Plasma discharges for energy storage:

the case of Dry Reforming of Methane

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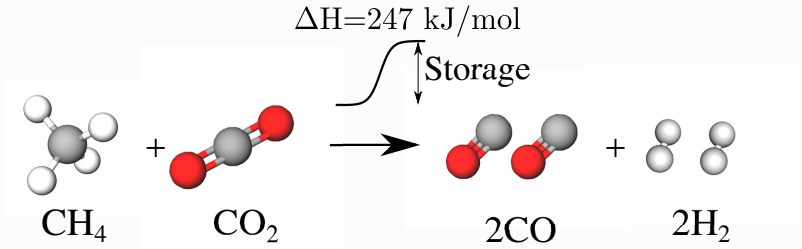
Dry Reforming of Methane (DRM)



CO + H_2 (syngas) $\xrightarrow{\text{Fischer–Tropsch}}$ **synthetic liquid fuel (methanol)**

Methane: two sides of the same coin

- CH_4 is abundant and *"clean"*:
  the fossil fuel of the future
- Low energy density per volume
- Powerful greenhouse gas

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European Commission – Press release

Reducing greenhouse gas emissions: Commission adopts EU Methane Strategy as part of European Green Deal

Brussels, 14 October 2020

The European Commission presented today an EU strategy to reduce methane emissions. Methane is the second biggest contributor to climate change, after carbon dioxide. It is also a potent local air pollutant causing serious health problems. Tackling methane emissions is therefore essential to reaching our 2030 climate targets and the 2050 climate neutrality goal, as well as contributing to the Commission's zero-pollution ambition.

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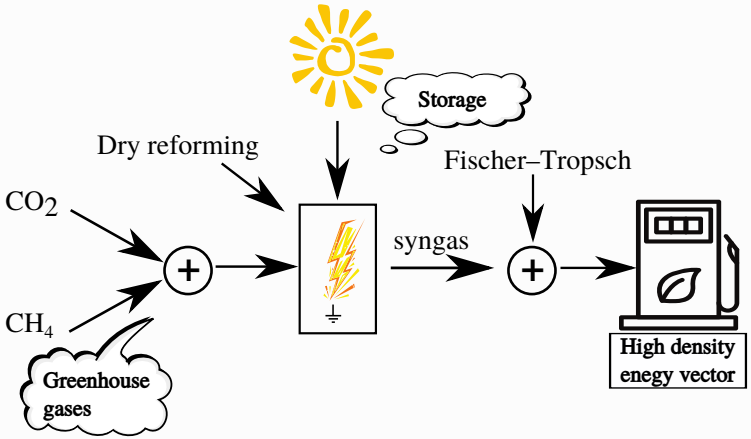
...

To **reduce methane emissions in the energy sector**, an obligation to improve detection and repair of leaks in gas infrastructure will be proposed and legislation to prohibit routine flaring and venting practices will be considered. The Commission will engage in a dialogue with its international partners and explore possible standards, targets or incentives for energy imports to the EU, and the tools for enforcing them.

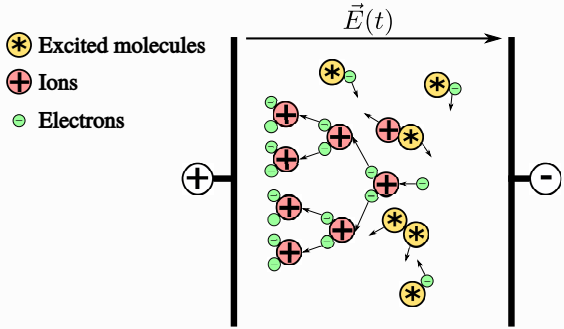
$$\mathbf{CO_2 + CH_4} \xrightarrow{\text{Dry reforming}} \mathbf{syngas} \xrightarrow{\text{Fischer–Tropsch}} \mathbf{methanol}$$

Full picture



Electrical discharges for Dry Reforming

- Non equilibrium as an alternative to thermal processes
- Scalability
- Low inertia



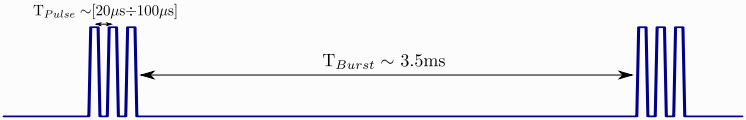
The experiment: nanosecond pulsed discharges

High flexibility in varying the timescale of the electric field:

- FWHM $\simeq$ 10 ns
- $E_{pulse} \simeq$ 10 mJ
- $P_{pulse} \simeq$ 1 MW (**!!!**)
- $\tilde{P} \simeq$ 10 W

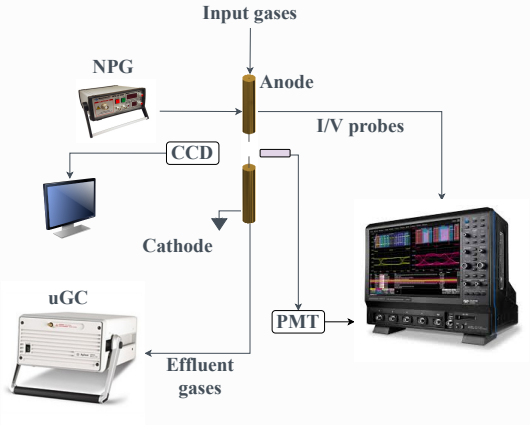
Periodic pulse train

Burst pulse train

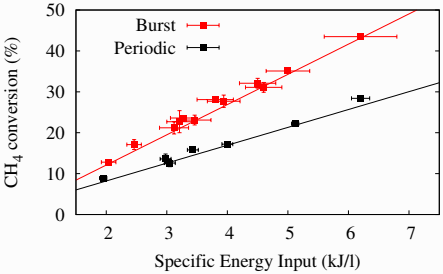


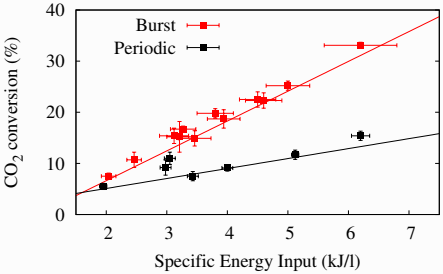
The experimental set-up

- Electrode configuration: pin-to-pin
- Nanosecond Pulse Generator: minimum T_{pulse}=10μs
- High bandwidth I/V probes
- Oscilloscope
- CCD: gateble camera
- PMT: Photo Multiplier Tube
- Product analysis: gas chromatography (uGC, GC-FID/MS)



Results


Burst
Periodic
CH_4 conversion (%)
Specific Energy Input (kJ/l)
0
10
20
30
40
50
2
3
4
5
6
7


Burst
Periodic
CO_2 conversion (%)
Specific Energy Input (kJ/l)
0
10
20
30
40
2
3
4
5
6
7

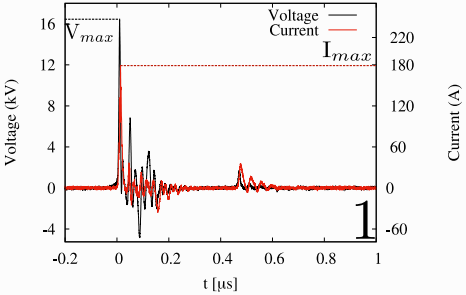
Insight: I-V characteristics

Two successive pulses in a burst with an inter-pulse time T_p=20μs

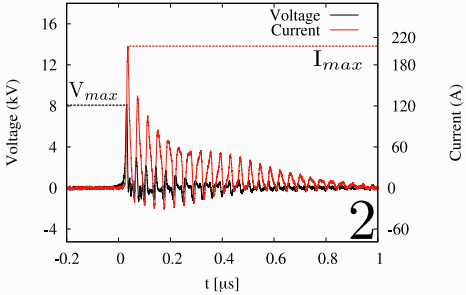
$\tilde{E}_e$: mean electron energy

$\tilde{\rho}_e$: mean electron density

$\tilde{E}_e \uparrow \quad \tilde{\rho}_e \downarrow$



$\tilde{E}_e \downarrow \quad \tilde{\rho}_e \uparrow$



Memory effect of the discharge

Below T_{pulse}=100μs the discharge shows a memory effect:

the subsequent pulses in a burst do not act independently, they occur in a perturbed environment because of the initial pulse

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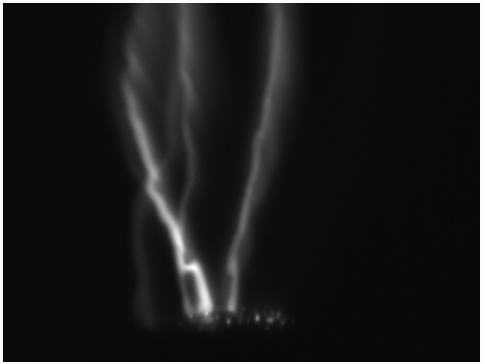
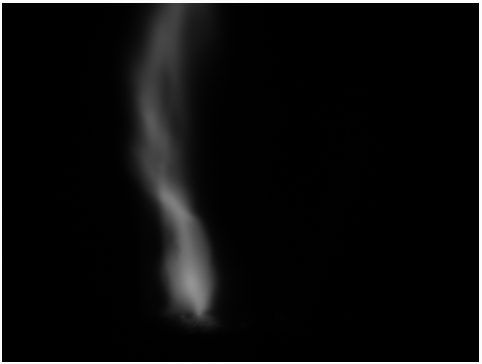
higher performances by giving the same energy in different ways

Memory effect: snapshots

Images of two burst pulse trains with three pulses



$T_{pulse}=500\mu s$

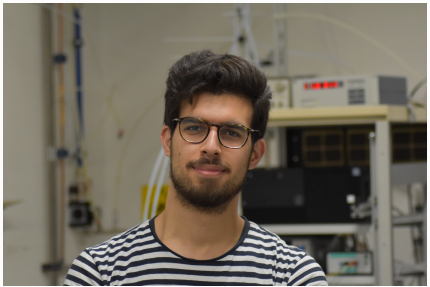


$T_{pulse}=20\mu s$

Conclusions

- Dry Reforming: a strategy for storing renewable power in chemical form by converting two greenhouse gases
- Electrical discharges: an equilibrium alternative to thermal processes
- **A repeated sequence of a few very close (20-40)μs pulses is more effective than a continuous train of relatively distant (0.8-2)ms pulses.**

Personalia



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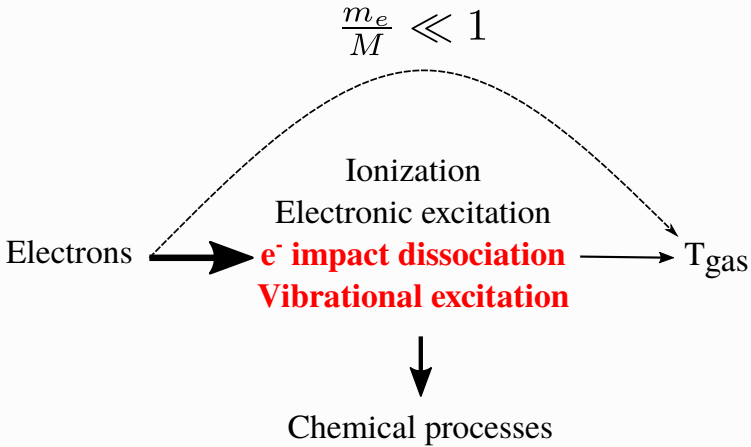
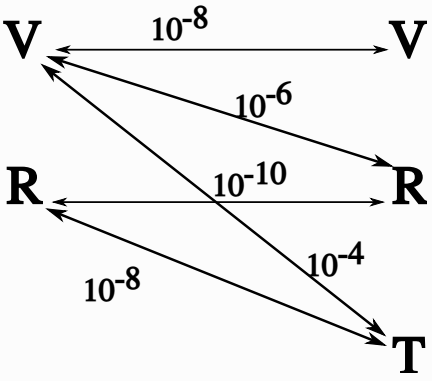
Non equilibrium



Non equilibrium

Collisional energy transfer

- VV: Vibration-to-vibration
- VR: Vibration-to-rotation
- VT: VIbration-to-Translation
- RR: Rotation-to-rotation
- RT: Rotation-to-Translation



Time expressed in seconds