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Adeline Andrieu, Jean-François Brillhac, Gontrand Leysens, Cornelius Schonnenbeck, Samuel Jeanjean, et al.. Combustibles métalliques durables pour la mobilité du futur. SFGP 2022, Société Française de Génie des Procédés, Nov 2022, TOULOUSE, France. hal-03979521

HAL Id: hal-03979521

<https://cnrs.hal.science/hal-03979521>

Submitted on 8 Feb 2023

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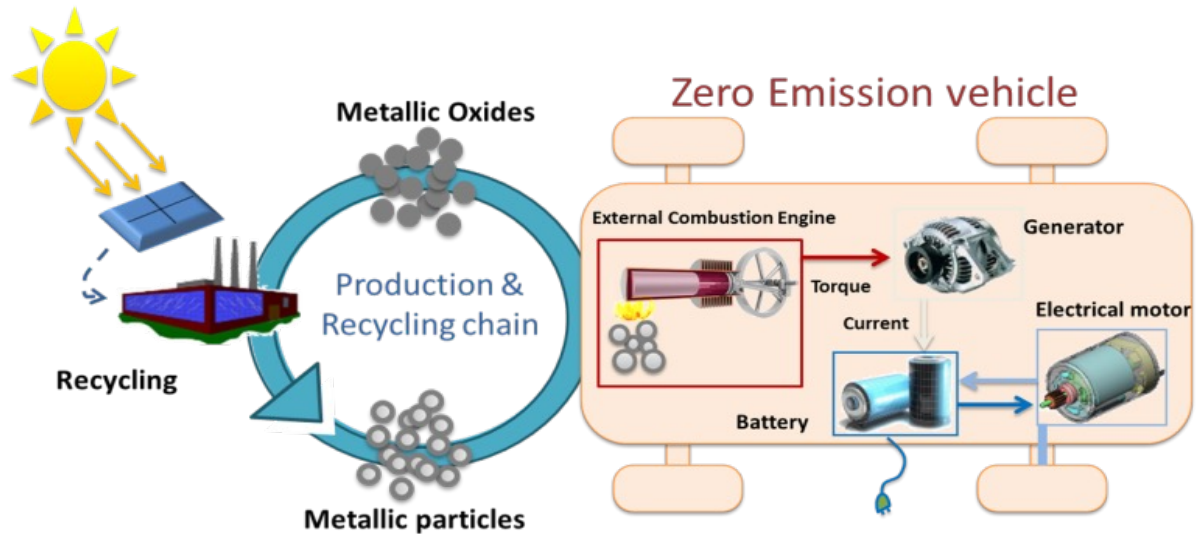
Combustibles métalliques durables pour la mobilité du futur

Adeline ANDRIEU¹, Jean-François BRILHAC¹, Gontrand LEYSSENS¹, Cornelius SCHONNENBECK¹,
Samuel JEANJEAN², Fabien HALTER², Christian CHAUVEAU²,
Youssef BERRO³, Marianne BALAT-PICHELIN³,
Clément DUMAND⁴

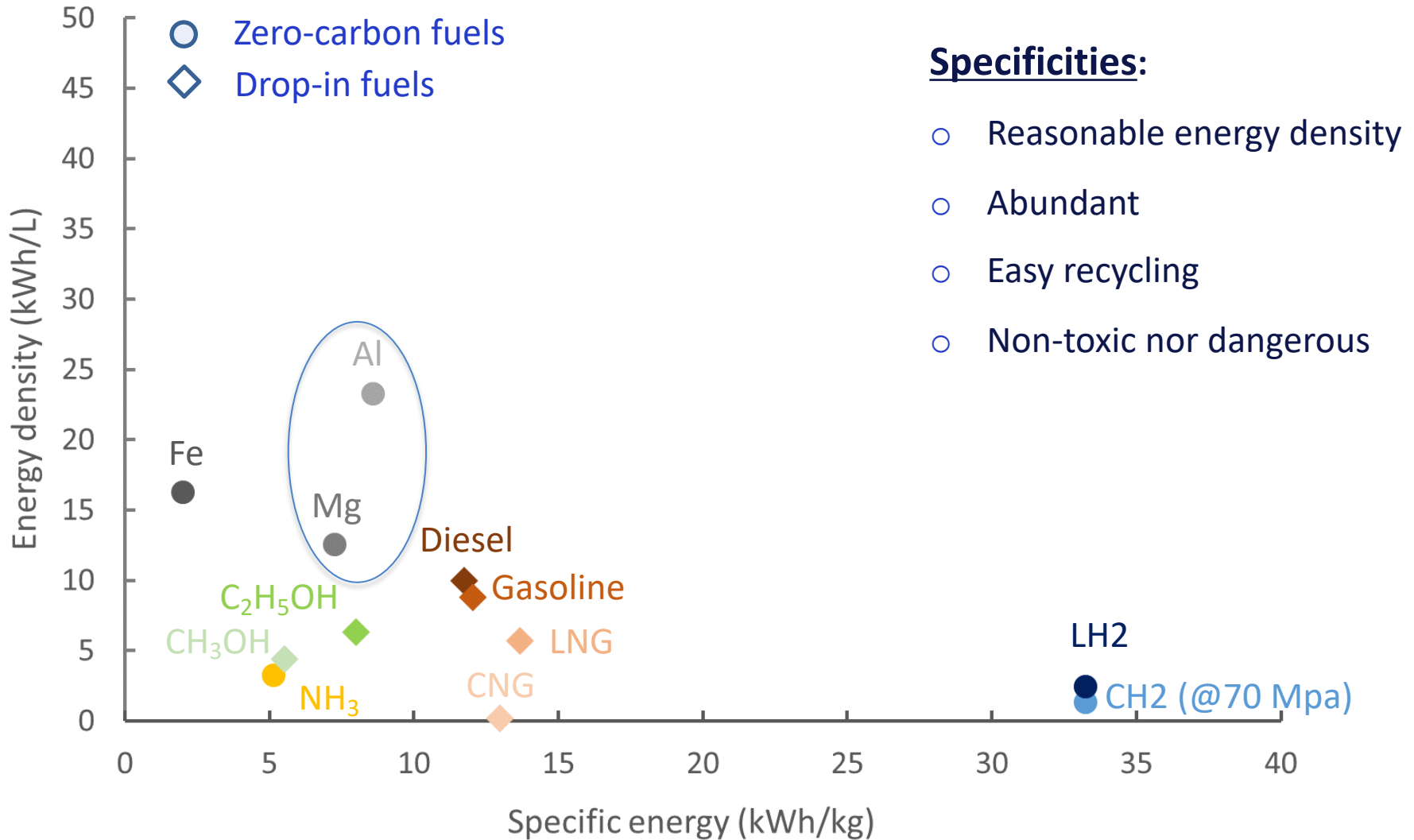
¹LGRE-UHA, UR 2334, ²ICARE-CNRS, UPR 3021, ³PROMES-CNRS, UPR 8521, ⁴STELLANTIS

SFGP 2022, Toulouse, 7-10 novembre 2022

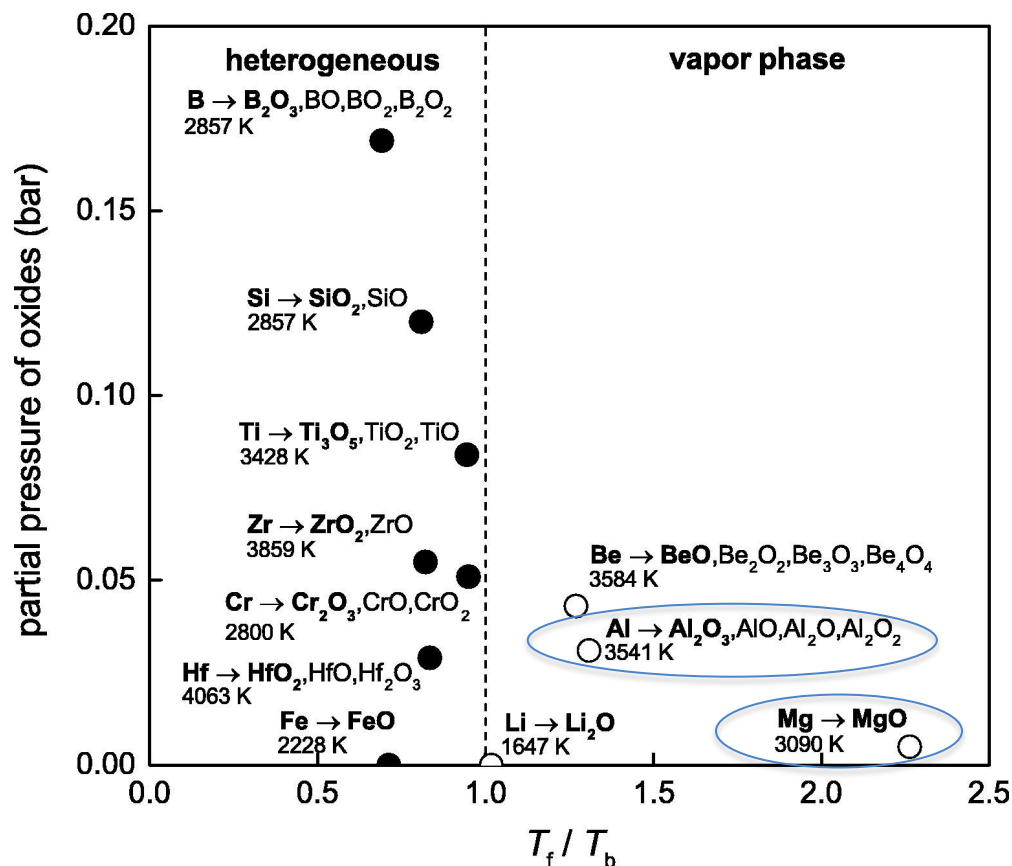
New energy system for vehicles



Metal selection

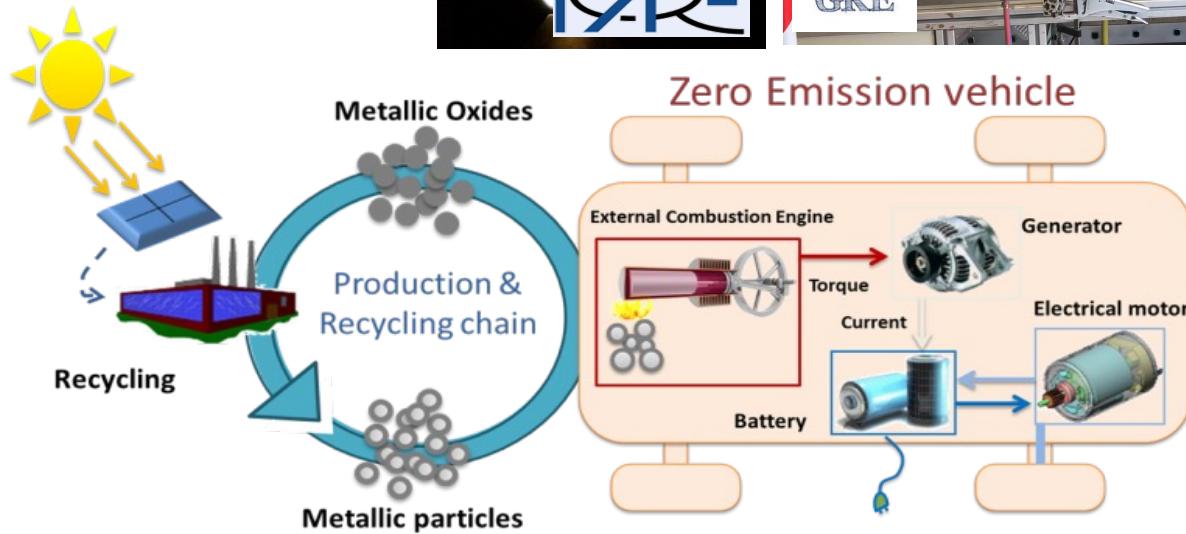
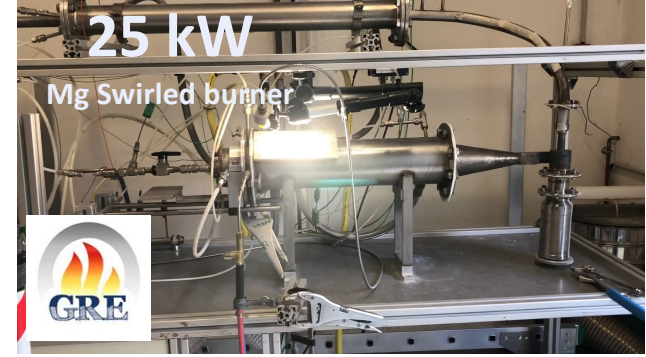


Metal particle combustion modes



Credits: Bergthorson et al.¹

1: Bergthorson JM, Goroshin S, Soo MJ, Julien P, Palecka J, Frost DL, et al. Direct combustion of recyclable metal fuels for zero-carbon heat and power. *Applied Energy*. 2015;160:368-82.

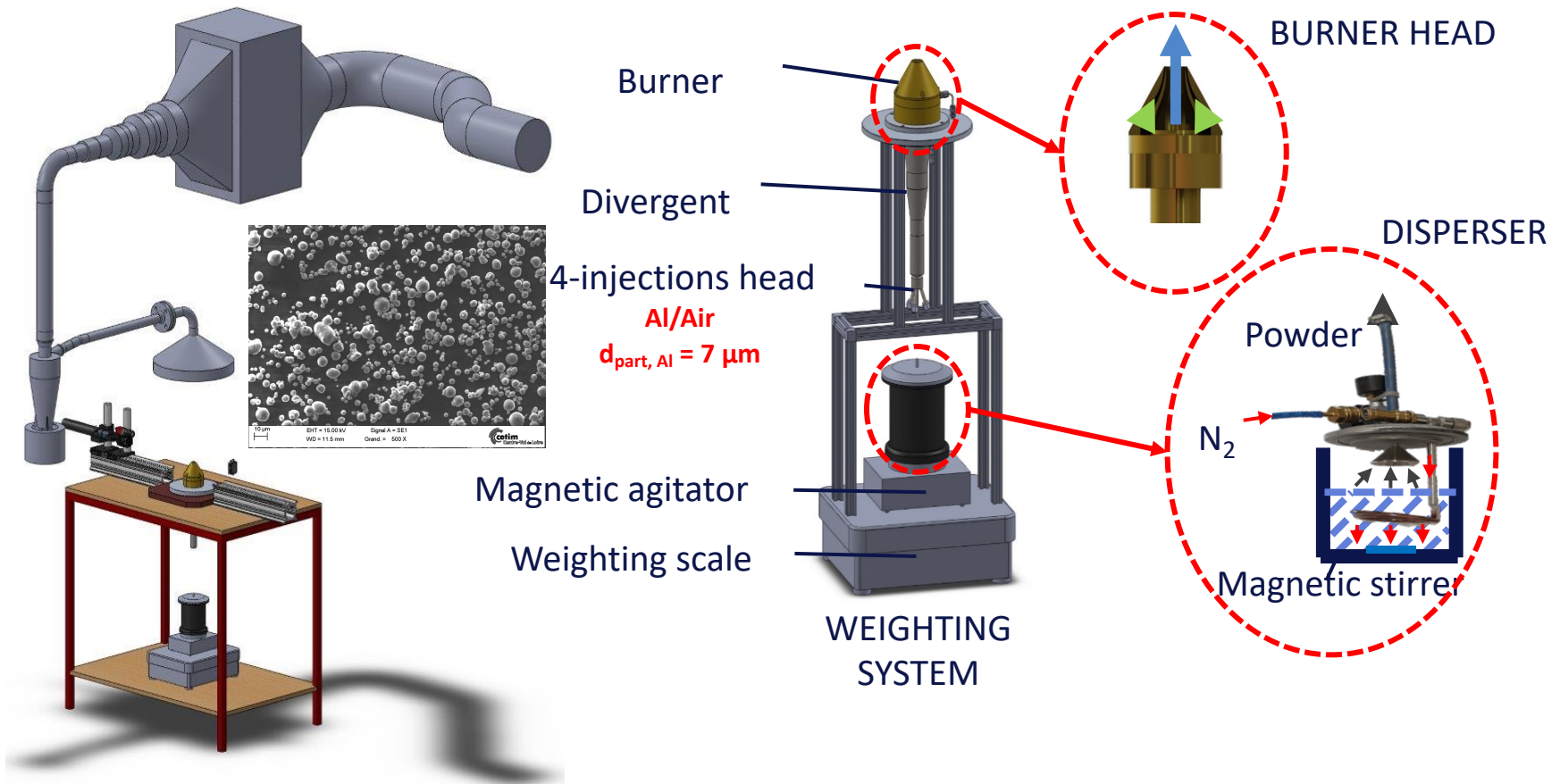


Objectives of the STELLAR Project

- (i) Flame stability
- (ii) Heat recovery
- (iii) Mitigation of NO_x emissions
- (iv) Oxide trapping
- (v) Recycling

Bunsen-type burner (ICARE)

in order to obtain a laminar, conical Al/air flame



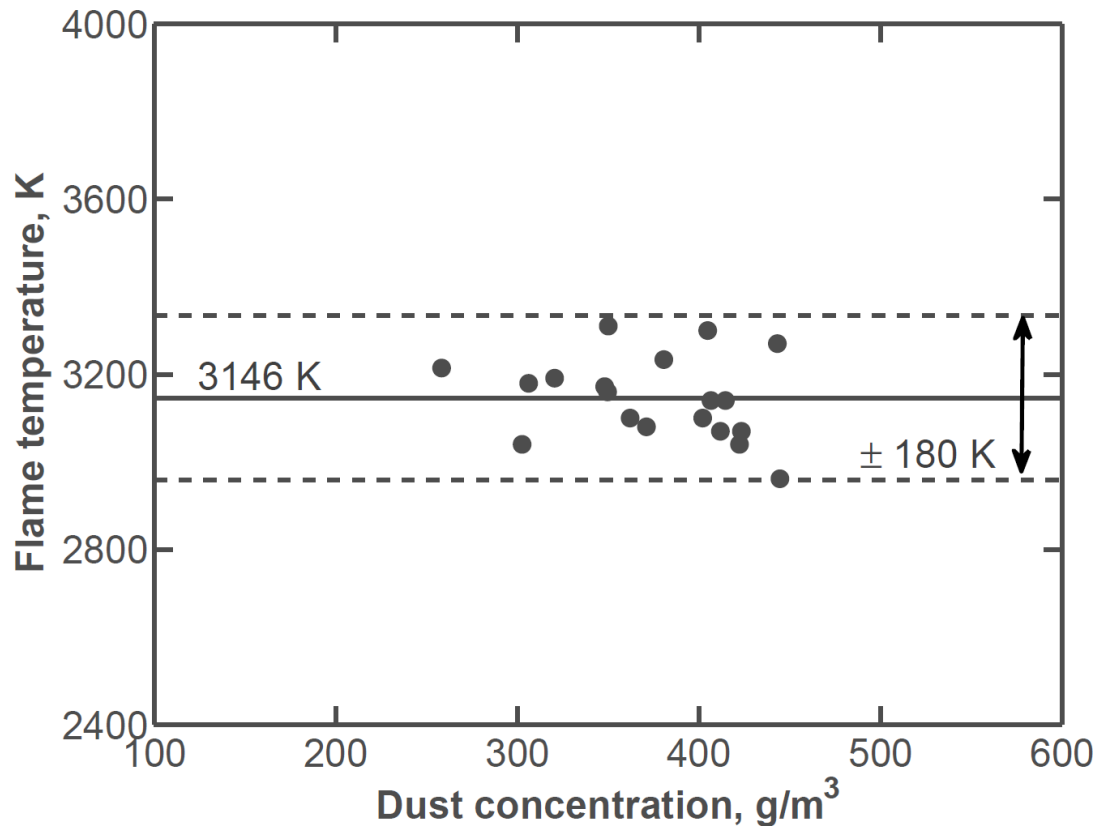
Laminar Al/air flame



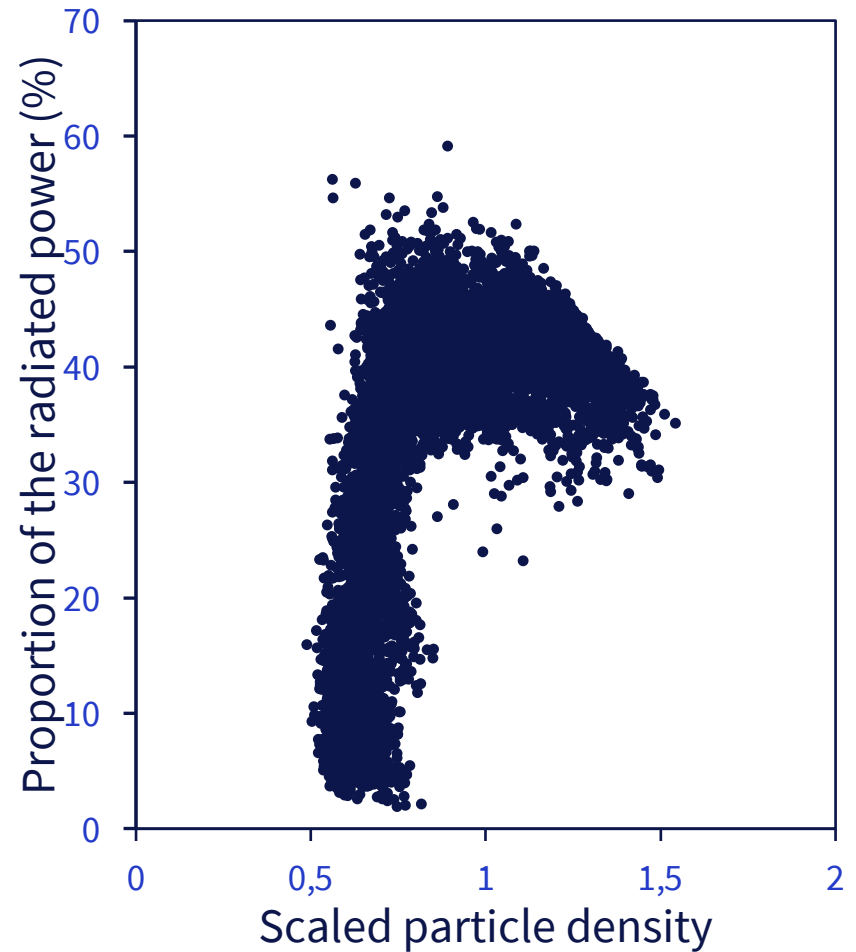
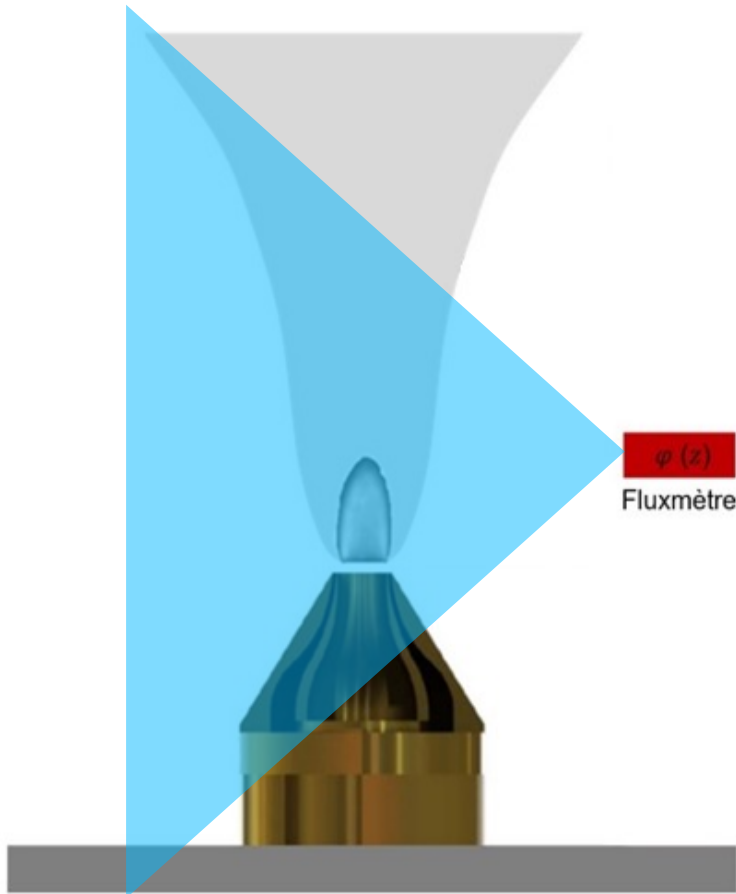
Gas phase temperature (Al/air flame)

For $0,8 < \phi < 1,5$, flame temperature remains constant.

- Adiabatic flame temperature: 3540 K.



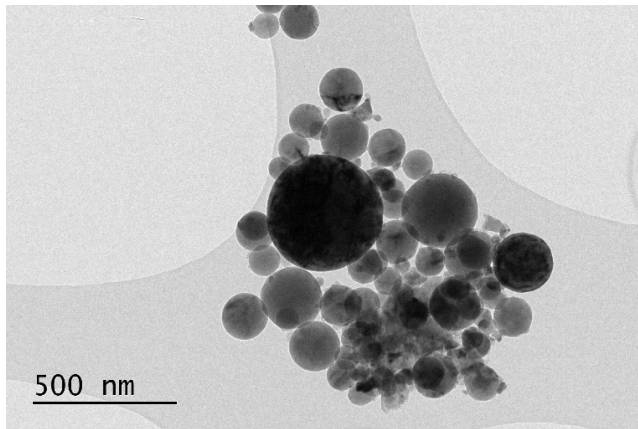
Flame radiation (Al/air flame)



- Radiation plays an extremely important role.

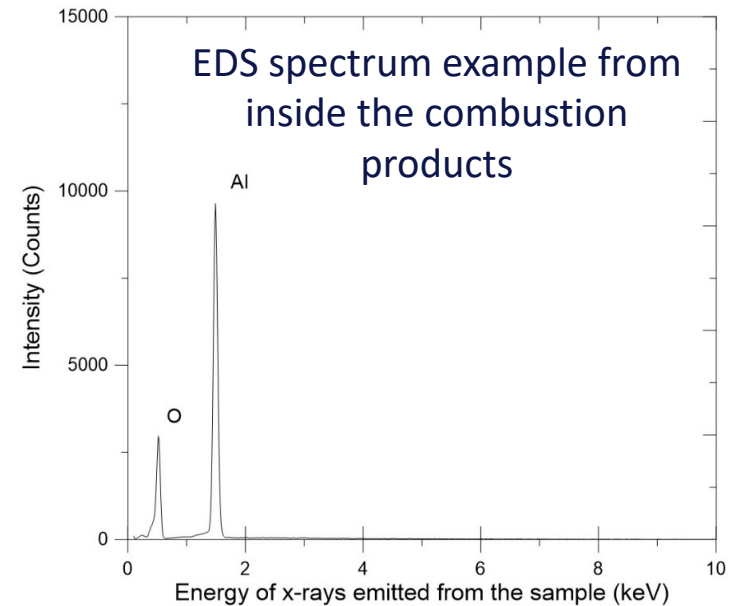
Condensed products (from Al/air flame)

N₂



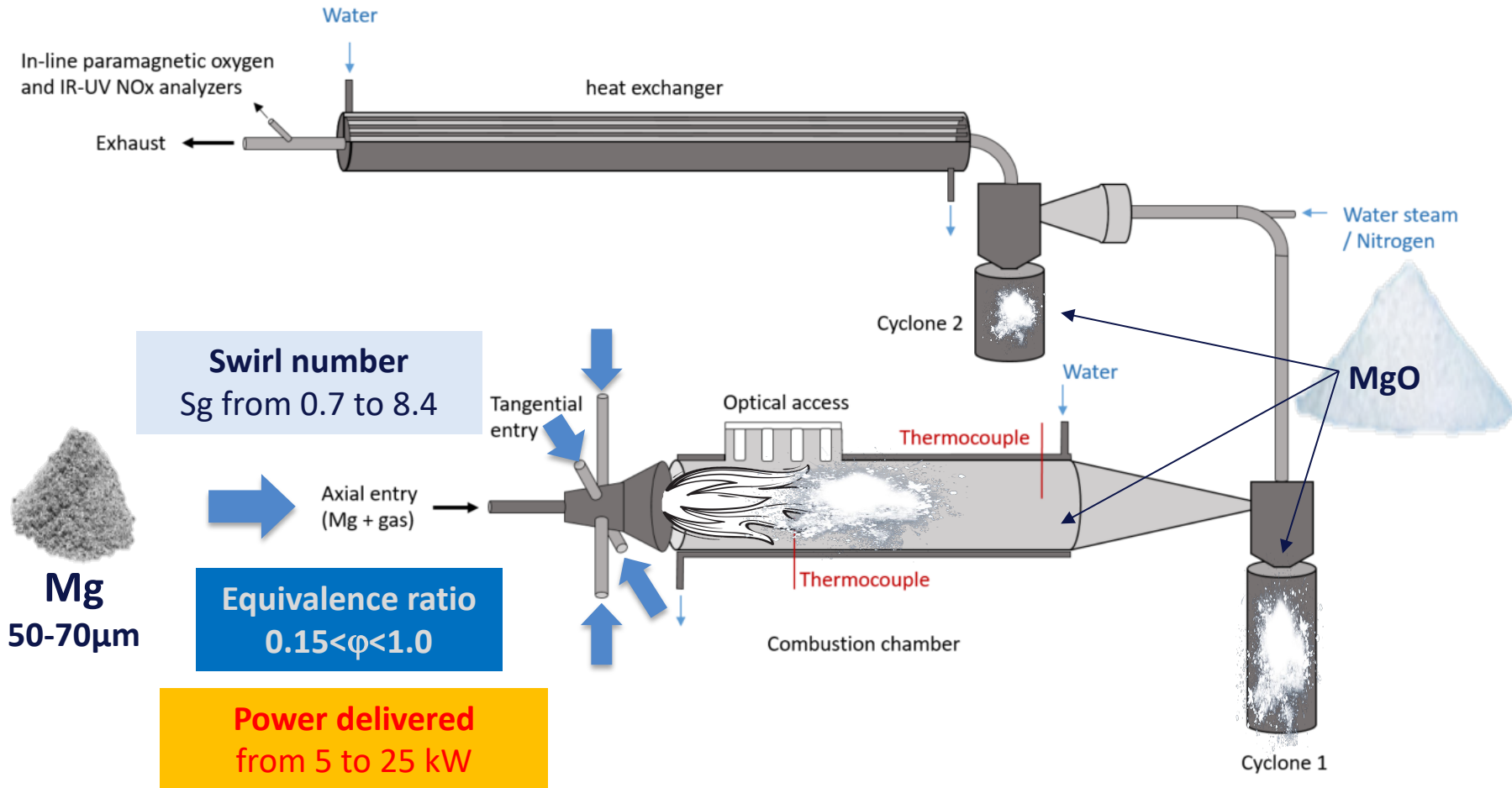
- TEM image of the nanoscale condensed combustion products

- Mean diameter of 110 nm

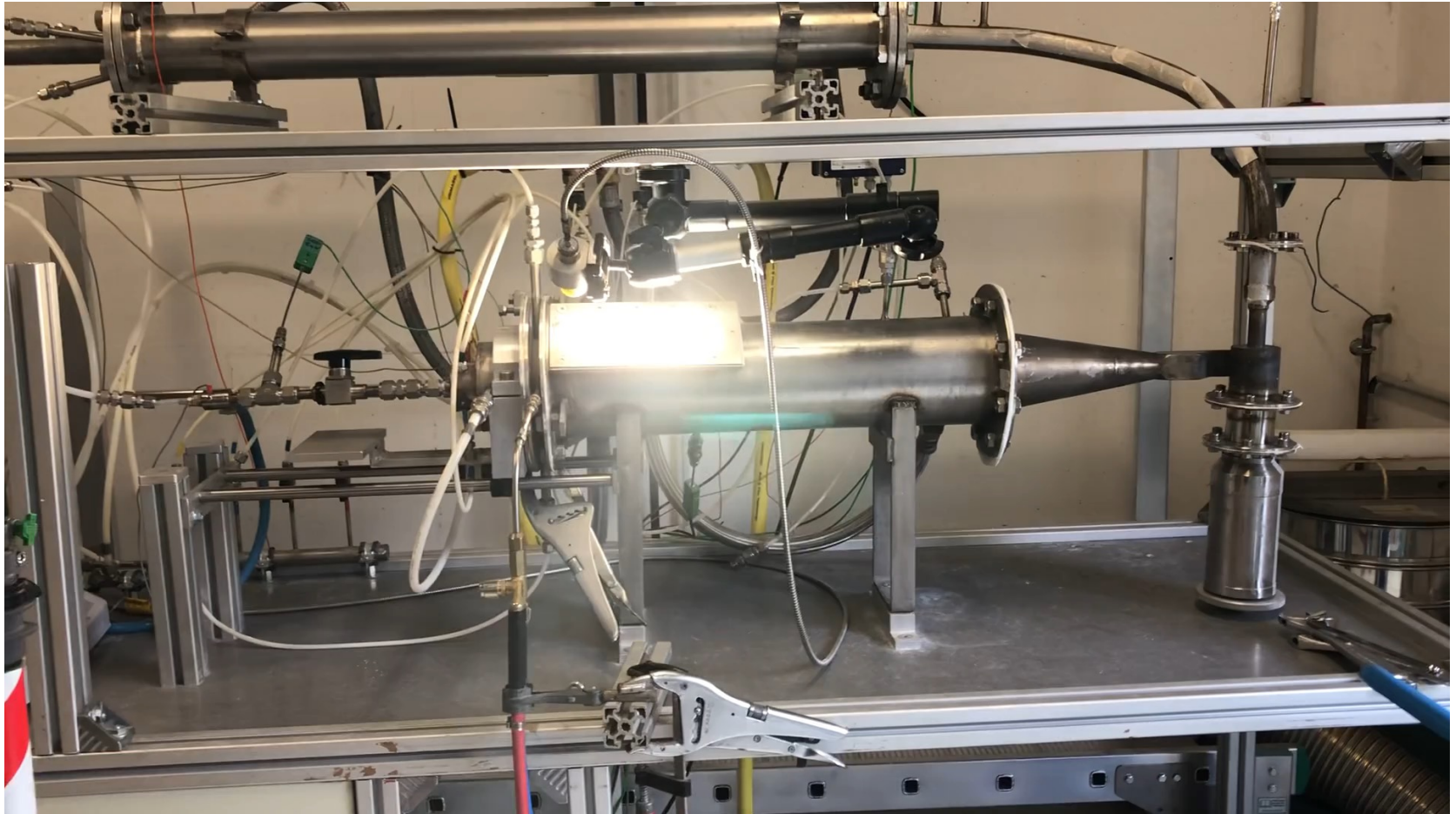


- Combustion efficiency close to unity

Mg/Air combustion system (LGRE)

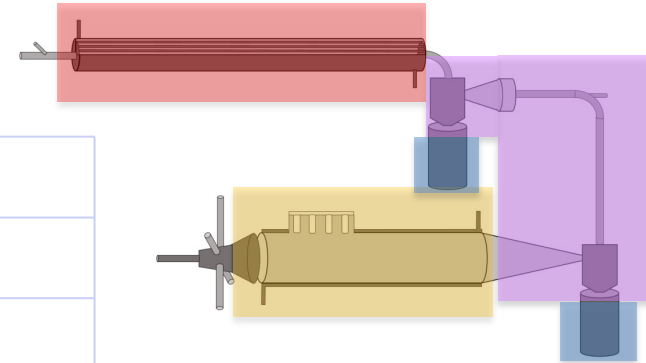
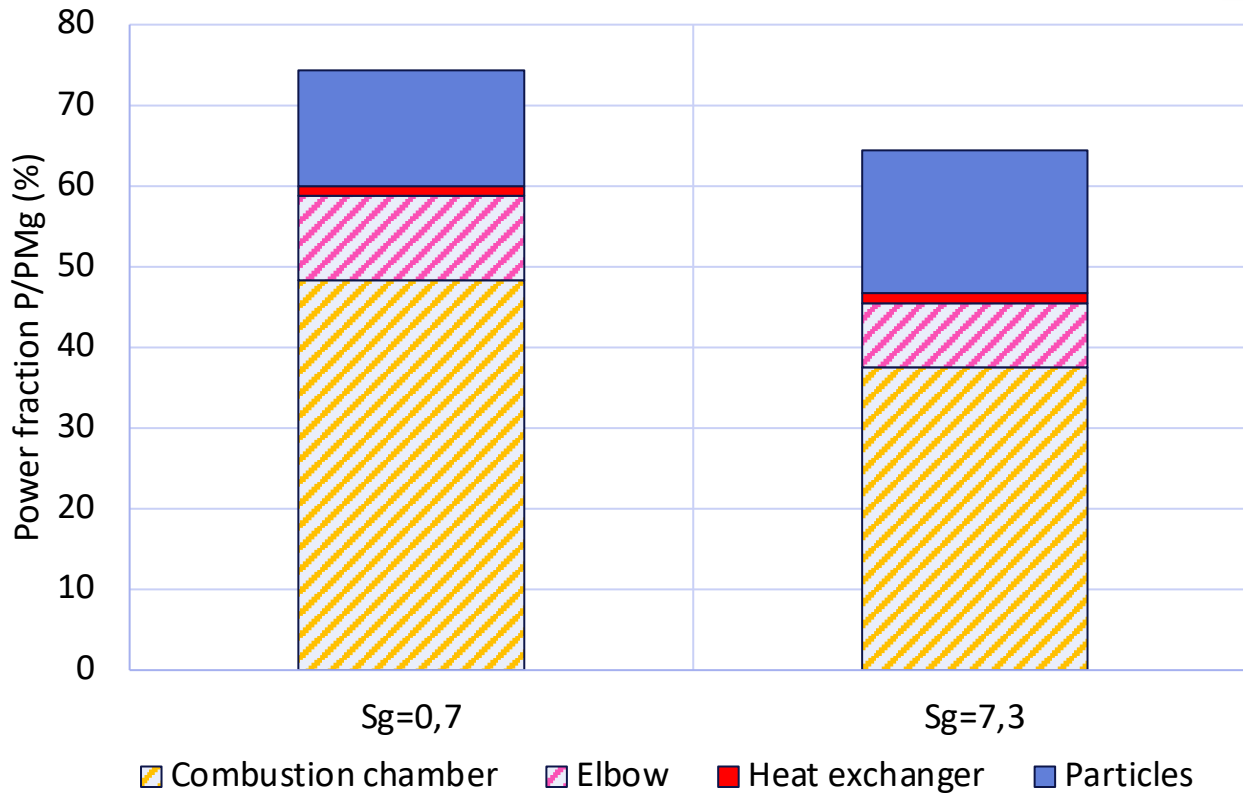


Mg/Air combustion system (LGRE)

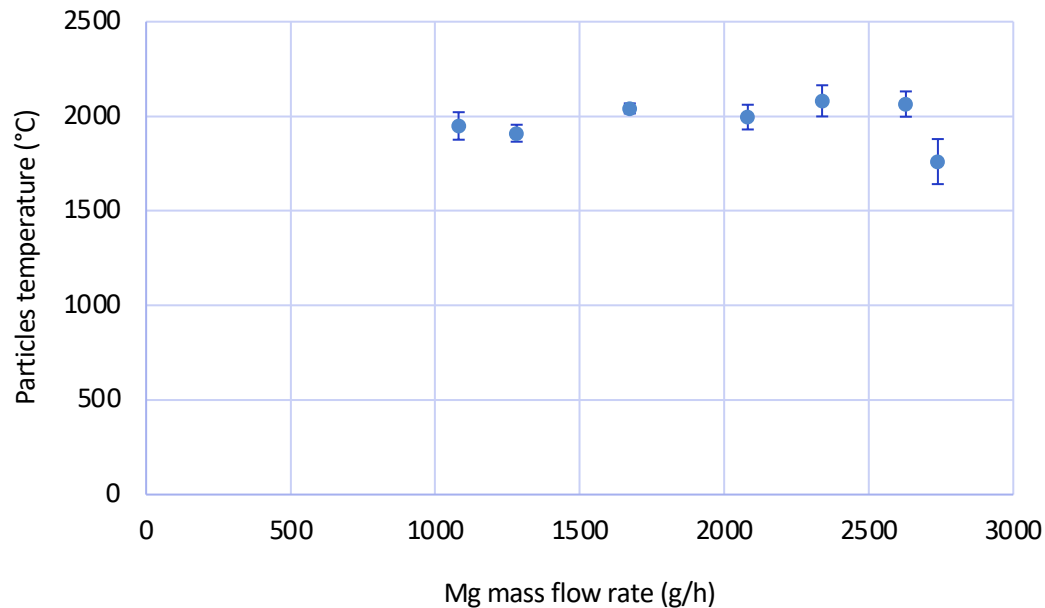
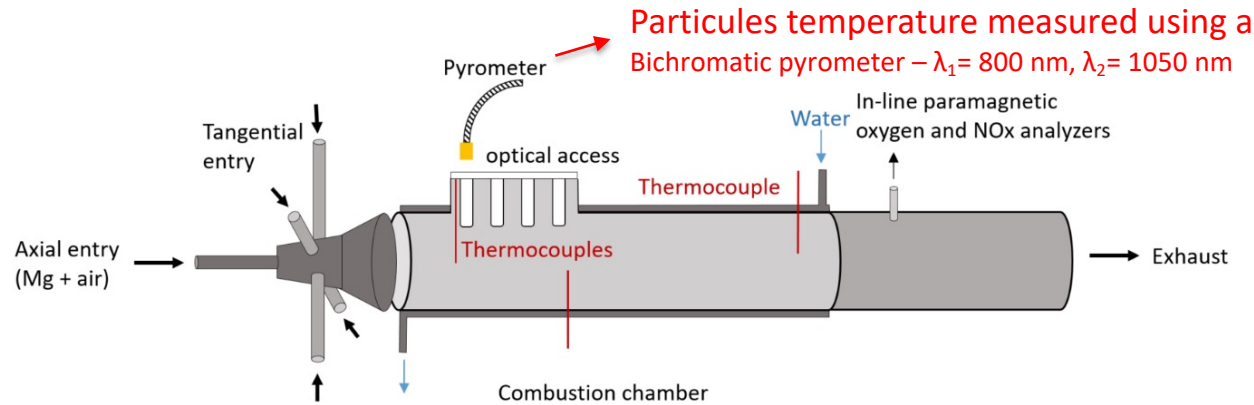


Mean Power distribution (Mg/air flame)

for $Sg=0.7$ and $Sg=7.3$

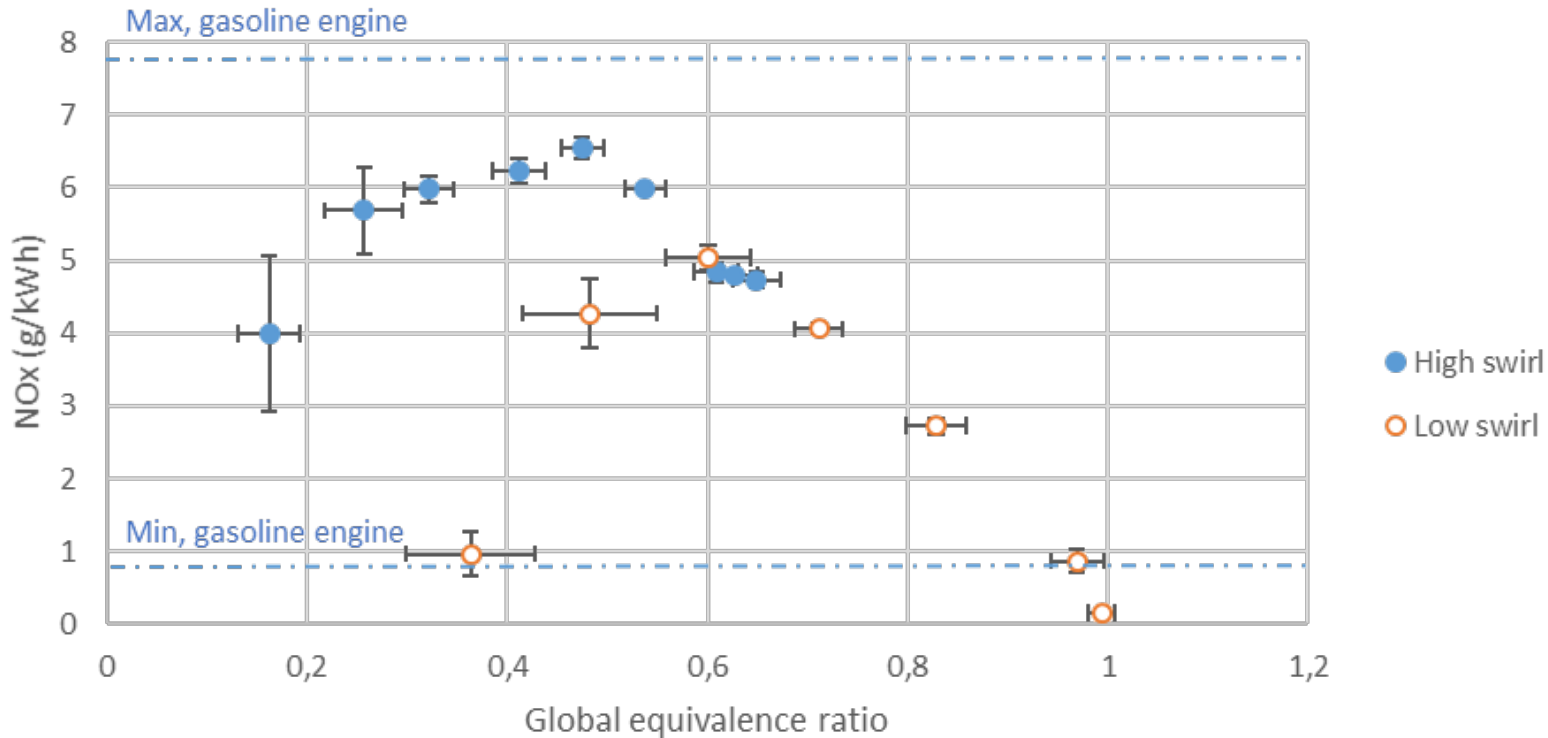


Particles temperature (Mg/air flame) for $S_g=7.3$



- The observed temperature is below the flame adiabatic temperature (water-cooled walls, cooled MgO screen).
- Particles temperature is not influenced by the global equivalence ratio.

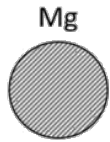
NOx emissions (Mg/air flame) for $S_g=0.7$ and $S_g=7.3$



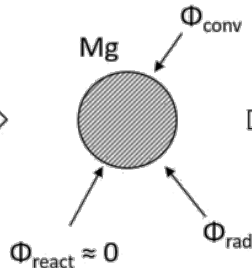
- Level of NOx emissions lower than that from a classical ICE engine

Mechanism proposed for Mg oxidation and subsequent NOx production

Injection
of Mg particles at
ambient temperature

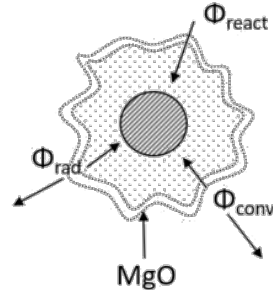


Heating-up
and ignition
(by radiation and
convection)



Slow oxidation
of Mg by O₂

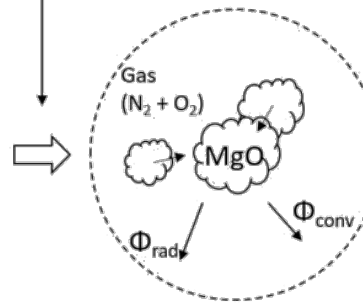
Vaporisation of Mg
and Oxidation
of Mg in gaseous phase
(duration ≈ 6 ms)



O₂ is consumed by Mg
oxidation
($2 \text{Mg} + \text{O}_2 \rightarrow 2 \text{MgO}$)
MgO temperature up to
2000/3000 °C

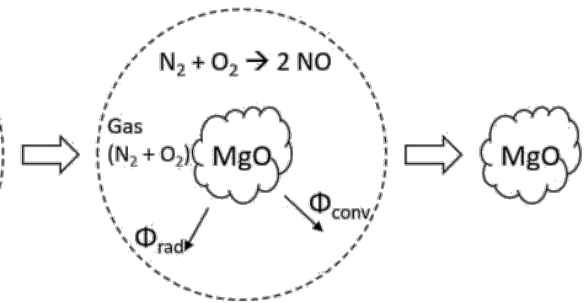
Condensation
of MgO

NOx formation starts when Mg is totally oxidized



$T_{\text{MgO}} \approx 2000/3000 \text{ °C}$
Gas surrounding the particles
is heated-up by MgO
O₂ concentration depends on
O₂ consumed by Mg oxidation

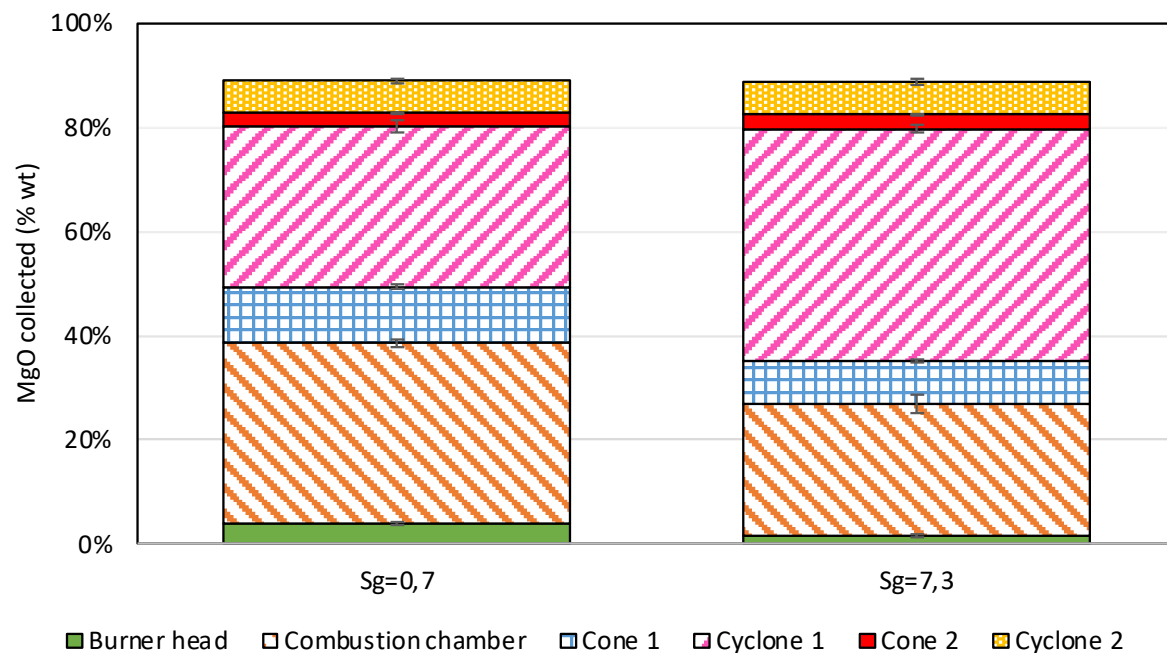
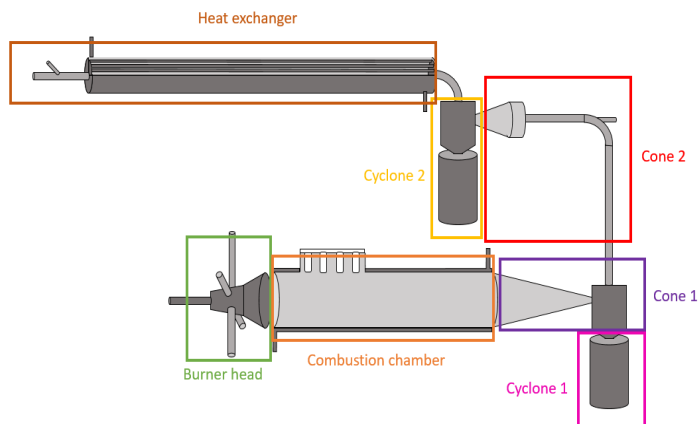
NOx formation



Part of the remaining
O₂ is consumed for
NOx yielding

Mass fraction distribution of collected MgO

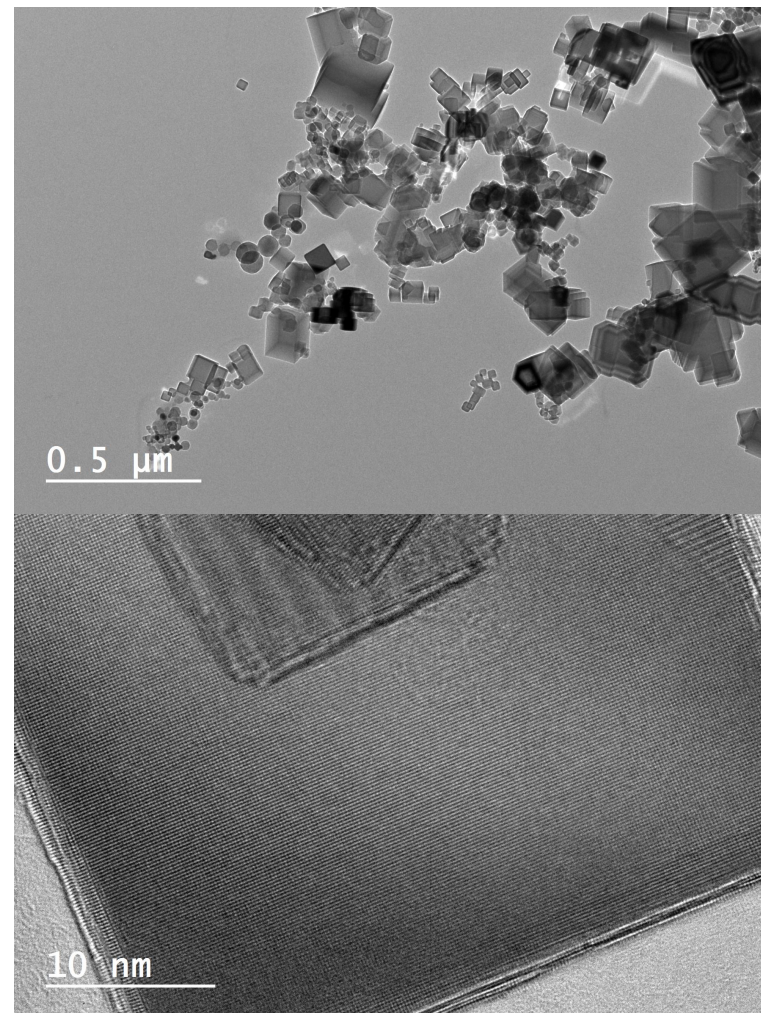
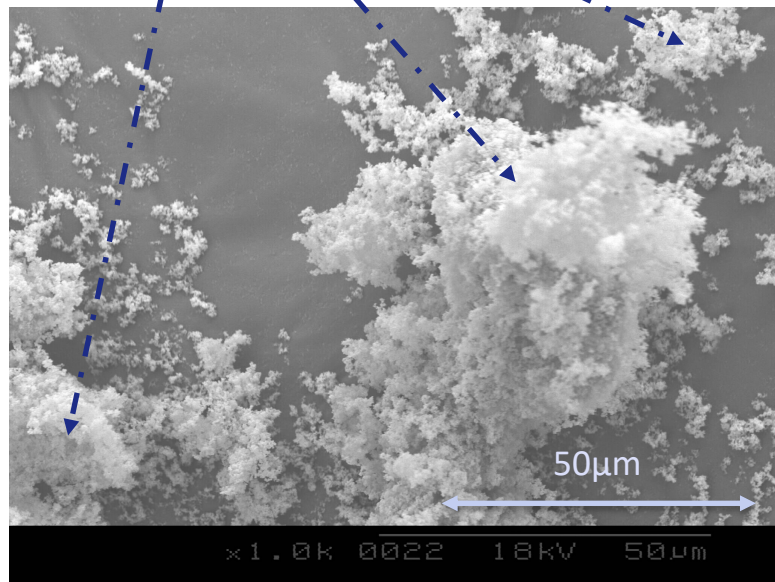
for $Sg=0.73$ and 7



- More than 90 %wt of MgO is trapped in the system (**for regeneration**)
- **Combustion efficiency close to unity**

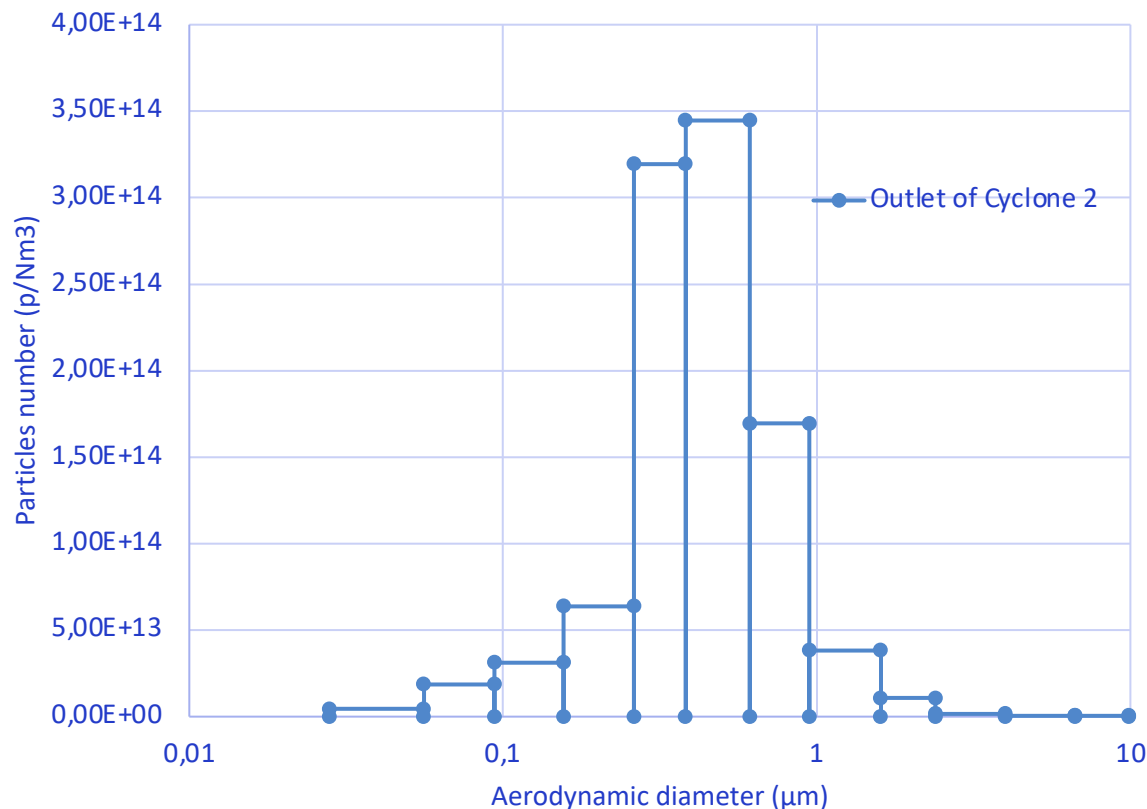
SEM and TEM images of condensed MgO particles for $S_g=0.7$

Agglomerates of aggregates
of MgO crystals



Size distribution of MgO particles in the exhaust gas

(ELPI measurements at the outlet of cyclone 2, $S_g=0.7$, $\Phi=0.6$)



- Number size distribution of the MgO particles at the cyclone outflow is widespread in the range 100nm-1 μm .

Conclusions and perspectives

The available data prove that metal fuels can be burned in power devices at nearly-**equivalent power densities** to modern hydrocarbon-fuelled systems.

NOx emissions can be controlled and more than 90%wt of the MgO produced is trapped in the system.

Metal fuels can be used directly for **heating applications** (high temperatures) or for producing **mechanical** and **electrical power**.

Metal powders could be potentially **retro-fitted** in coal power stations, or those fuelled by biomass.

Thanks for attention