



The SOLHYCARB Project

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Project Overview

Hydrogen from Solar Thermal Energy:

High temperature solar chemical reactor for co-production of hydrogen and carbon black from natural gas cracking

10 participants from 7 countries

Project coordination: CNRS-PROMES, France

Duration: 48 months

Partnership

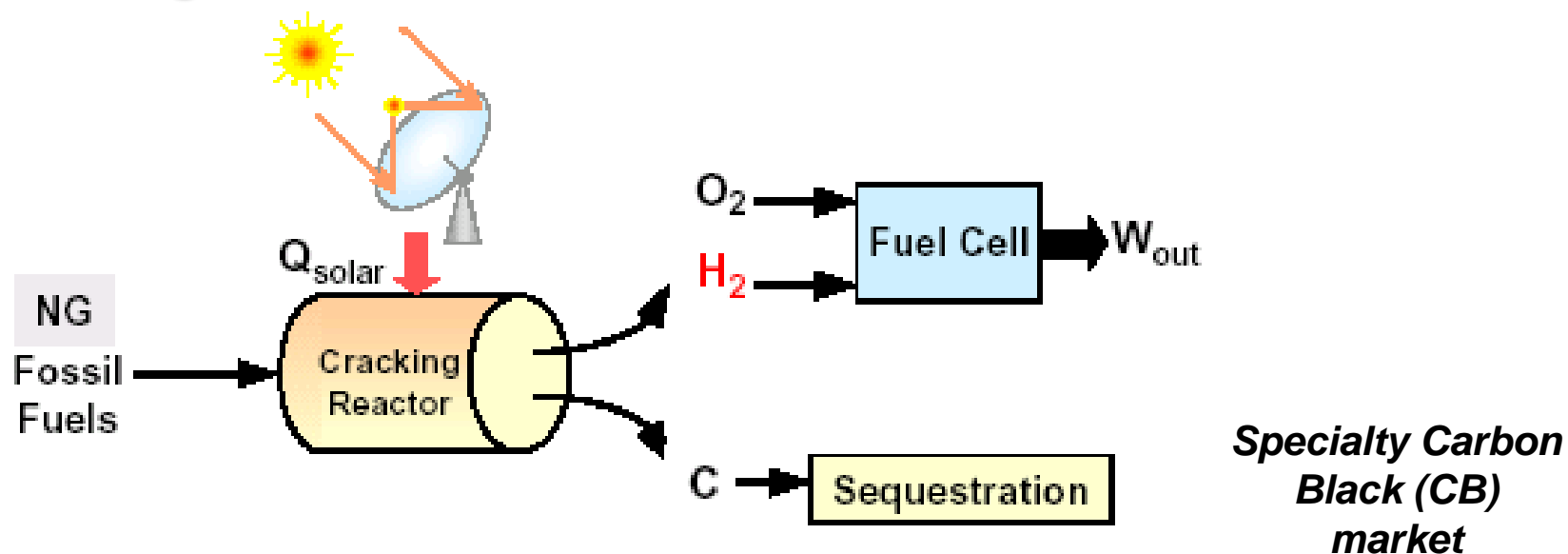
1. Laboratoire Procédés, Matériaux, et Energie Solaire **(CNRS/PROMES) France**
2. Eidgenössische Technische Hochschule Zürich **(ETH) Switzerland**
3. Paul Scherrer Institute **(PSI) Switzerland**
4. Weizmann Institute of Science **(WIS) Israel**
5. Centre for Research and Technology Hellas / Chemical Process Engineering Research Institute **(CERTH/CPERI) Greece**
6. Deutsches Zentrum für Luft-und Raumfahrt, e.V., Inst. for Techn. Thermodynamics, Solar Research Division **(DLR) Germany**
7. TIMCAL BE **(TIMCAL) Belgium**
8. Solúcar **(SOLUCAR) Spain**
9. VEOLIA Environnement – CREED **(CREED) France**
10. N-GHY **(N-GHY) France**



Project Objectives

Solar Upgrade and Decarbonization of Fossil Fuels

Solar cracking (No catalyst): $\text{CH}_4 \rightarrow \text{C}_{\text{solid}} + 2 \text{H}_2$ ($\Delta H^0 = 75,6 \text{ kJ/mol}$)



Project Objectives

1. Design and construction of innovative solar reactors;
2. Solar reactors testing and modeling, and performance evaluation;
3. Analysis, purification, and industrial uses of the produced gas;
4. Measurement of CB characteristics and properties;
5. Technical-economical design of decentralized (dish) and large scale solar processes (based on the solar tower concept).

Project Objectives

Measurable objectives of the project

Solar reactors	Lab-scale 1-10 kW and pilot-scale 50 kW
Reactor operating temperature	1500-2300 K
Methane decomposition	80%
Hydrogen yield in the off-gas	75%
H₂ and CB production	3 standard m³/h H₂ and 1 kg/h C
Produced CB properties	Equivalent to industrial CB grades
Solar chemical plant design	Cost of H₂ versus CB market price

Environmental and economical issues

⇒ **Uses renewable energy / Solar energy storage & transportation**

⇒ **Zero CO₂ emission** (sequestration of C, marketable CB)

⇒ Solar process avoids 14 kg CO₂ / kg H₂
+ Energy saving: 277 MJ / kg H₂

(with respect to reforming and conventional CB processing « Furnace process »)

H₂ cost prospects: depends on the price of the synthesized CB

14 € /GJ for CB at 0.66 €/kg (lowest grade used in tires)

10 € /GJ for CB at 0.80 €/kg

5 € /GJ for CB at 1.1 €/kg (price of conductive CB > 2 €/kg)

→ **Preliminary process economics favorable**

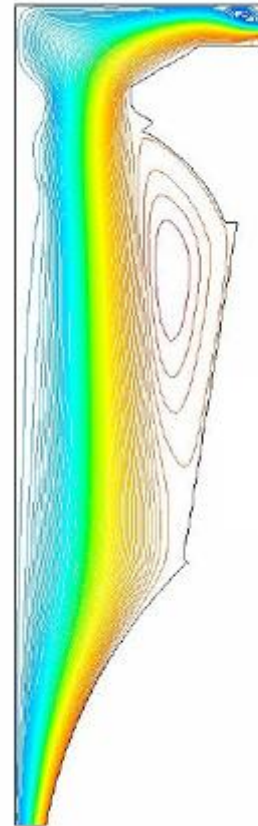
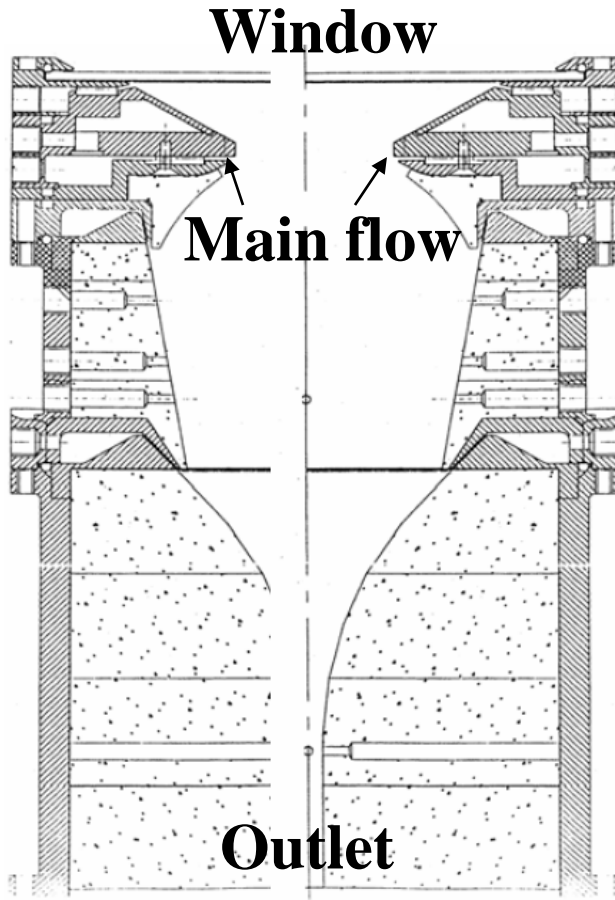


SOLHYCARB

Project Results



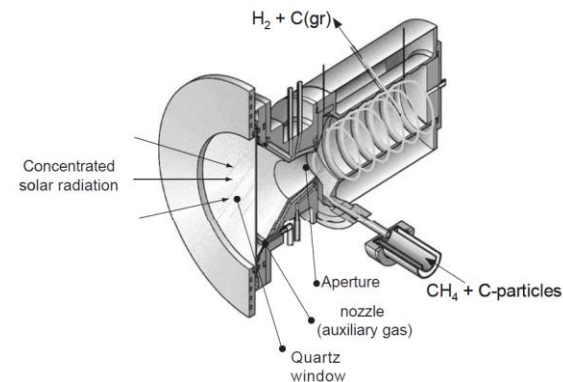
Direct heating solar reactor



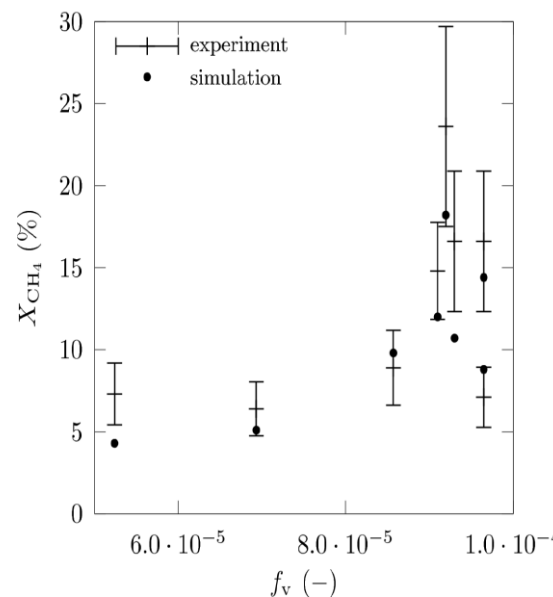
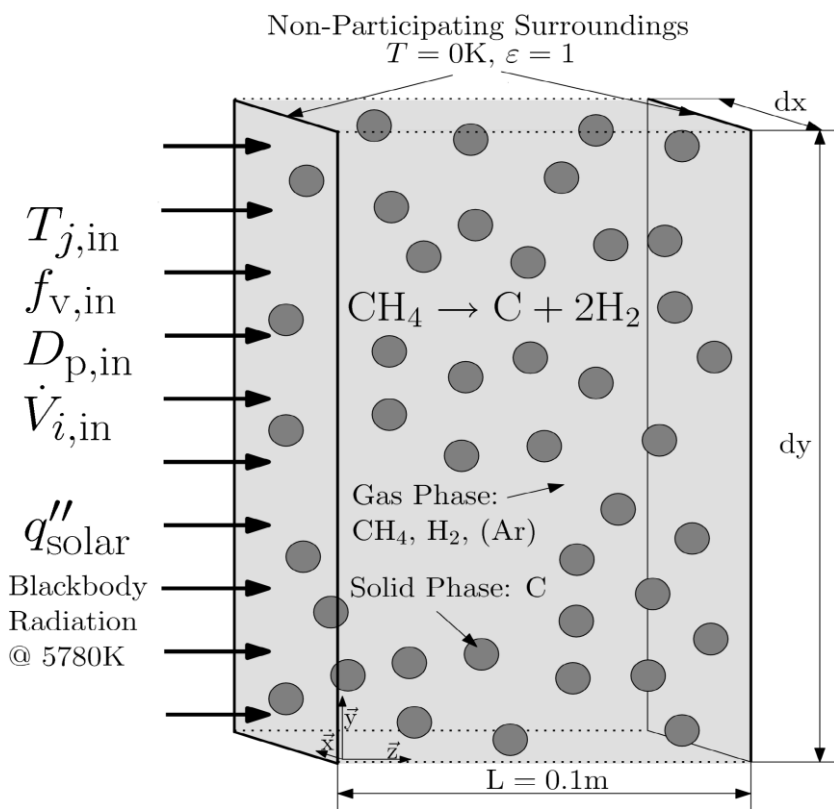
Contours of Stream Function (kg/s)

Nearly complete methane conversion at a maximum temperature of 2000K with particle seeding

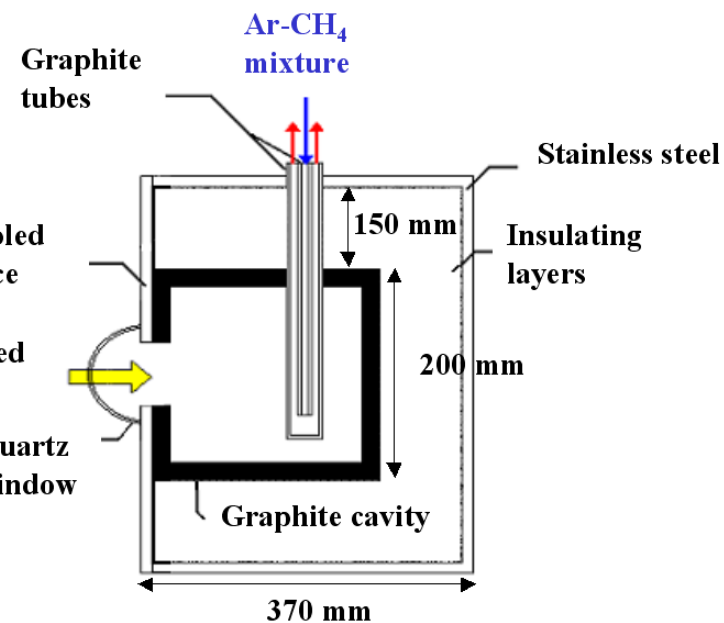
Direct heating reactor: modelling and experimental validation



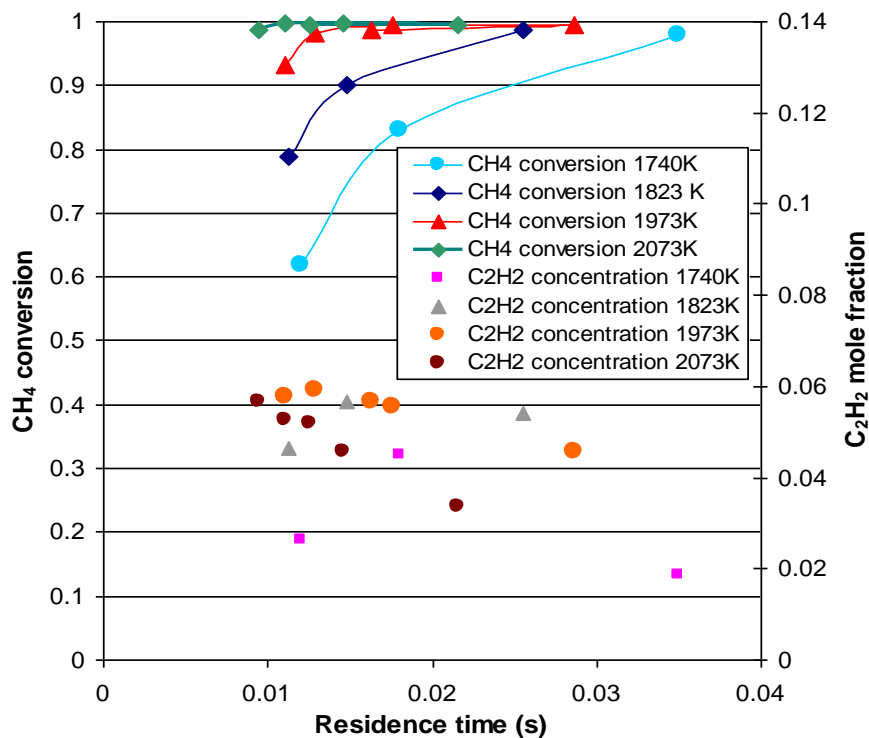
Experimental reactor for the model validation



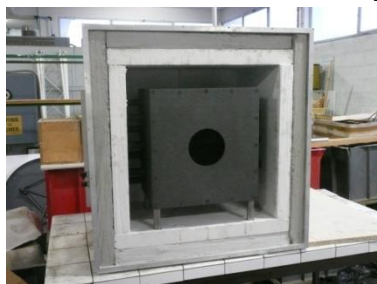
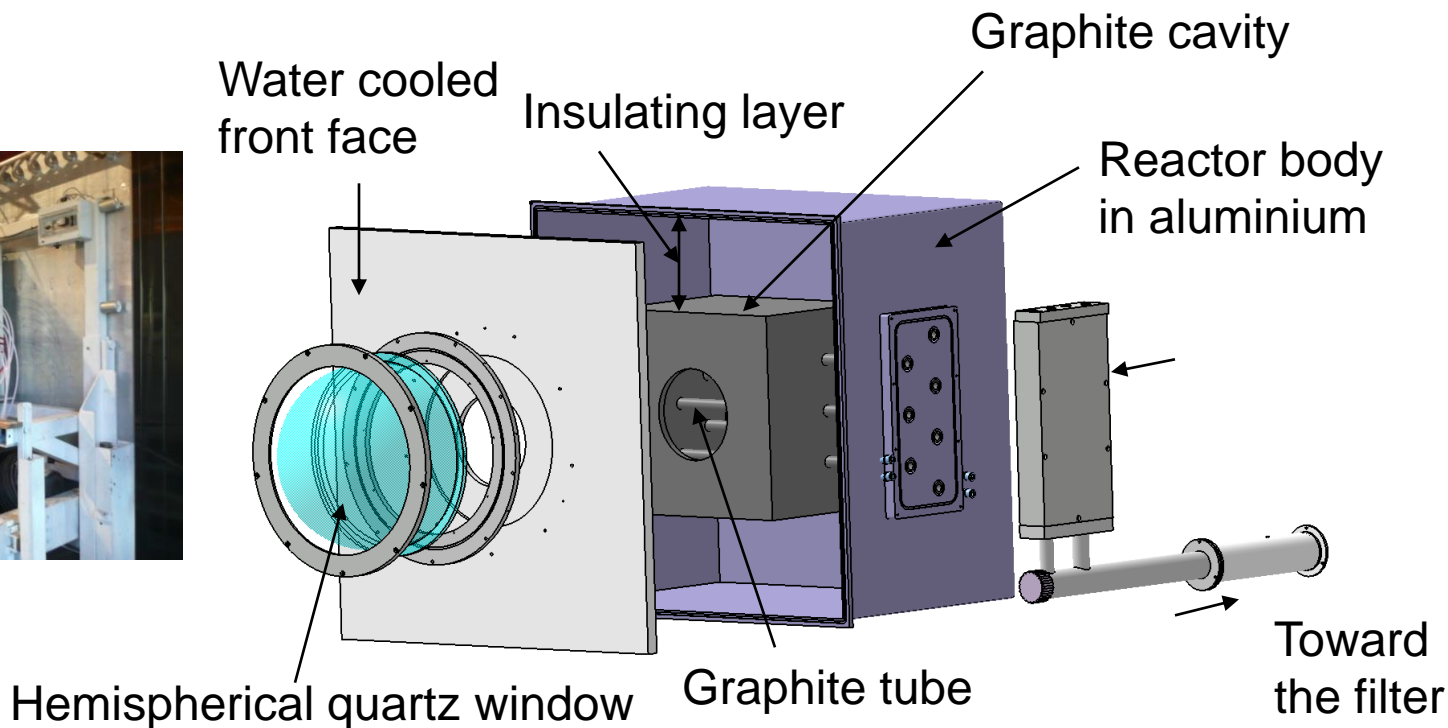
Indirect heating reactor at 10 kW scale



Temperature and residence time are 2 key parameters



Indirect heating reactor at 50kW scale



Expected production at 50kW scale (with C and H balances from a test reactor with a plasma heating source): about 2.47 Nm³/h H₂ and 386 g/h carbon black for 1.47 Nm³/h of CH₄ injected



Kinetic analysis

$$m = 0.84 \quad k_0 = 2.32 \cdot 10^9 \frac{1}{s} \left(\frac{\text{mol}}{\text{m}^3} \right)^{0.16} \quad E_a = 259 \frac{\text{kJ}}{\text{mol}}$$

reaction order

pre-exponential factor

activation energy

➤ $T = T(x)$ (✓)

➤ $p = p(x)$ ✓

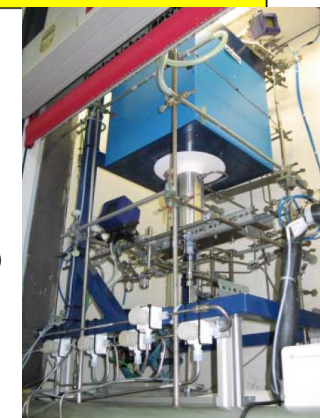
➤ Laminar flow ✗

➤ Formation of by-products ✗

$$-r_{\text{CH}_4} = k(T) \cdot c_{\text{CH}_4}^m$$

$$k(T) = k_0 \cdot e^{-\frac{E_a}{R \cdot T}}$$

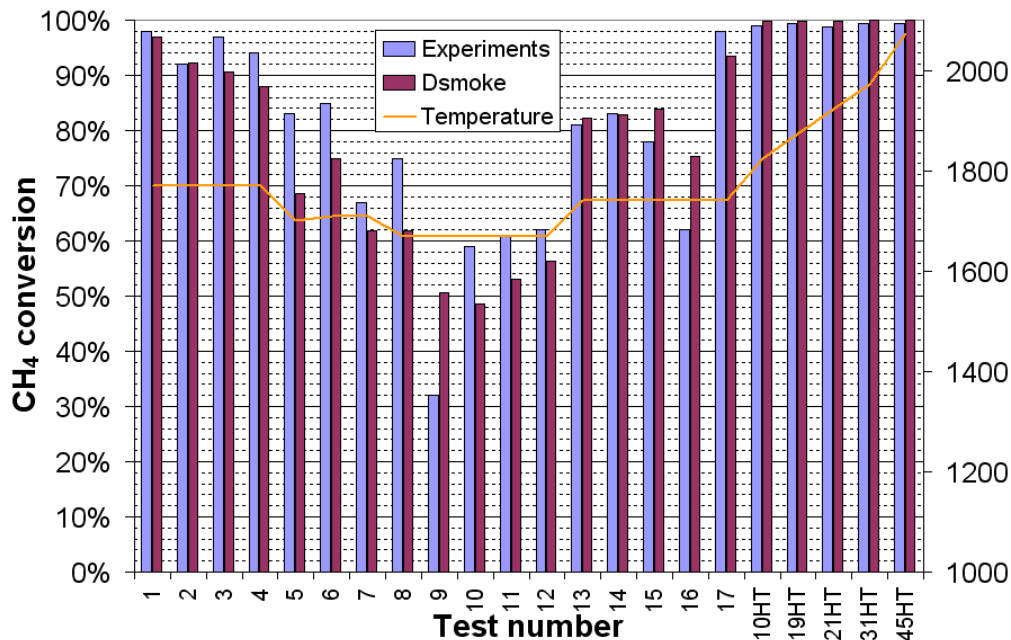
Experimental set-up
(tubular reactor)



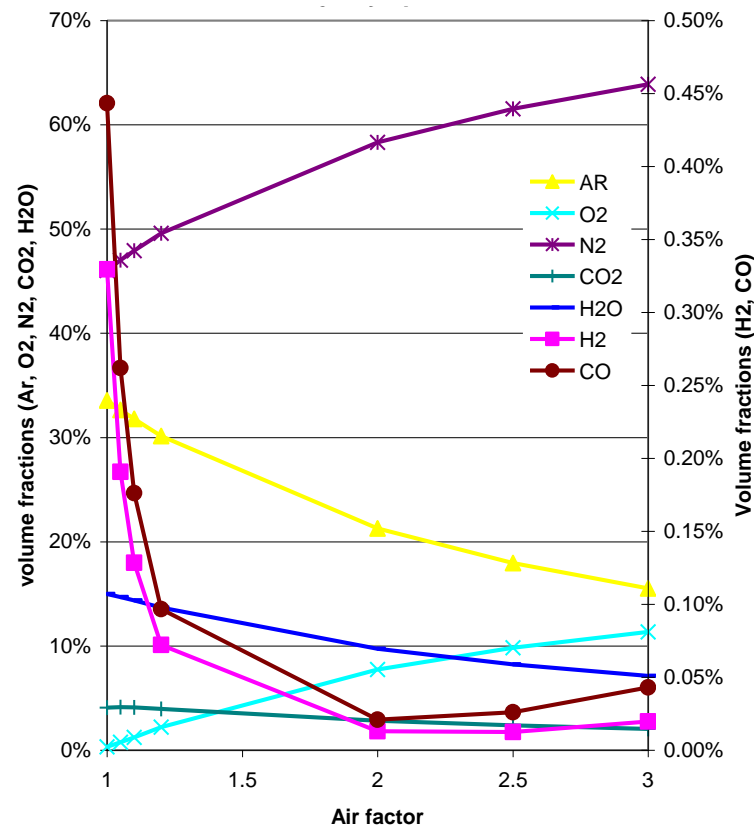


Kinetic simulation

N-GHY Fuel Processors for Fuel Cells



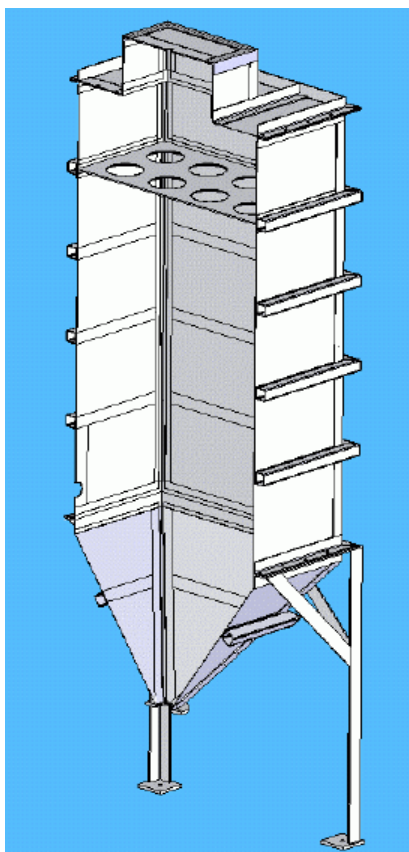
Validation of the Dsmoke code with experimental results from CNRS



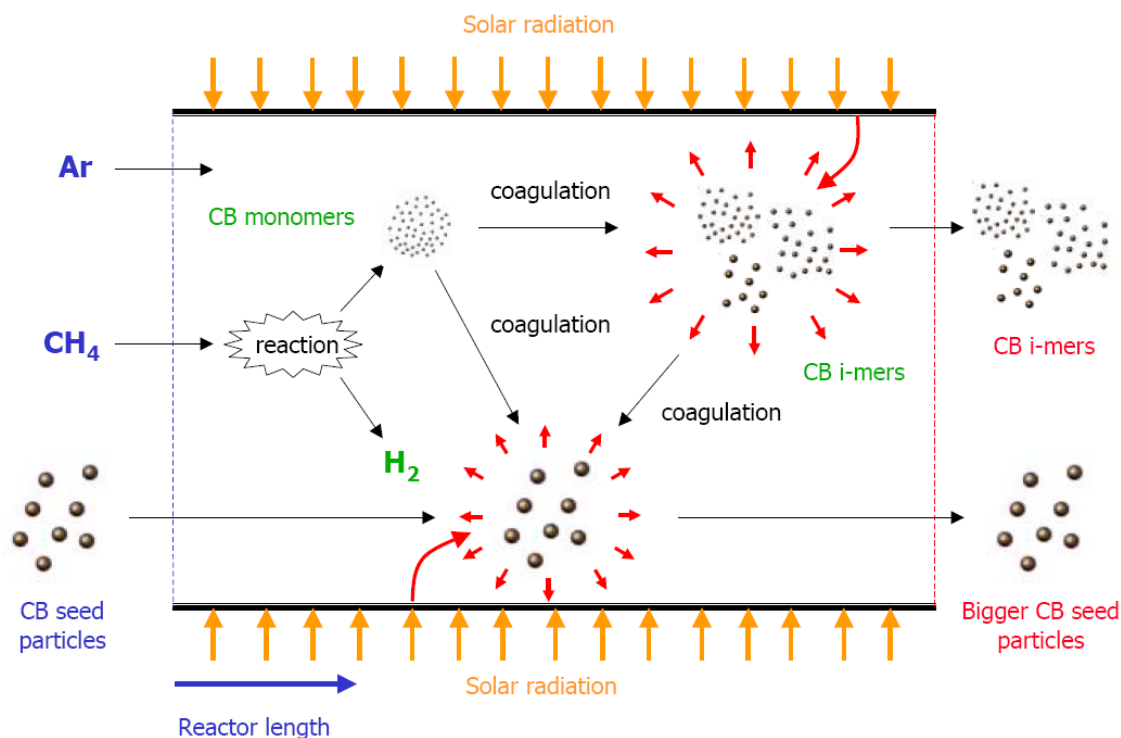
Study on the combustion of the exhaust gases



Particle population model and filter design

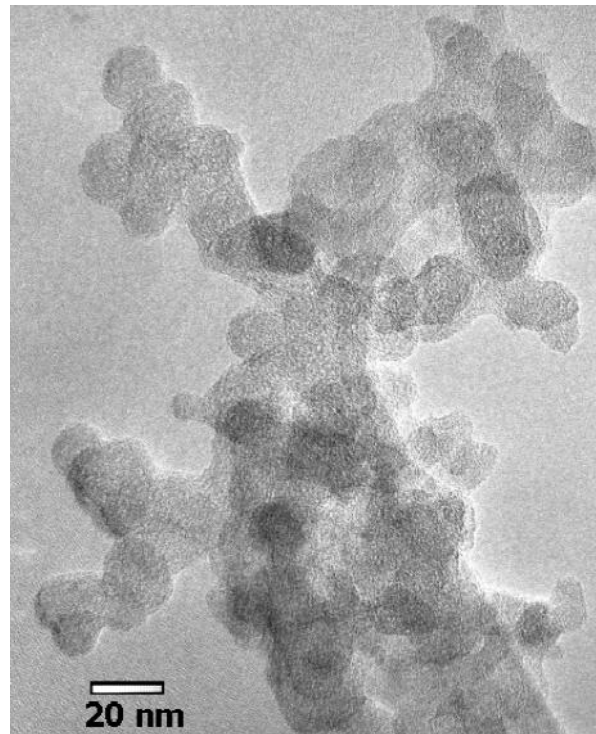
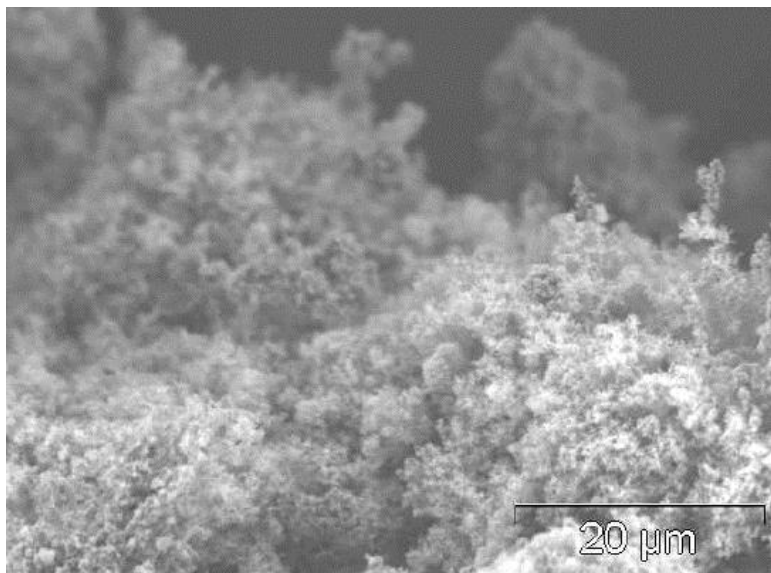


Filter bag



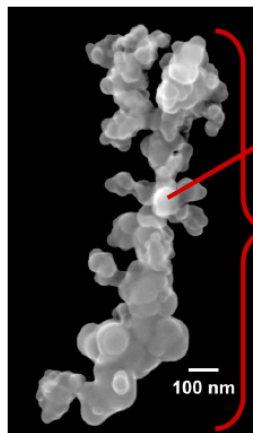
Carbon black formation mechanisms

Carbon characterisation



Specific surface area (BET) up to 200m²/g

Particle size around 30nm



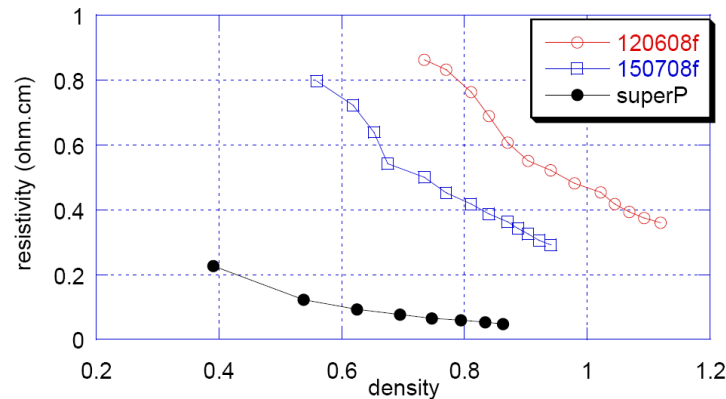
Aggregation of

- Spherical **primary particles**
- Nano-sized

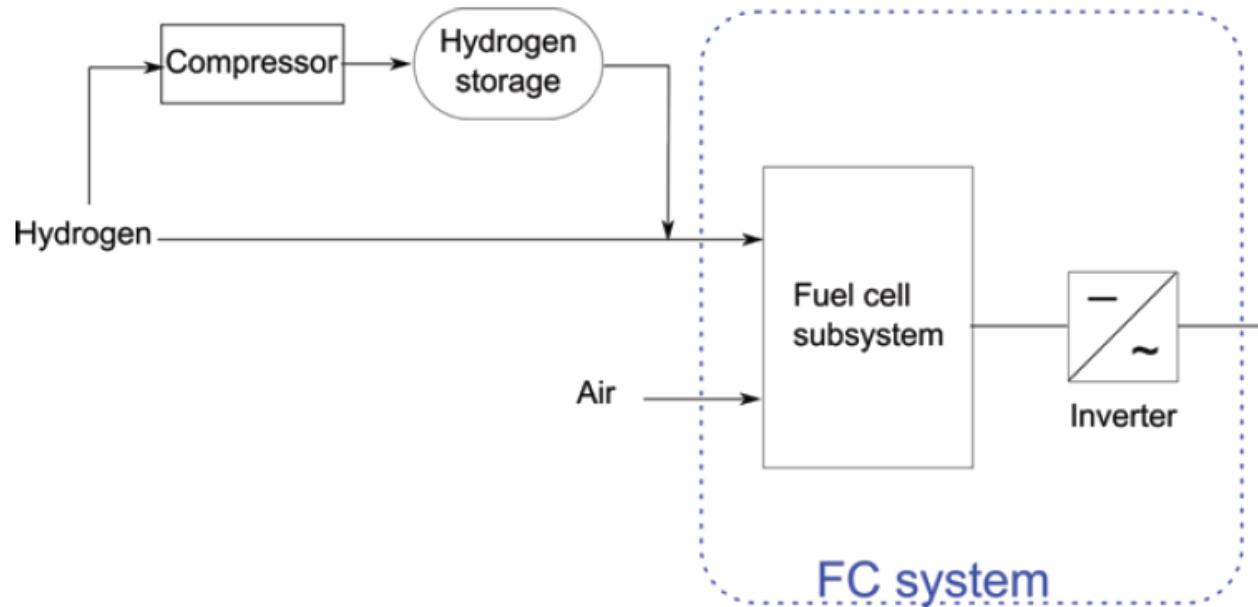
to

- Porous **secondary particles**
- Structured

Agglomeration to **ternary particles**



Conversion of hydrogen at small scale



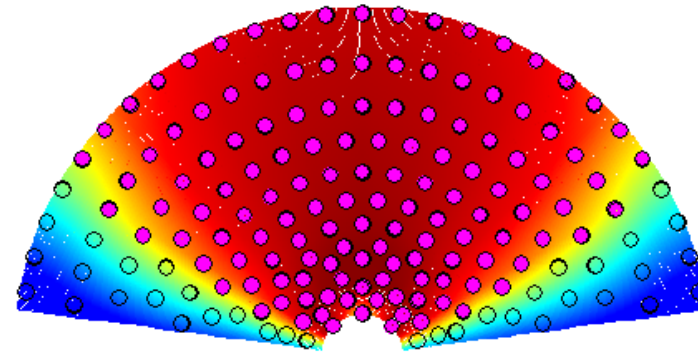
Very high costs of electricity for decentralised units (100kW) equipped with a PEMFC

ABENGOA SOLAR

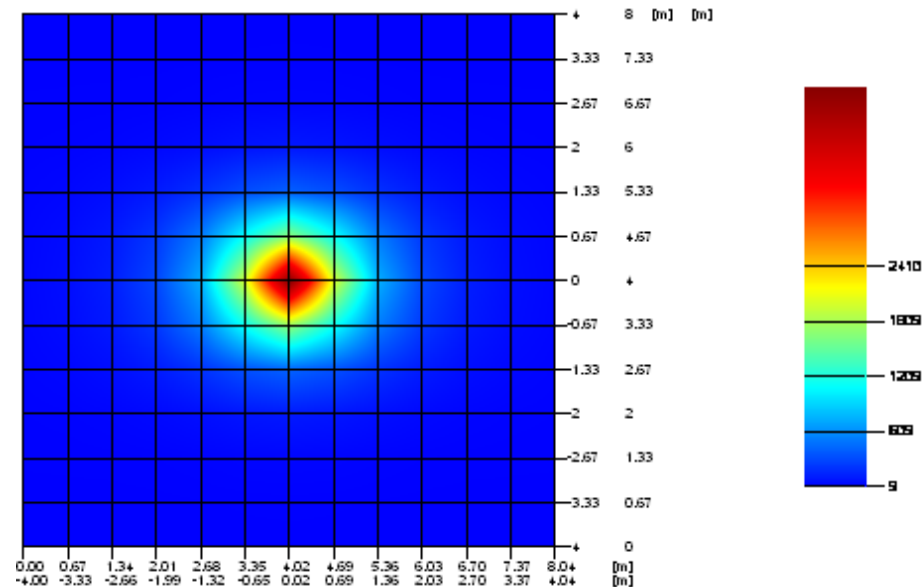
Heliostat field design



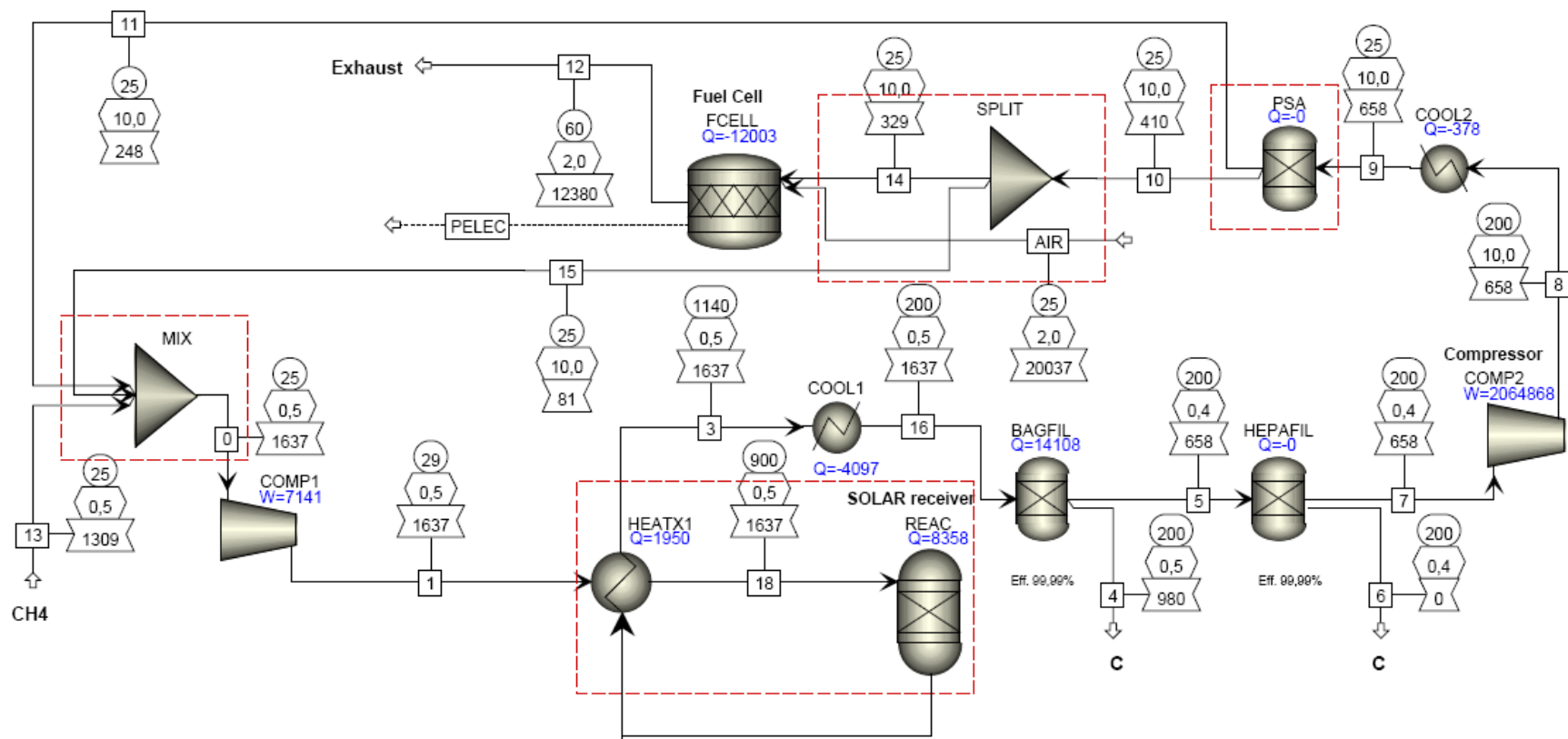
High temperature processes require optimization of the solar concentrating system



10 MW_{th}



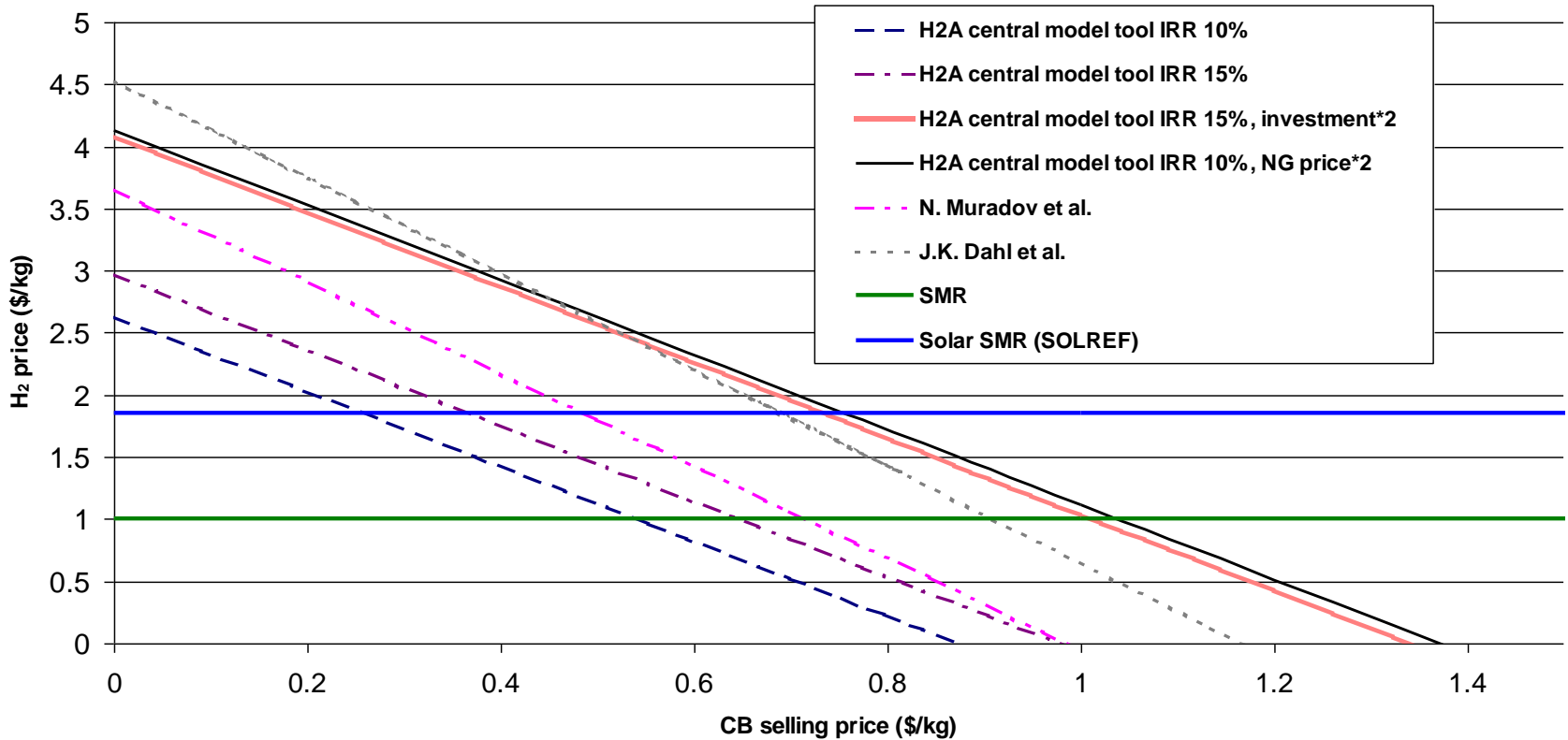
Global flowsheet (10MW_{th})



CH₄ in=1310kg/h, C out=980kg/h, H₂ out= 330kg/h



Cost Analysis (10MW_{th})



Hydrogen cost

Thank you for attention

