Carbon nanomaterials from methane pyrolysis as functional additives for advanced polymer composites

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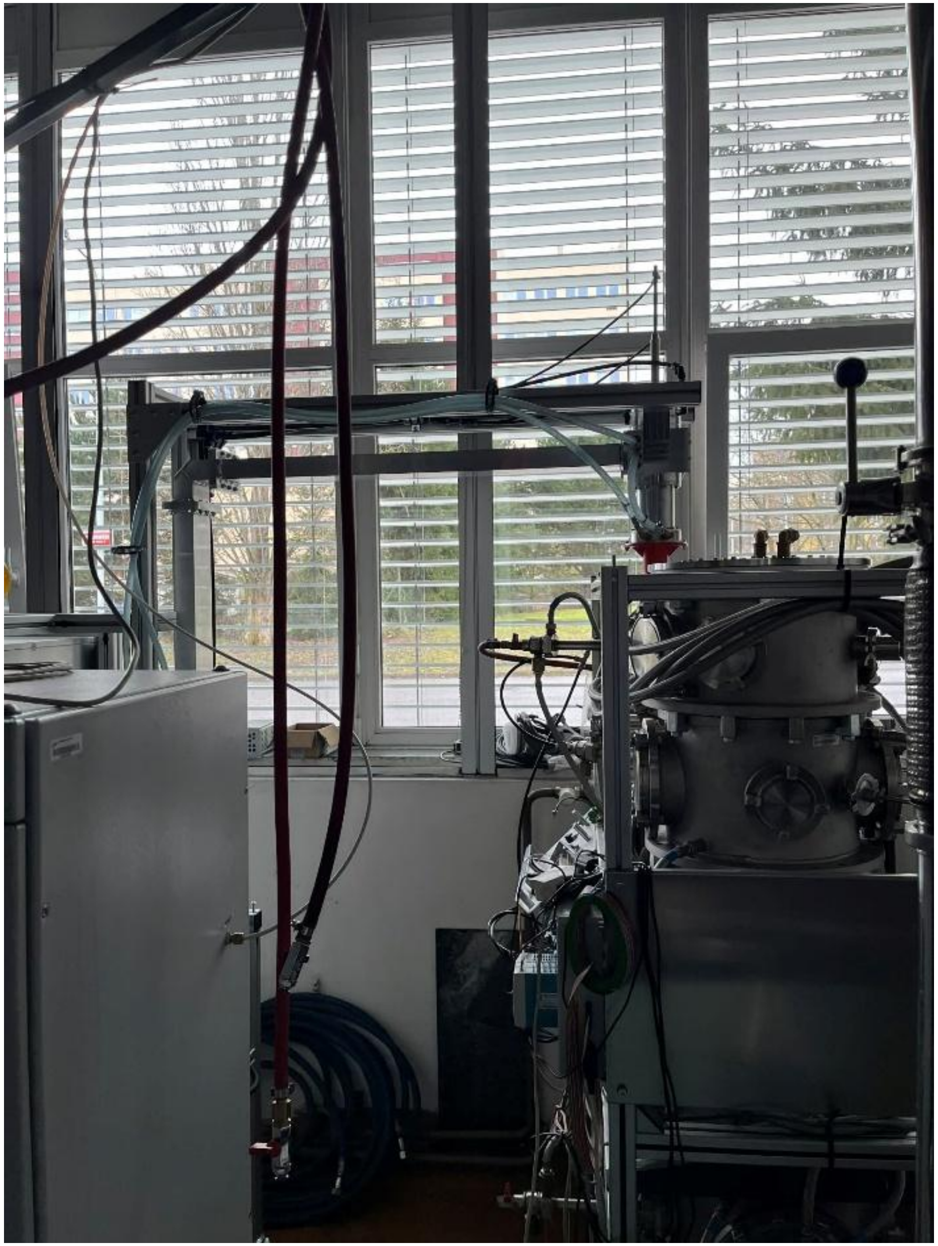
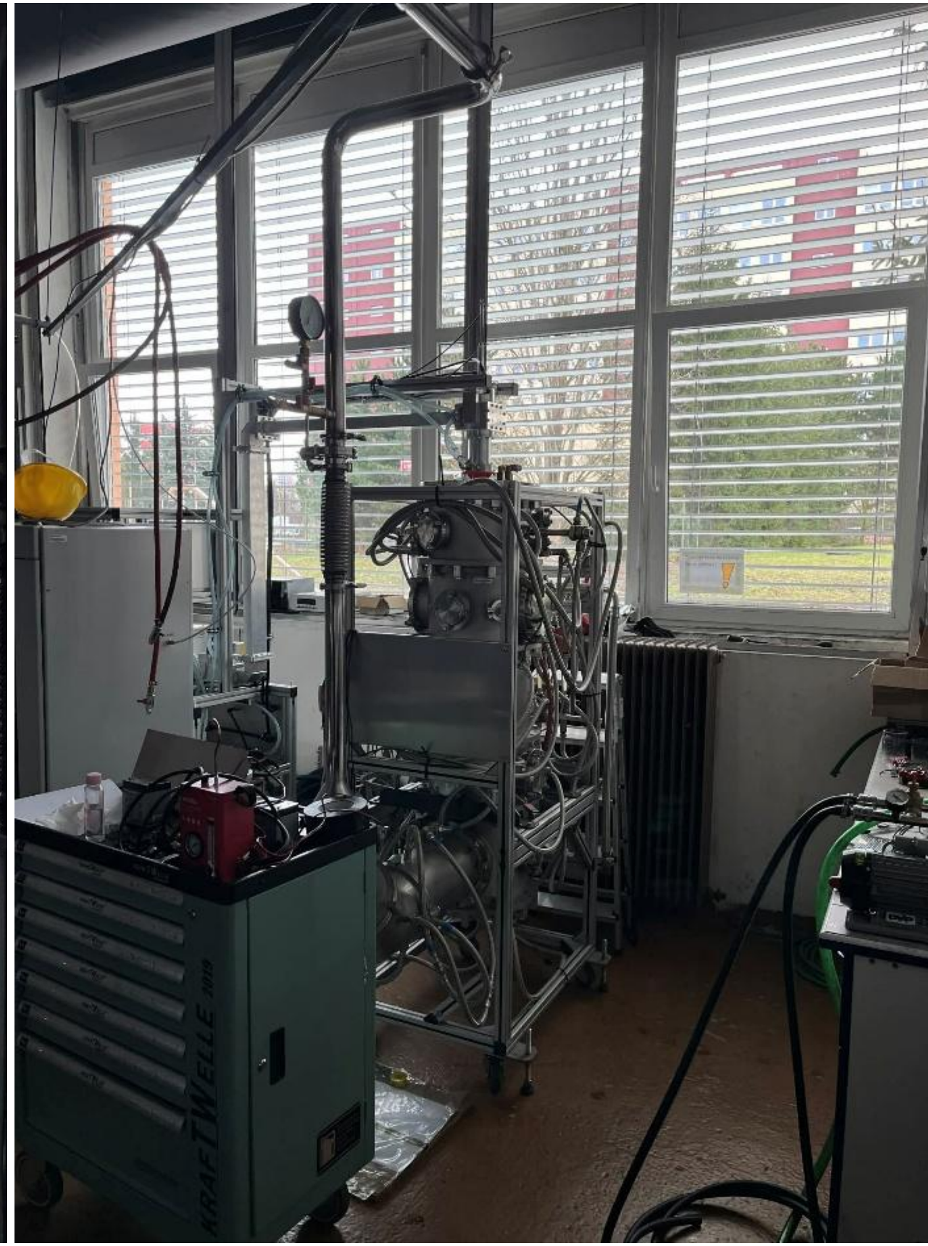
Possibilities

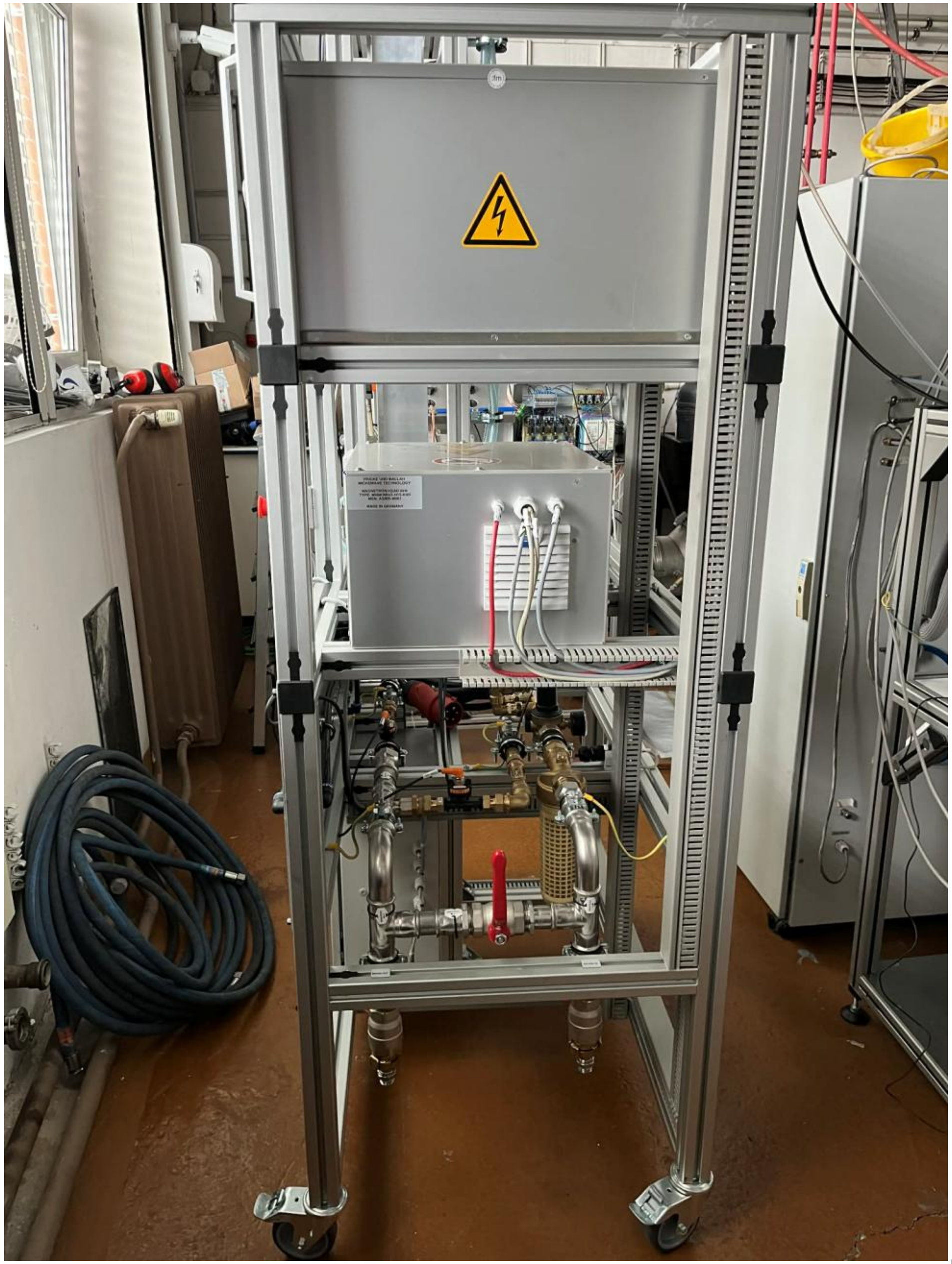
1. **Microwave thermal plasma pyrolysis** of methane for the hydrogen and nanoparticles as well as quantum dots production.

2. **Modelling and calculation** of plasma and output gas properties using computational fluid dynamics, thermodynamic equilibrium, energetic and economic balances.

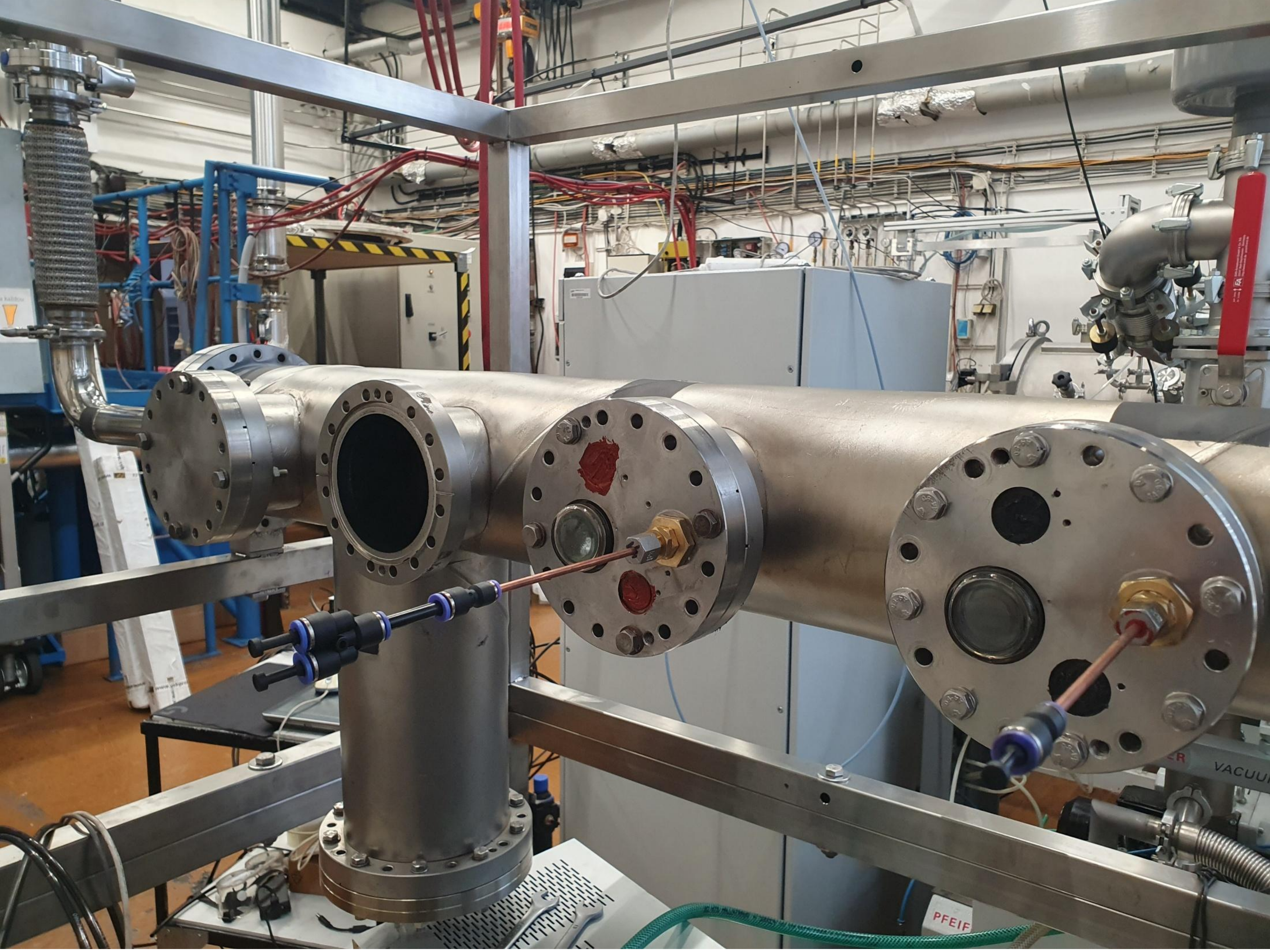
3. **Experimental characterization** of output gas as well as nanoparticles including mass spectrometry, chromatography, luminescence and magnetic resonance data interpretation

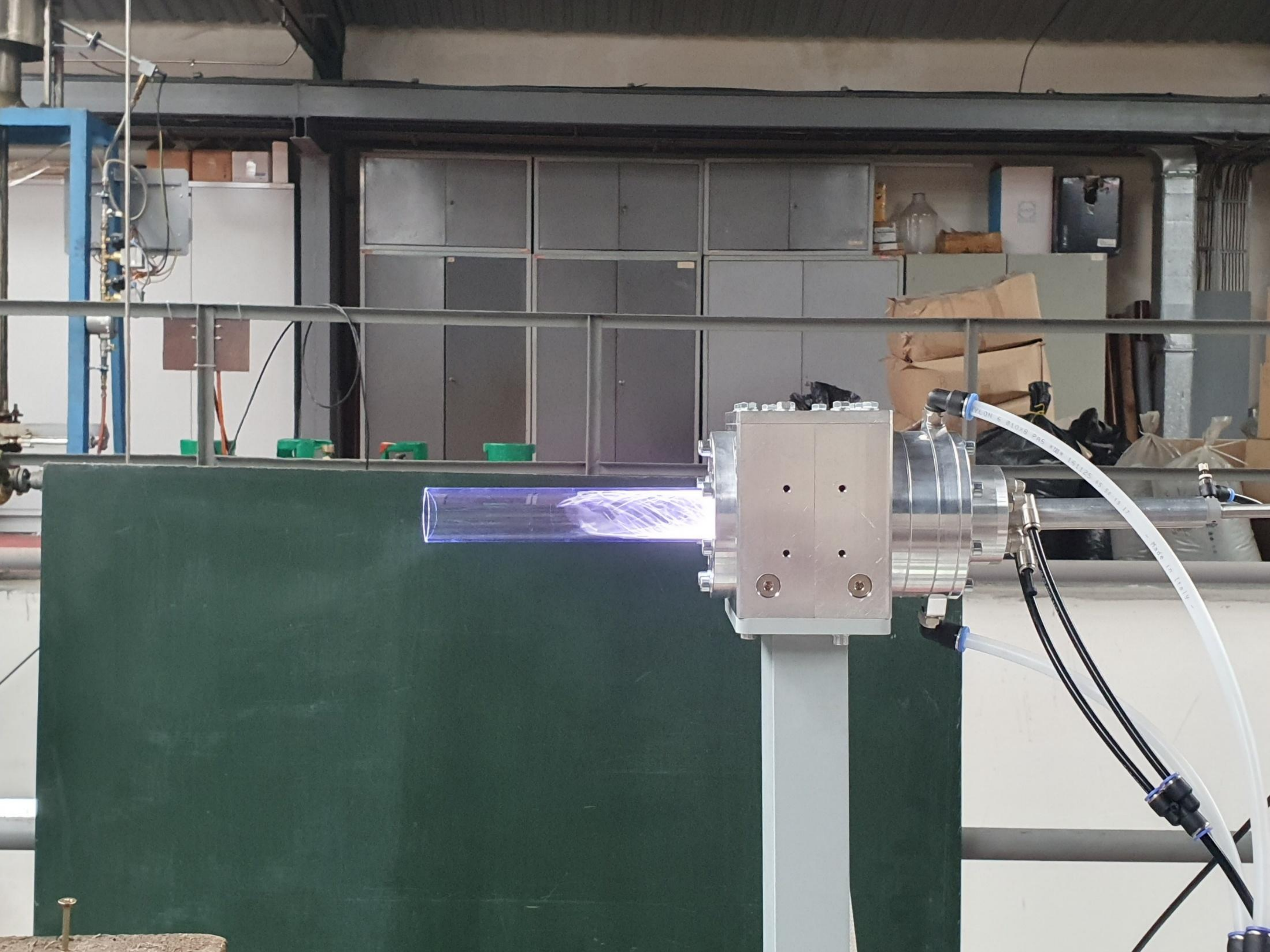


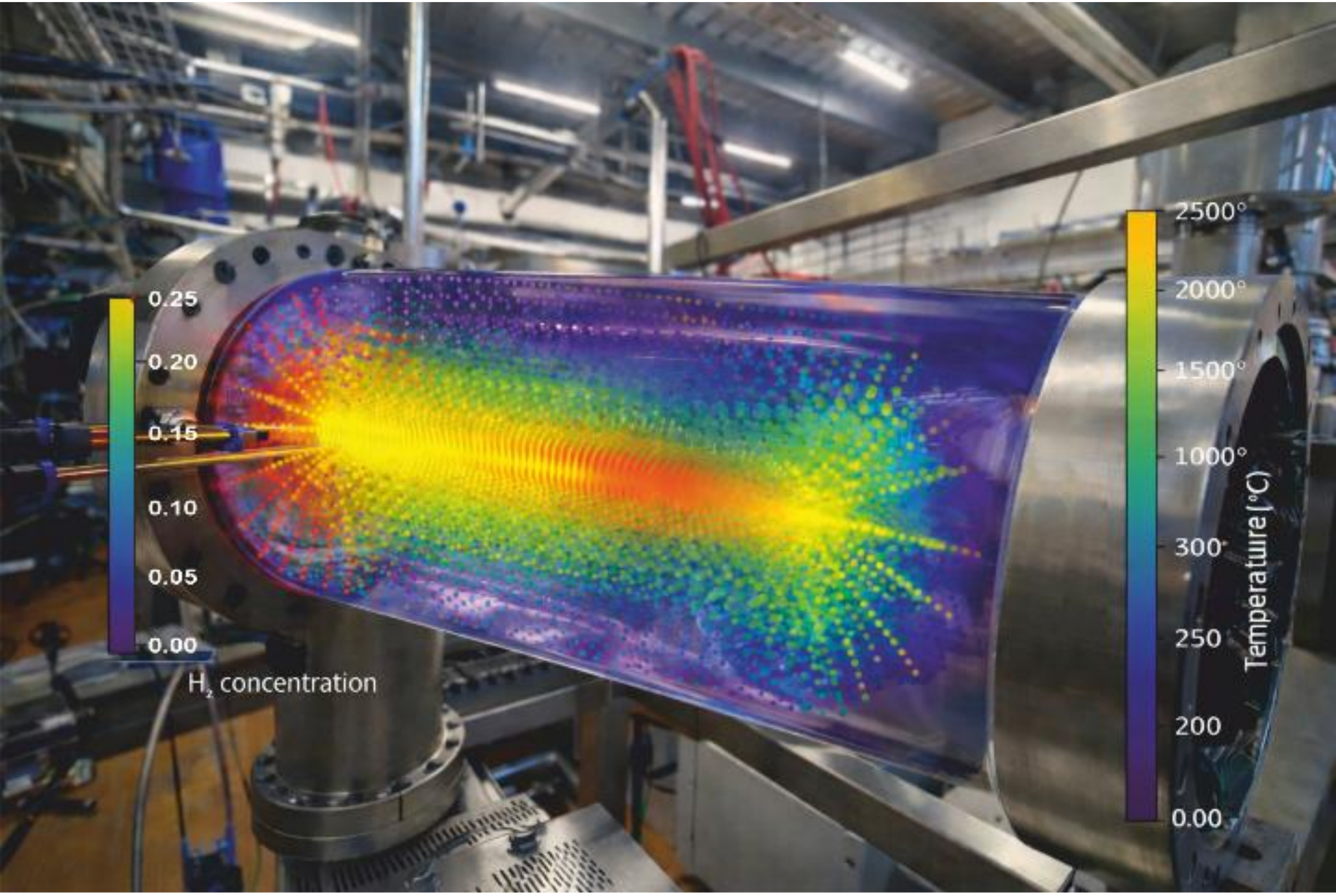

KRAFTWELLE



OmniStar
PFEIFFER VACUUM

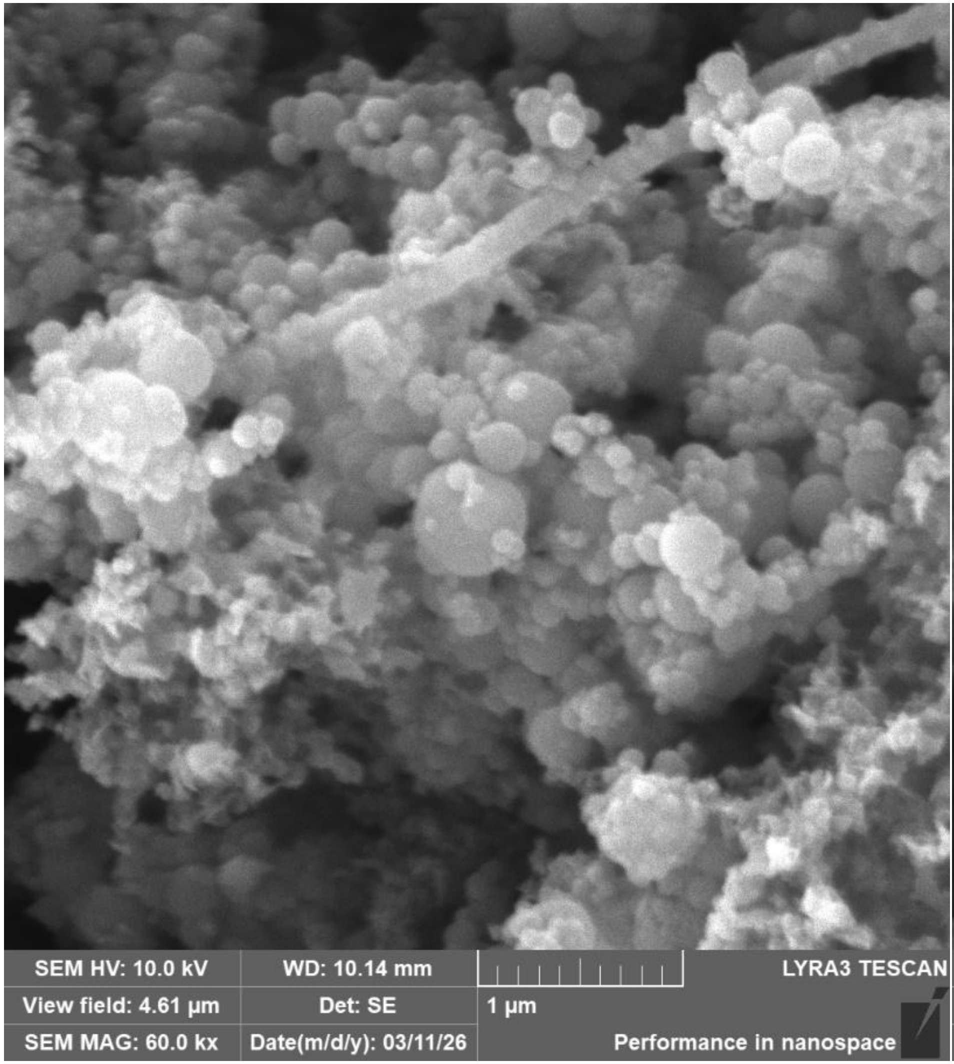




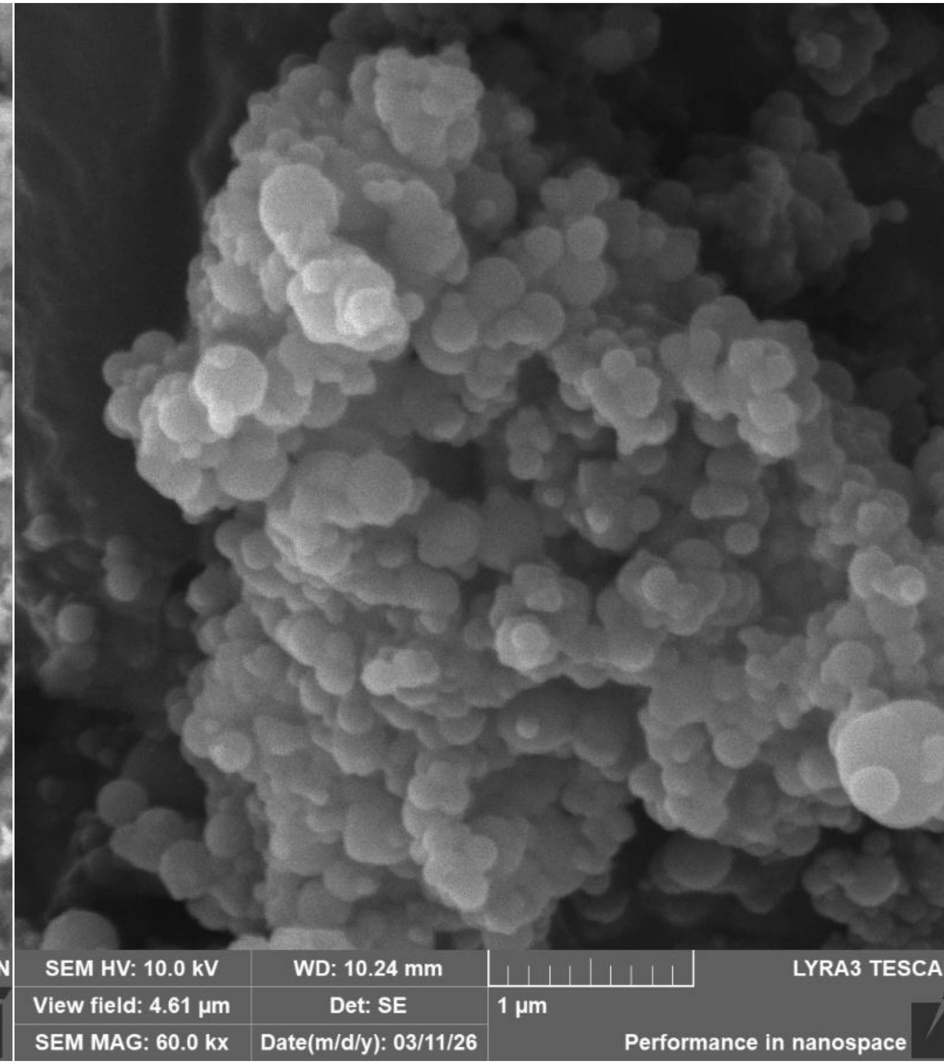

0.25
0.20
0.15
0.10
0.05
0.00
H₂ concentration
2500°
2000°
1500°
1000°
300°
250
200
0.00
Temperature [°C]

The effect of thermal plasma on any substance can be imagined as a sandstorm with lightnings – similar to the effect of abrasives

SEM images

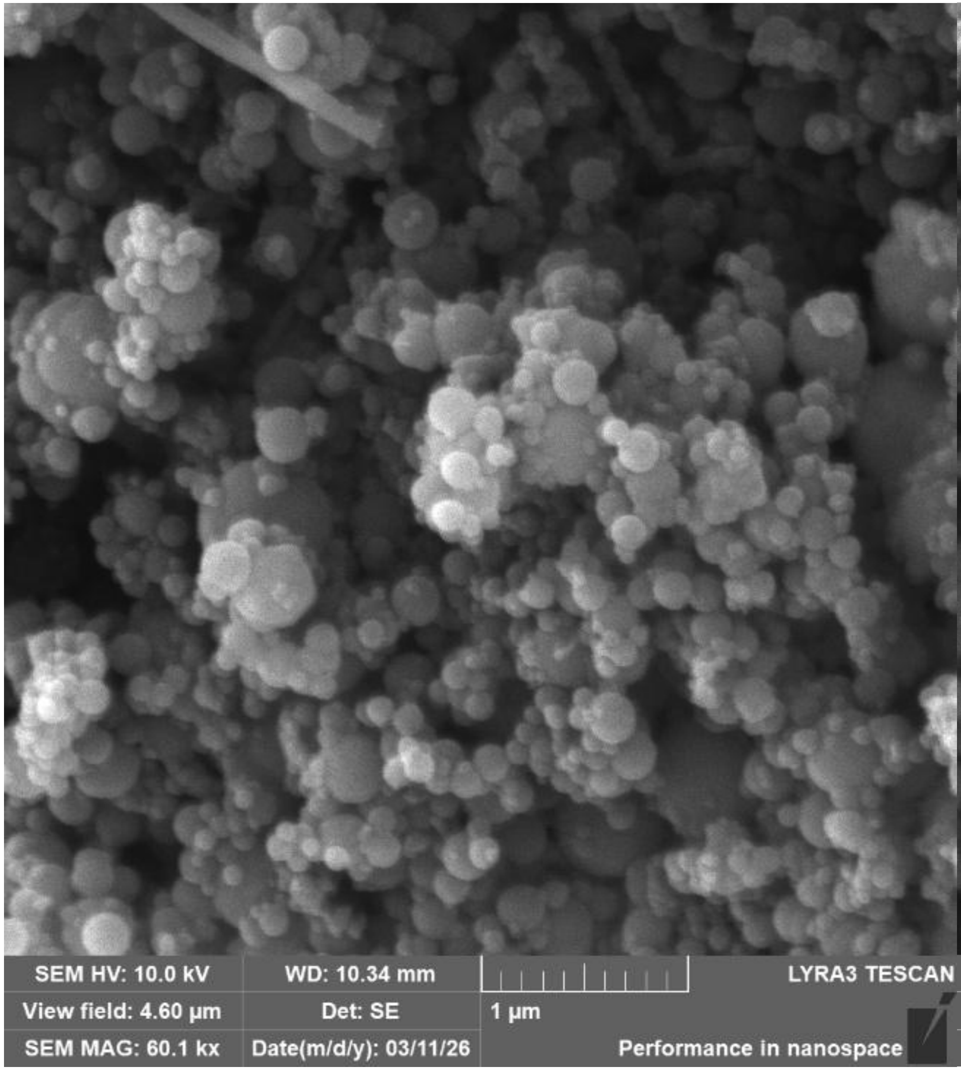


Front



Funnel

SEM images



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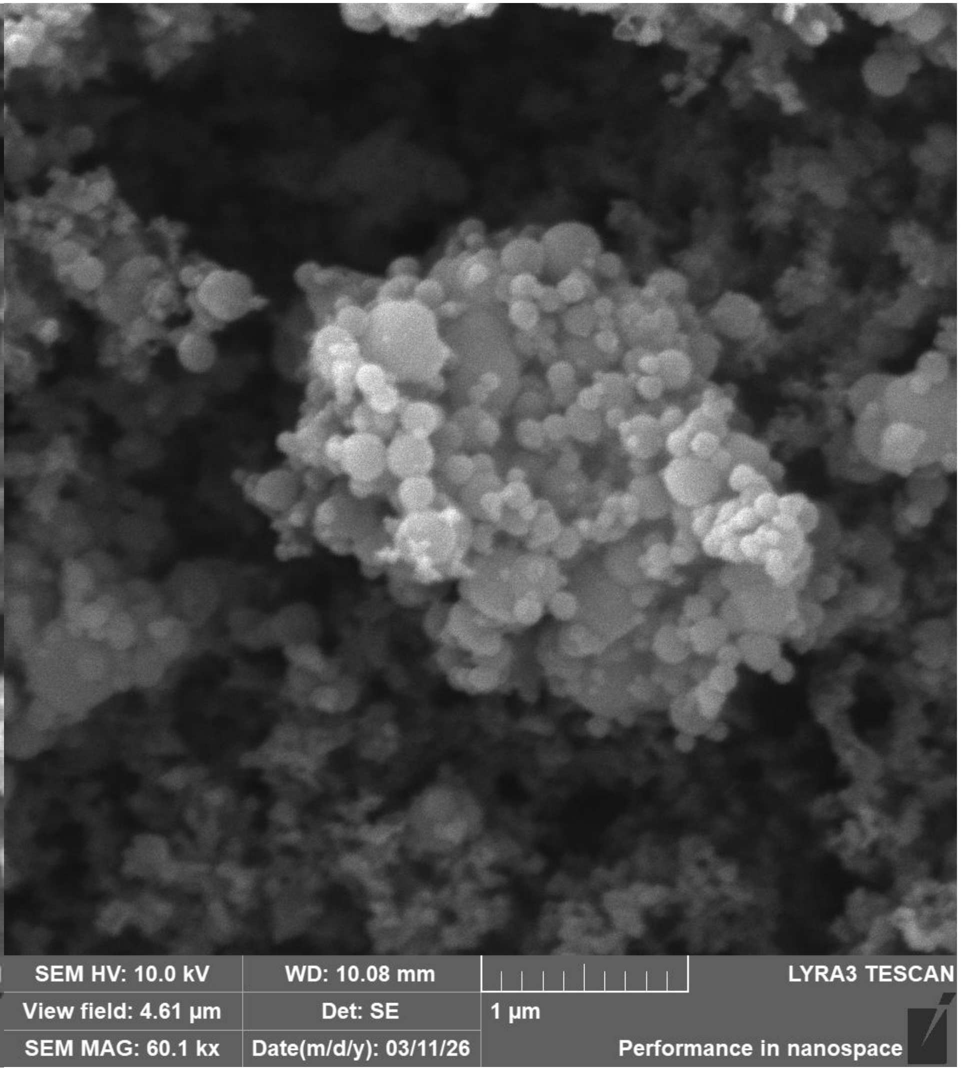
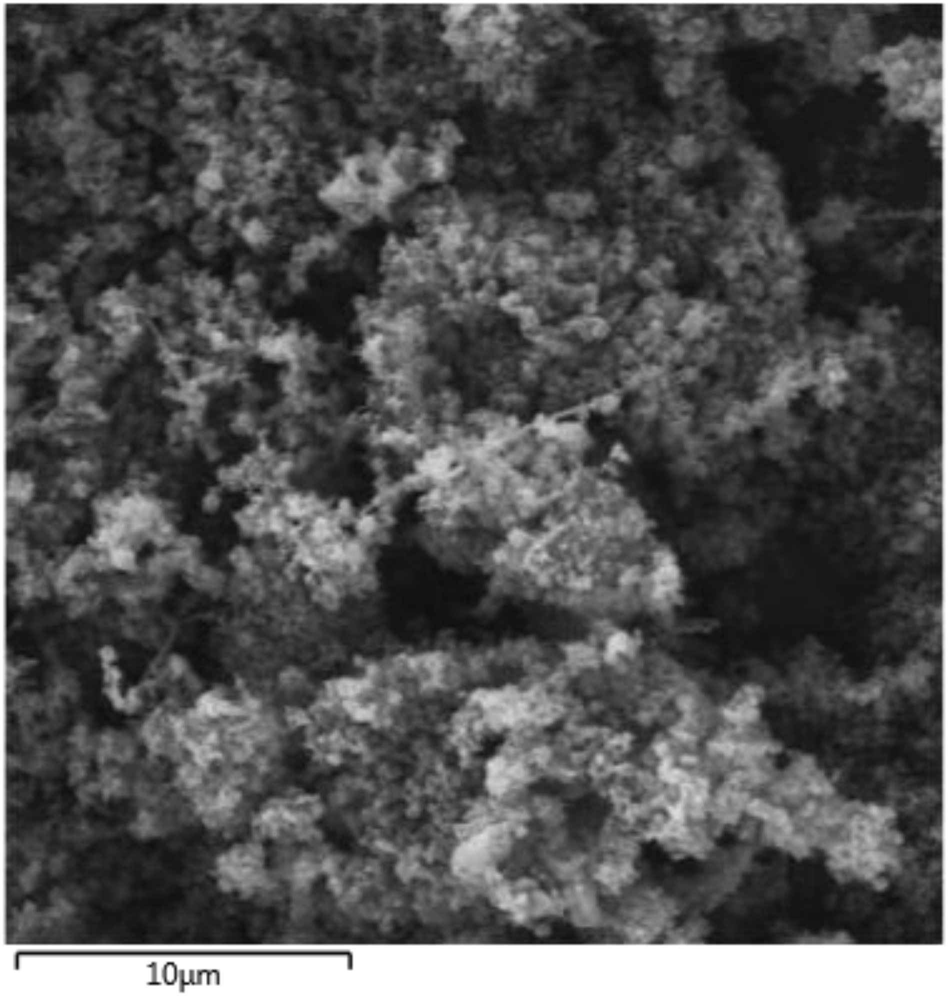
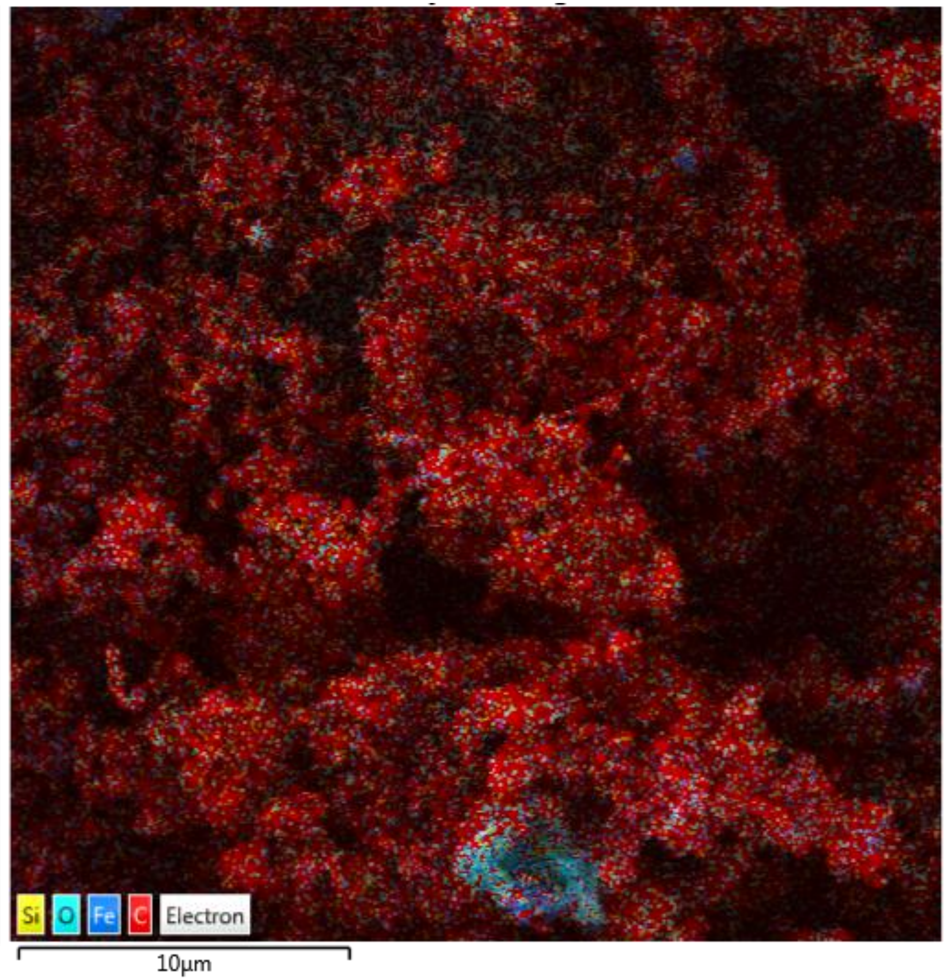


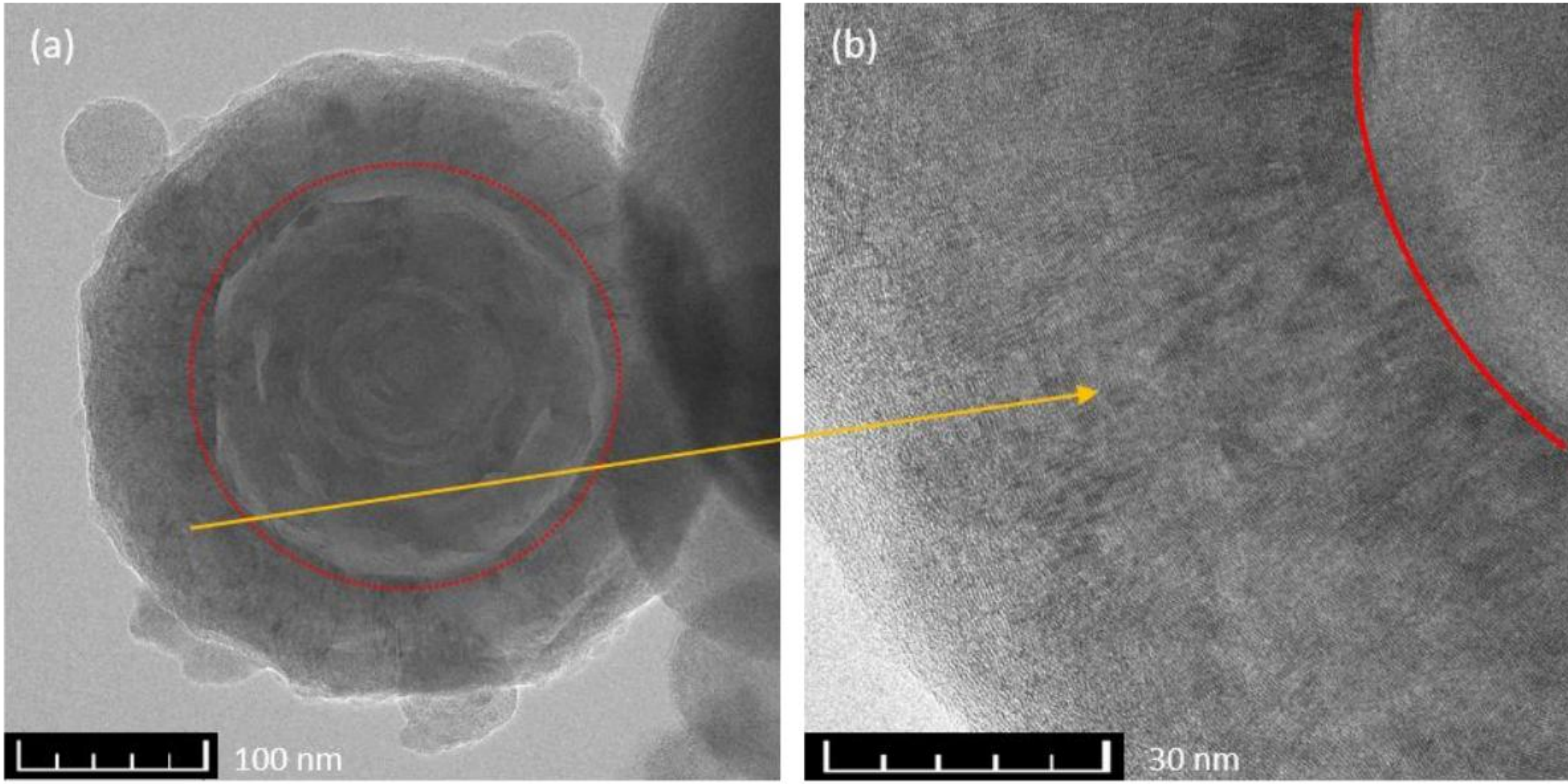
Back2

SEM + EDX images. Front





Peculiarities of the carbon nanoparticles synthesized



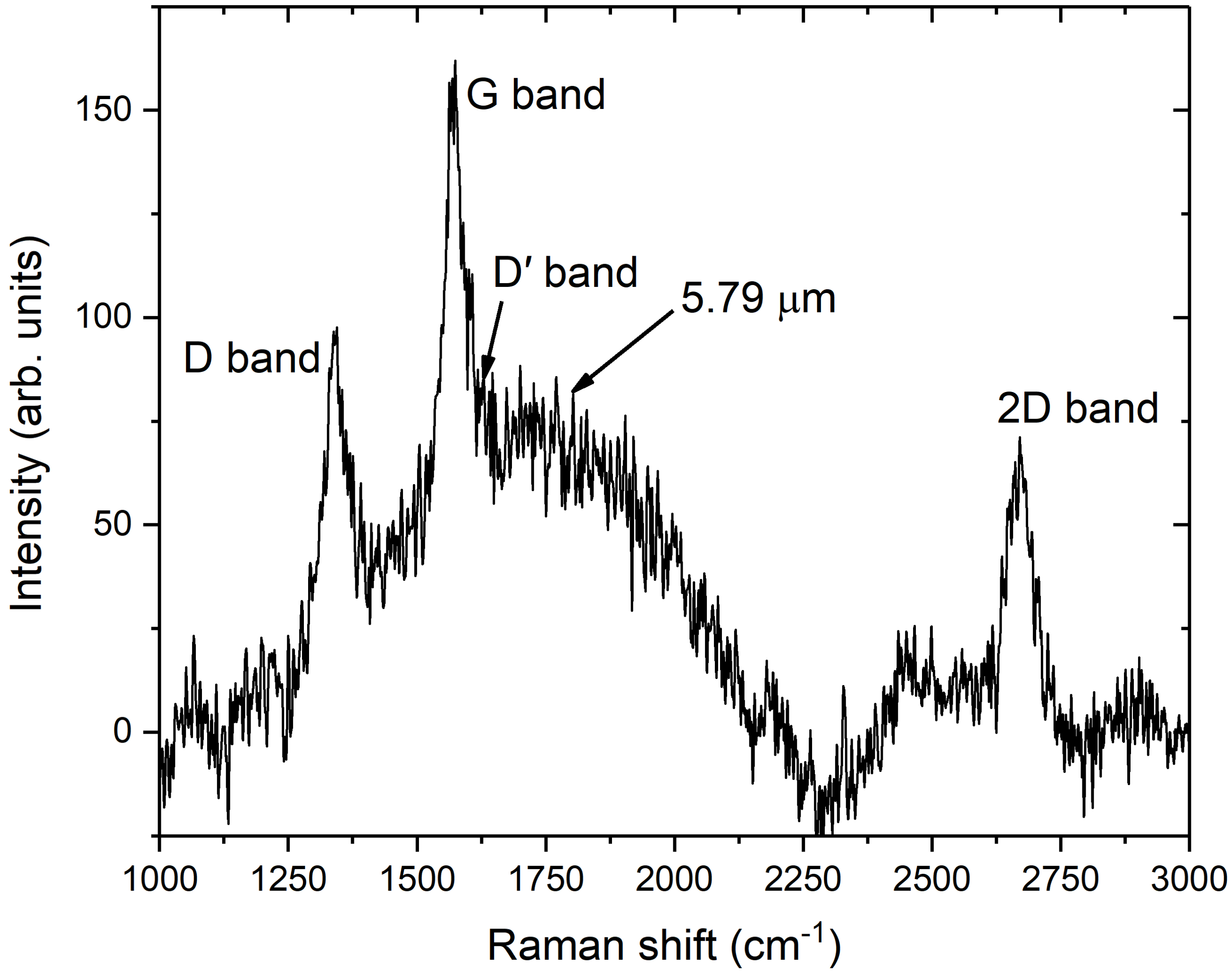
J. Fathi, A. Mašláni, M. Hlína, F. Lukáč, R. Mušálek, O. Jankovský, M. Lojka, A. Jiříčková, S. Skoblia, T. Mates, N. N. B. Jaafar, Sh. Sharma, D. Pilnaj, M. Pohořelý, M. Jeremiáš, Multiple benefits of polypropylene plasma gasification to consolidate plastic 2 treatment, CO2 utilization, and renewable electricity storage, submitted to Fuel (2023)

Phase Analysis of Samples (XRD)

- **Main peaks (all samples):**
  - **C (graphite)** – *$P6_3/mmc$* → dominant phase (~95 vol%)
  - **α-Fe** – *Im3m*
  - **FeN_x ($x \approx 0.05$)** – *Fm3m*
- **Specific to sample Mw251105flowt:**
  - **SiO_2 (quartz)** – *$P3_121$*
- **Minor peaks (all samples):**
  - likely **Fe_3C** – *Pnma*

(Summary: The structure is strongly dominated by graphite, with minor contributions from iron and its compounds; quartz is additionally detected in one sample.)

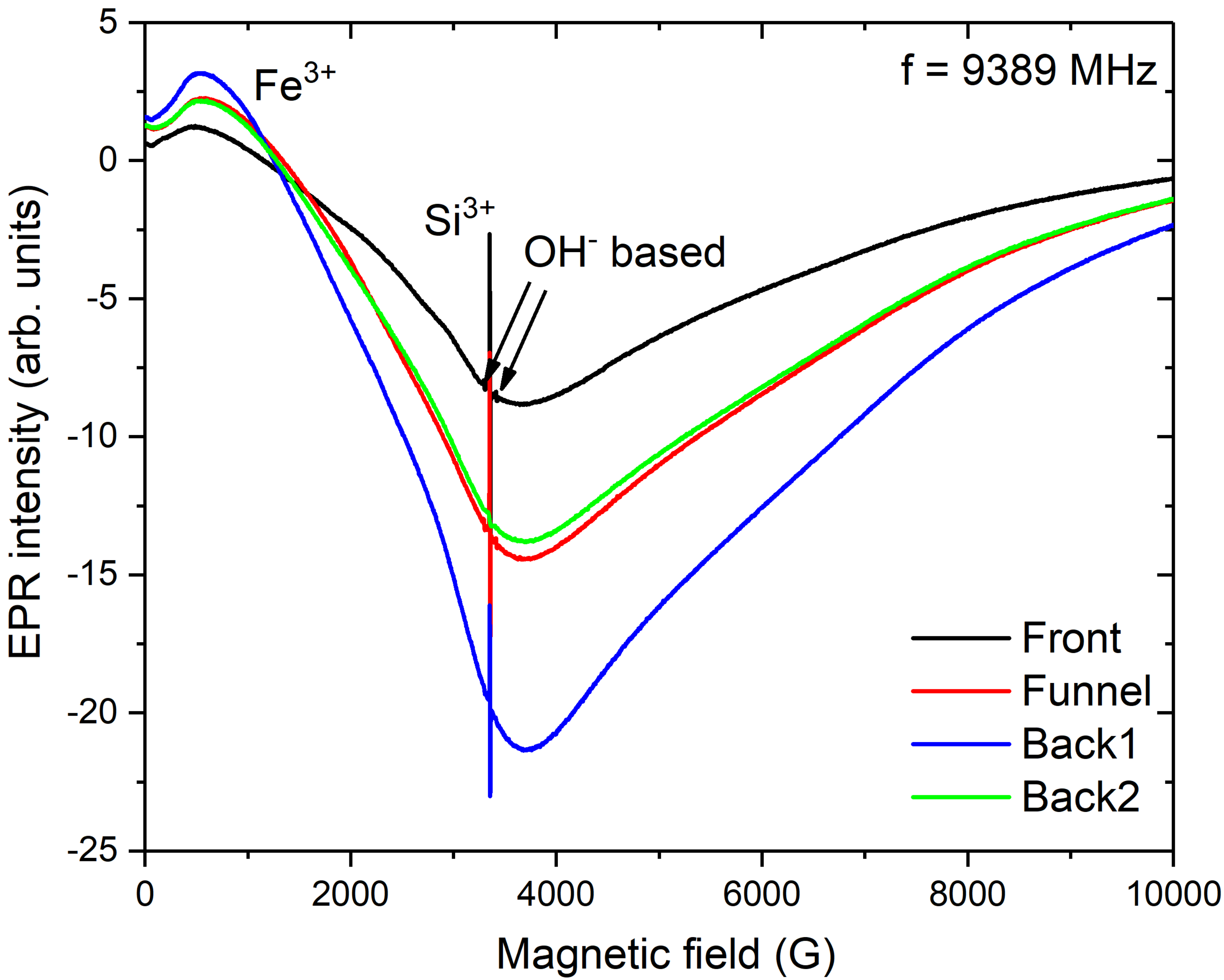
Raman



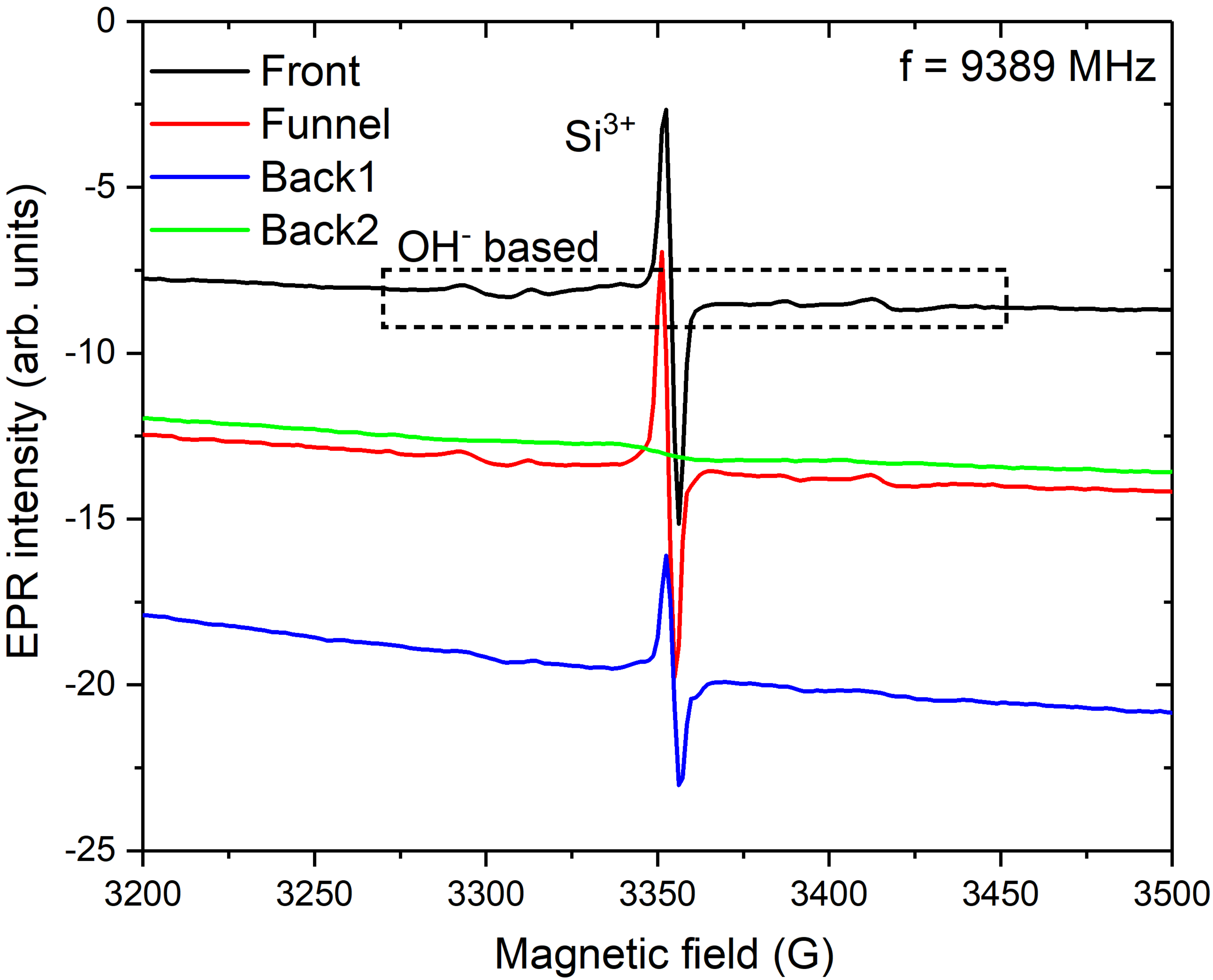
Typical Raman spectrum of carbon nanoparticles

- **D band (~1350 cm⁻¹):** associated with structural defects and disorder in the carbon lattice
- **G band (~1580–1600 cm⁻¹):** corresponds to the in-plane vibration of sp²-bonded graphitic carbon
- **D′ band (~1620 cm⁻¹):** defect-related shoulder
- **2D band (~2700 cm⁻¹):** linked to graphitic stacking and structural ordering

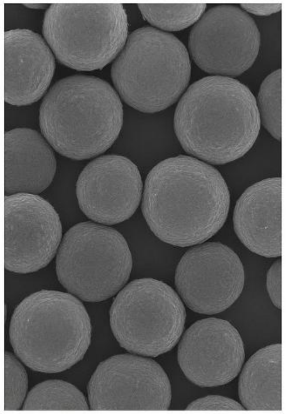
Electron Paramagnetic Resonance

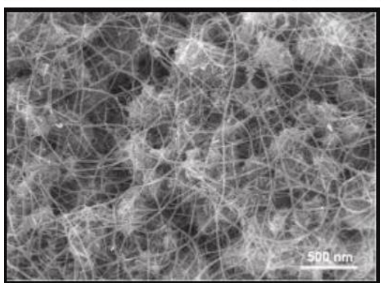


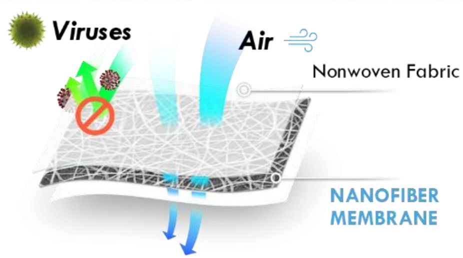
Electron Paramagnetic Resonance



Motivation – general







Growing need for low-carbon hydrogen
Hydrogen is essential for the future of energy, chemical production, and environmental technologies. However, current methods of its production are environmentally demanding or economically inefficient.

Inefficient use of methane as a source of carbon and energy
Methane is often flared or released into the atmosphere from biogas plants, landfills, or industrial processes. Converting it into hydrogen and valuable carbon nanostructures increases its utility while reducing its environmental impact

Low rate of recycling and regeneration of carbon filters
Most filters (e.g., activated-carbon filters) are disposed of once saturated. Plasma regeneration makes it possible to significantly reduce costs and create a circular carbon cycle.

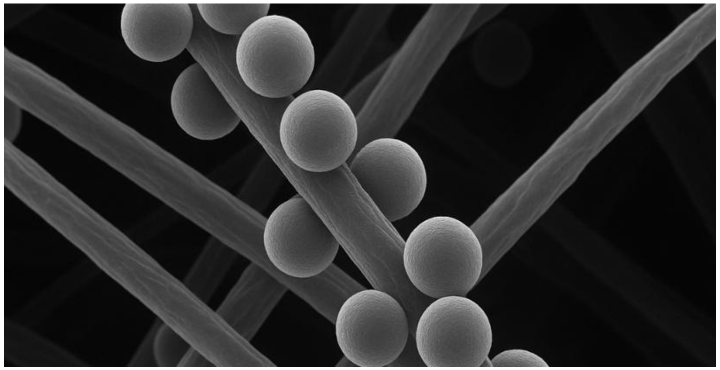
Need to develop nanostructures with defined functions for filtration
Intelligent filters require particles with controlled morphology, size, and surface chemistry — precisely the properties enabled by plasma synthesis

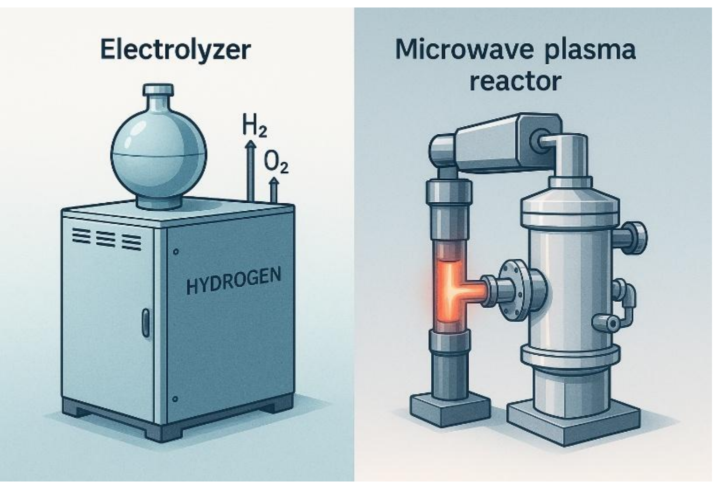
Industrial relevance and immediate applicability
The project addresses the **needs of companies** operating in filtration, safety, and water and gas management (SIGMA, CHV, HVM Plasma), which require innovations with a high TRL.

Strategic importance for the circular economy

Carbon material cycle: CH_4 → carbon nanostructures → filtration materials → plasma regeneration → repeated use

Motivation – specific



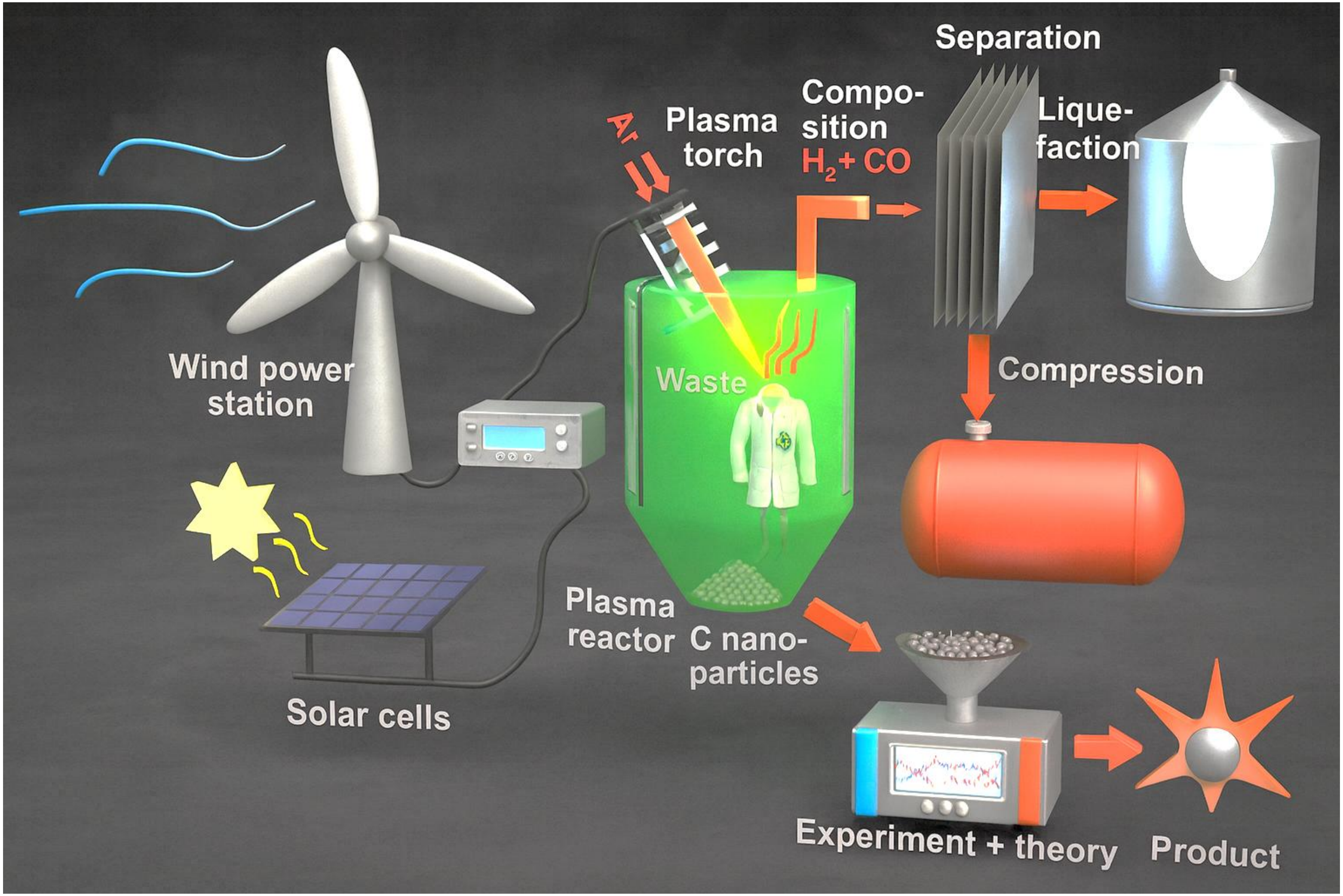


Comparison between electrolyzer and thermal plasma system

Parameter	**Standard Electrolyzer (PEM/Alkaline)**	**Microwave Plasma Torch 2.45 GHz, 6 kW + 4 kW Auxiliary Systems**
Type of input	Water + electricity	Methane (CH_4) + electricity
Installed electrical power	e.g., 1 MW (scalable)	**6 kW plasma + 4 kW pumps/filtration = 10 kW**
Specific electricity consumption	**≈ 52 kWh/kg H_2**	**≈ 15 kWh/kg H_2**
Electricity cost per kg H_2	52 × 0.15 = **7.8 €/kg H_2**	15 × 0.15 = **2.25 €/kg H_2**
Consumption of additional media	Water (negligible cost)	**~4 kg CH_4 / kg H_2**
Methane cost per kg H_2	–	4 × 0.4 ≈ **1.6 €/kg H_2**
Total variable cost per kg H_2 (without by-product valorization)	**≈ 7.8 €/kg H_2**	**≈ 3.85 €/kg H_2**
By-product	O_2 (low value, limited market relevance)	**Carbon nanostructures (C)** – potentially **high-value product**
Potential revenue from by-product	Low	Significant potential (nanocarbon, activated carbon, CNTs, etc.)
CO_2 emissions from the process	Indirect – depends on electricity mix	Depends on CH_4 origin and carbon handling (can approach CO_2-neutral)
Suitability for integration into filtration systems	Indirect	**Direct integration with carbon nanomaterial production for filters**

Perspectives of energy + waste to X approach

Future vision of a concept



Thank you for your attention!