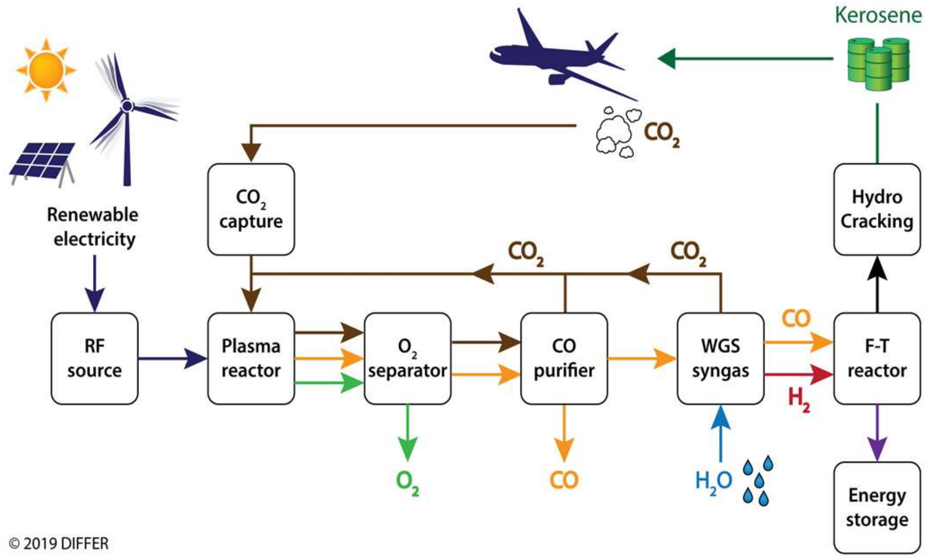
Kerogreen project



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 (KIT)

Main challenges

- 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

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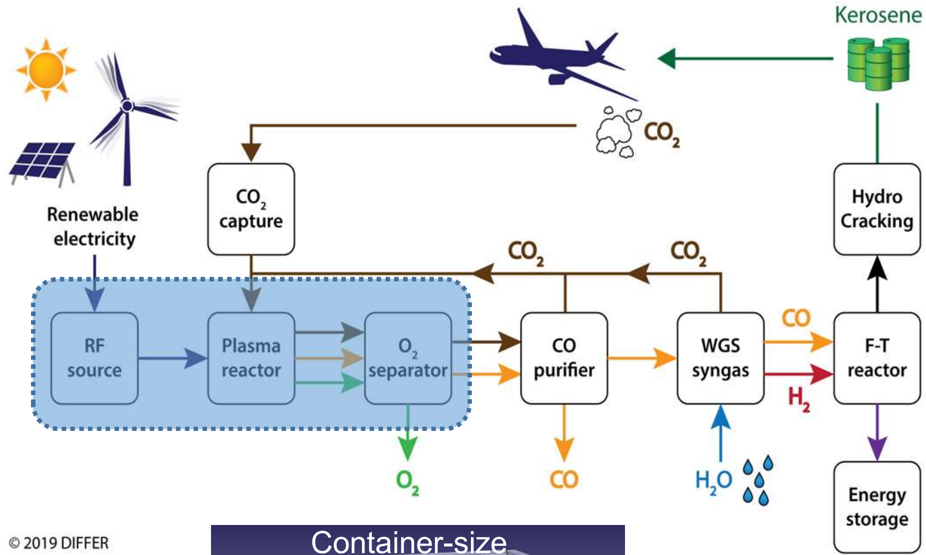
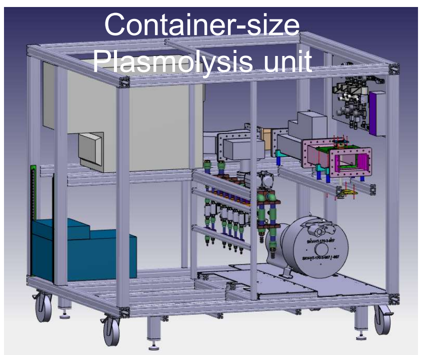
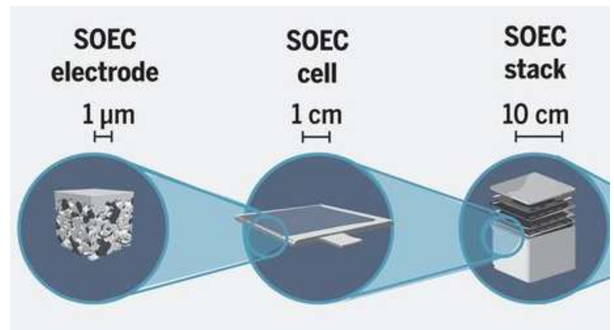
Kerogreen project





DIFFER involvement

- Plasma modeling and optimization for process chain
- Plasma upscaling from 1 to 6 kW
- Material requirements for using SOEC as oxygen separator
- SOEC upscaling from 1W to 1.5 kW



DOI: 10.1126/science.aba6118

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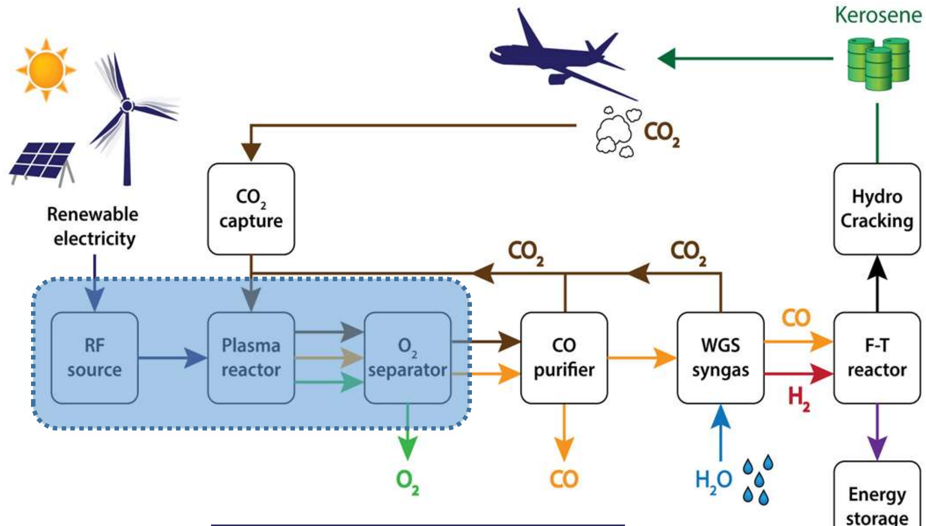
Kerogreen project



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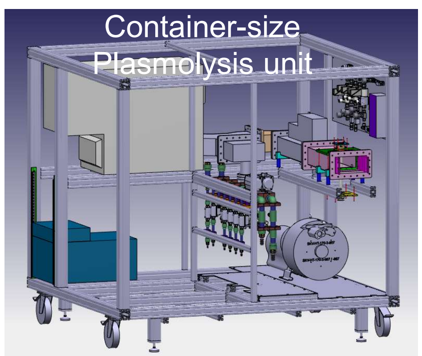

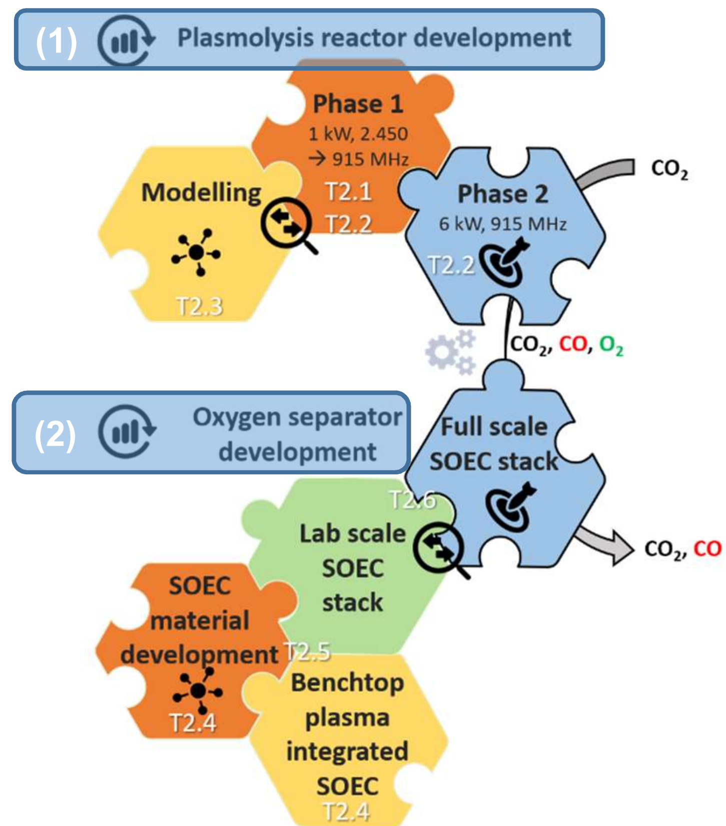

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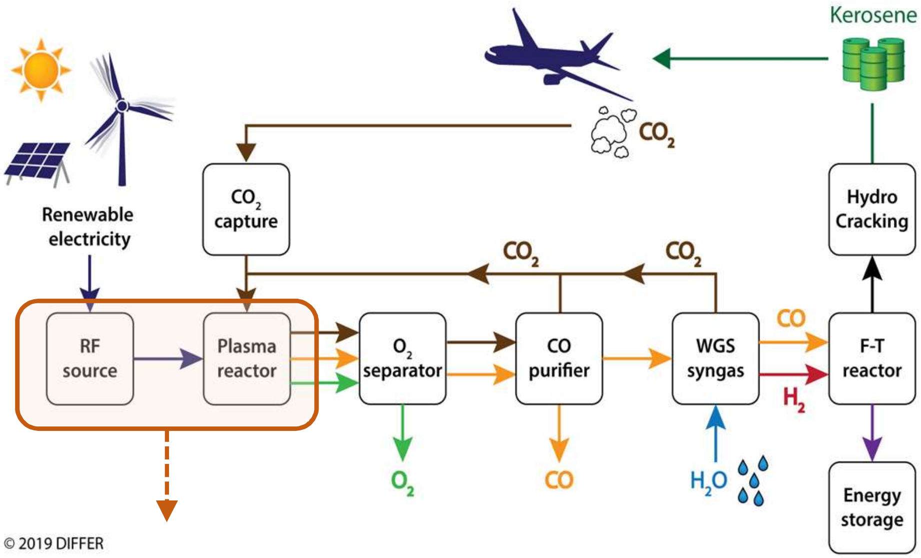
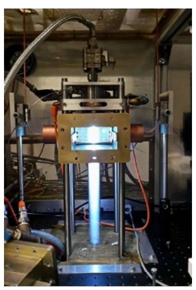
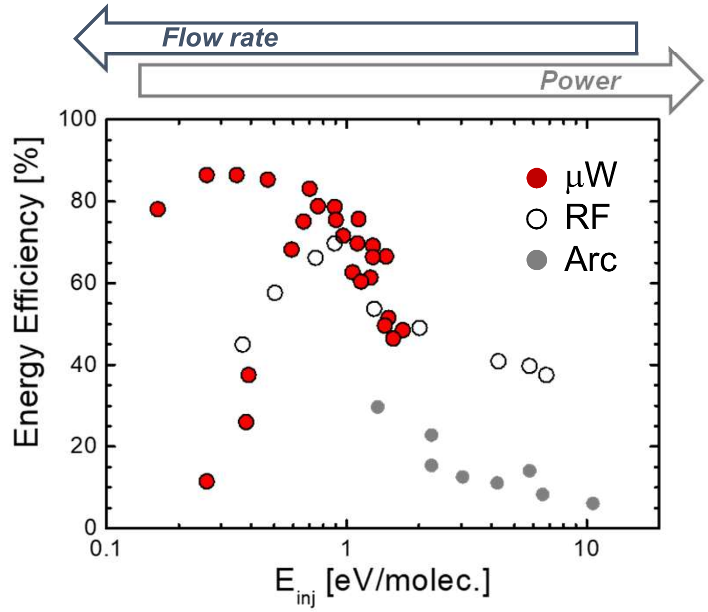
CO_2 plasmolysis: Why?







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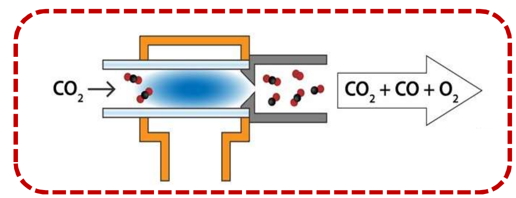

CO_2 plasmolysis: $2CO_2 \rightarrow 2CO + O_2$

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

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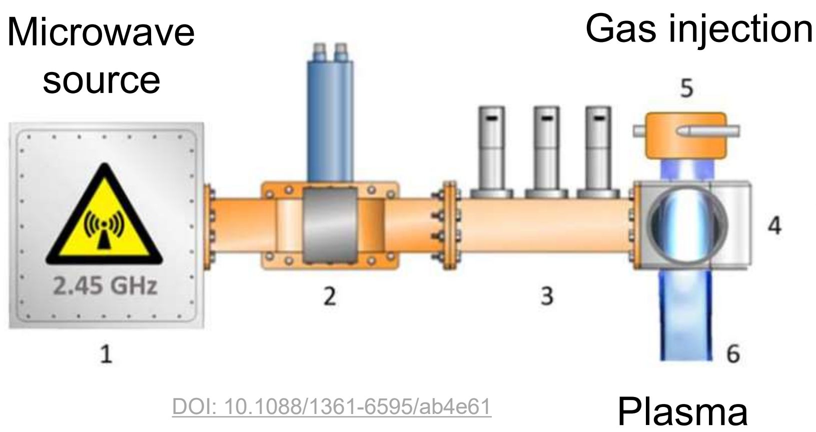
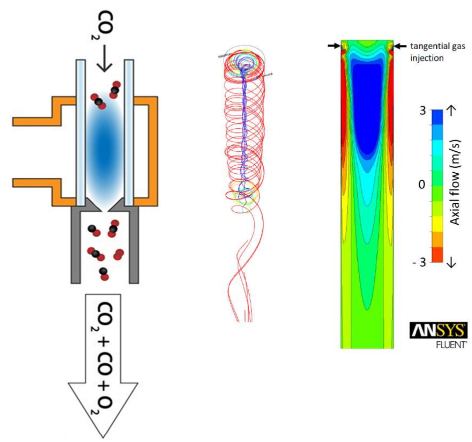
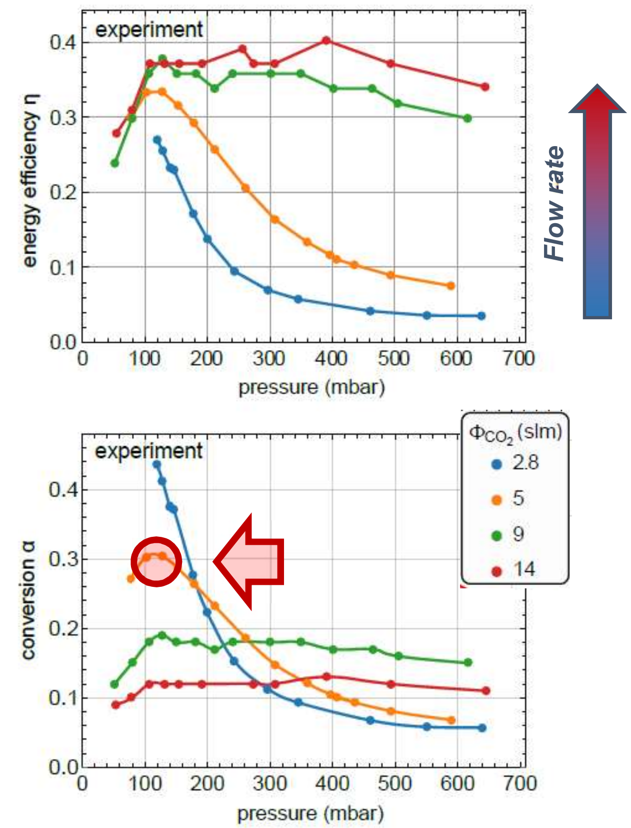
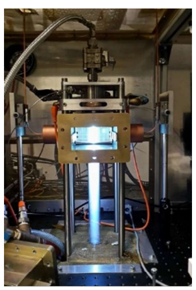
CO_2 plasmolysis: How?



DOI: 10.1088/1361-6595/ab4e61







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

- Conversion & efficiency interdependent (complex!)
- Different discharge modes
- Gas temperatures >> 1000 K

A.J. Wolf et al. The J. of Physical Chemistry C, 124 (2020) 16806

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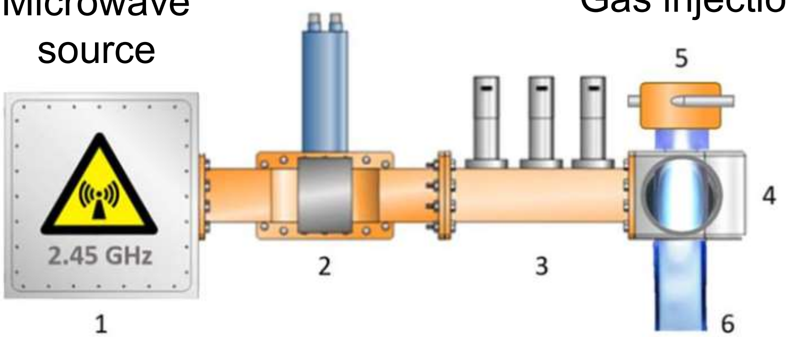
CO_2 plasmolysis: How?

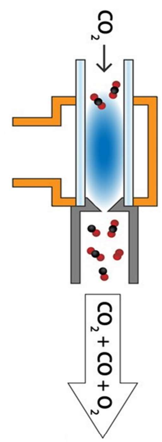
Microwave source

Gas injection

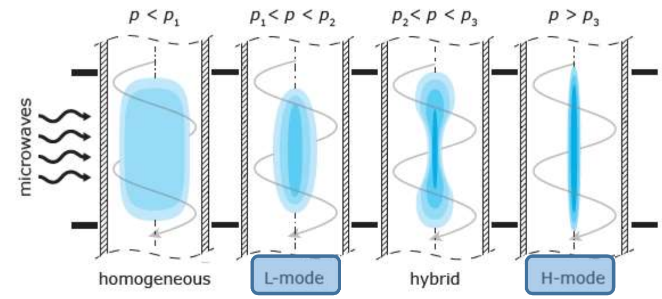


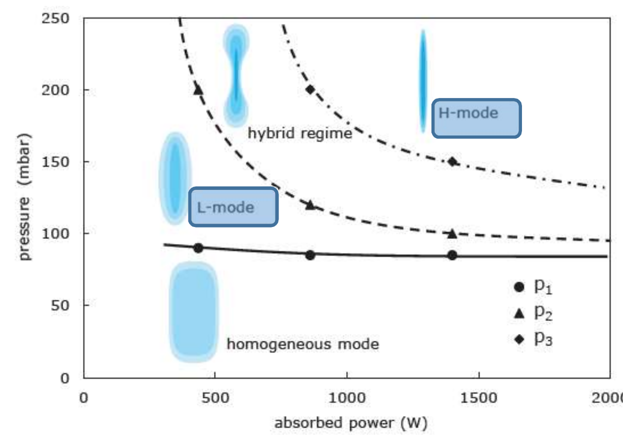
DOI: 10.1088/1361-6595/ab4e61

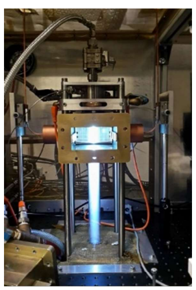
Plasma



Discharge modes







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CO_2 plasmolysis: How?

DIFFER

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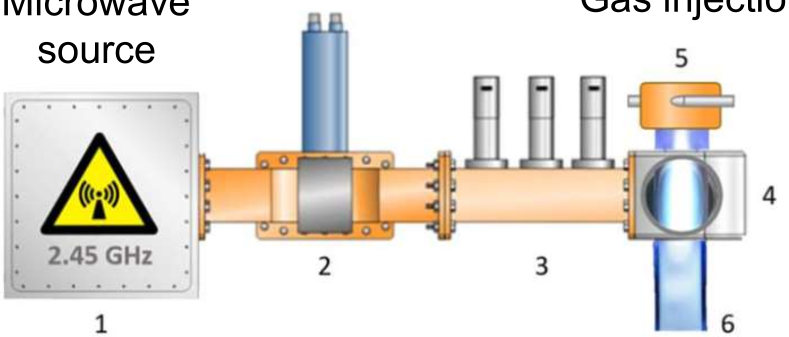

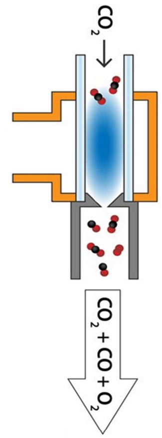

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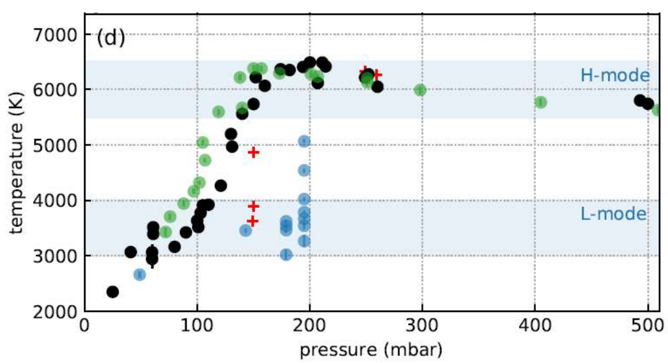
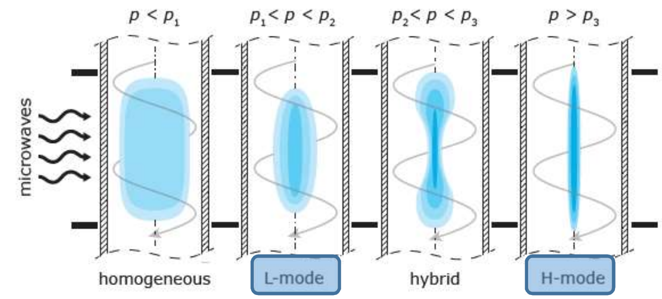
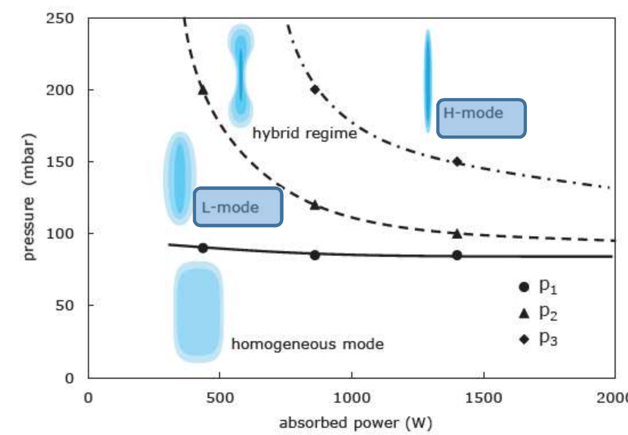
Plasma

Gas temperatures



Discharge modes





A.J. Wolf et al. Plasma Sources Sci. Techn., 29 (2020) 025005

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CO_2 plasmolysis: Challenges & Take away (I)

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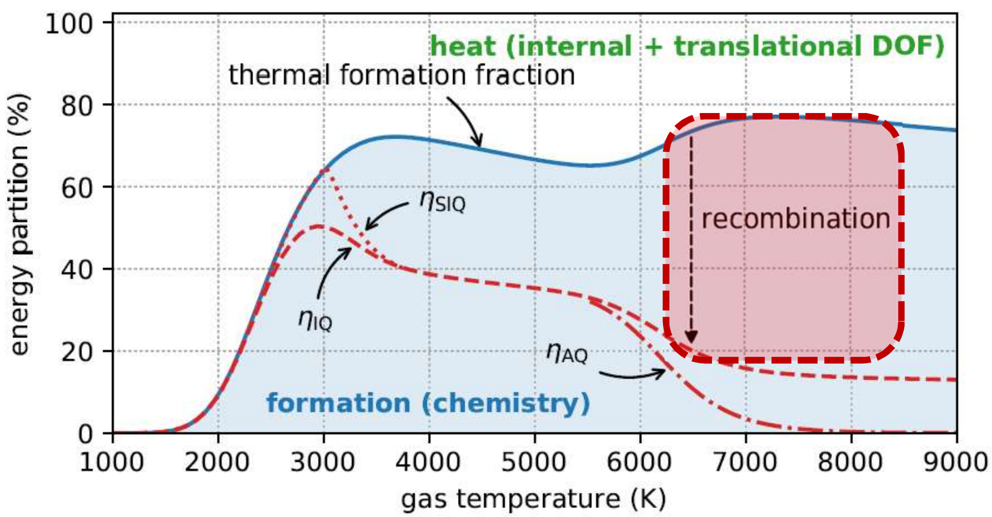
CO formation



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Gas temperature

- Processes & efficiency determined by gas temperature
- Gas temperature cannot be set
- Pressure determines discharge mode (and T)
- T >> 1000 K (material challenge !)

CO yield

- CO yield determined by recombination
- Final CO yield depends of the way of extraction
- Flow pattern = recirculation zones
  - Quick expansion (pumping required ☹)
  - Fast, significant cooling (quenching, Q) (material + surface area challenge)

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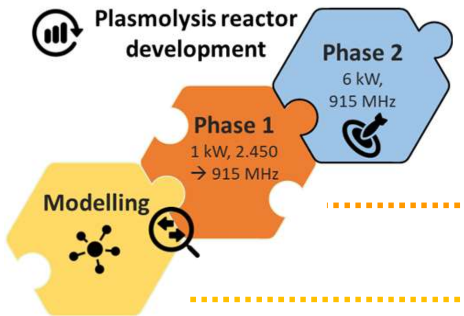
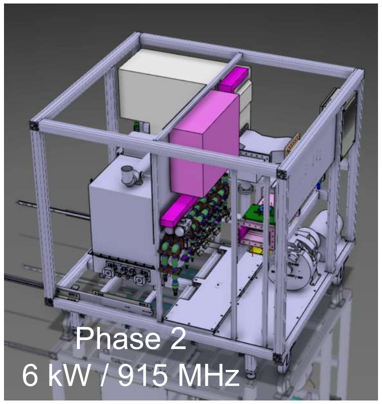
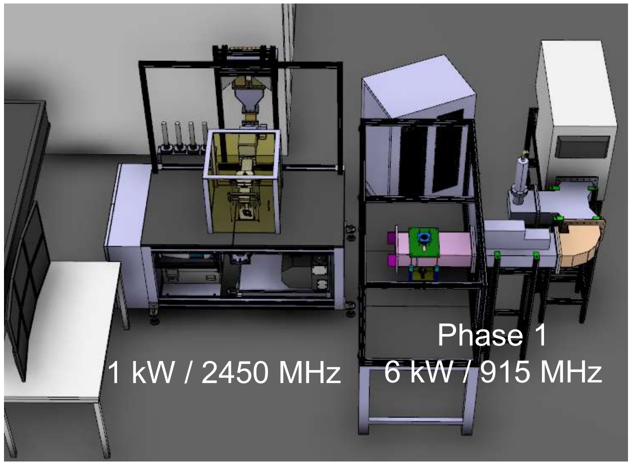
CO_2 plasmolysis: Scale up



	Power [kW]	Frequency [MHz]	Scale
Phase 2	6	915	Container/ Module
Phase 1	6	915	Lab
(InitSF)	1-2	2450	Lab





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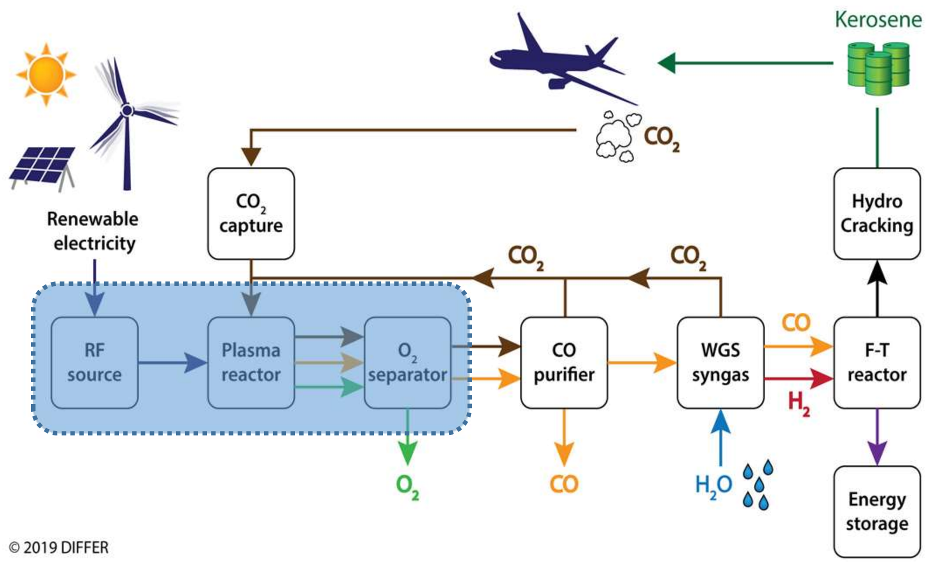
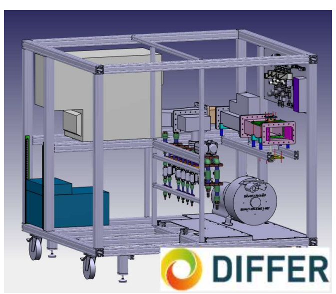
Kerogreen project: Merging Technologies





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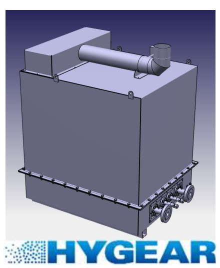

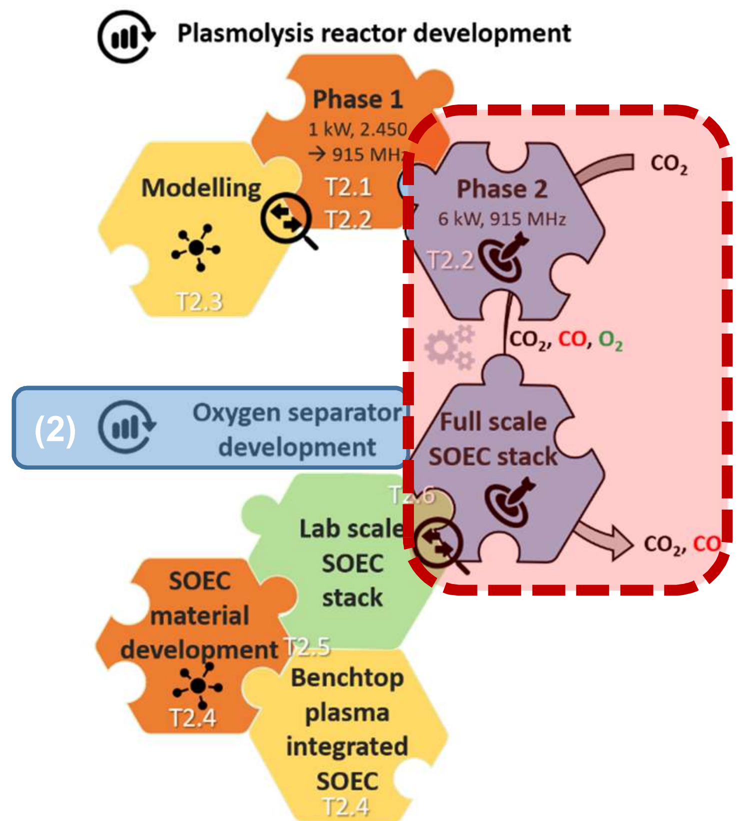

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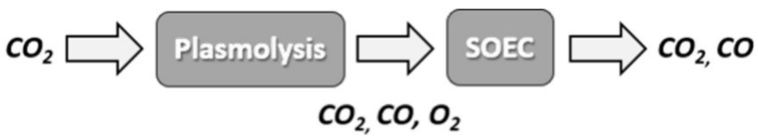
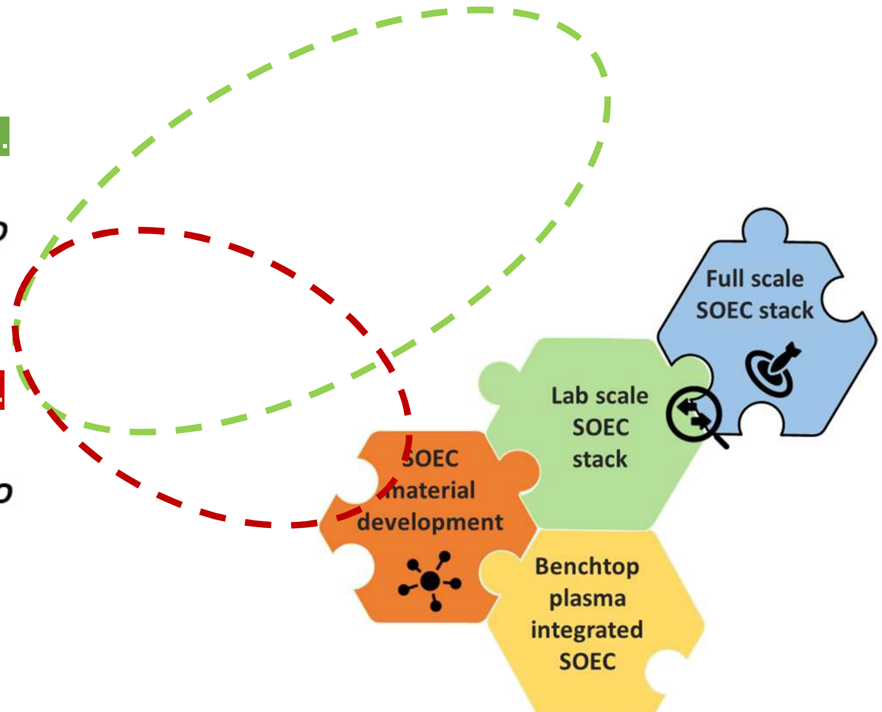
Kerogreen project: Oxygen separation

- Oxygen separation by solid-oxide electrolyte cells (SOECs)
- Approaches
  - Downstream (!)



  - Plasma-integrated



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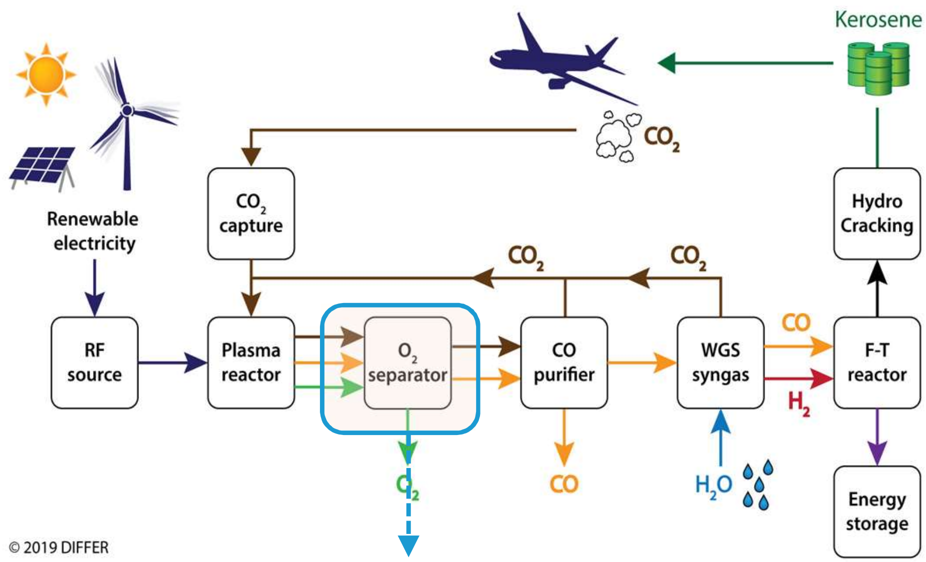
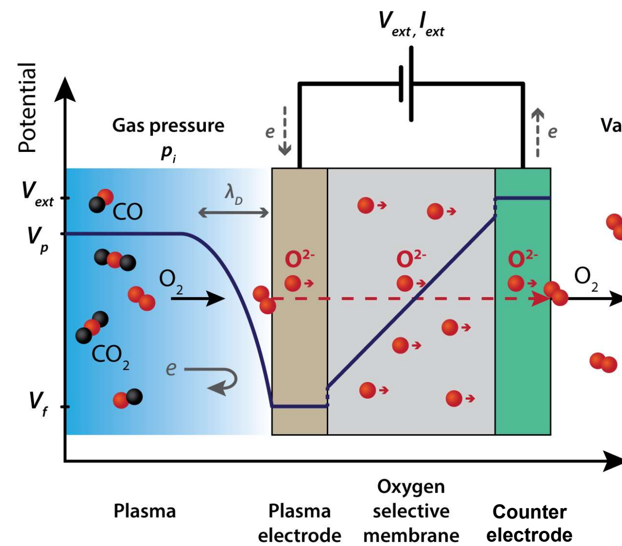
SOEC as oxygen separator





?

O_2 separation

- Difficult process
- Lack of literature
- SOEC: Electrochemical O_2 pumping

Plasma electrode reactions

- $O_2 + 4e^- \rightarrow 2O^{2-}$ (desired)
- $CO_2 + 2e^- \rightarrow CO + O^{2-}$ (neutral)
- $2CO + O_2 \rightarrow 2CO_2$ (unwanted)

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SOEC as oxygen separator

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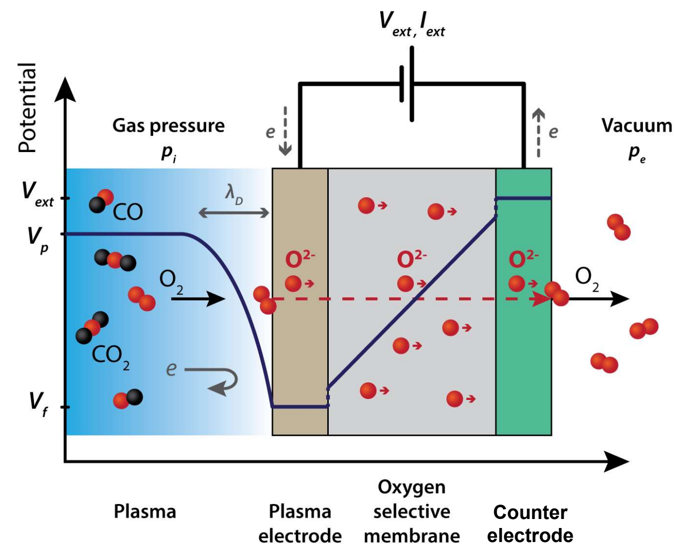
Functionalities

- **For both electrodes:**
  Mixed electronic & ionic conductivity
  Low overpotential losses (gas composition, T)
- **Plasma electrode**
  Unconventional mixture (CO_2 / CO / O_2)
  Poor CO activity
- **Electrolyte**
  Oxygen ion conductivity
  Low resistance → thin
- **Overall**
  High oxygen fluxes
  Stability



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Material screening

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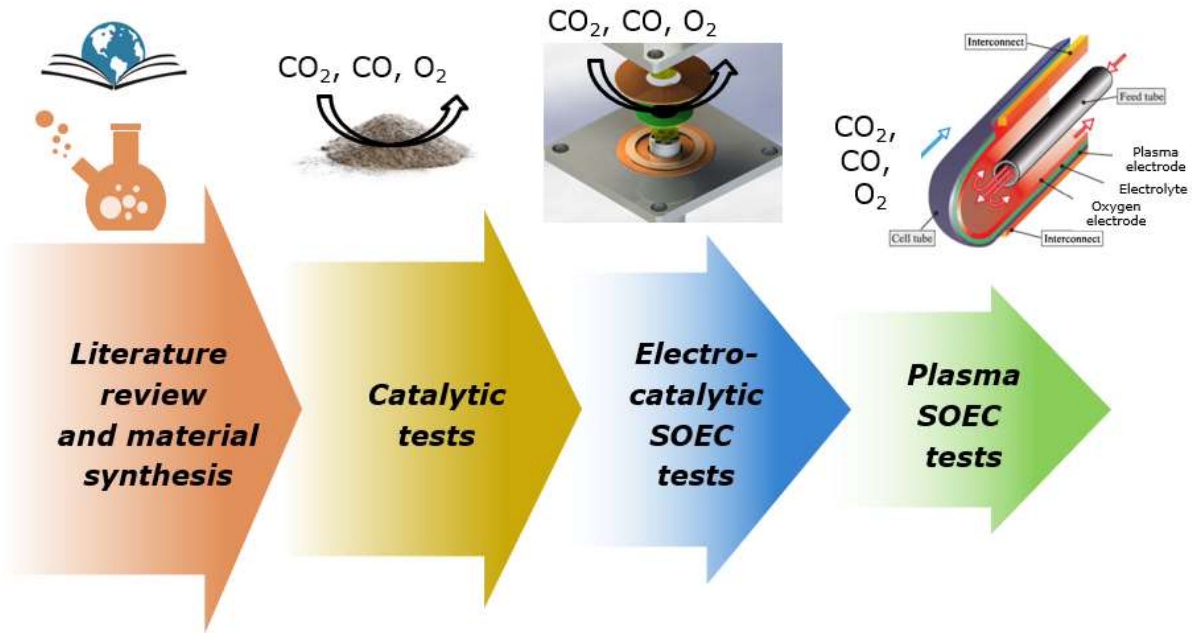
Plasma electrode development

- Literature review
- Material synthesis — Cerpotech
- Catalytic tests
- SOEC electrocatalytic tests
- Plasma SOEC integrated tests



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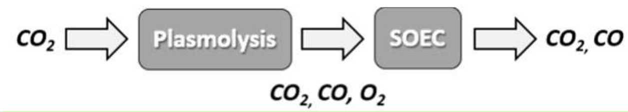
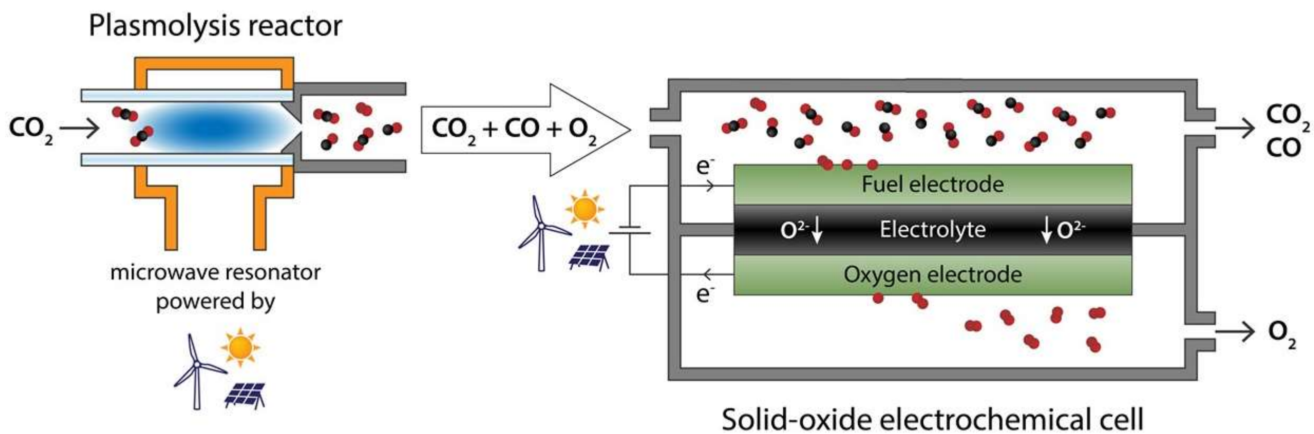
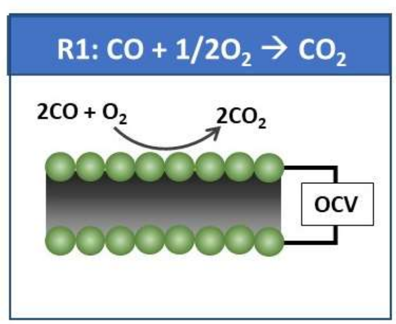
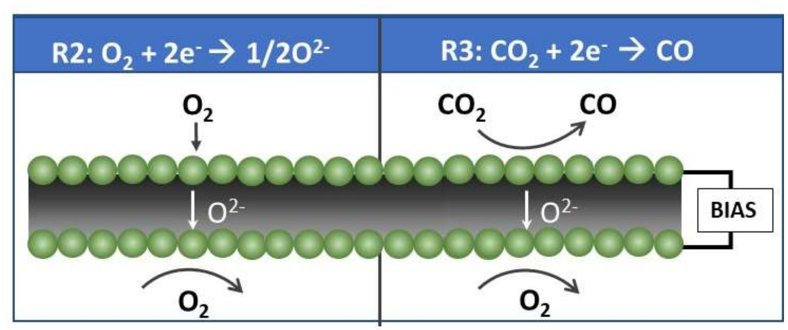
Possible reactions









Unwanted ***Desired*** ***Neutral***

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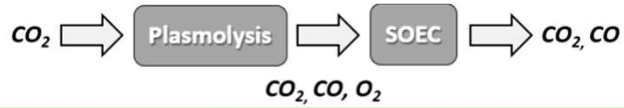
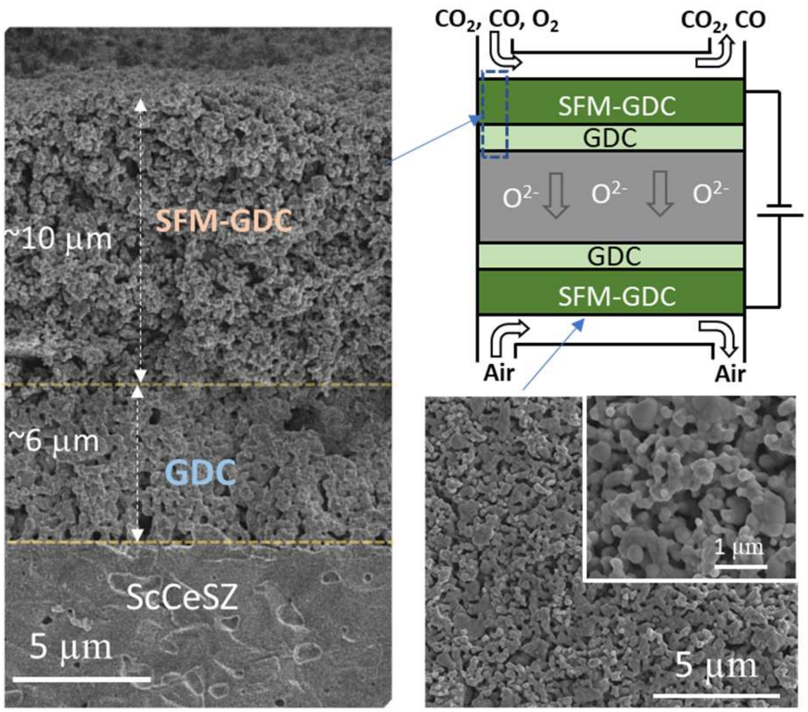
Electrochemical characterization

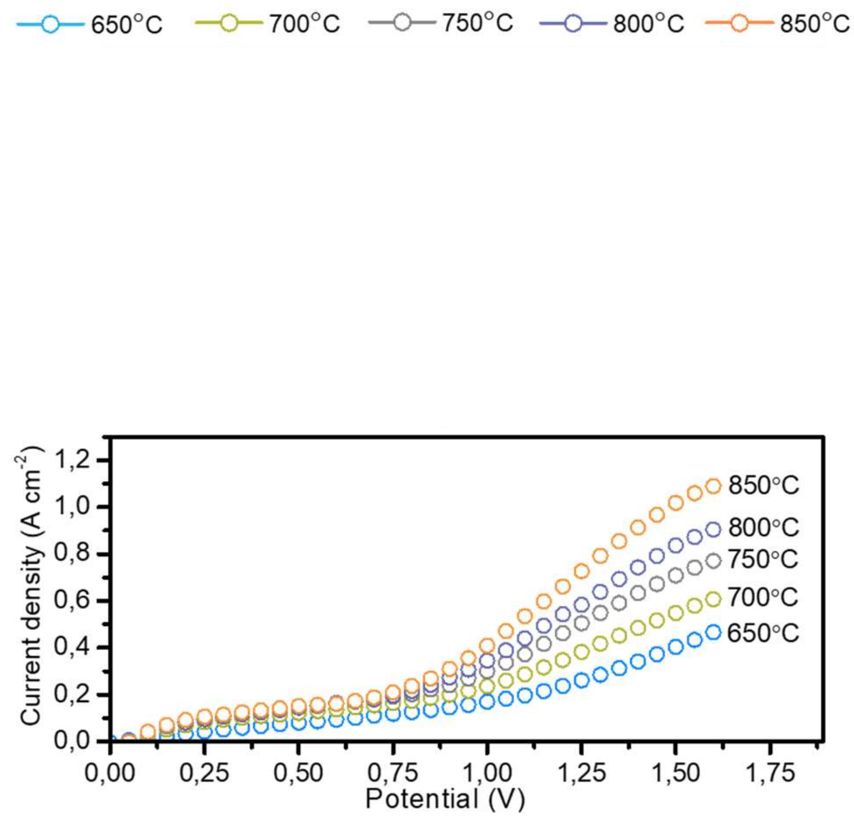


SFM: $Sr_2Fe_{1.5}Mo_{0.5}O_{6-\delta}$

CO_2 plasmolysis equivalent gas mixture

DOI: 10.1016/j.ijhydene.2010.08.016





A. Pandiyan et al. (in preparation)

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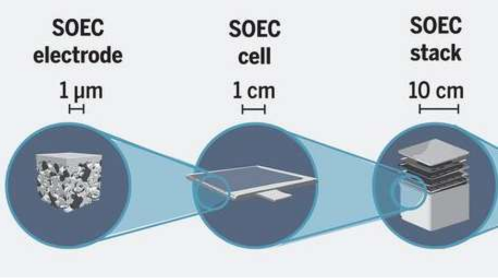
Oxygen separation: Challenges & Take away (II)

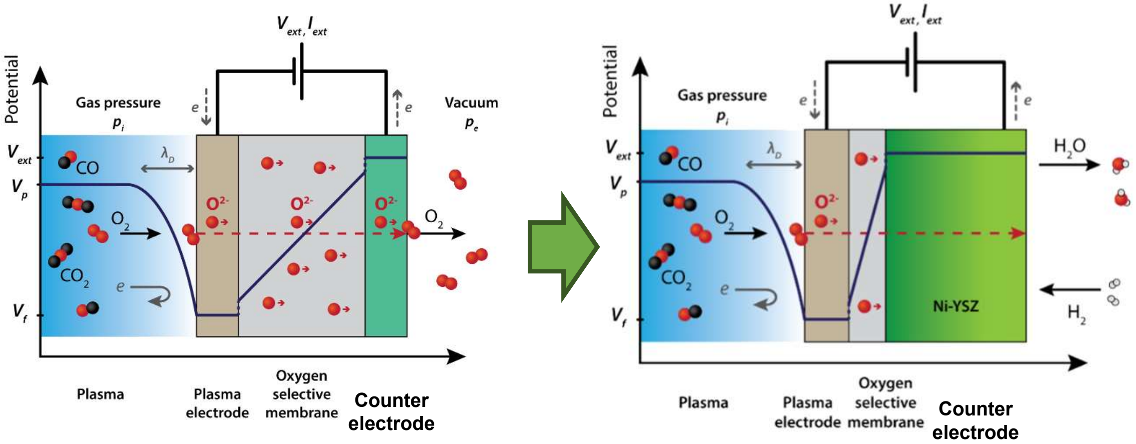
Cell level

- Oxygen separation from CO_2 plasmolysis equivalent mixtures has been demonstrated on cell level.
- SOEC operation with CO_2 plasmolysis equivalent mixtures improves materials stability.
- Limited choice of (commercially available) materials (material challenge!)
- Plasma-integrated approach being developed at DIFFER (TRL 1!)



Stack level & KEROGREEN chain integration

- Advanced SOEC architectures will decrease ohmic losses:
  - allow operation at lower T (less CO losses),
  - while preserving high oxygen pumping rates.
- KEROGREEN: Commercial SOFC vendor → 1.5 kW unit (incl. H_2 co-electrolysis)



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