DIFFER

Dutch Institute for Fundamental Energy Research

CO_2-Neutral Fuels

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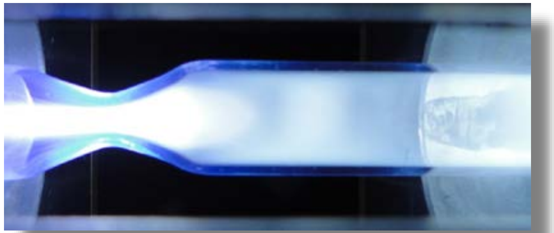
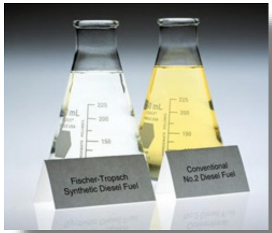
Smart CO_2 Transformation

EERA European Energy Research Alliance



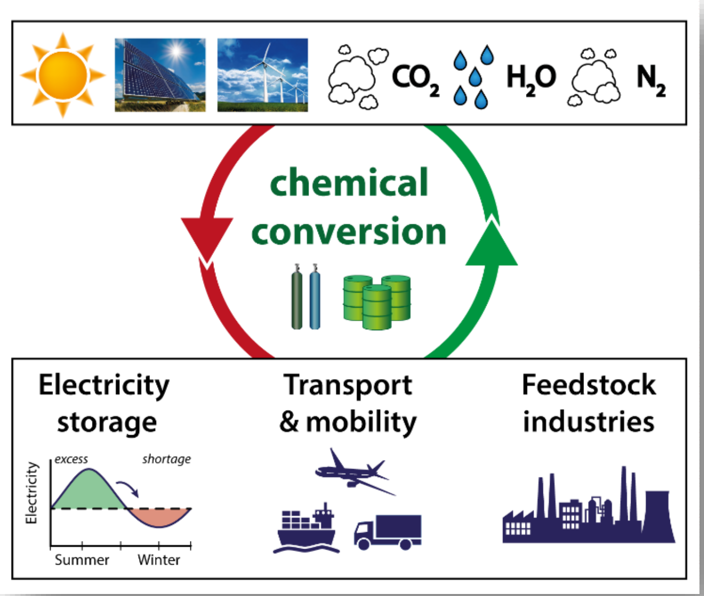



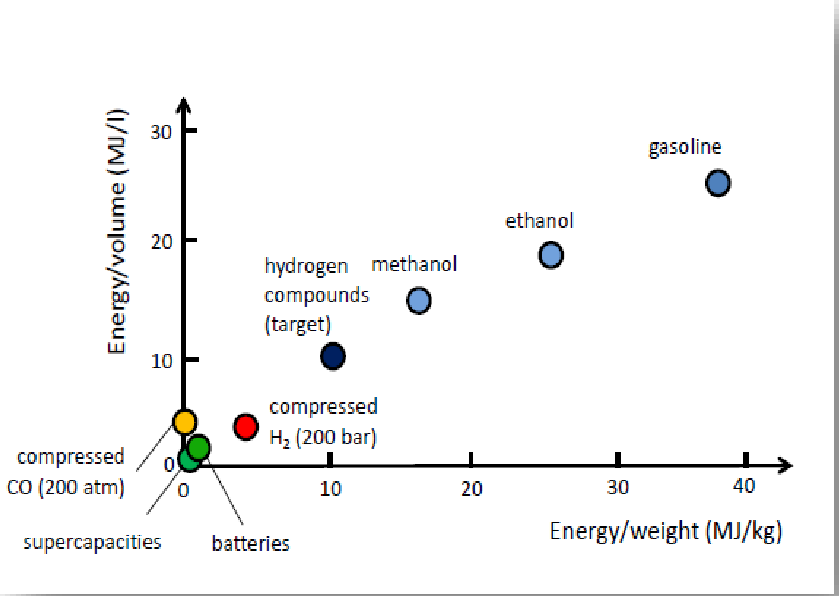
CO_2 Neutral fuels: What are they?

Hydrocarbons synthesised from water and air

- powered by Renewable Electricity
- CO_2 recirculated after use

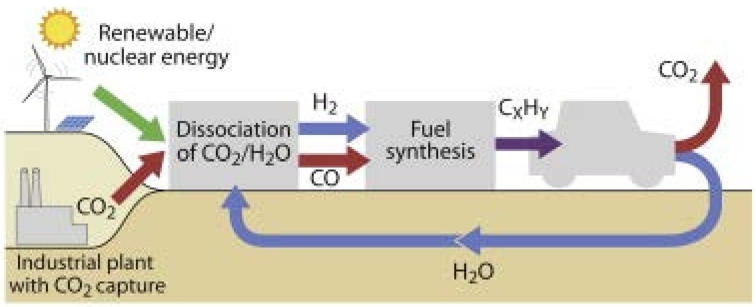
Characterised by high energy density and existing infrastructure





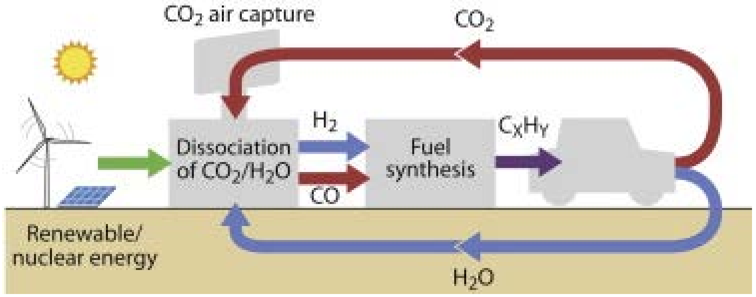
Carbon neutral fuel cycle: P2X – CCU

Point source capture of fossil CO_2
→ not climate neutral, emission delayed



Power-to-X
X = gas or liquid fuel or chemicals

Direct air capture of CO_2
→ climate neutral fuel cycle



P2X + CCU
CCU: carbon capture and utilisation

Graves et al., Ren. Sustain. Energy Rev. **15**, 1, (2011)

P2X is most critical part both technically and economically

<u>Technology benchmark: costs of H_2</u>
- Electrolysis >6 €/kg H_2 (fossil fuel <1 €/kg H_2)
- CO_2 capture: point source 40 €/tonne, direct air 400 €/tonne

Splitting H_2O and / or CO_2 by electrolysis

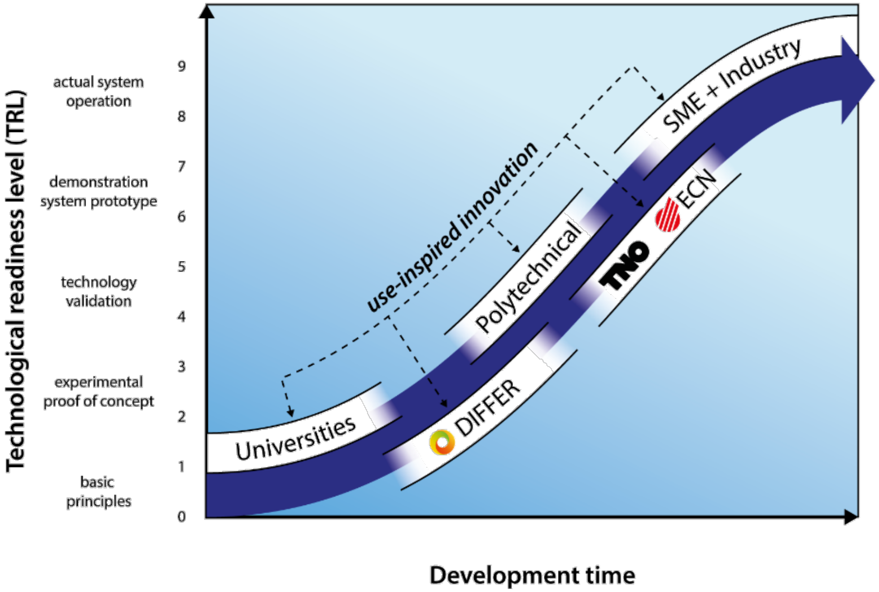
- **Alkaline** electrolyte (100 yrs large scale mature technology)
  - Power density low (< 0.5W/cm^2)
  - Low hydrogen output pressure (< 30bar)
  - Safety (caustic electrolyte)
- **PEM** (polymer electrolyte membrane), pre-commercial
  - Power density ~1W/cm^2
  - Rapid dynamic response
  - Degradation membrane
  - Catalyst material Pt, Ir (Scarce)
  - MW unit (Siemens)
- **SOEC** (solid-oxide electrolyser cell)
  - High power density, energy efficiency, output pressure
  - High Temperature operation (800°C and pressure 50-100 bar)
  - Co-electrolysis H_2O and CO_2
  - Degradation under high current density operation

The DIFFER Institute, Eindhoven, NL

Science for Future Energy

Mission: Basic **scientific research** into
Fusion Energy and **Solar Fuels**,
Based on in house **high-quality technical infrastructure**,
collaboration with Academia, National Research Organisations and Industry,
building a **national community** in **energy research**.

Relocated mid 2015
University Campus Eindhoven

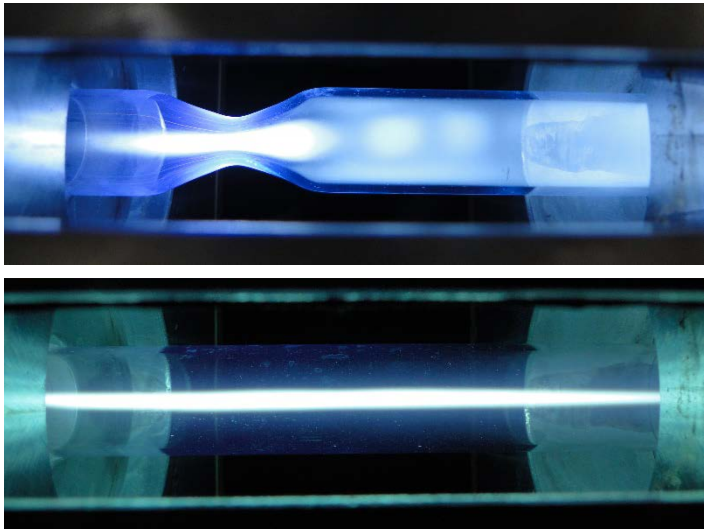


Why plasma for CO_2 conversion?

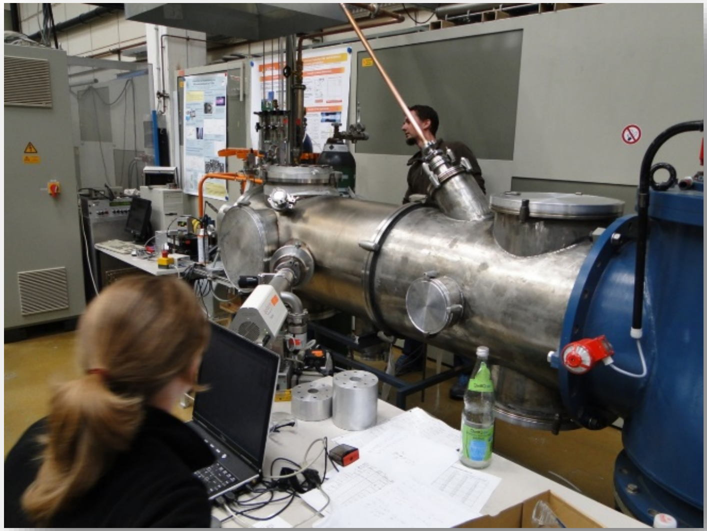
Characteristics of CO_2 plasmolysis

Ease conditions for CO_2 splitting by channelling energy in molecular vibration to break chemical bond, not to heat the gas (non-equilibrium)

- Energy efficiency comparable to Electrolysis (~60% demonstrated)
- High productivity: large gas flow and power flow density (45W/cm^2)
- Fast dynamic response to intermittent power supply
- No scarce materials employed (Pt catalyst in PEM)



30 kW @ 915 MHz



Out of equilibrium $T_{vib} > T_0$ chemistry

Chemical reaction scheme

$CO_2 \rightarrow CO + O$ (ΔH=5.5 eV)

followed by reuse energetic **O** radical

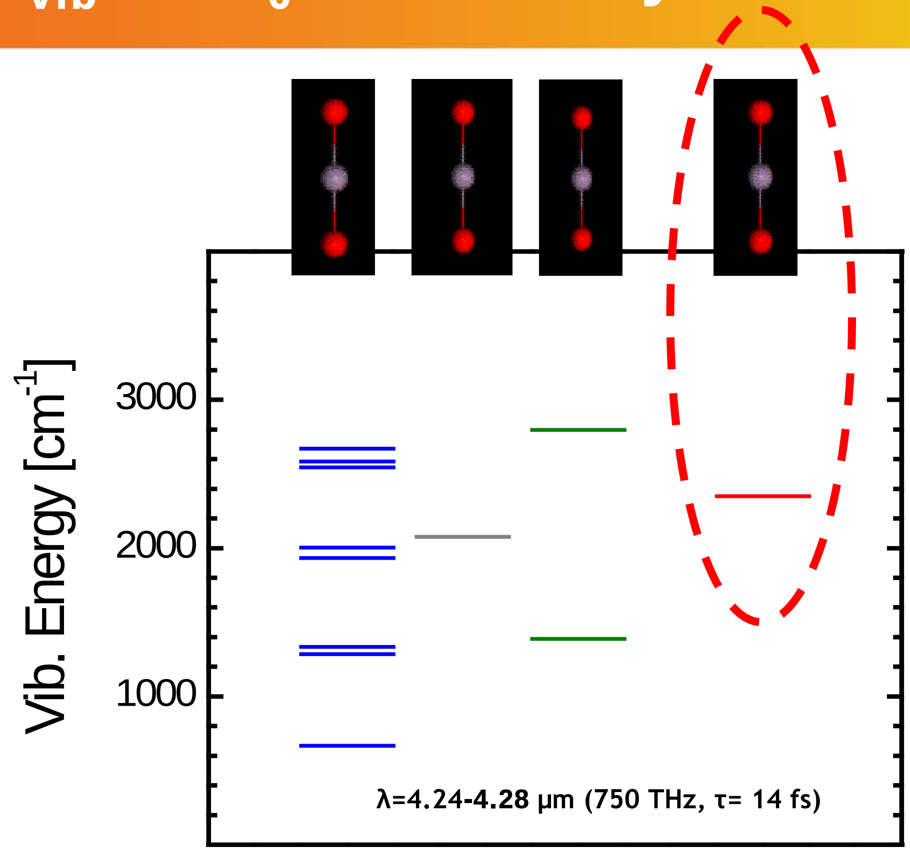
$CO_2 + O \rightarrow CO + O_2$ (ΔH=0.3 eV)

Net

$CO_2 \rightarrow CO + ½\ O_2$ (ΔH=2.9 eV)

Efficiency to be increased by

Concentration of electron energy on vibrational excitation of CO_2 in asymmetric stretch mode

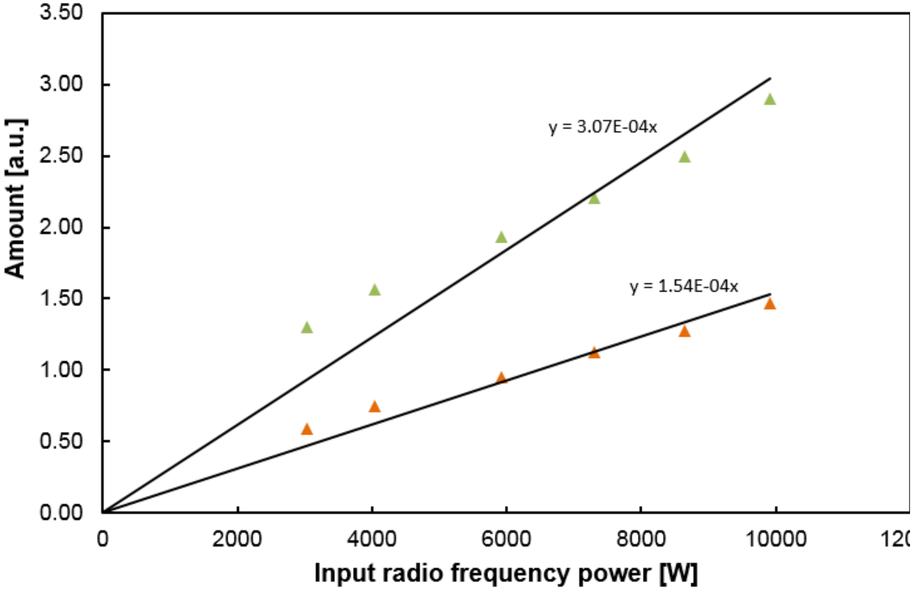


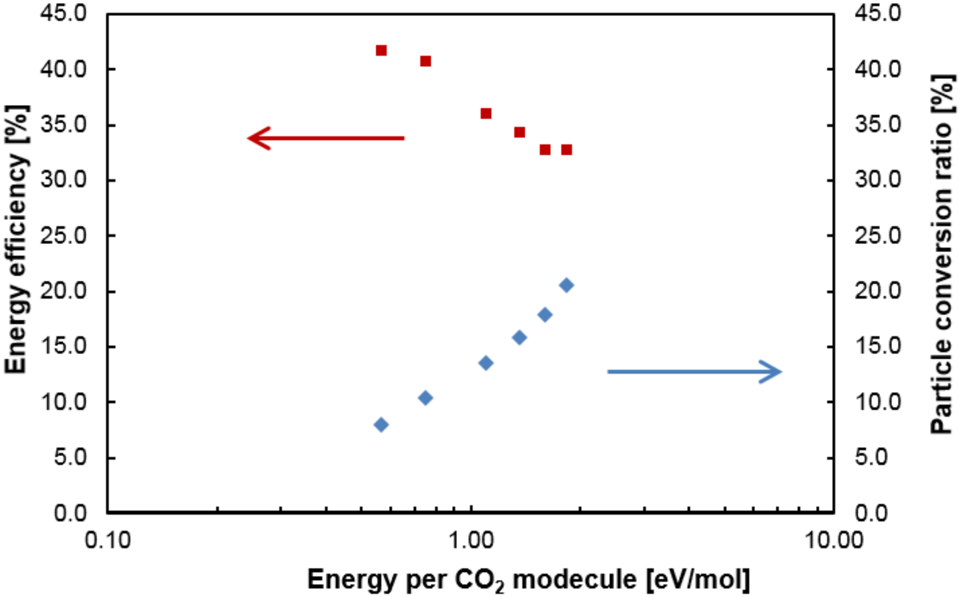
Arrhenius/Fridman:
Activation energy reduced by vibration energy

$k = A \exp (\alpha E_v - E_a)/kT$

Experimental Results

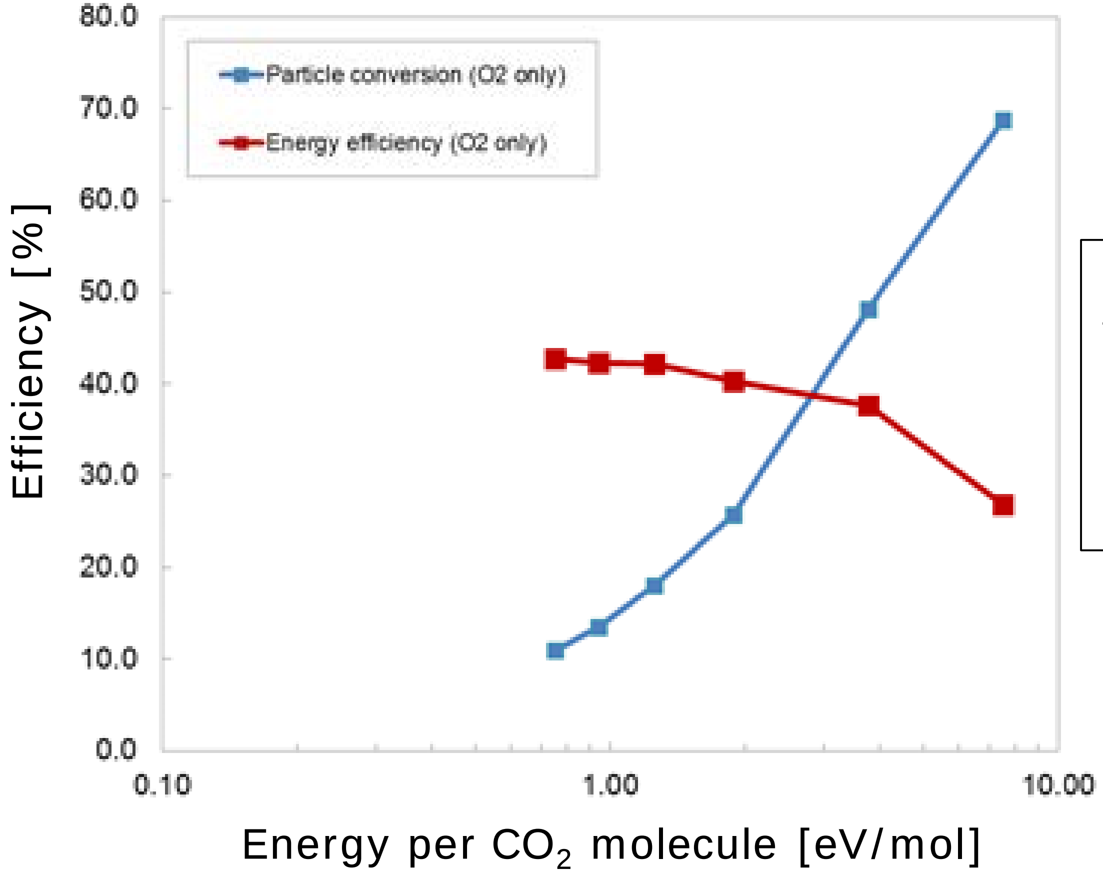
- CO and O_2 production as function **RF Power**





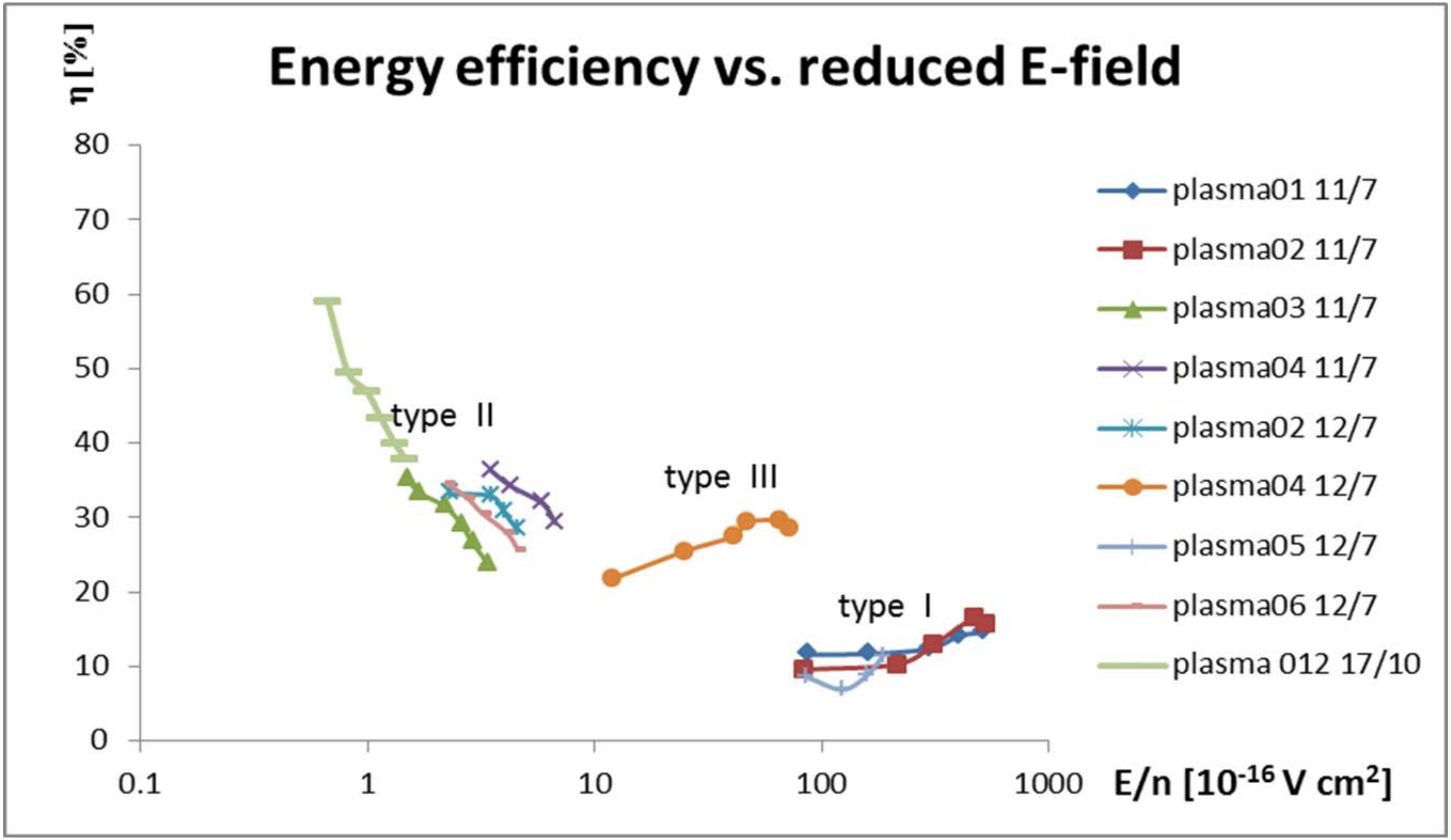
Experimental Results

- CO production as function **Gas flow**

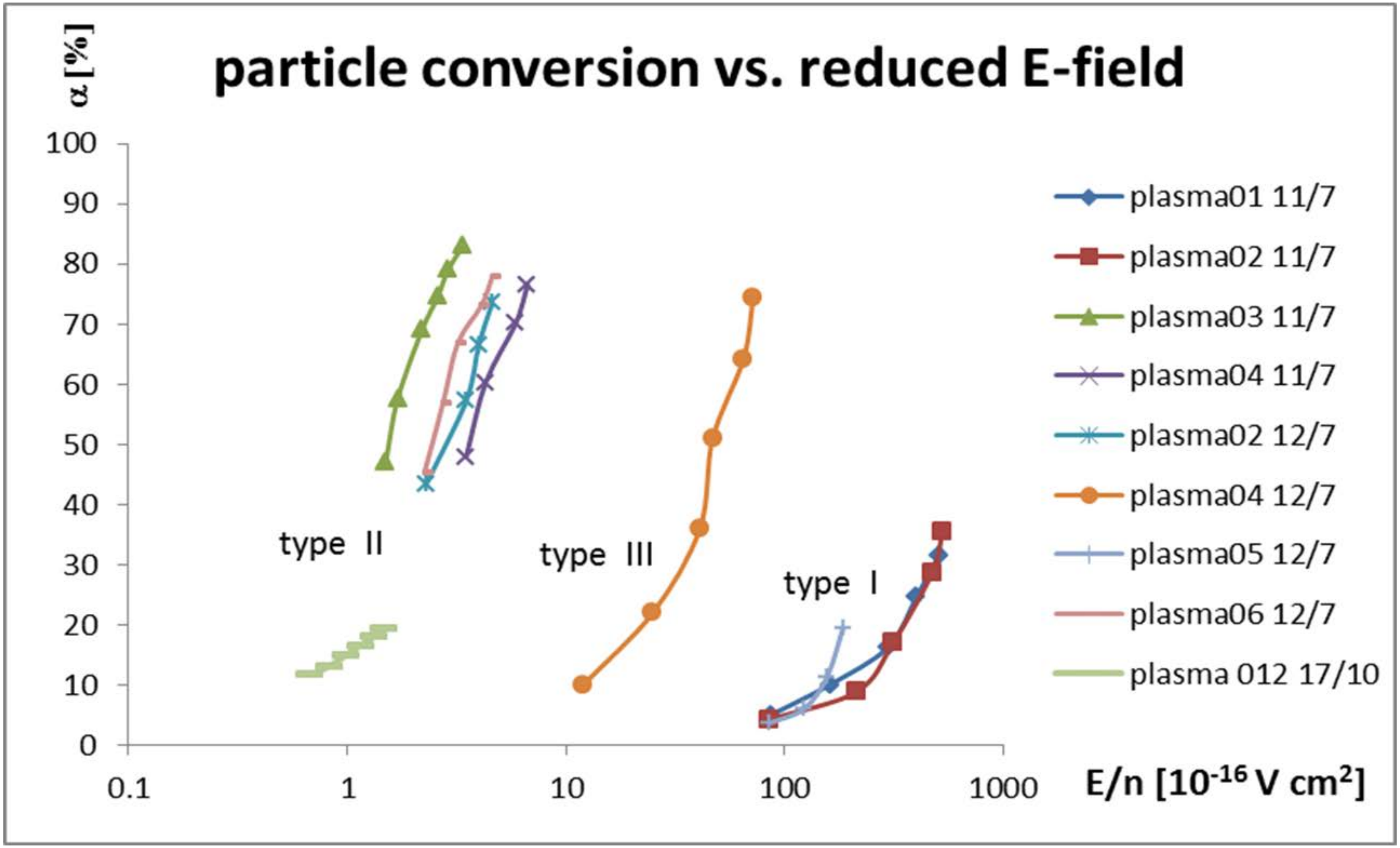


10 kW RF absorbed
75 slm CO2, conversion 10% CO
(non optimised for safety risk)
Pressure 500 mbar,
Energy Efficiency 30%

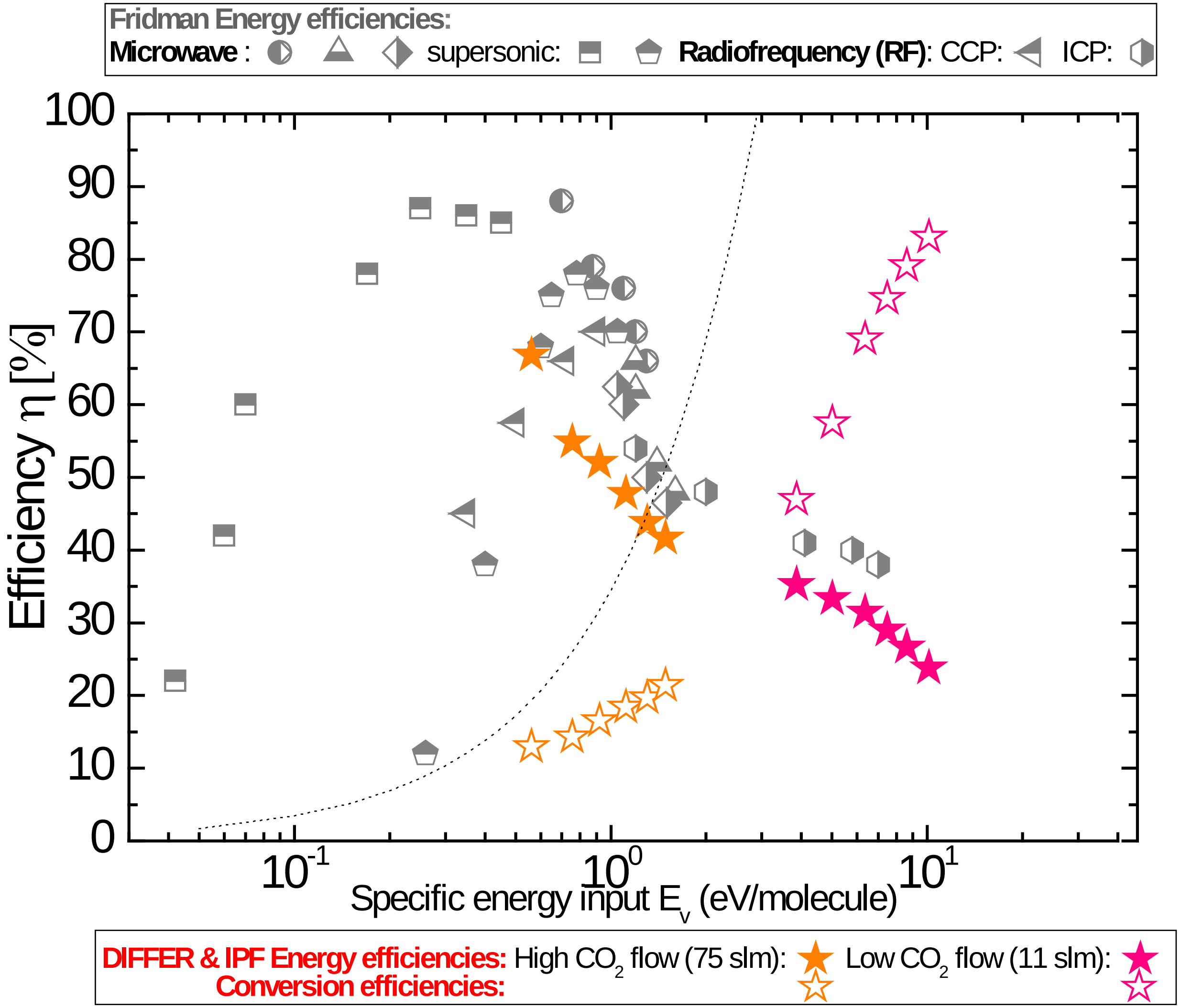
Experimental Results



Experimental Results

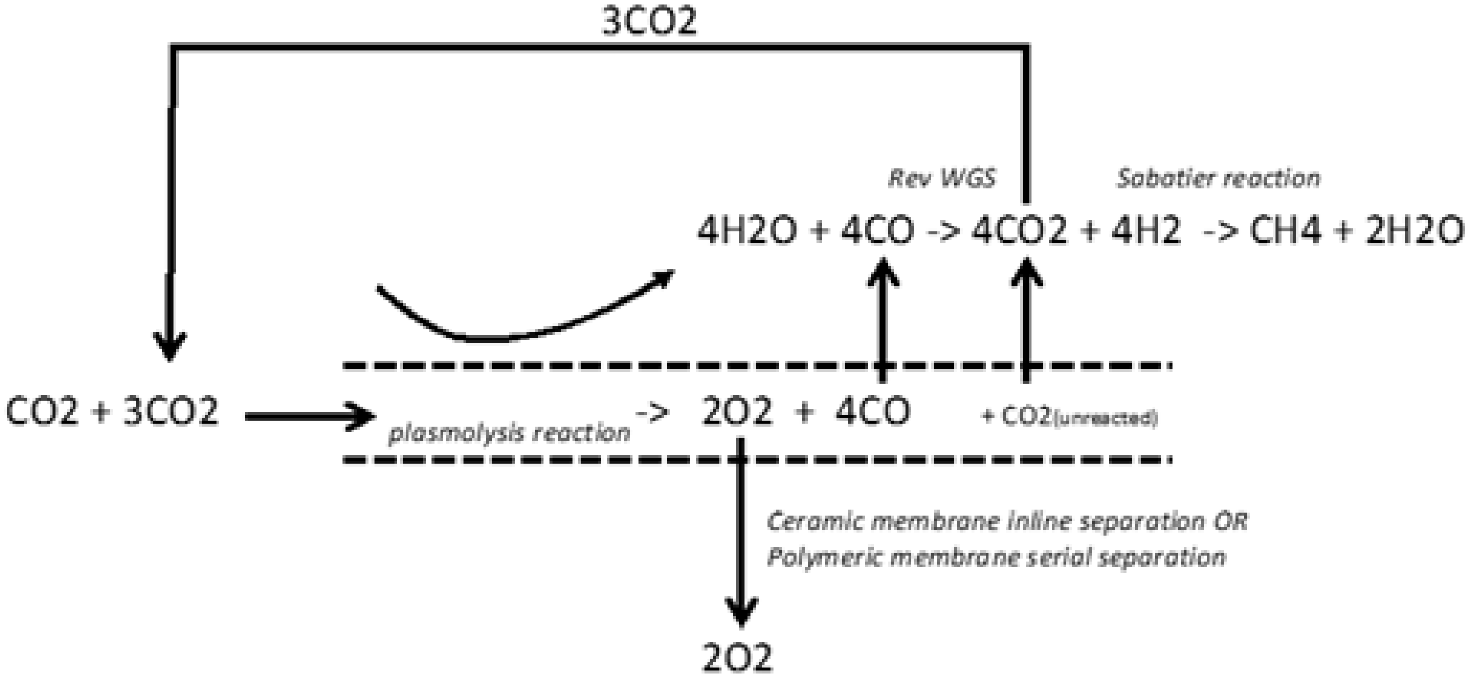


Energy efficiency of CO_2 plasma conversion



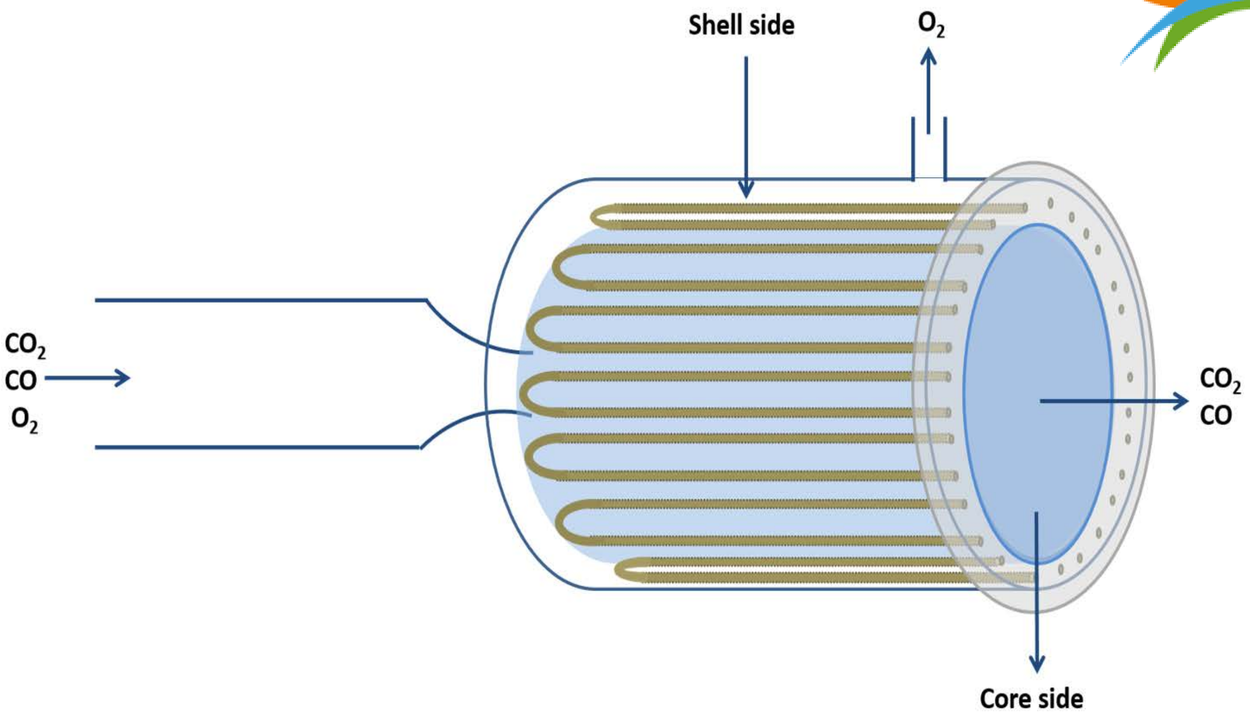
O_2 separation from CO (similar sized)

- MIEC mixed ion electron conductive membrane (pressure driven) BSCF ($Ba_{0.5}$ $Sr_{0.5}$ $Co_{0.8}$ $Fe_{0.2}$ O_{3-d}) has been shown to produce an O_2 flux of 60-80 ml/cm^{2}per min.
- Electro chemical Oxygen pump (Voltage driven) YSZ (Yttrium stabilized Zirconia).

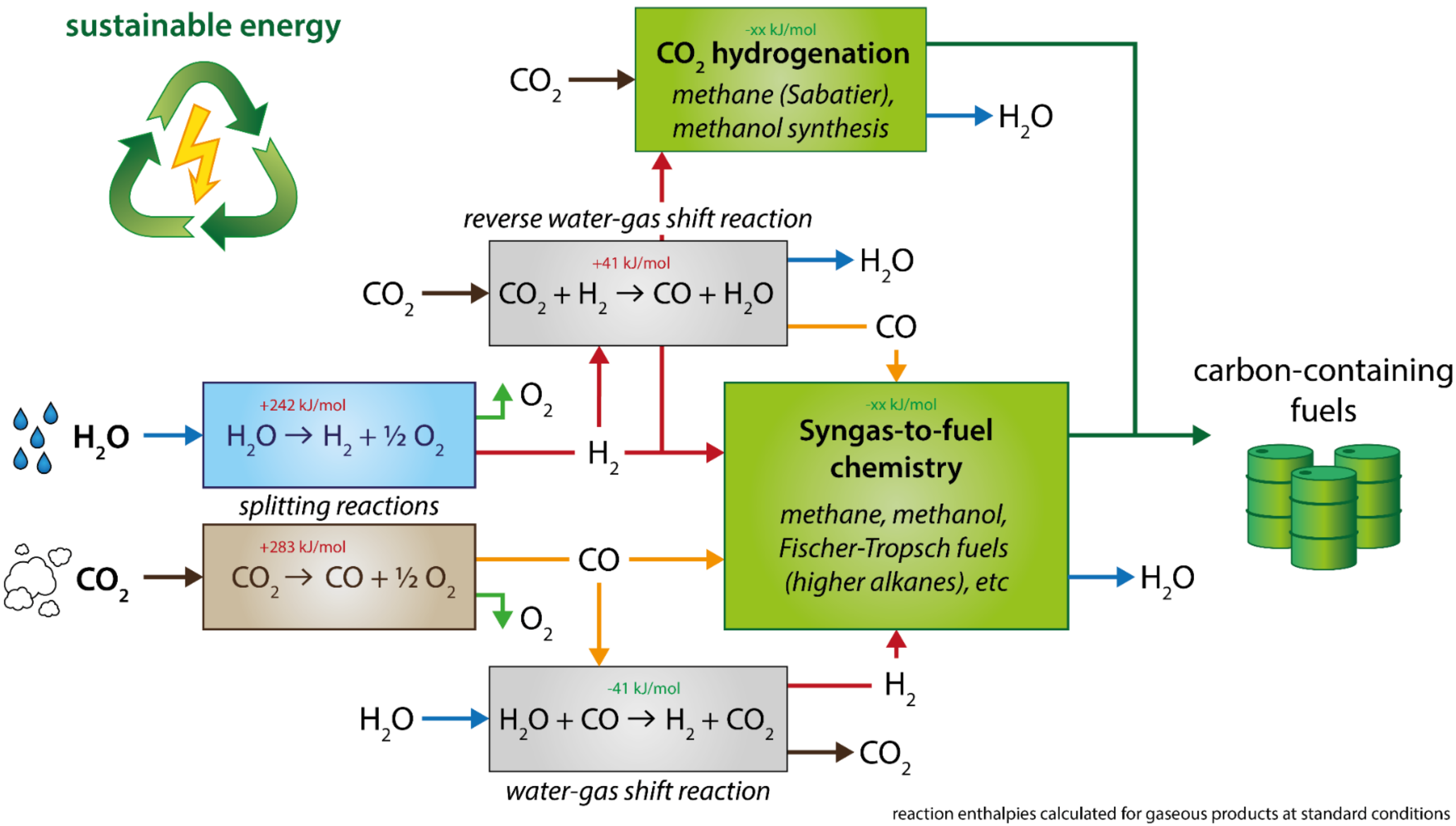


Separation of CO, O_2, CO_2 mixture

YSZ Oxygen selective membrane to separate O_2 from CO, CO_2 mixture
Hairpin shaped membranes fitted into SS assembly



From H_2O and CO_2 to sustainable hydrocarbons



Conclusions

- P2X provides vast seasonal energy storage capacity and flexibility of supply from Renewables
- P2X-CCU enables a CO_2 neutral fuel cycle based on hydro-carbons and existing infrastructure
- Technical challenge: innovation in CO_2 splitting and CO-O_2 separation
- Economic challenge: cost reduction, government regulation, business case expected to emerge around 2030, cost of CO_2 to reach € 200/tonne