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Combustibles métalliques durables pour la mobilité du futur

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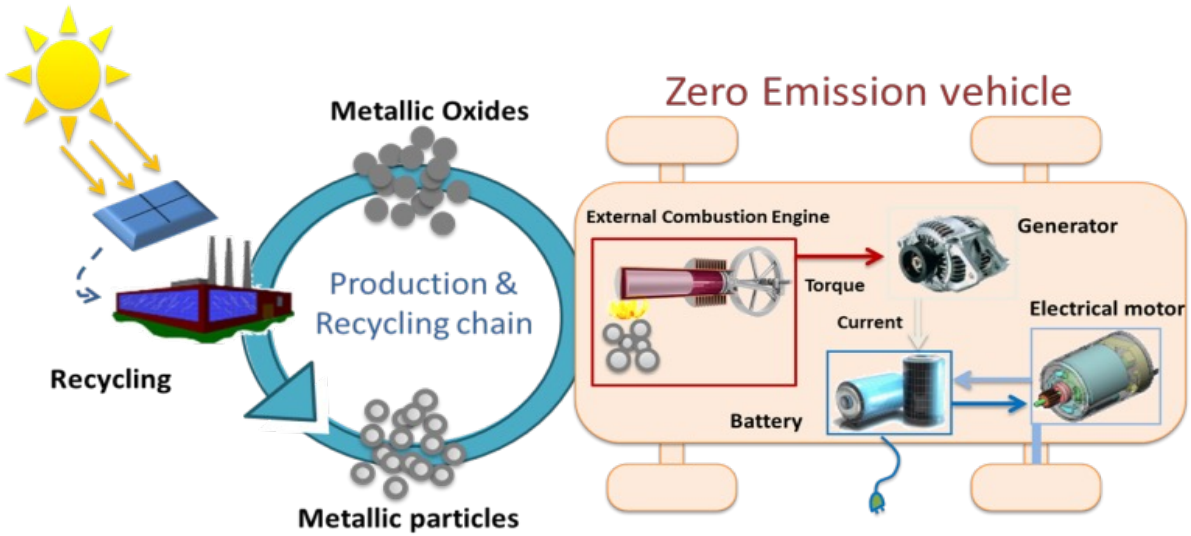
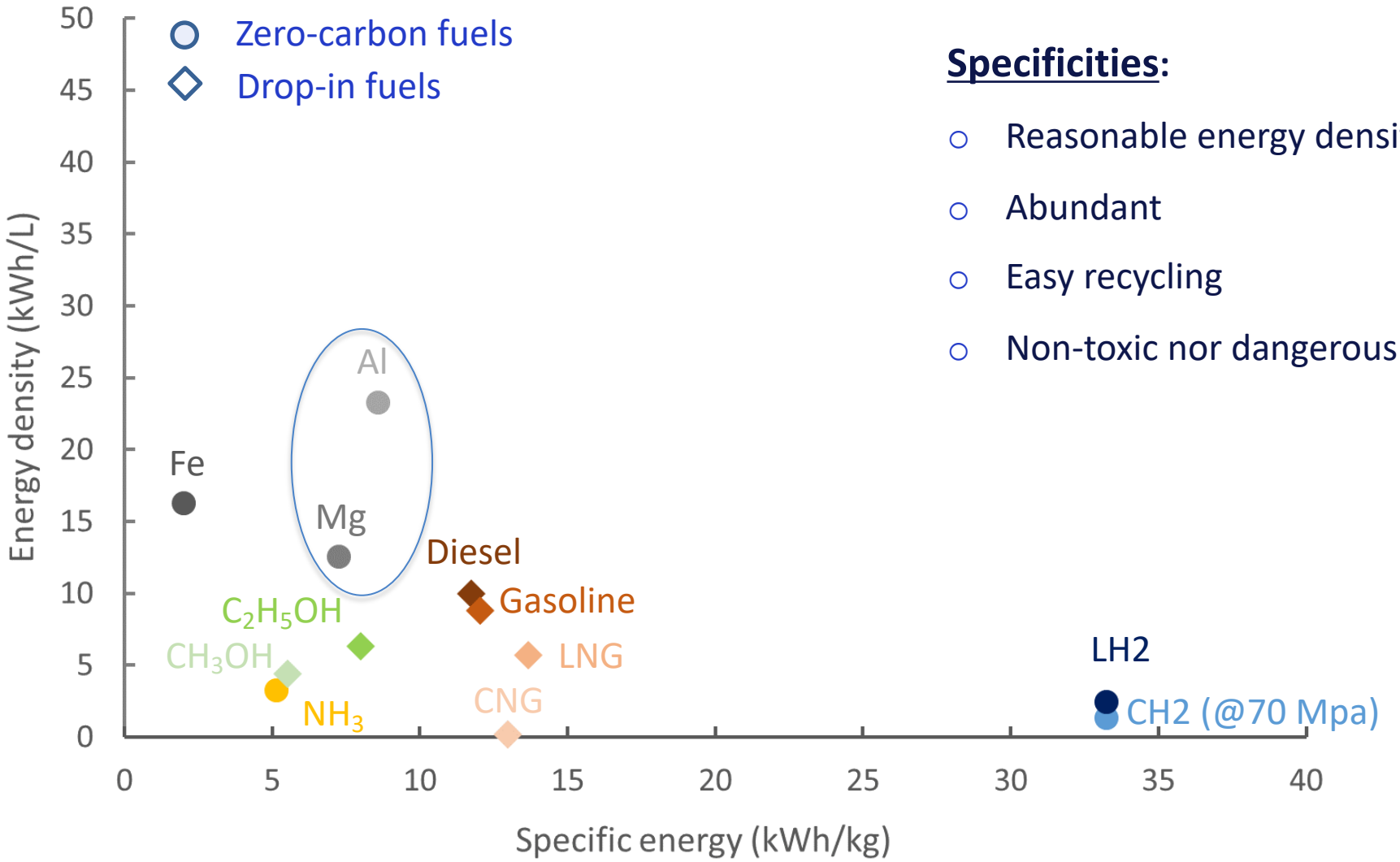
SFGP 2022, Toulouse, 7-10 novembre 2022

New energy system for vehicles



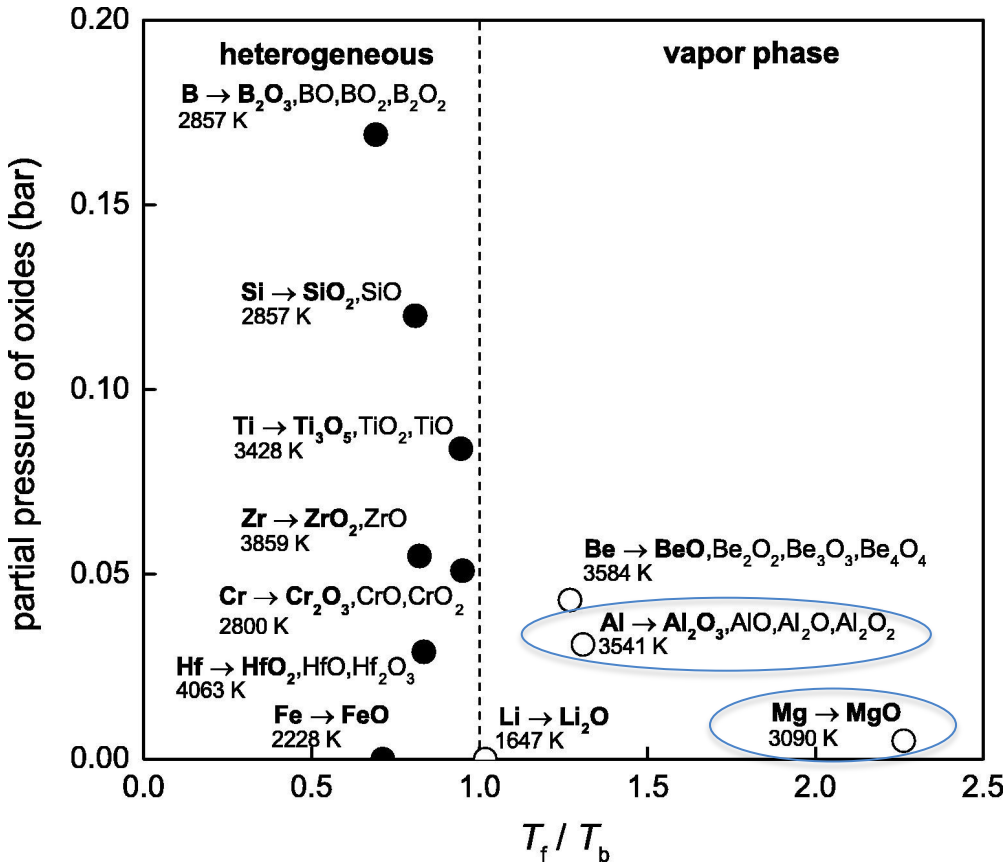
Metal selection



Specificities:

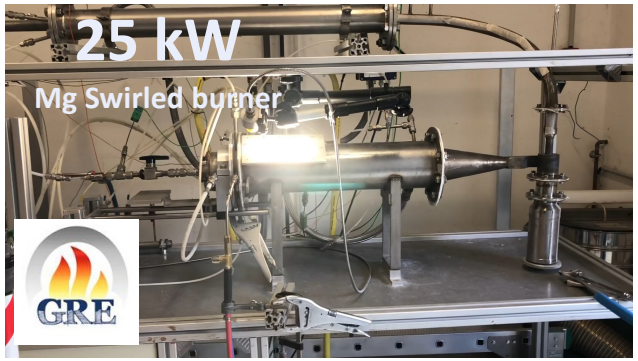
- Reasonable energy density
- Abundant
- Easy recycling
- Non-toxic nor dangerous

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.



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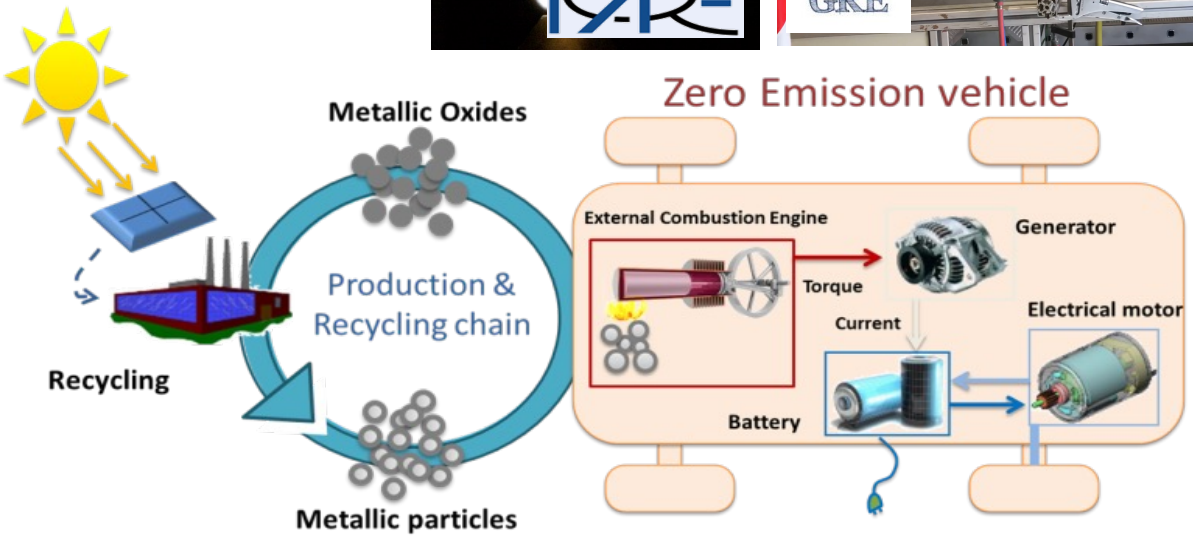


STELLANTIS

anr agence nationale de la recherche AU SERVICE DE LA SCIENCE

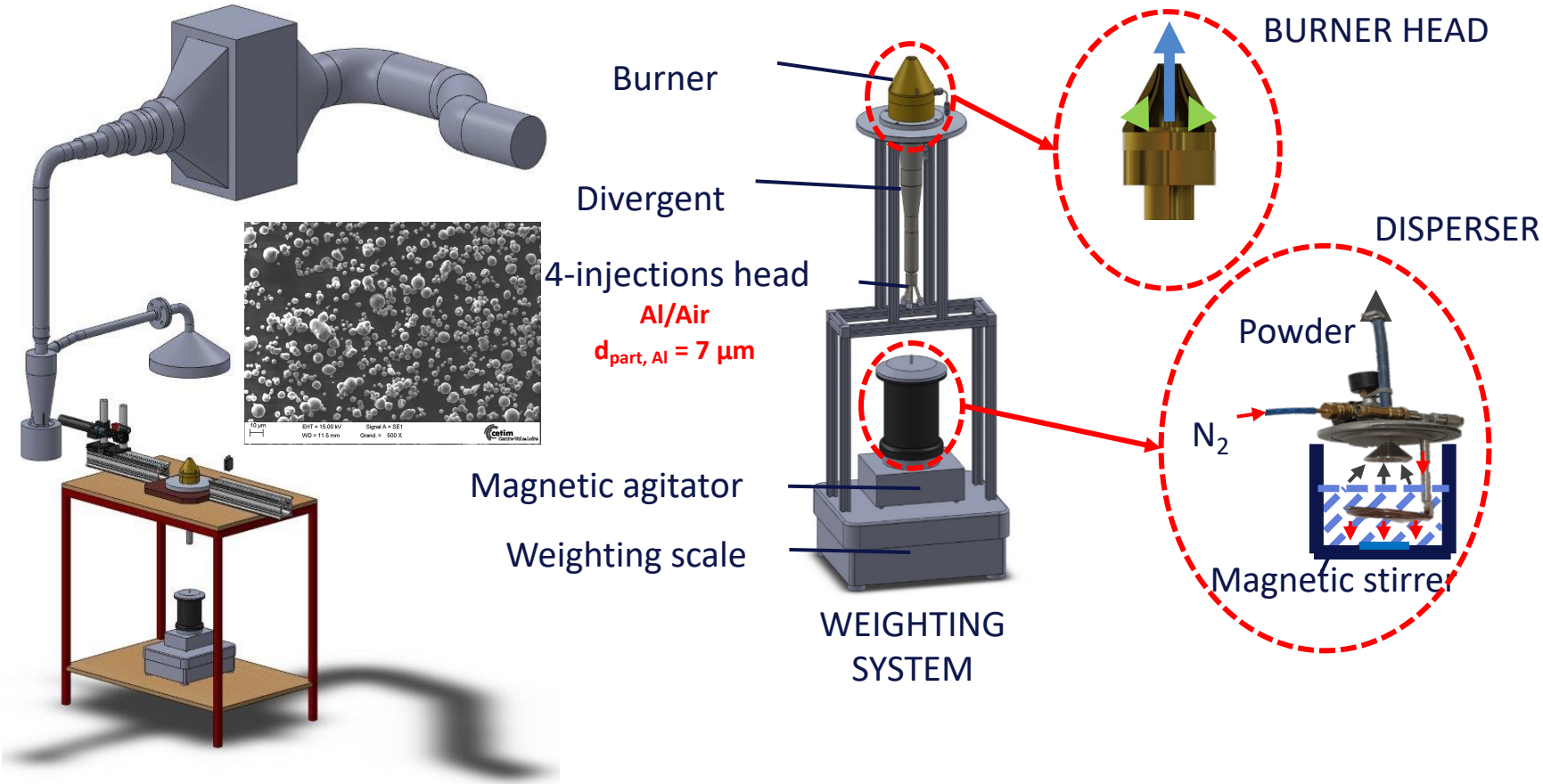
STELLAR Project (ANR-18-CE05-0040)

Objectives of the STELLAR Project

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

Bunsen-type burner (ICARE)

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

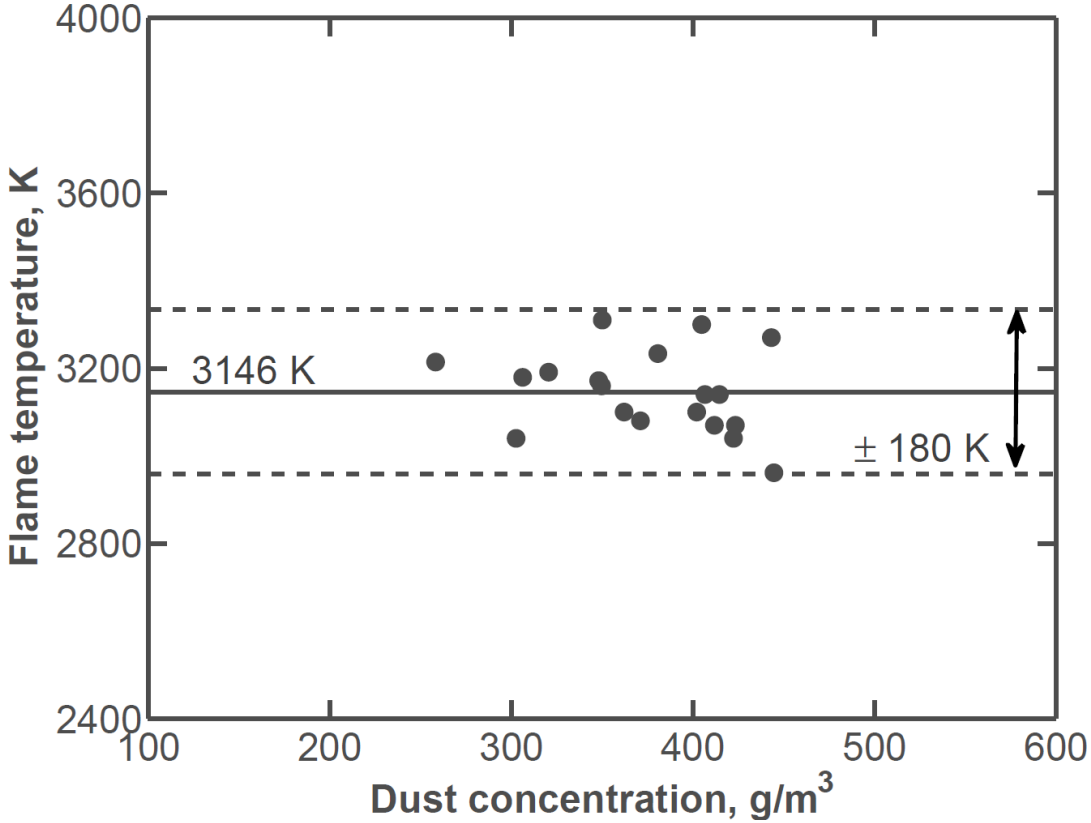


Laminar Al/air flame

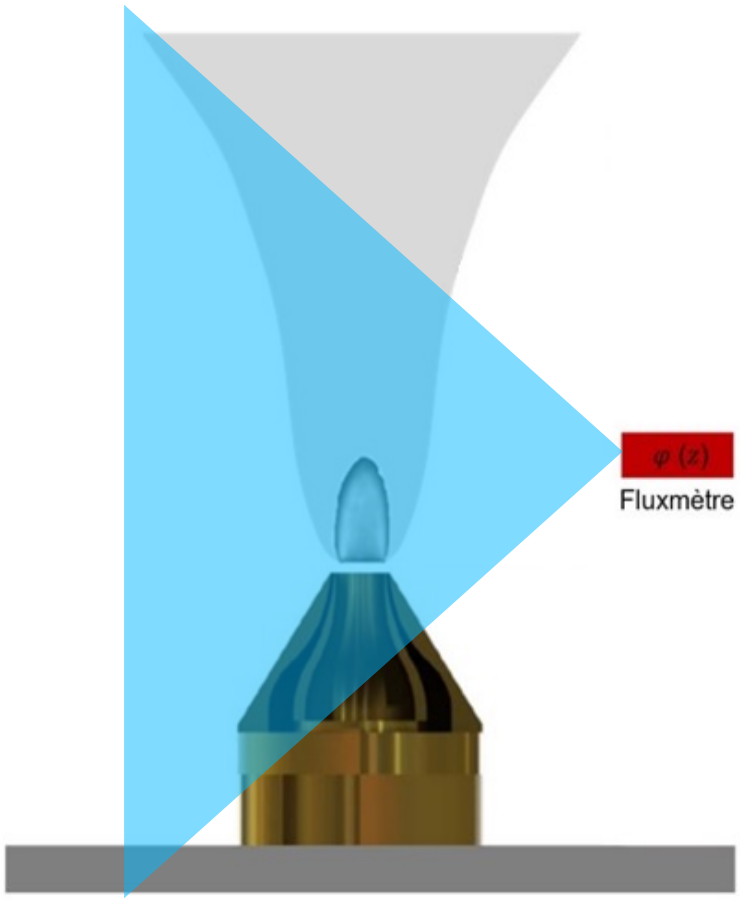
Gas phase temperature (Al/air flame)

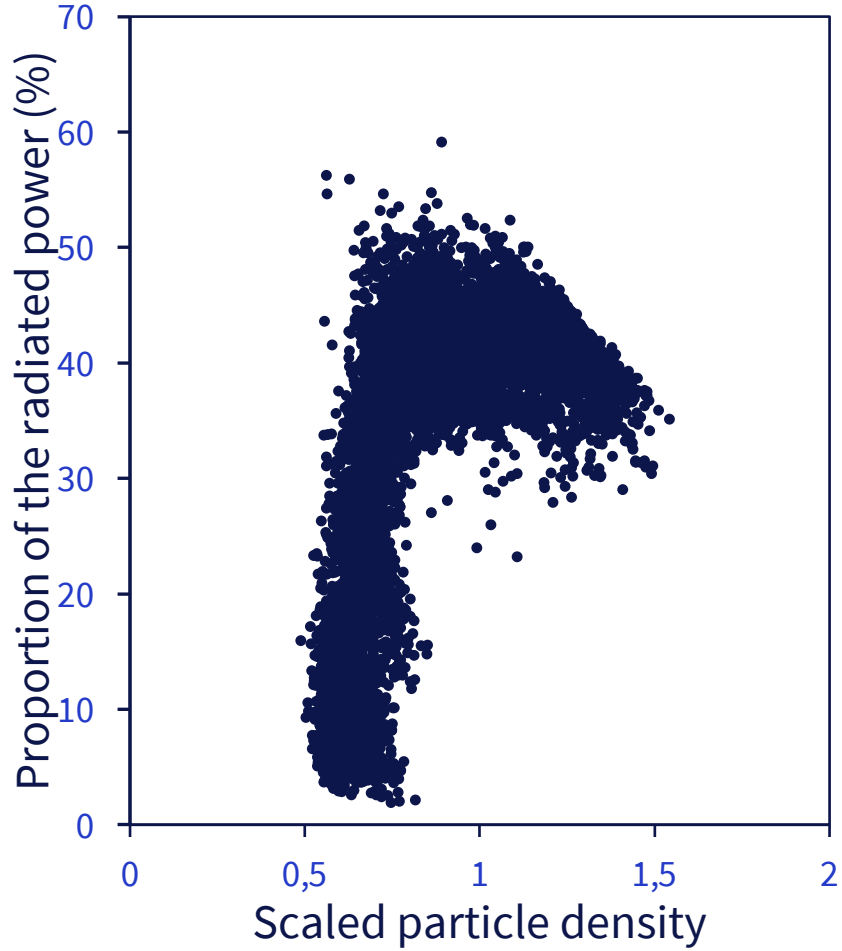
For $0,8 < \phi < 1,5$, flame temperature remains constant.

- Adiabatic flame temperature: 3540 K.



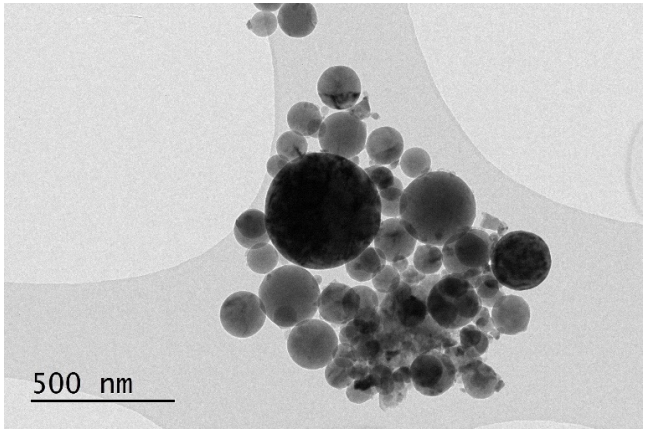
Flame radiation (Al/air flame)



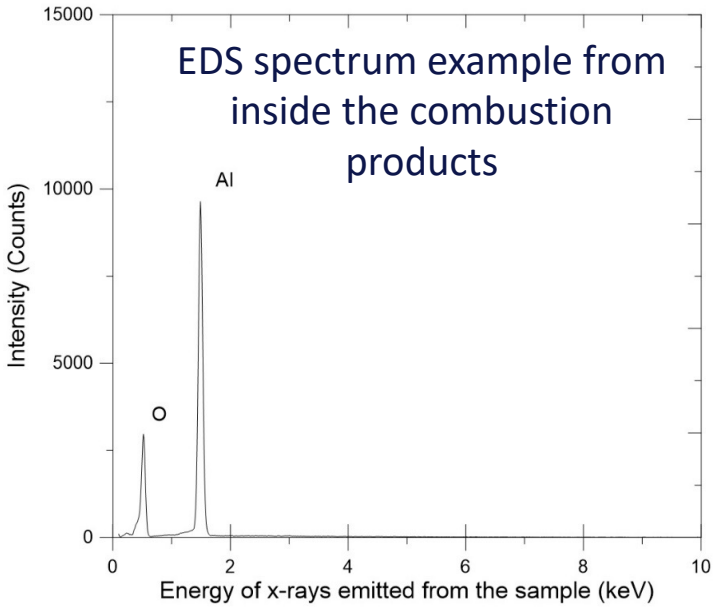


- **Radiation plays an extremely important role.**

Condensed products (from Al/air flame)

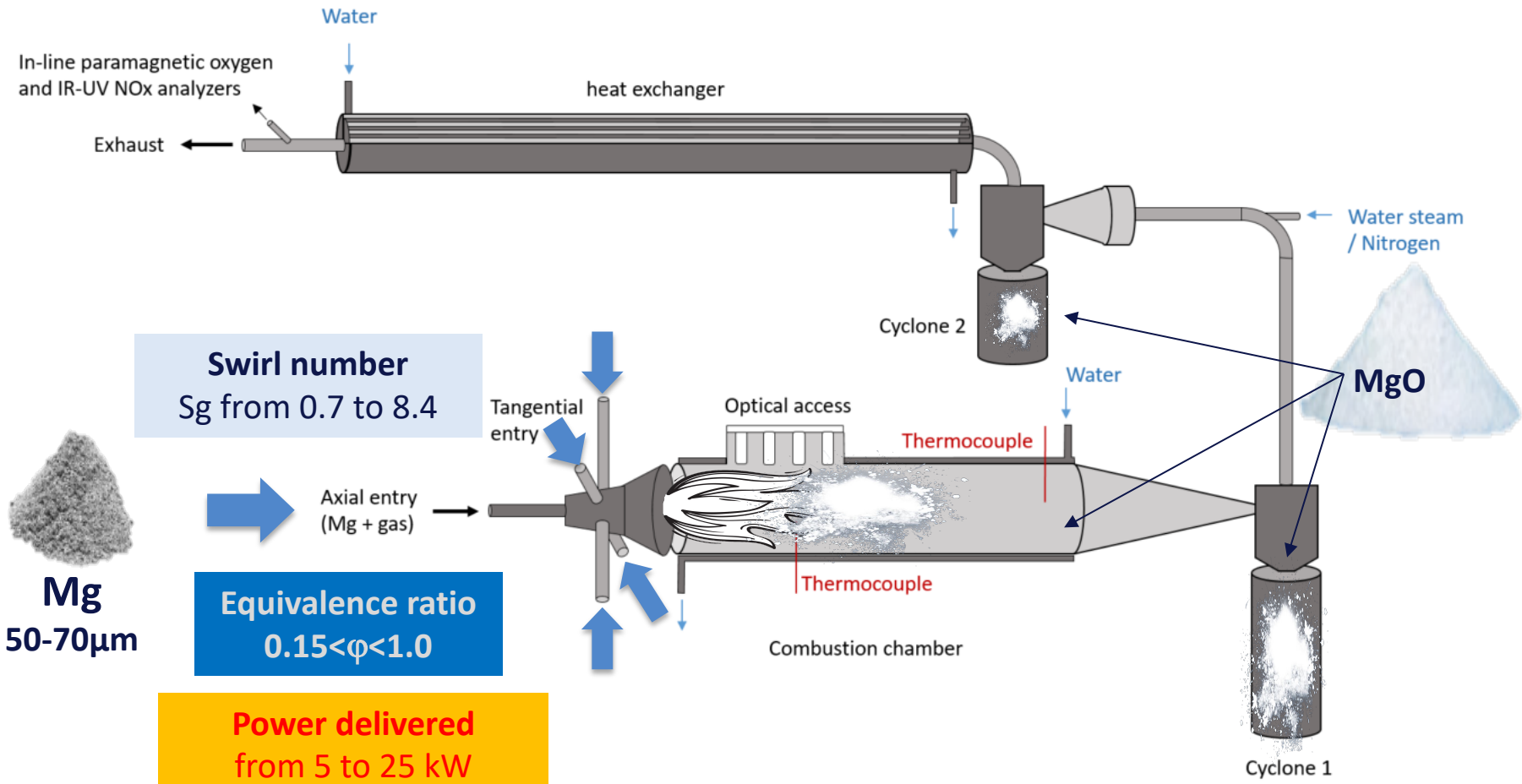


- TEM image of the nanoscale condensed combustion products



- **Mean diameter of 110 nm**
- **Combustion efficiency close to unity**

Mg/Air combustion system (LGRE)

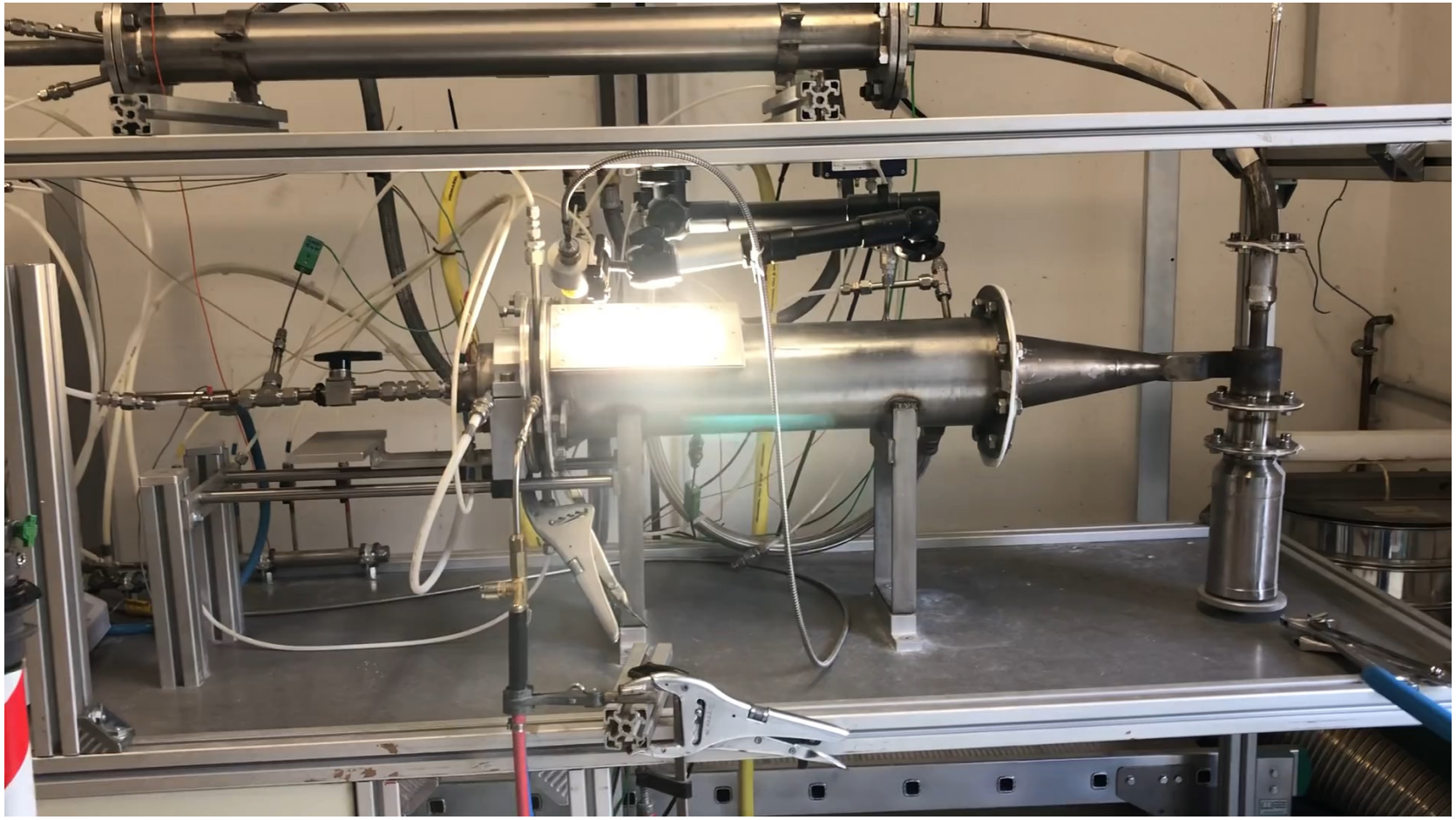


Swirl number
Sg from 0.7 to 8.4

Equivalence ratio
0.15<φ<1.0

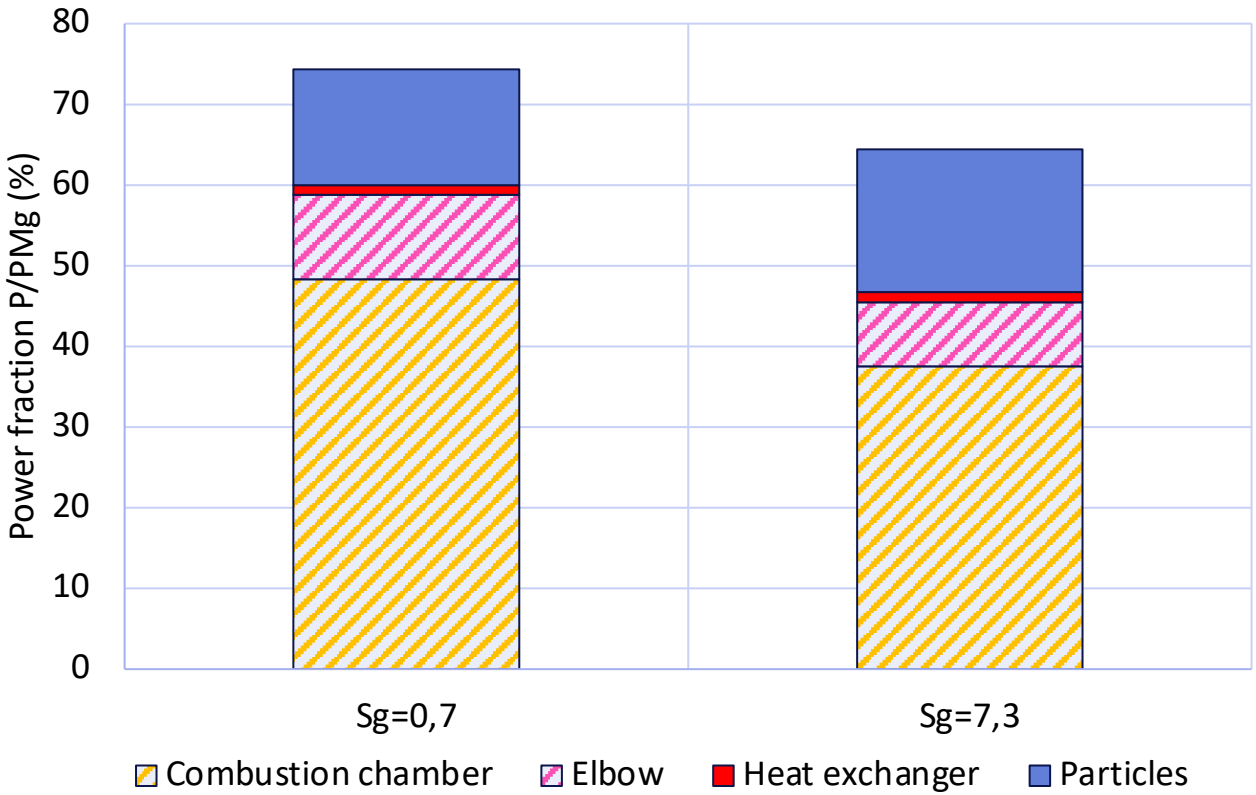
Power delivered
from 5 to 25 kW

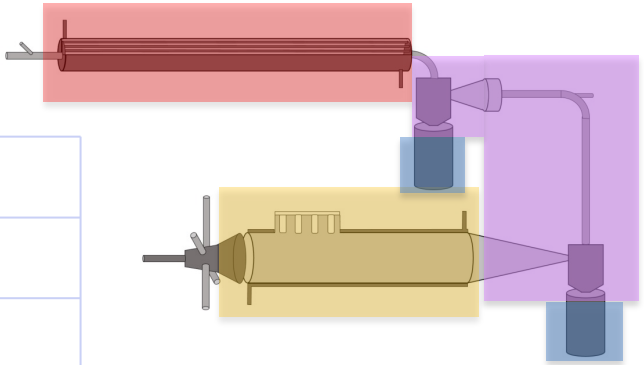
Mg/Air combustion system (LGRE)



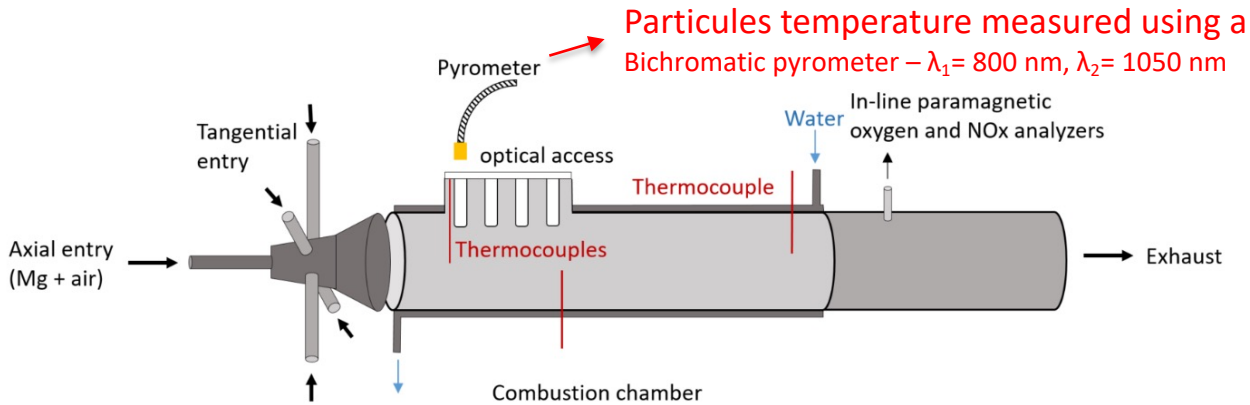
Mean Power distribution (Mg/air flame)

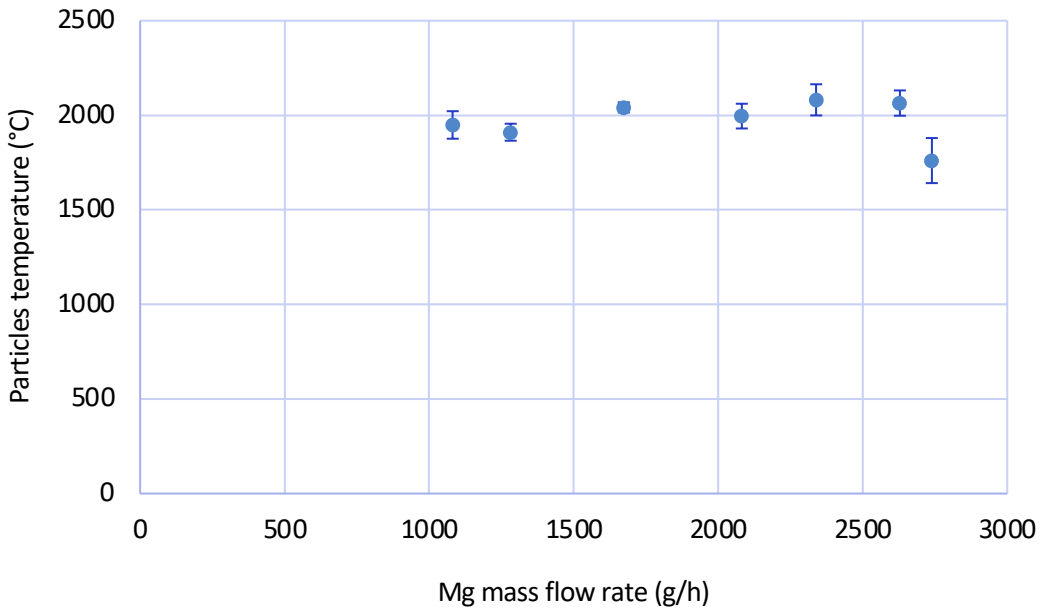
for Sg=0.7 and Sg=7.3





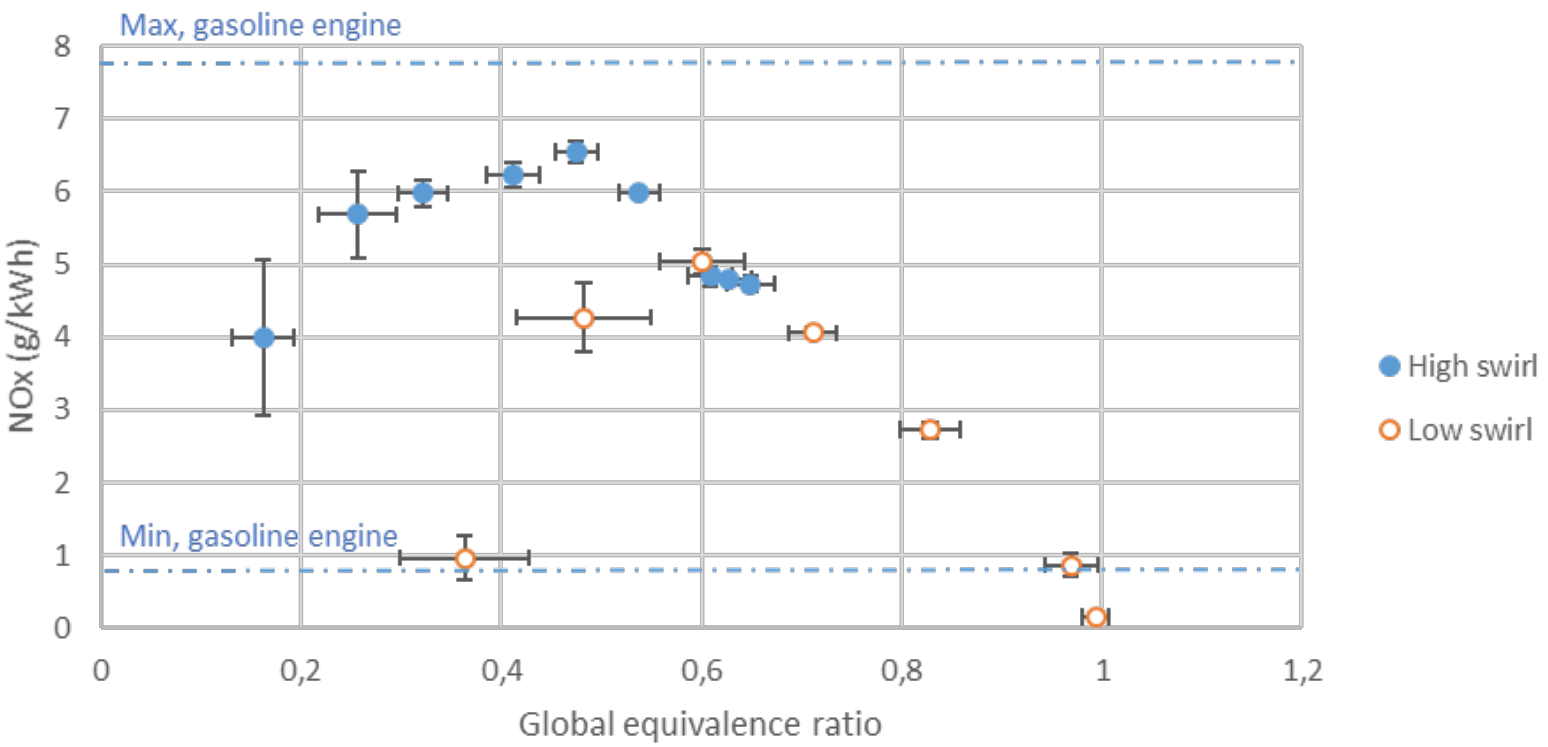
Particles temperature (Mg/air flame) for Sg=7.3





- 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 Sg=0.7 and Sg=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

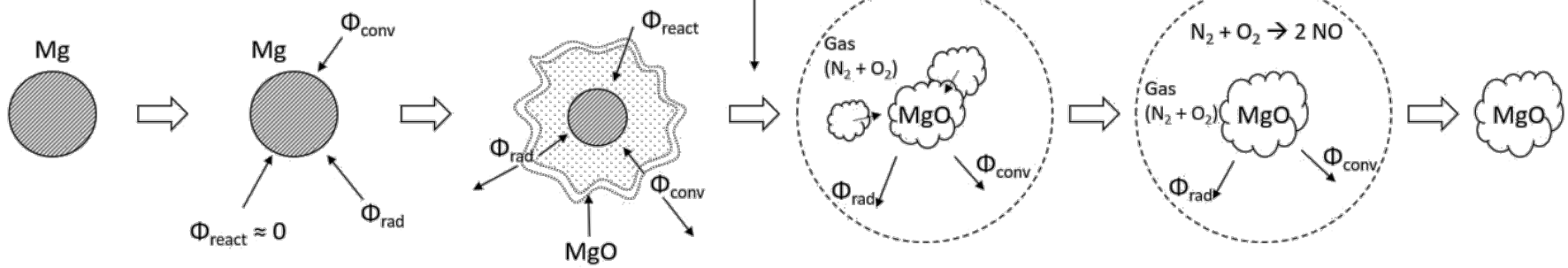
Heating-up and ignition (by radiation and convection)

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

Condensation of MgO

NOx formation

NOx formation starts when Mg is totally oxidized



Slow oxidation of Mg by O_2

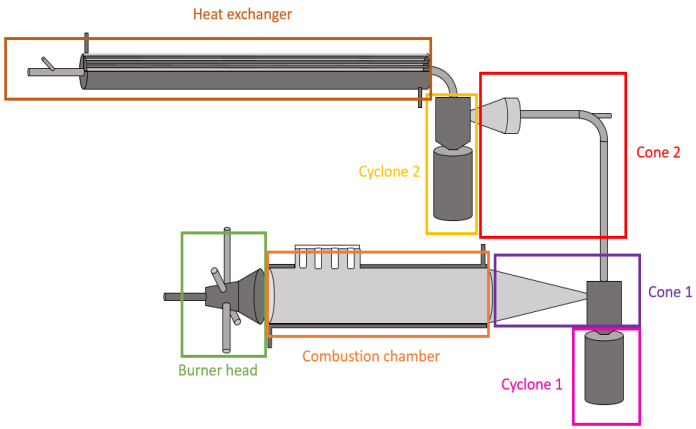
O_2 is consumed by Mg oxidation ($2\ Mg + O_2 \rightarrow 2\ MgO$)
MgO temperature up to 2000/3000 °C

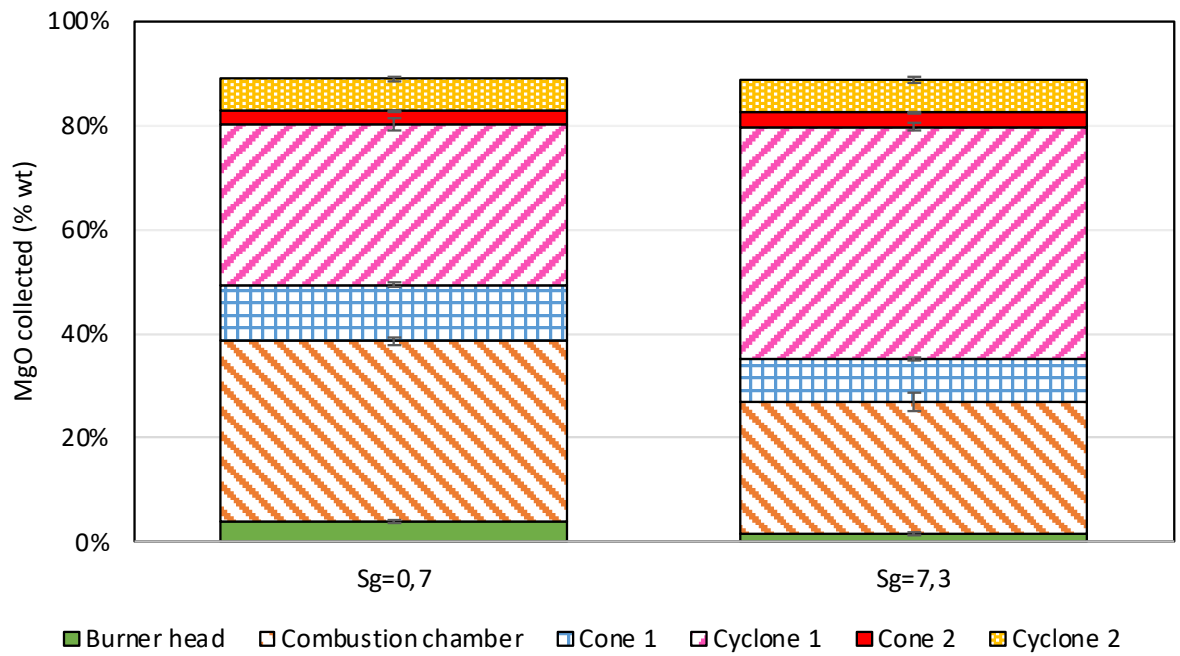
$T_{MgO} \approx$ 2000/3000 °C
Gas surrounding the particles is heated-up by MgO
O_2 concentration depends on O_2 consumed by Mg oxidation

Part of the remaining O_2 is consumed for NOx yielding

Mass fraction distribution of collected MgO

for Sg=0.73 and 7

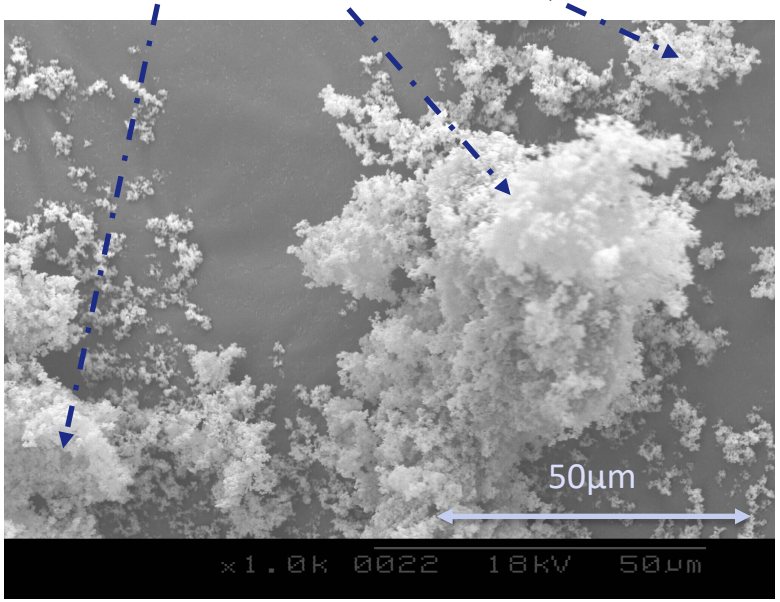


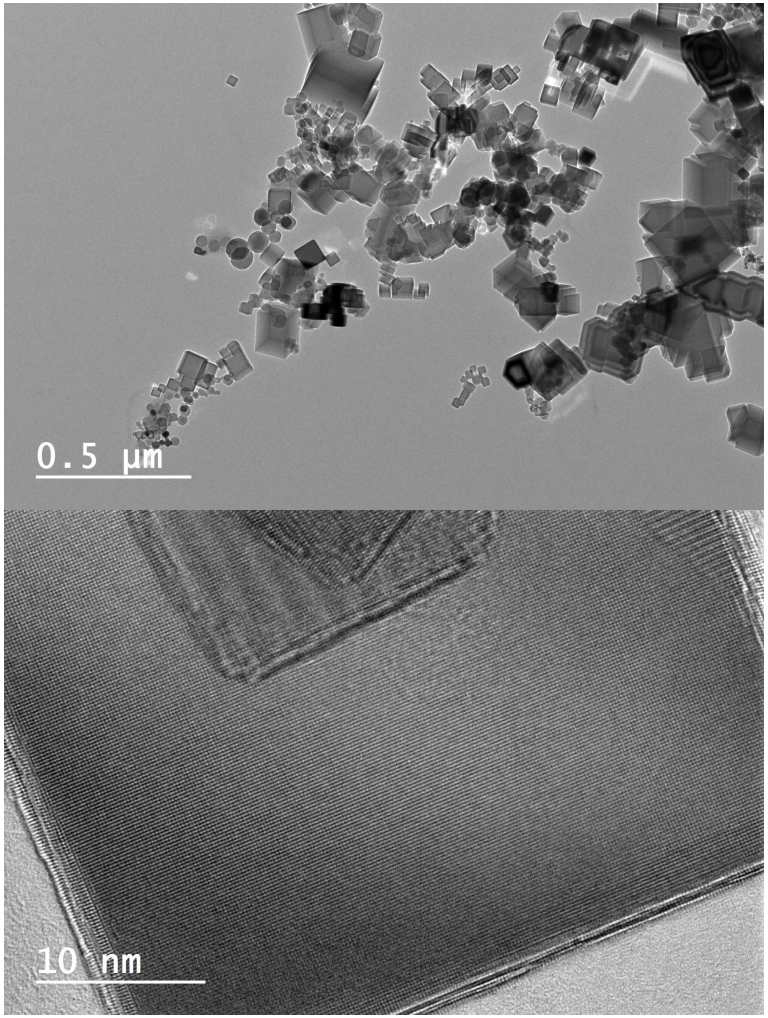


- More than 90 %wt of MgO is trapped in the system **(for regeneration)**
- **Combustion efficiency close to unity**

SEM and TEM images of condensed MgO particles for Sg=0.7

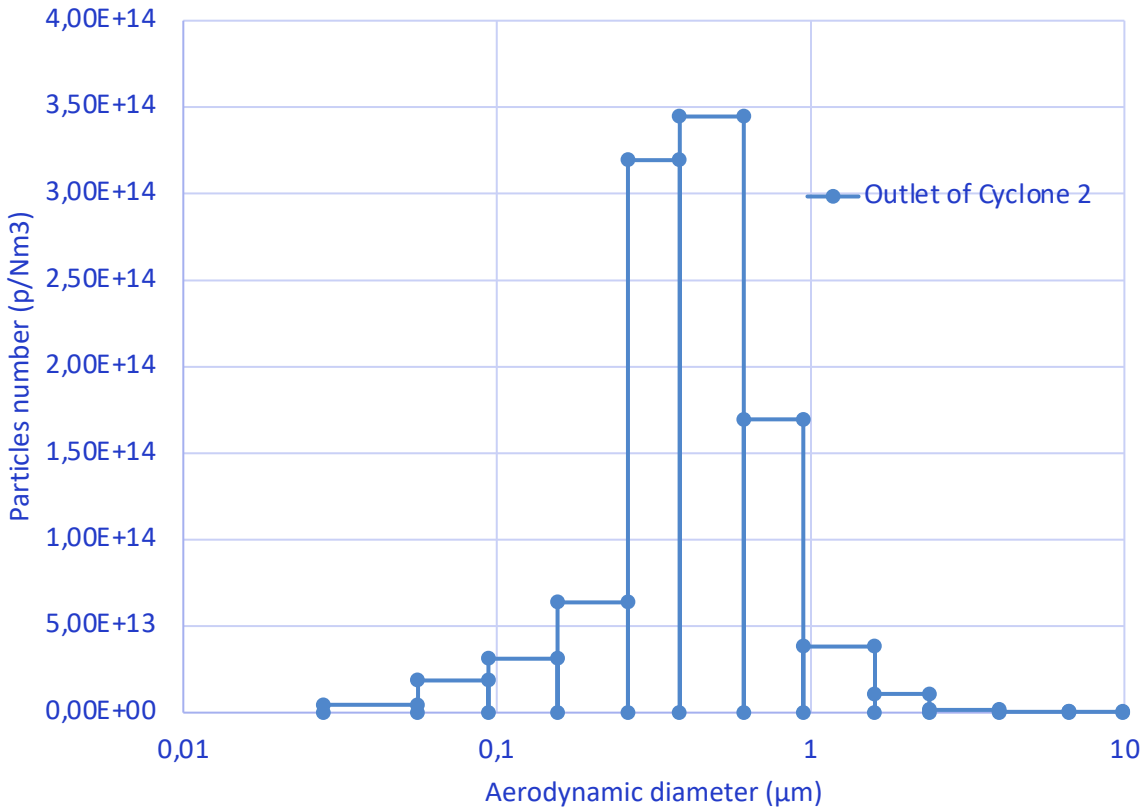
Agglomerates of aggregates of MgO crystals





Size distribution of MgO particles in the exhaust gas

(ELPI measurments at the outlet of cyclone 2, Sg=0.7, Φ=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