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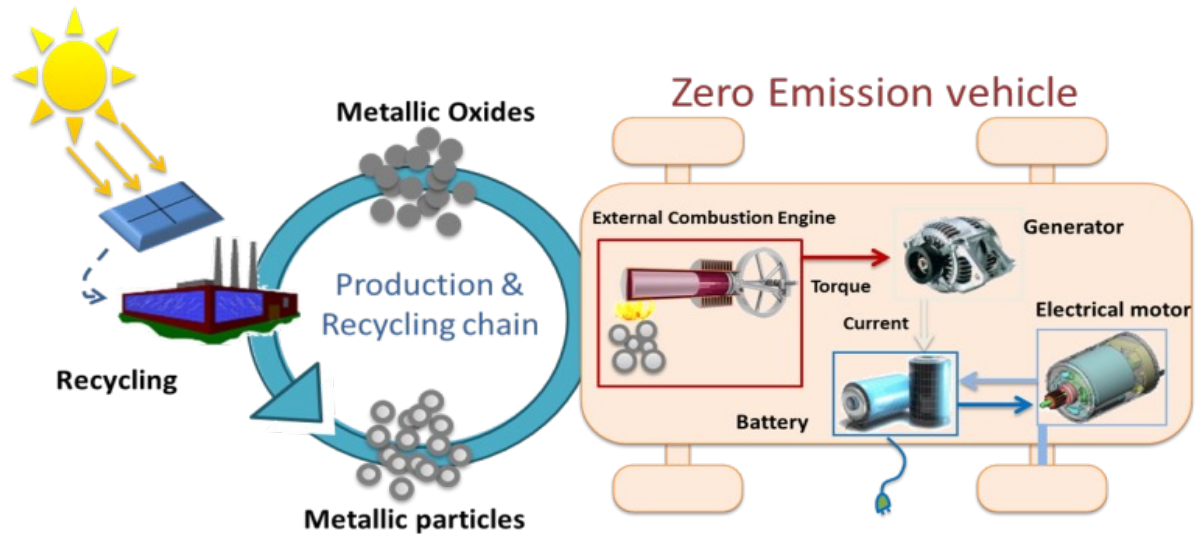
Combustibles métalliques durables pour la mobilité du futur

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

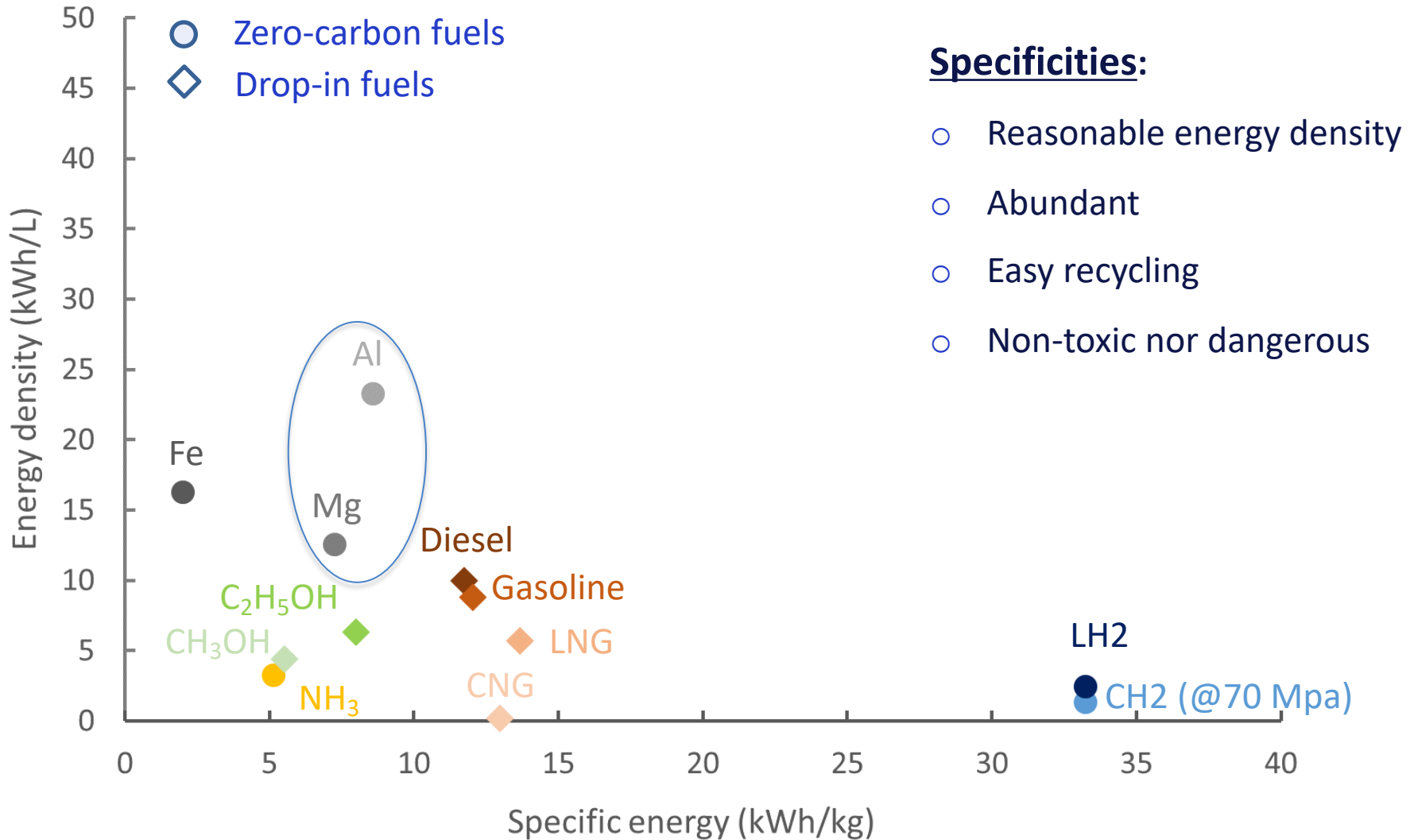
¹LGRE-UHA, UR 2334, ²ICARE-CNRS, UPR 3021, ³PROMES-CNRS, UPR 8521, ⁴STELLANTIS

SFGP 2022, Toulouse, 7-10 novembre 2022

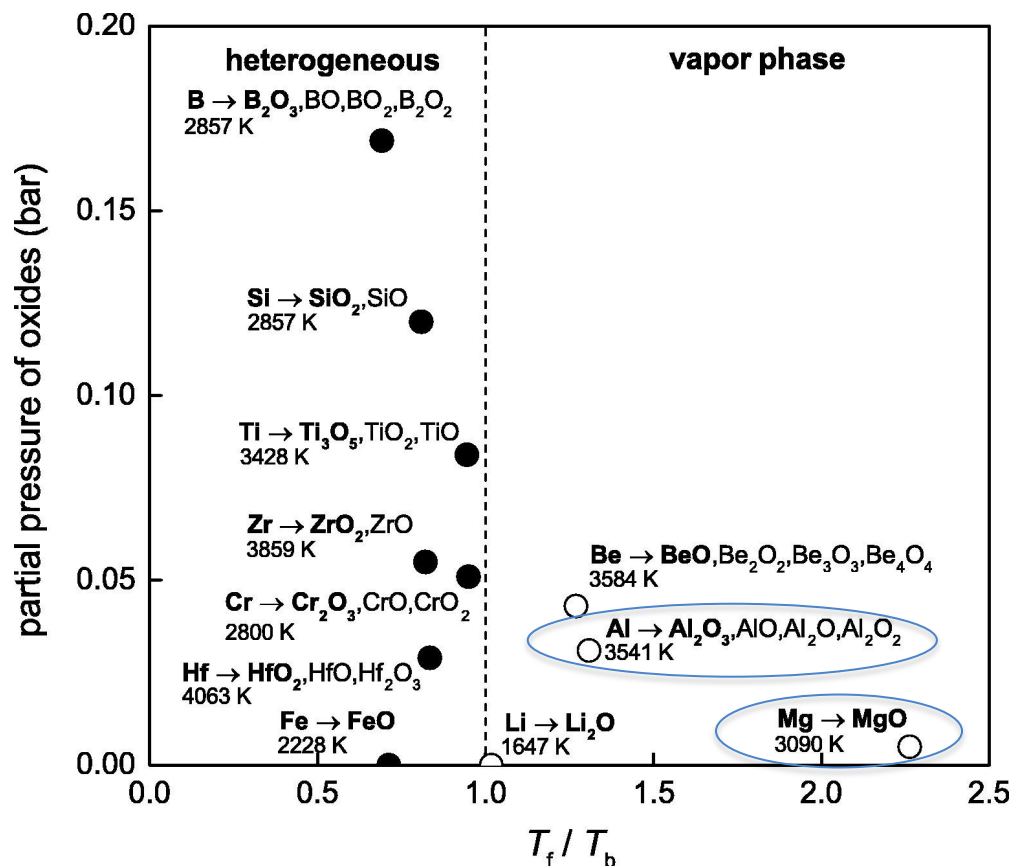
New energy system for vehicles



Metal selection

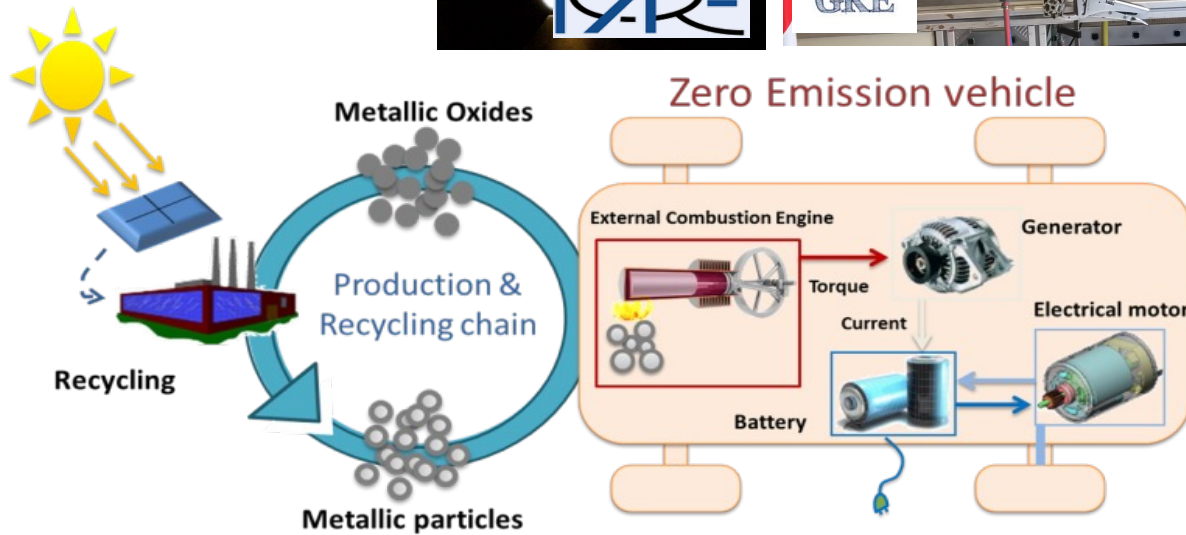
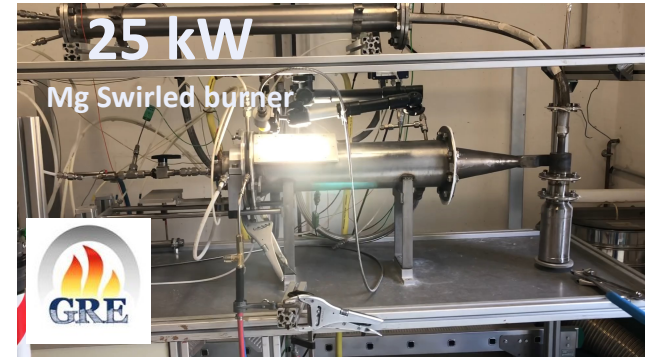


Metal particle combustion modes



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.

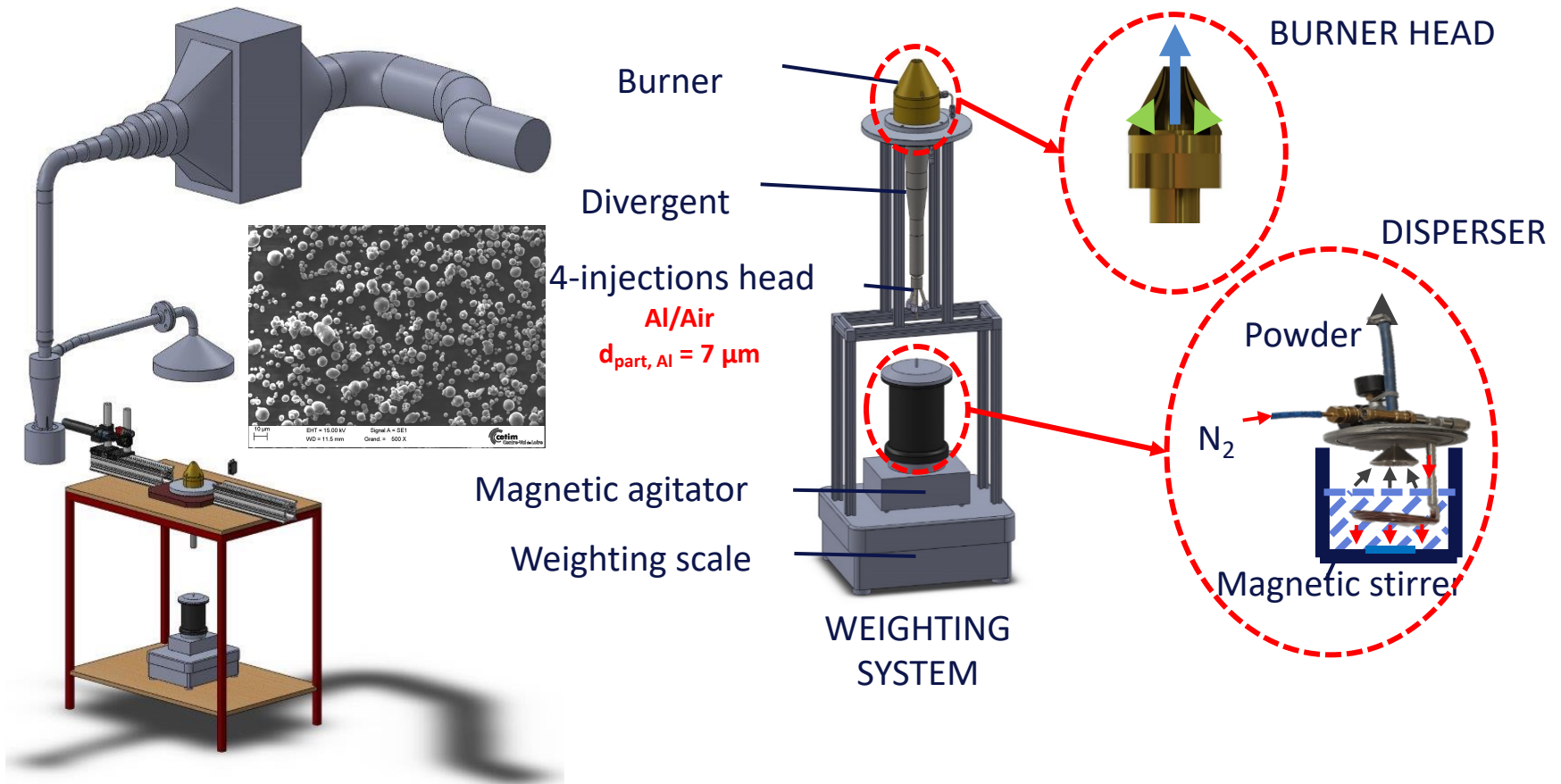


Objectives of the STELLAR Project

- (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



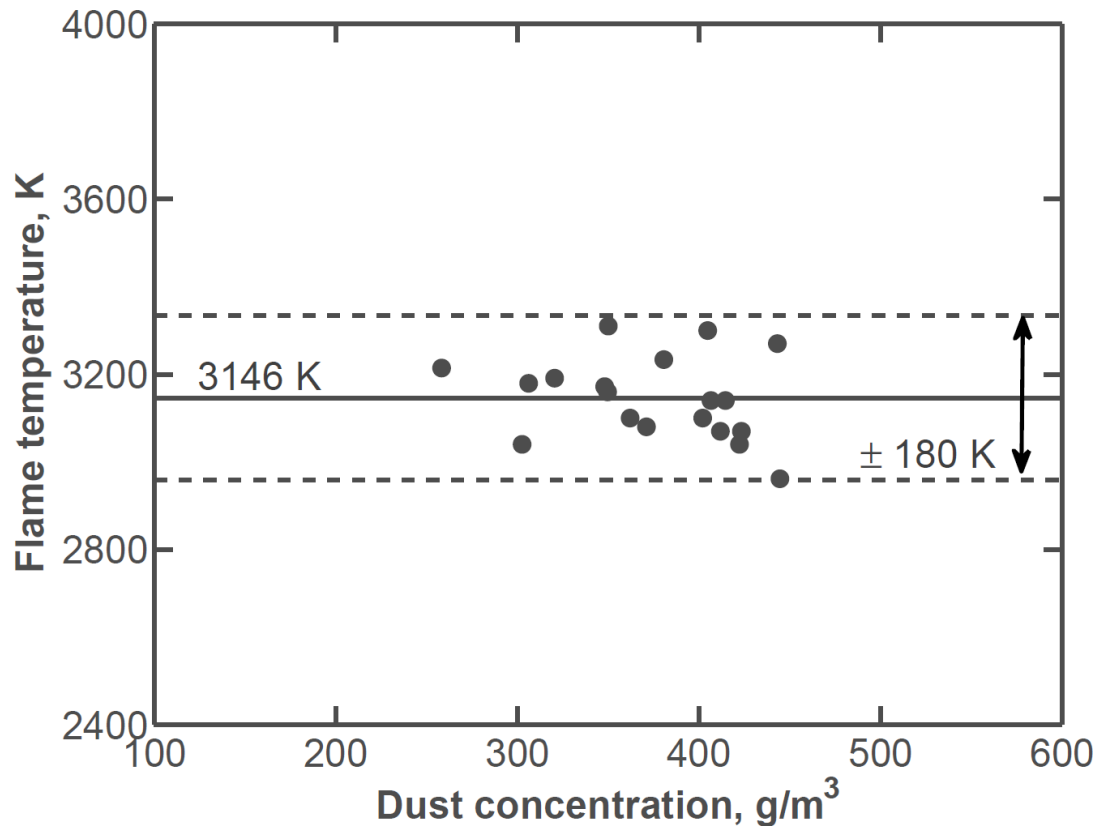
Laminar Al/air flame



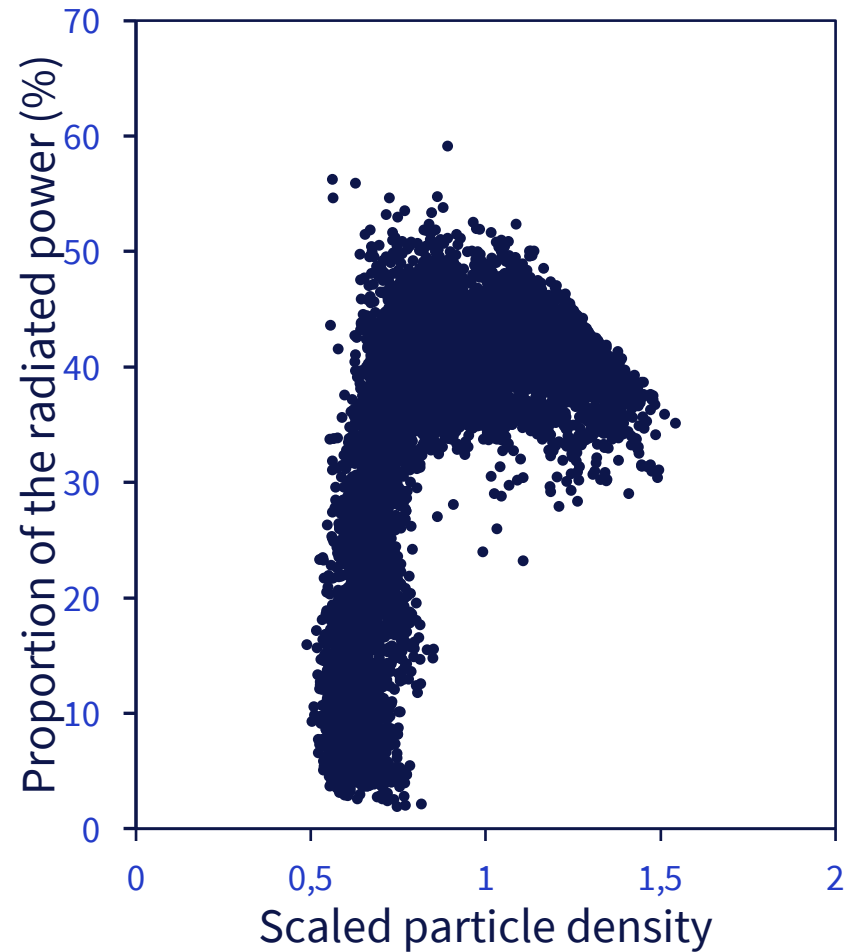
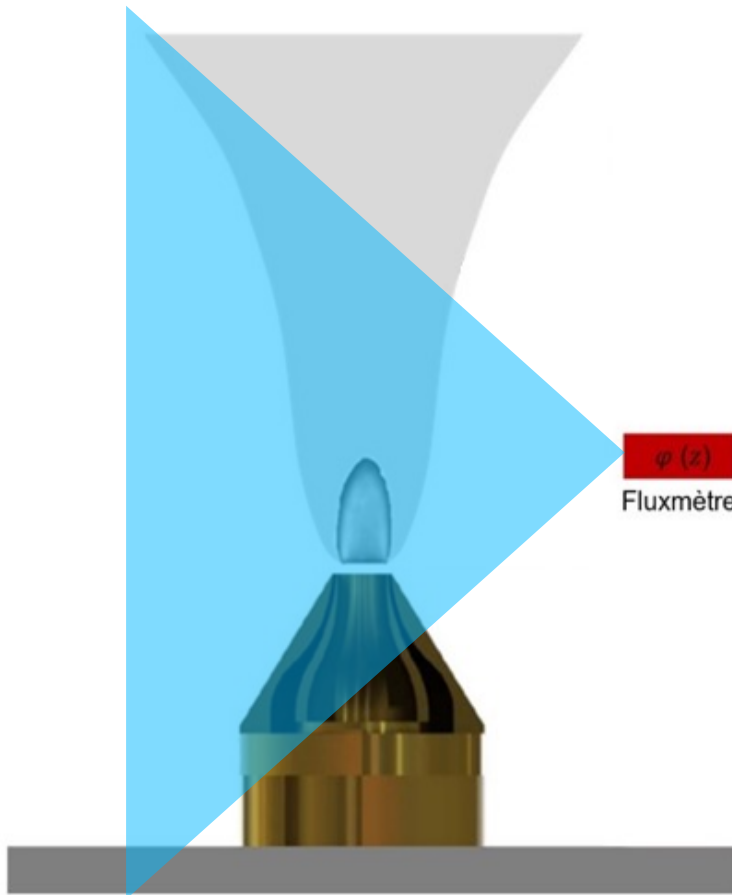
Gas phase temperature (Al/air flame)

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

- Adiabatic flame temperature: 3540 K.



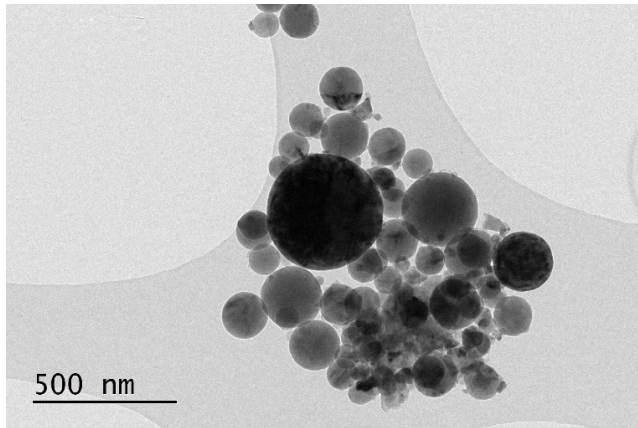
Flame radiation (Al/air flame)



- Radiation plays an extremely important role.

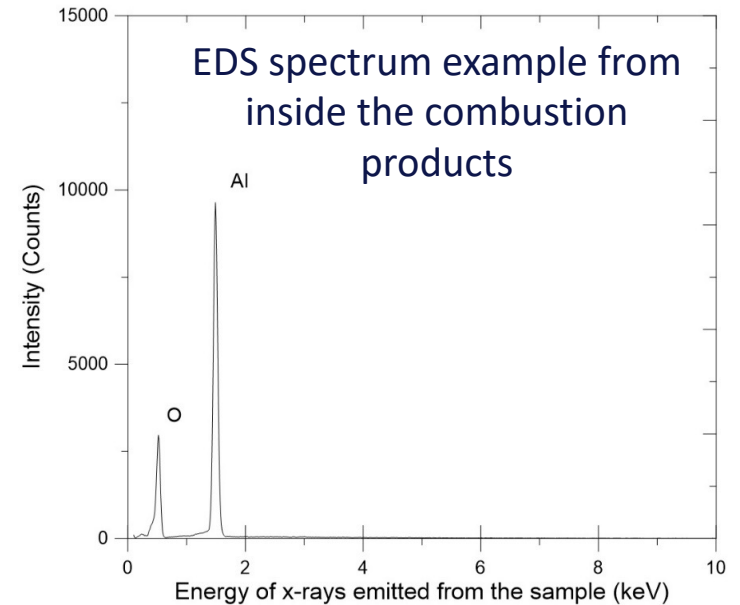
Condensed products (from Al/air flame)

N₂



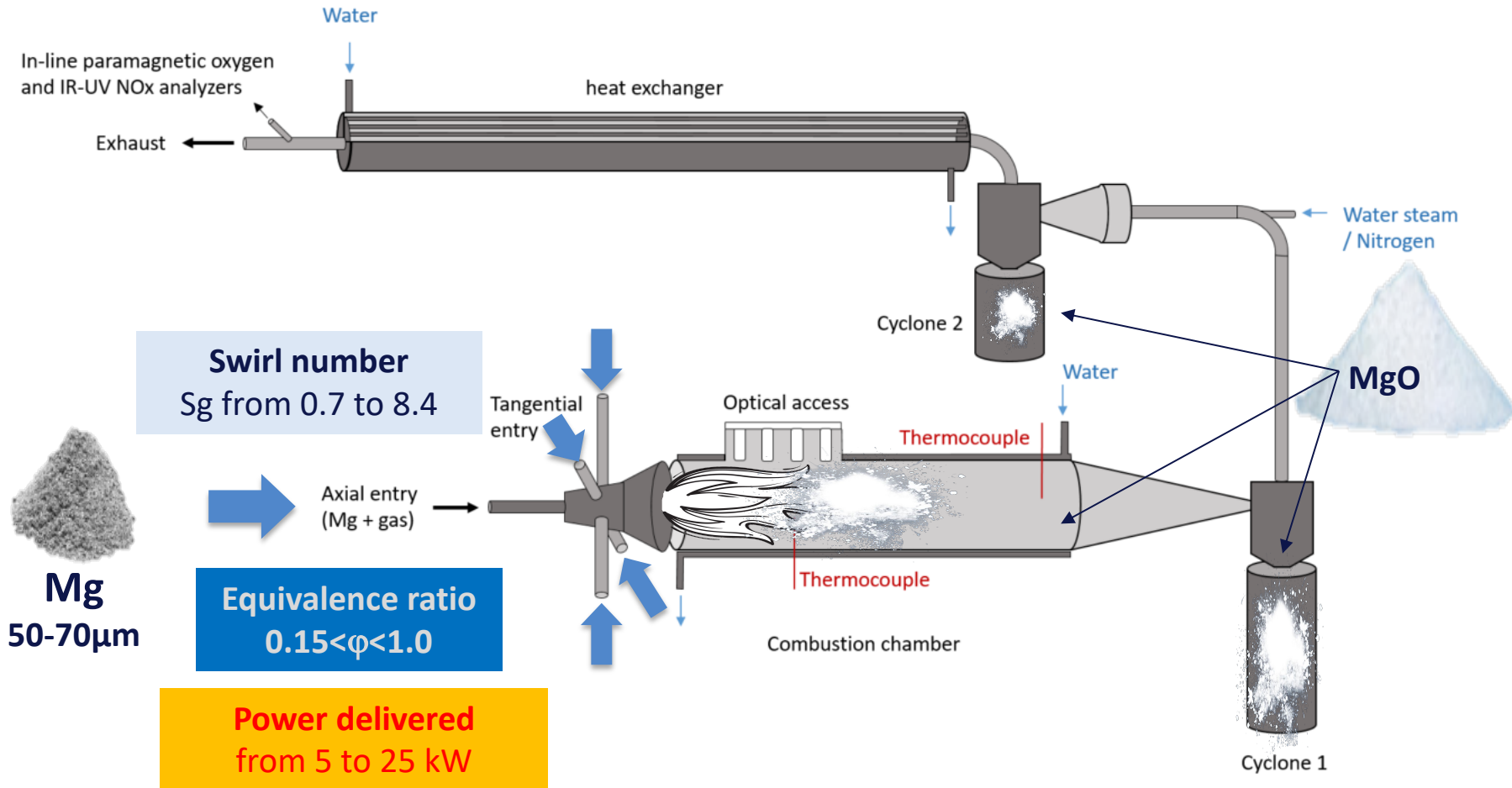
- TEM image of the nanoscale condensed combustion products

- Mean diameter of 110 nm

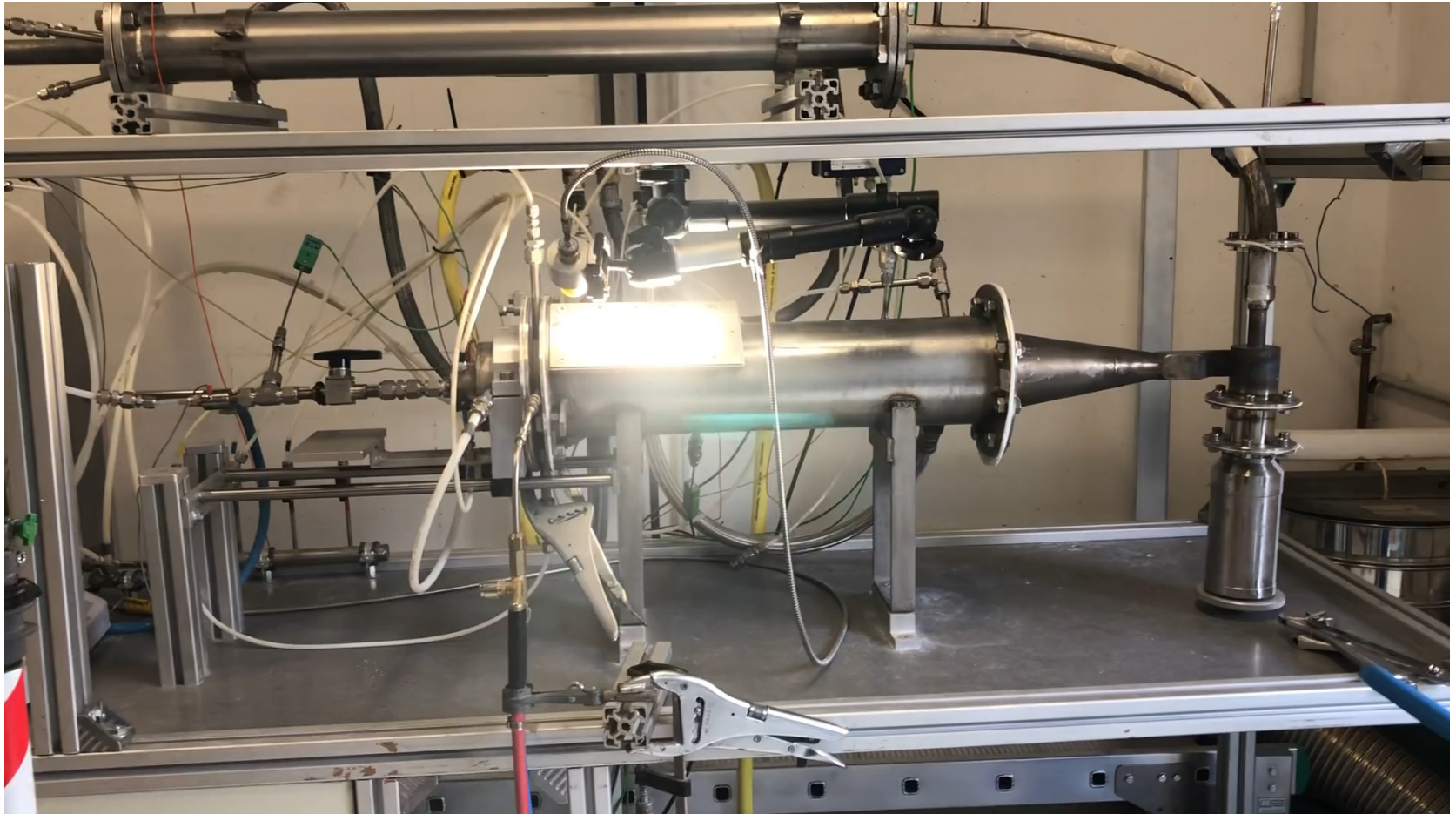


- Combustion efficiency close to unity

Mg/Air combustion system (LGRE)

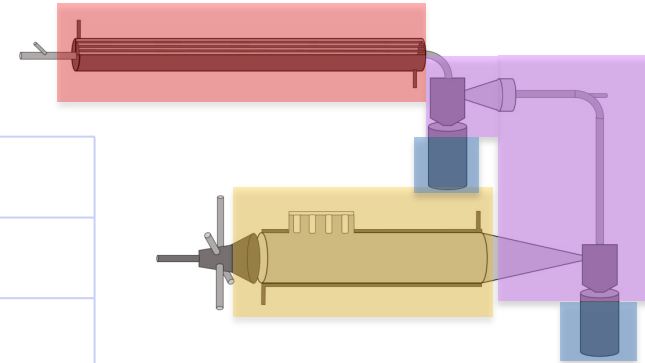
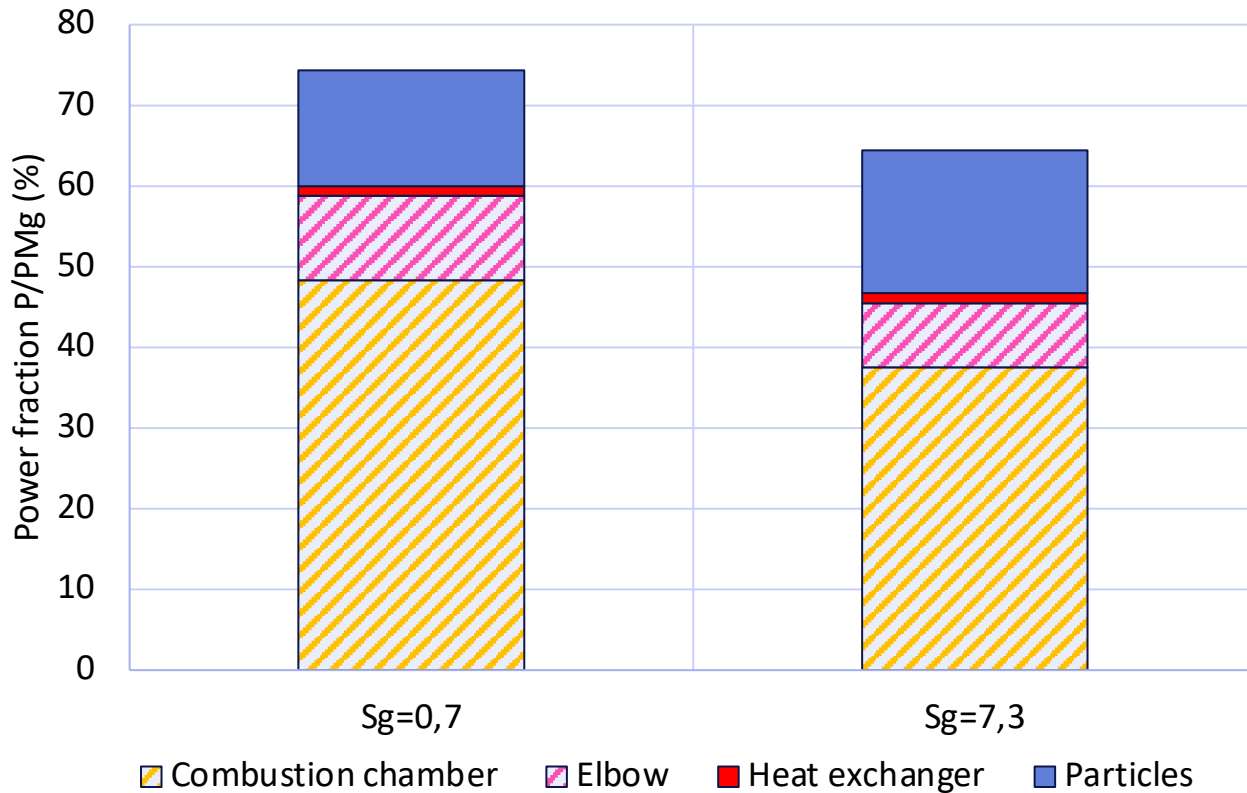


Mg/Air combustion system (LGRE)

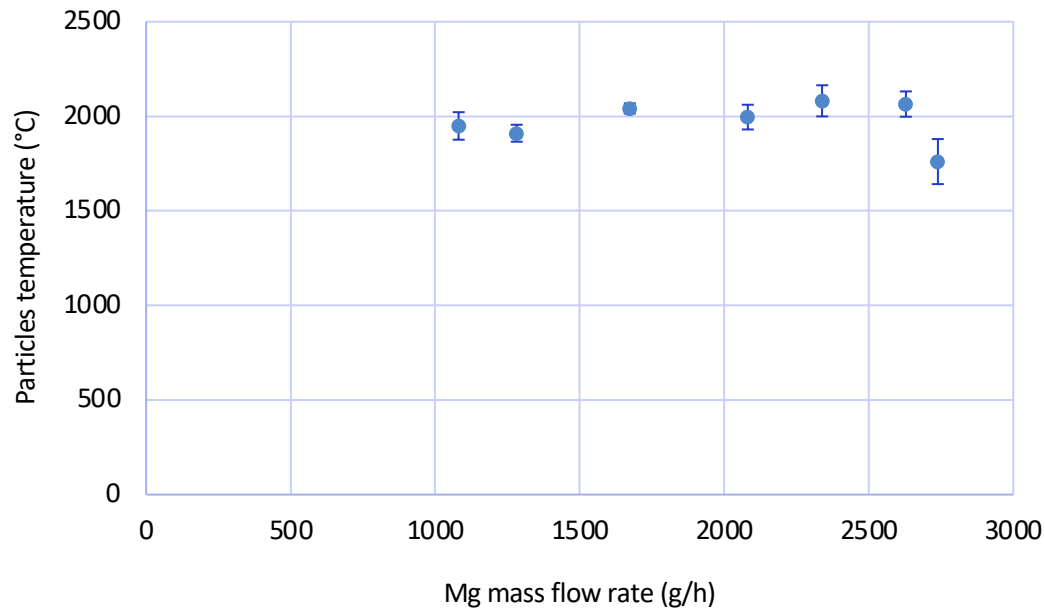
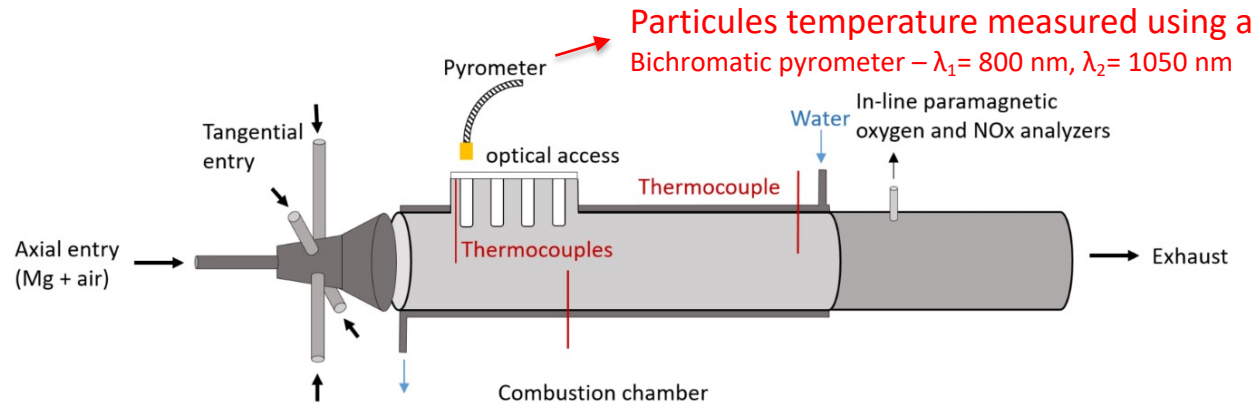


Mean Power distribution (Mg/air flame)

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

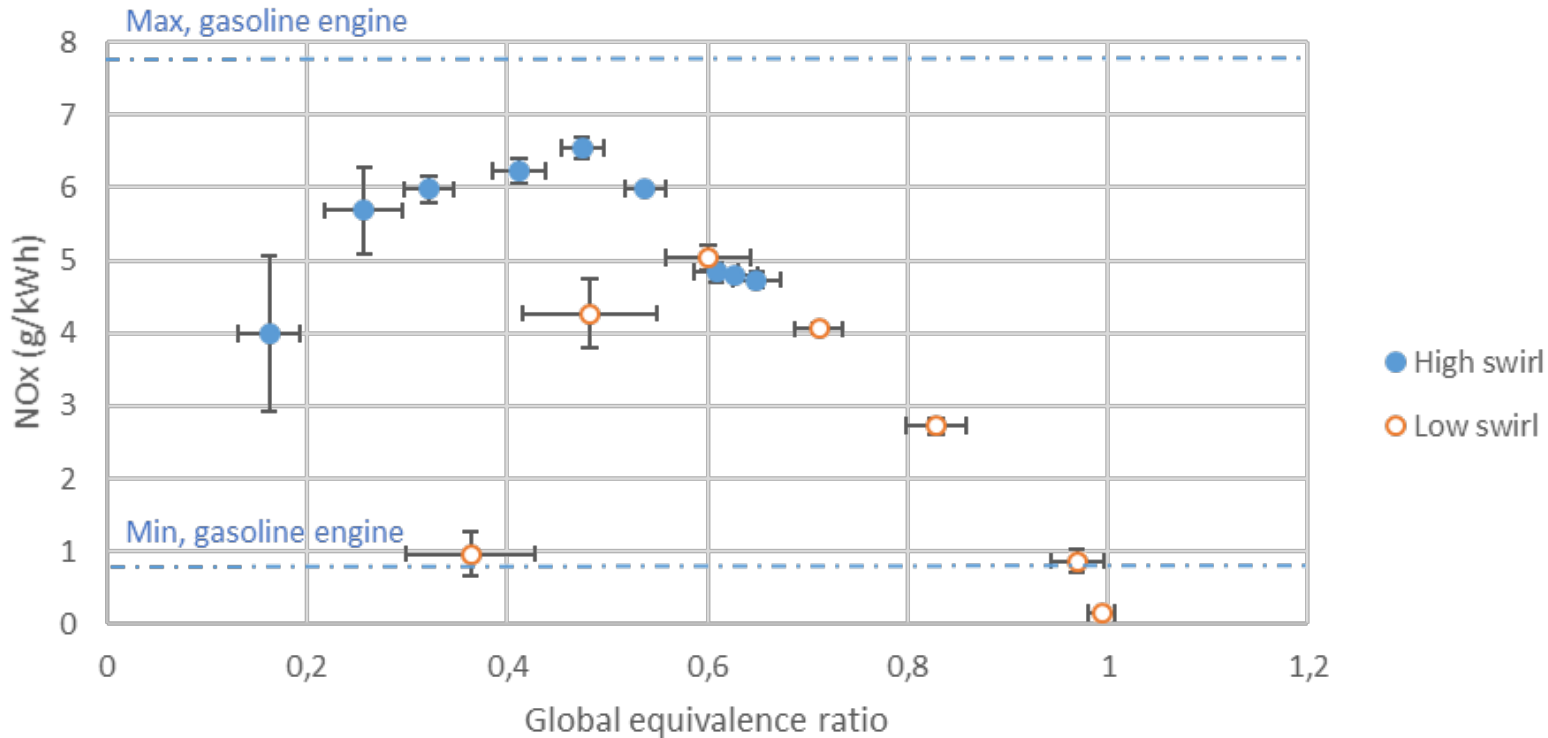


Particles temperature (Mg/air flame) for $S_g=7.3$



- 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.

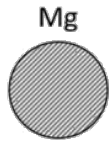
NOx emissions (Mg/air flame) for $S_g=0.7$ and $S_g=7.3$



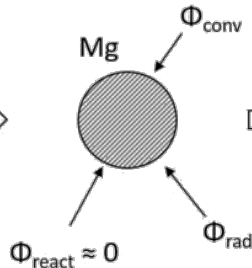
- Level of NOx emissions lower than that from a classical ICE engine

Mechanism proposed for Mg oxidation and subsequent NOx production

Injection
of Mg particles at
ambient temperature

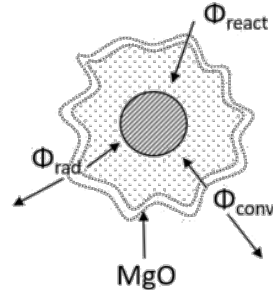


Heating-up
and ignition
(by radiation and
convection)



Slow oxidation
of Mg by O₂

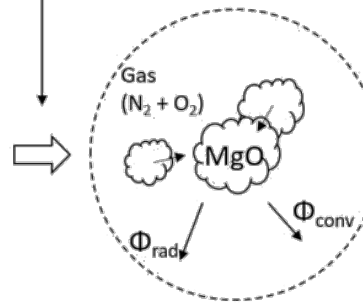
Vaporisation of Mg
and Oxidation
of Mg in gaseous phase
(duration ≈ 6 ms)



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

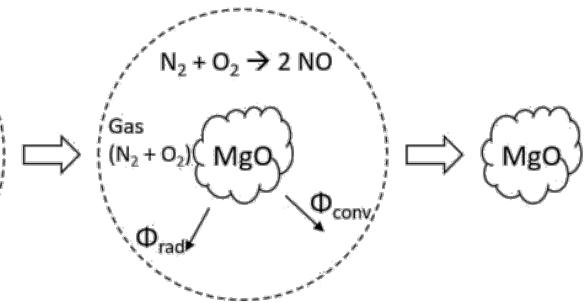
Condensation
of MgO

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

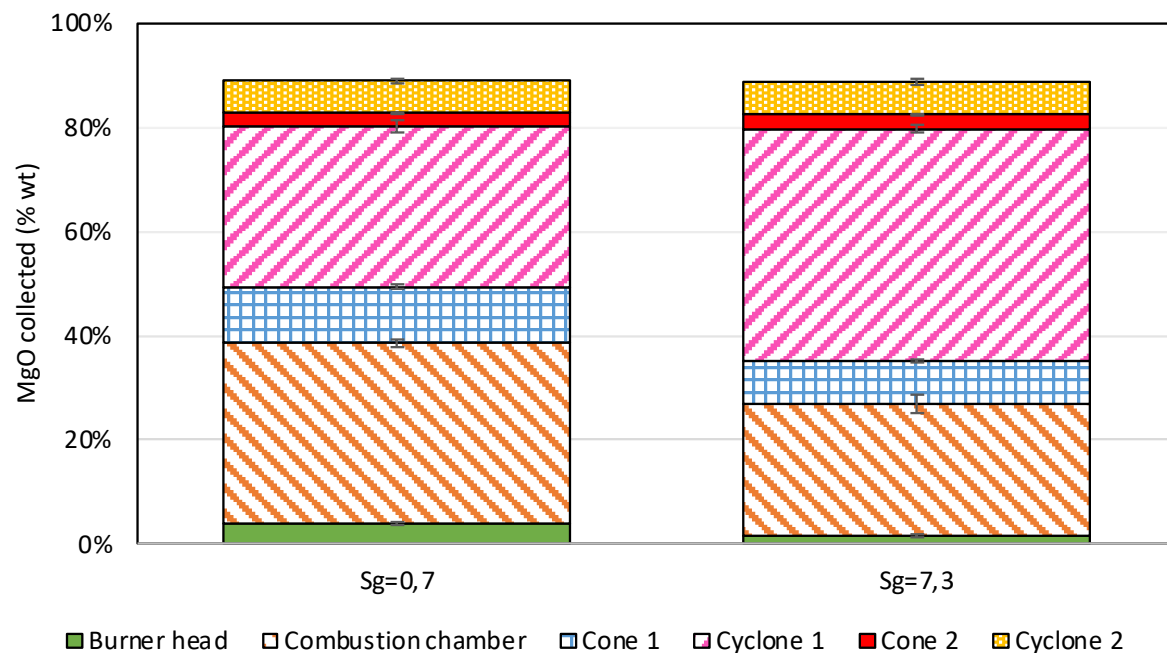
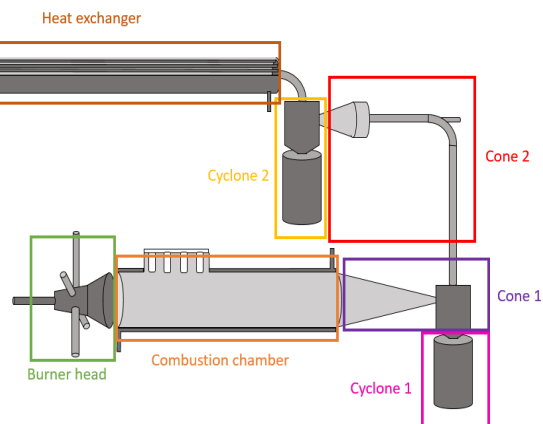
NOx formation



Part of the remaining
O₂ is consumed for
NOx yielding

Mass fraction distribution of collected MgO

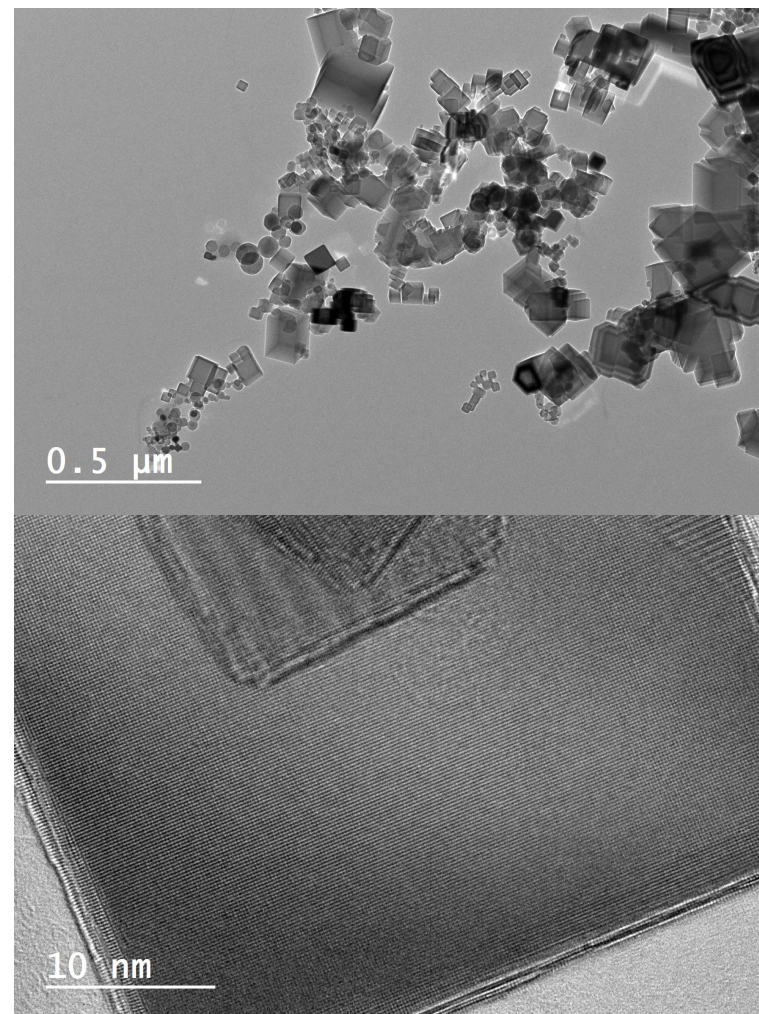
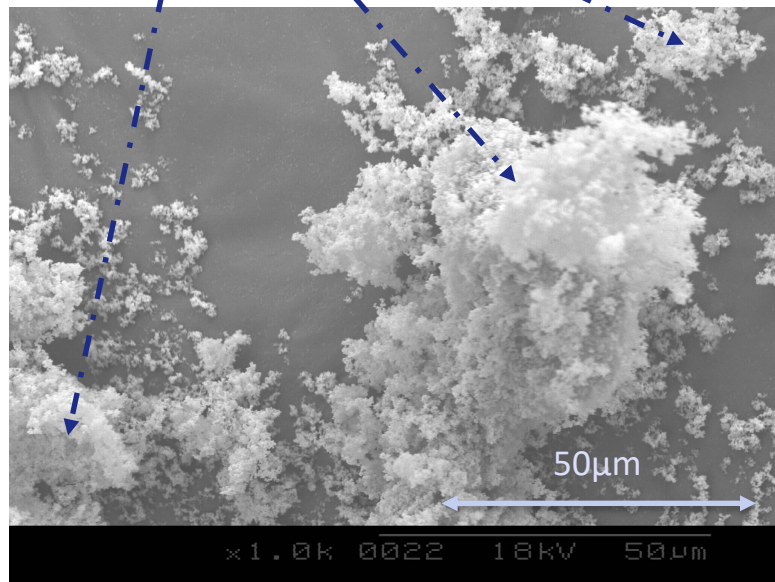
for $Sg=0.73$ and 7



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

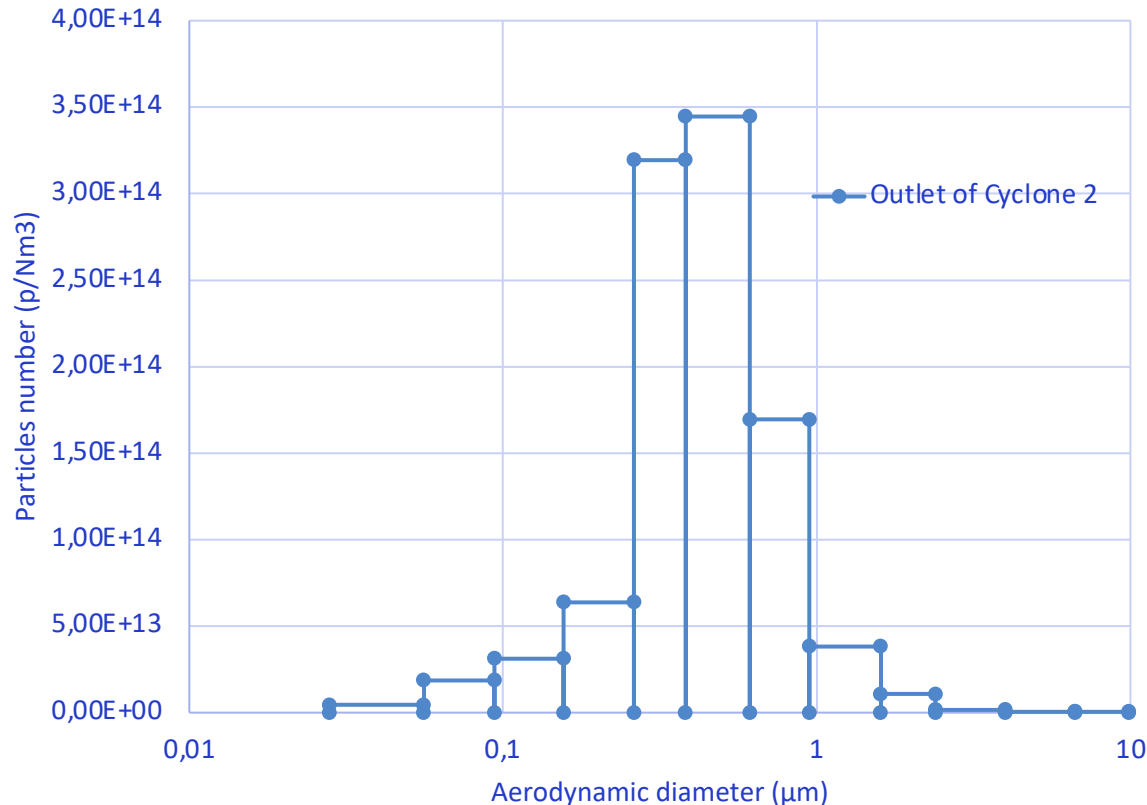
SEM and TEM images of condensed MgO particles for $S_g=0.7$

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-1μm.

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