Functionalized, Structured Reactors for Sustainable Mobility and Clean Energy

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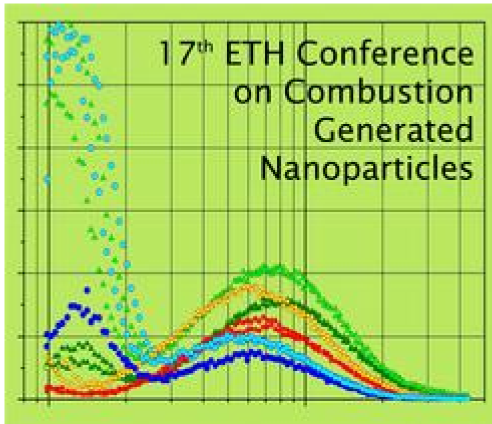

AEROSOL & PARTICLE TECHNOLOGY LABORATORY

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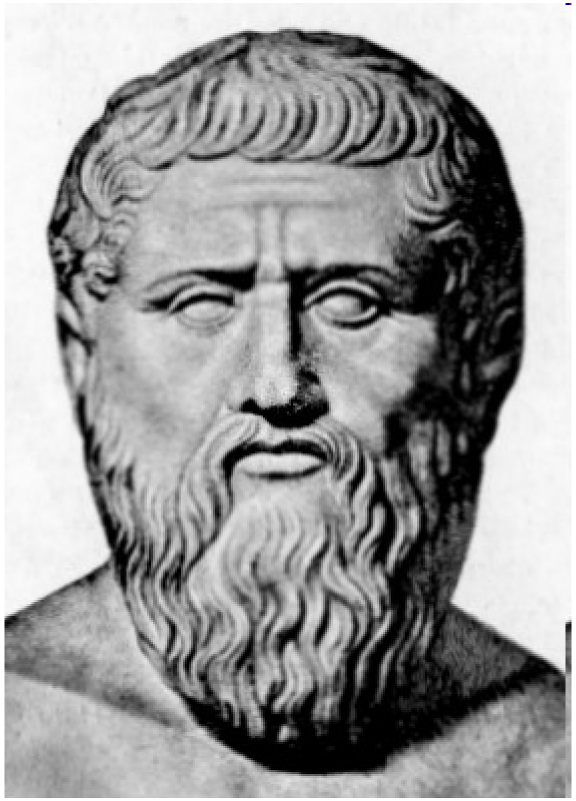
Outline

- Motivation and introductory material
- Sustainable Mobility (Emission Control)
- Clean Energy (Carbon Neutral Fuels)
- Conclusions

The Challenge of Sustainable Development



“…γῆ μὲν ὁπόση πόσους σώφρονας ὄντας ἱκανὴ τρέφειν, πλείονος δὲ οὐδὲν προσδεῖ…”

Πλάτων, Νόμοι, 360 π.Χ.

“…The land must be sufficient to support no more than a certain number of people living with moderation…”

Plato, Laws, 360 B.C.

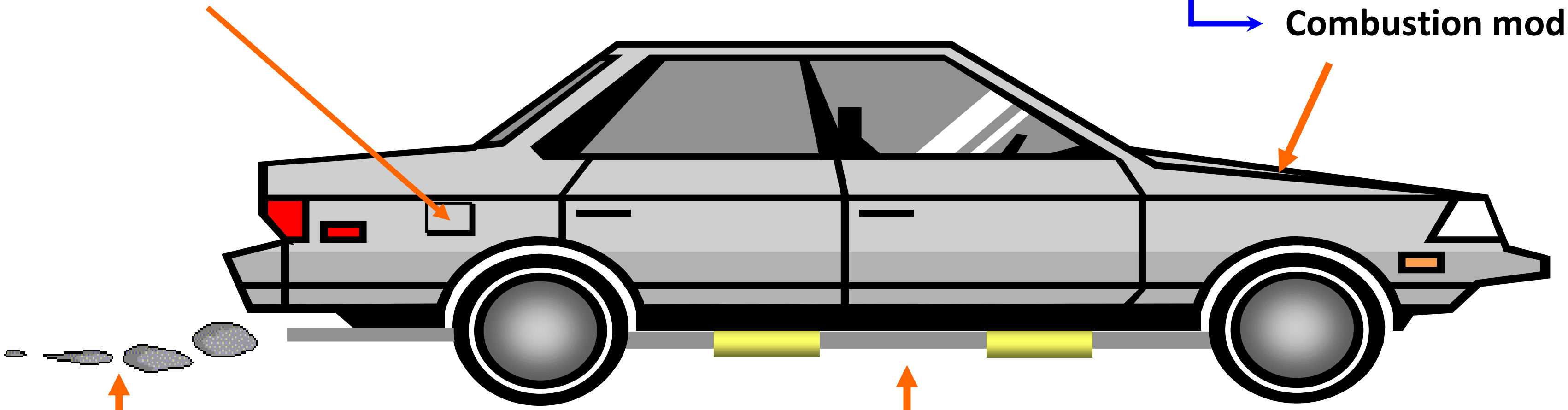
Aspects of Sustainable Mobility

Fuel & Lubricant

- Composition, additives, source…

In-cylinder measures

- Fuel Injection
- Engine management
- Combustion mode



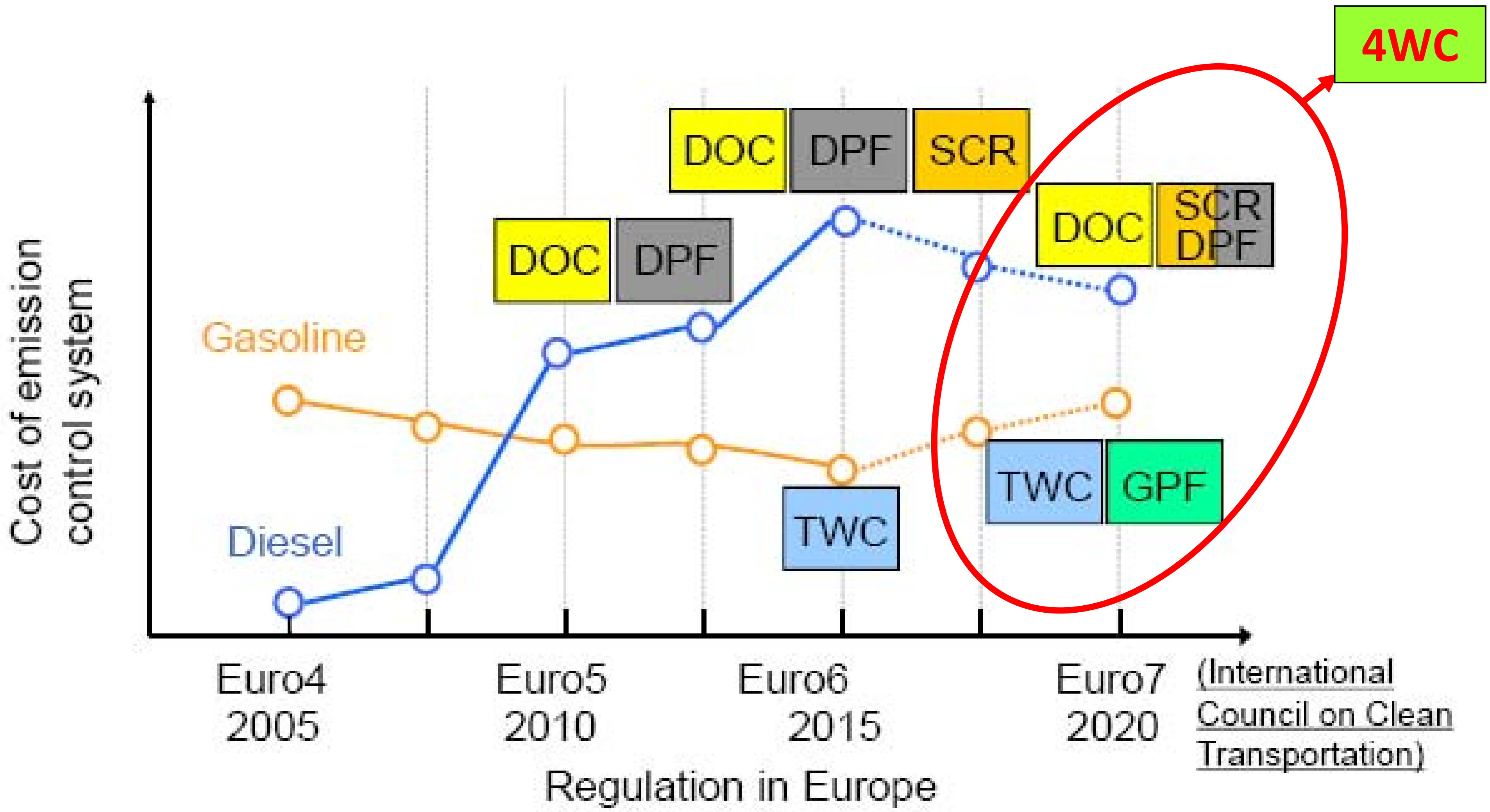
Emissions Characterization and Impact

- Gaseous emissions (regulated/non-regulated)
- Particulate emissions ("size"/composition, number concentration)
- Biological impact

Exhaust Emission Control System

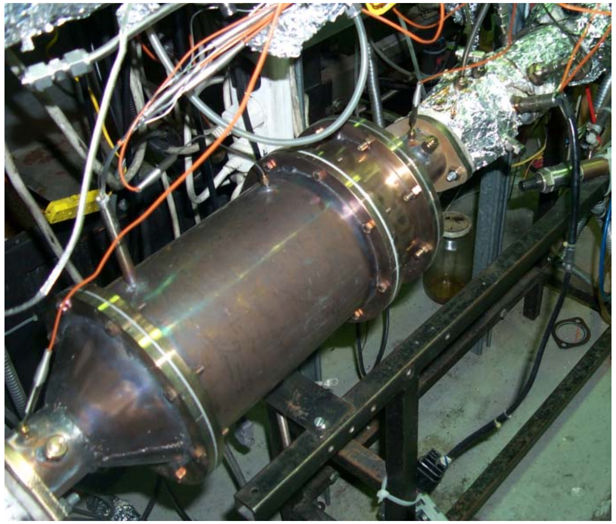
- Novel component designs (TWC, DOC, DPF, GPF, SCR, LNT, LNC,…)
- System Integration/Optimization/Control

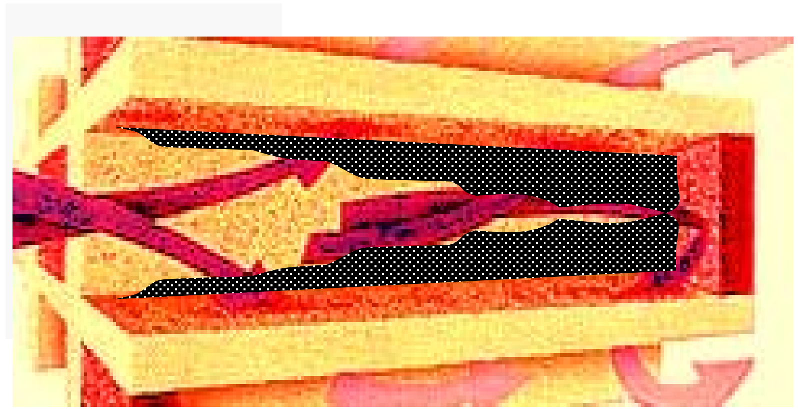
Cost of Emission Control System is Increasing



Ohno, IQPC (2012)

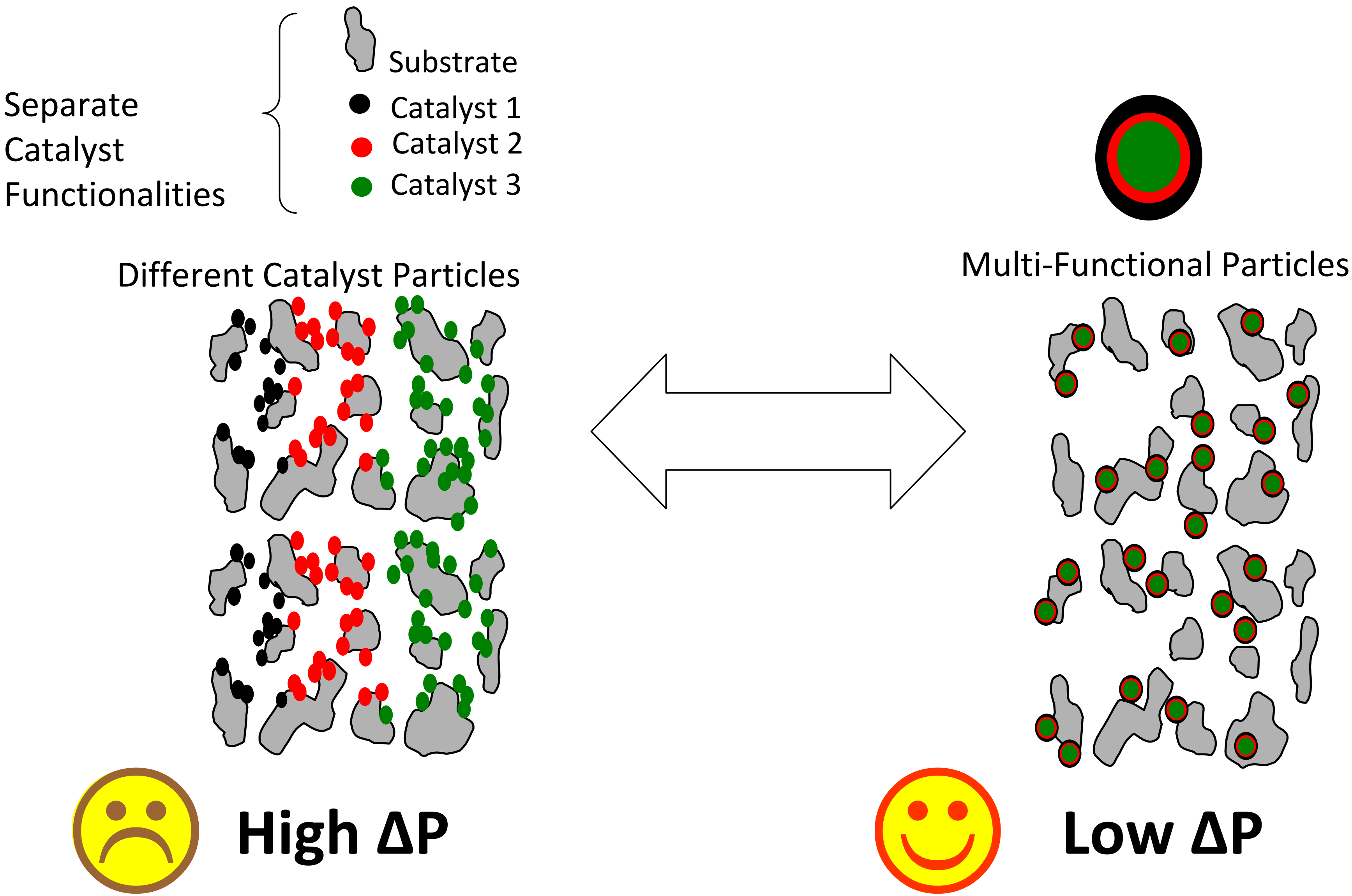
Functions of an
Emission Control Reactor (4WC)





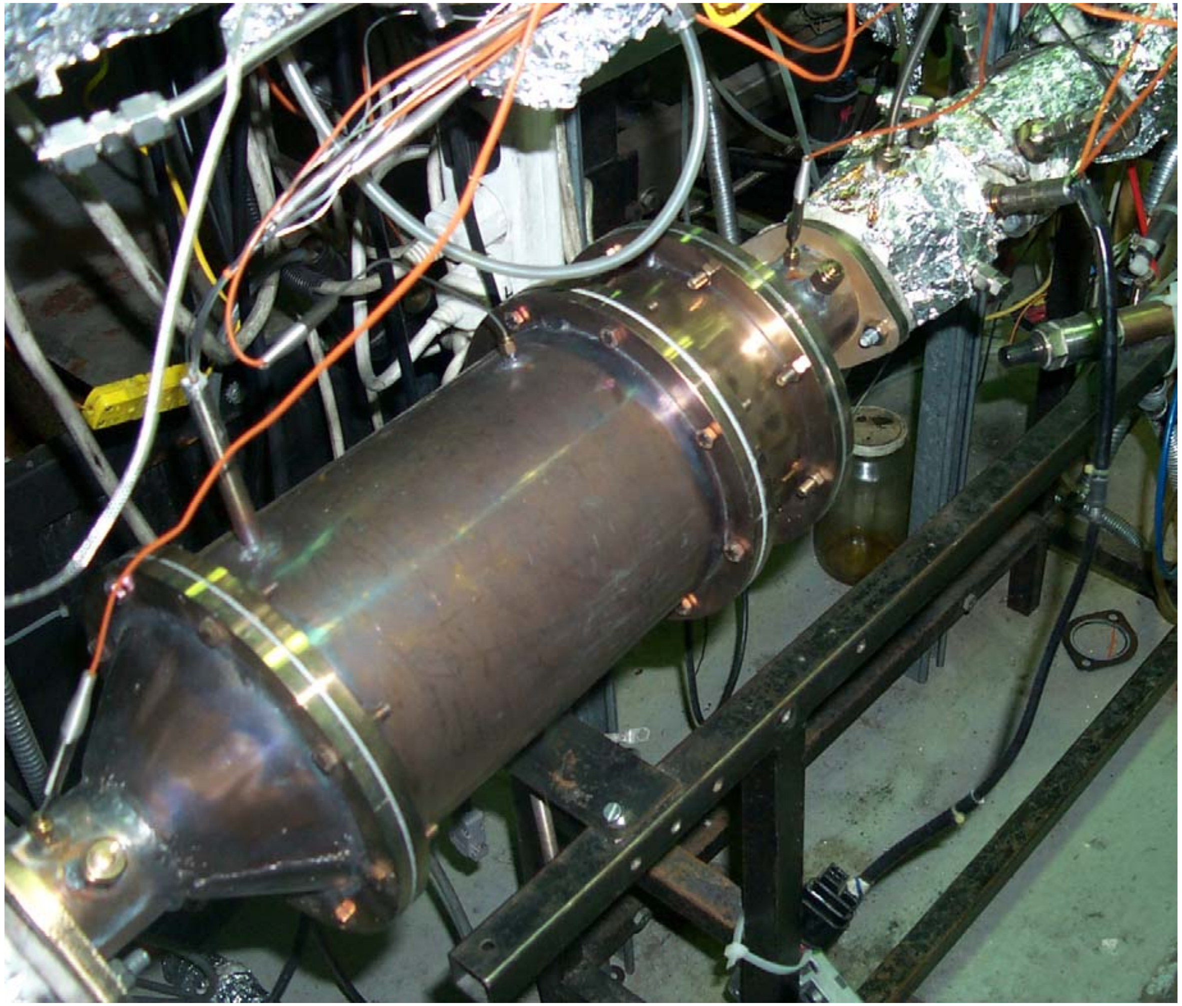
- **Nanoparticle Separation:** Filtration & Pressure Drop
- **Reactor:** Soot, CO/HC/NO oxidation, NOx reduction
- **Ash Accumulator:** Aging performance

Adding Multiple Catalytic Functions to a Wall-Flow-Filter



Multi-Functional Filter-Reactor (MFR)

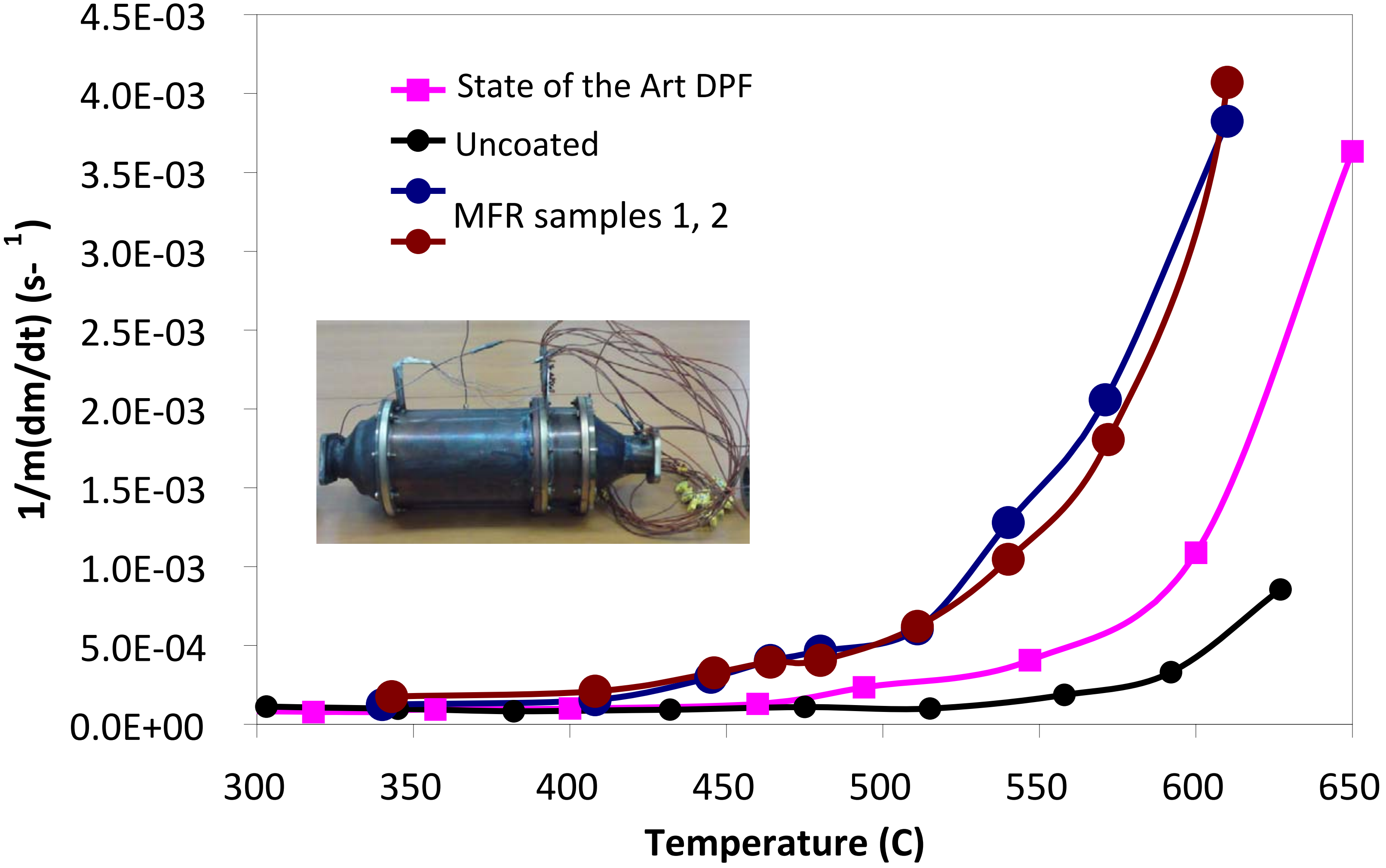
The MFR is a “single brick” solution for nanoparticle removal and soot, CO and HC oxidation, while NOx removal functions are in development.



SAE 2009-01-0287

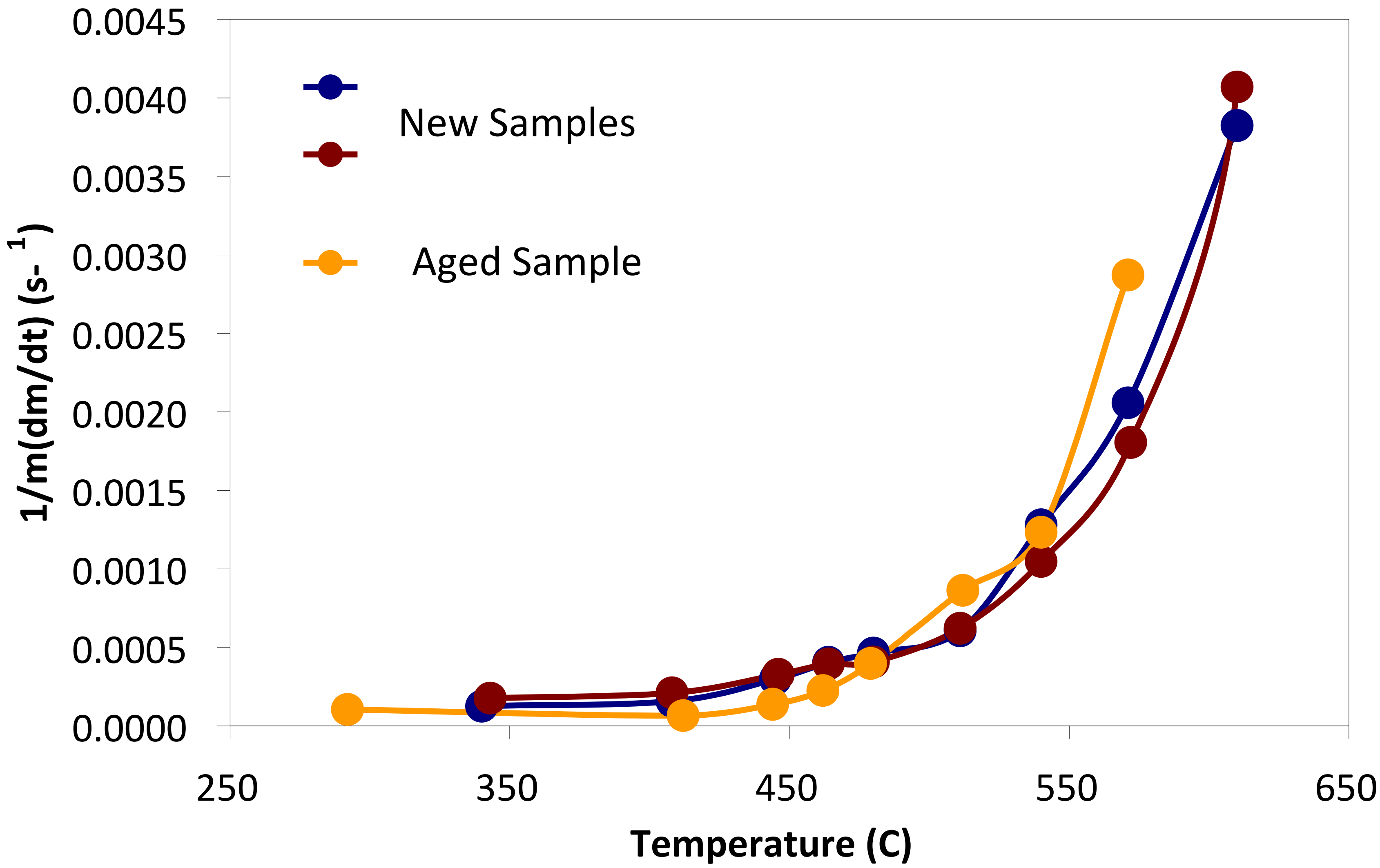
MFR Assessment

4 times higher soot oxidation rate at 550 C compared to a State of the Art DPF

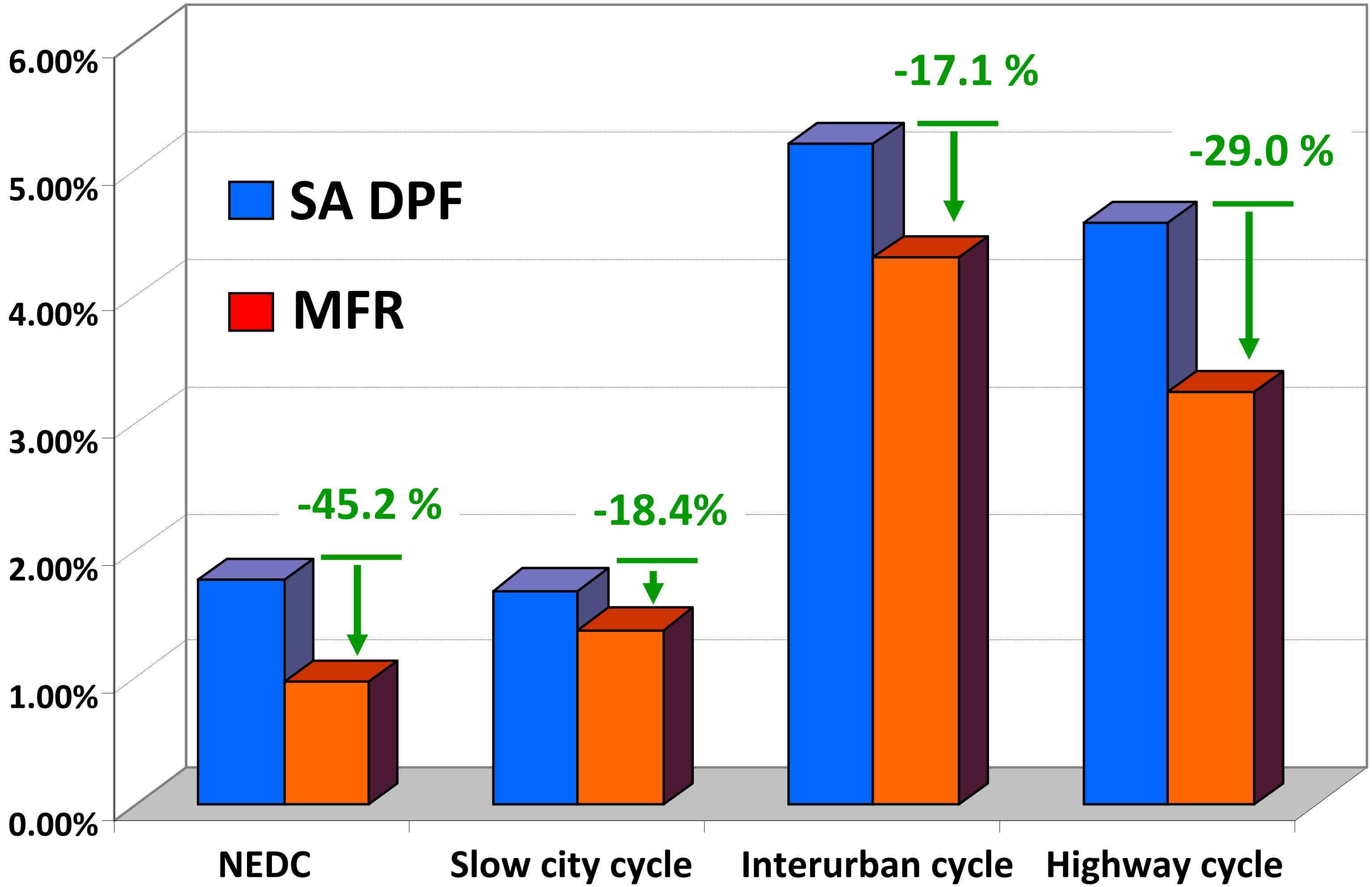


SAE 2009-01-0287

Effect of Aging
(equivalent to 100 loading/regenerations ~10^5 km)



Fuel penalty comparison for different driving cycles

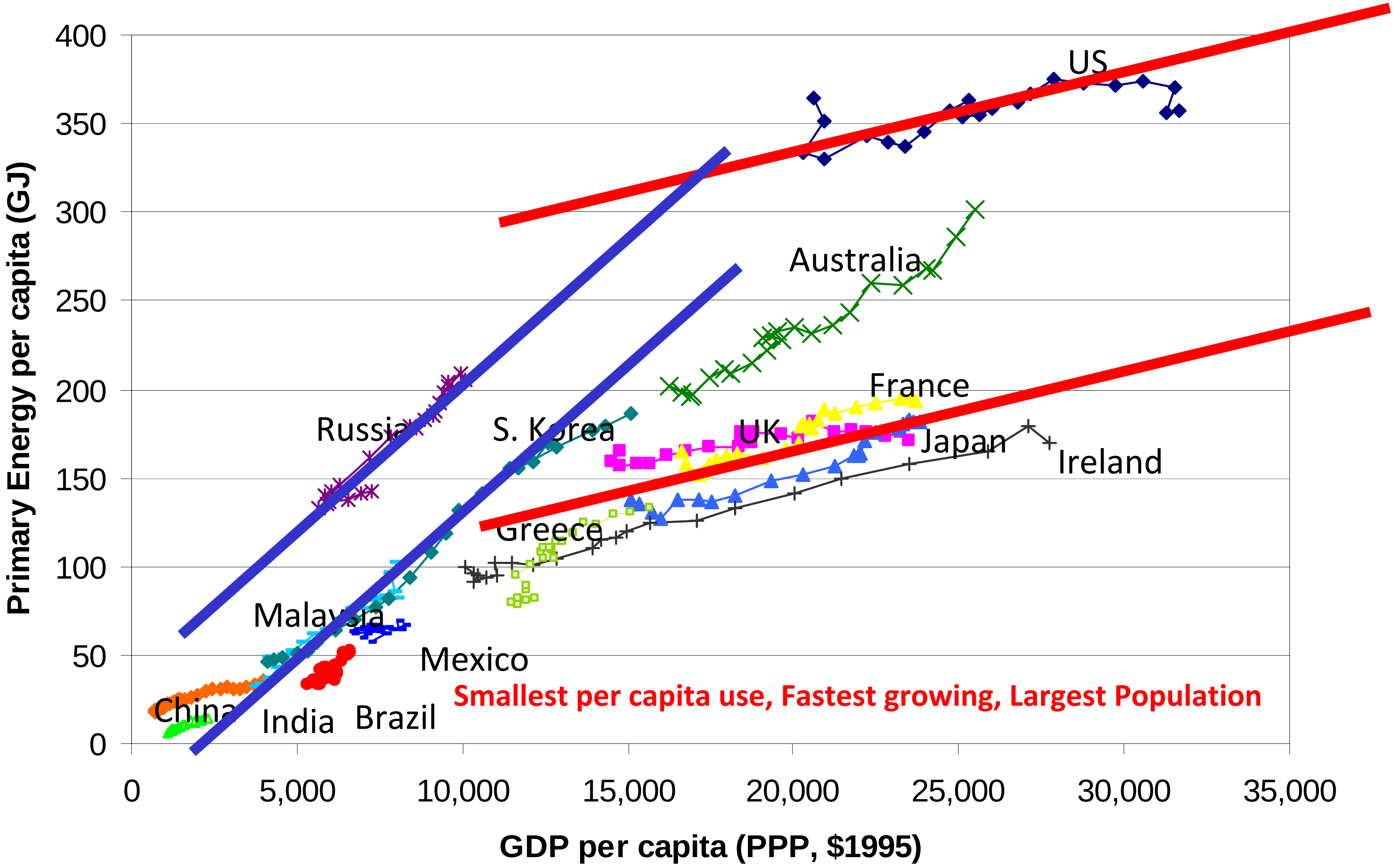


SAE 2011-01-0606

Sustainability vs Economic Growth

Energy Consumption and Economic Growth

energy demand and GDP per capita (1980-2002)



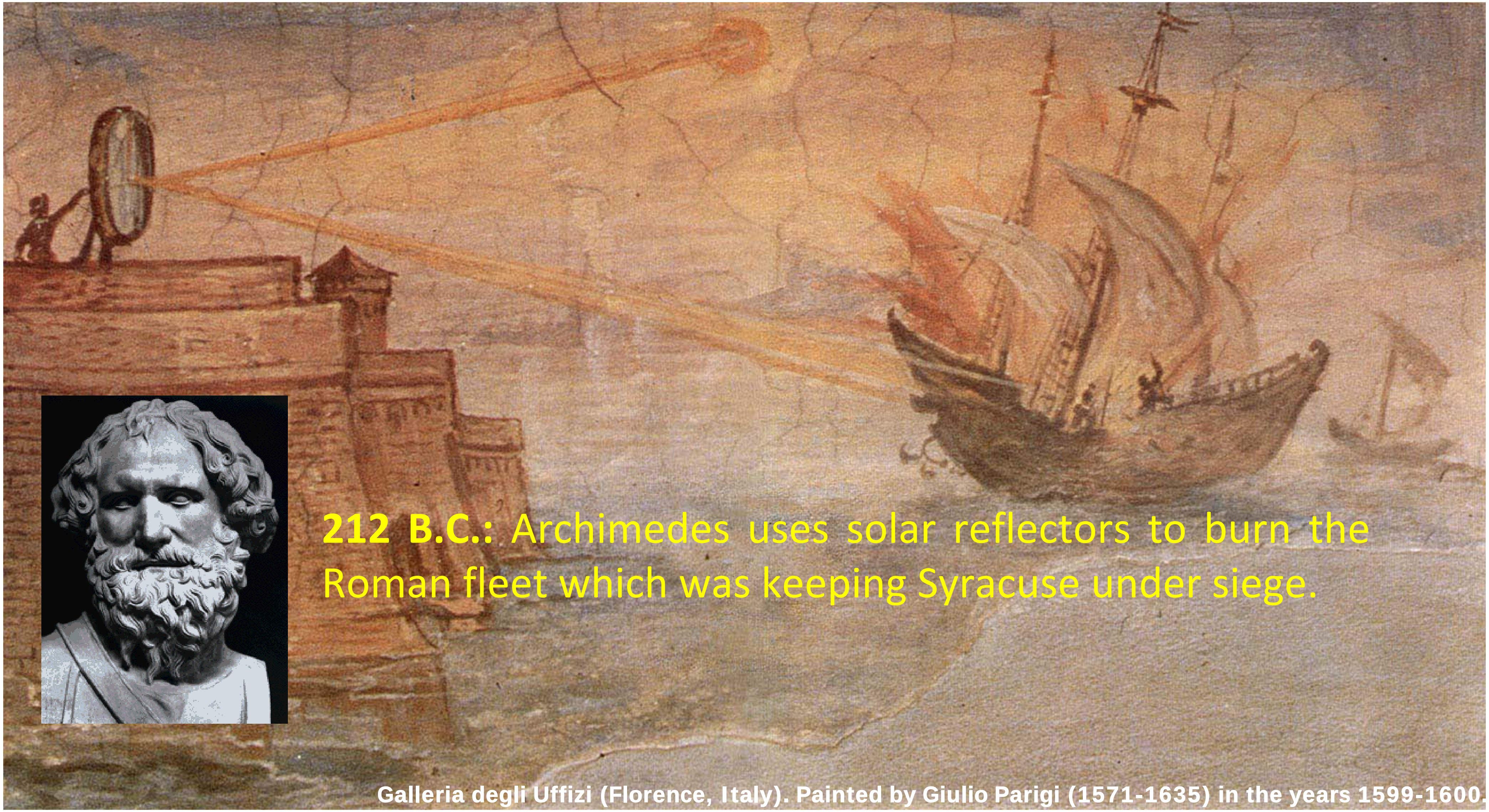
Source: UN and DOE EIA

The TeraWatt Challenge
(R. Smalley, 2004)

- Earth Capacity: 5×10^9 people
- Population (Oct 2011): $>7 \times 10^9$
- Population in 2050: $>10 \times 10^9$
- Energy Requirement: ~ 60 TW

Deus Ex Machina: The Sun

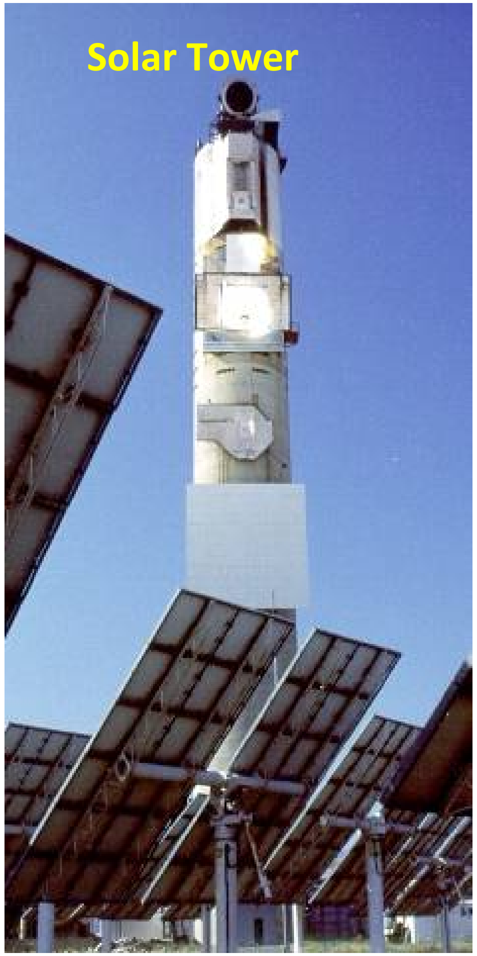
Concentrated Solar Radiation



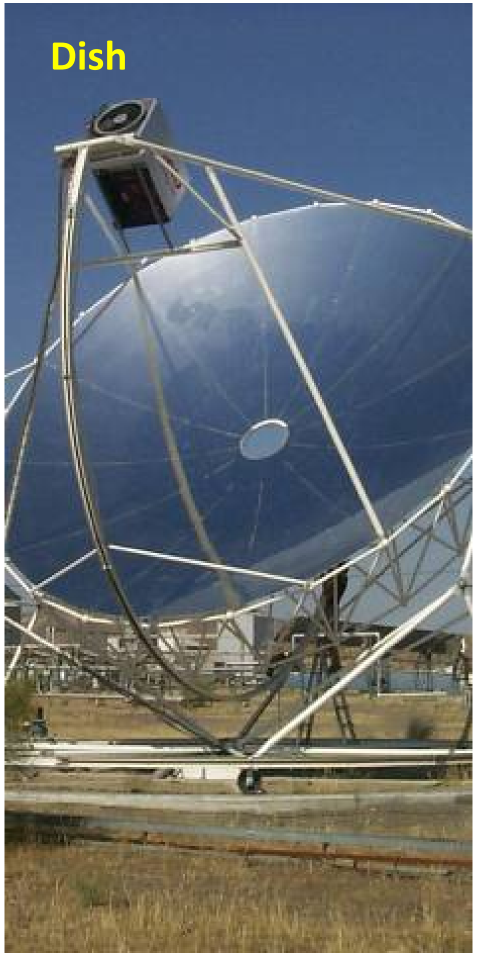
Concentrated Solar Power (CSP) Plants

1981 – today

250-625 C

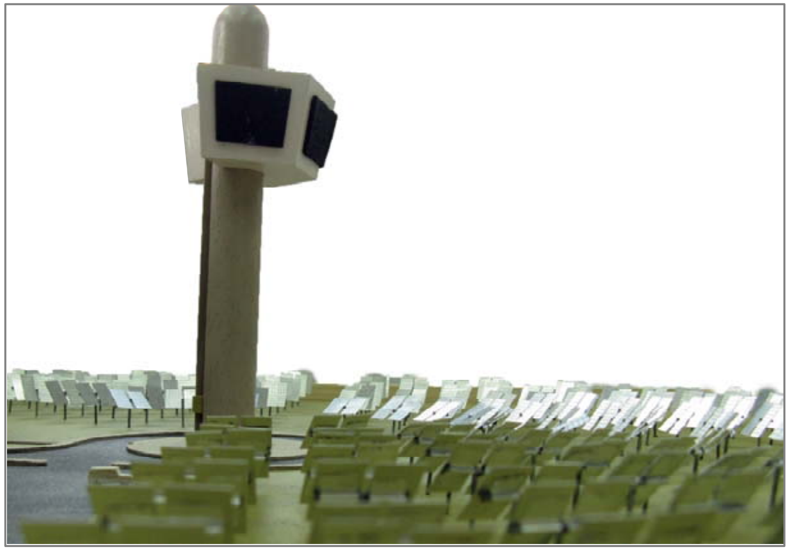


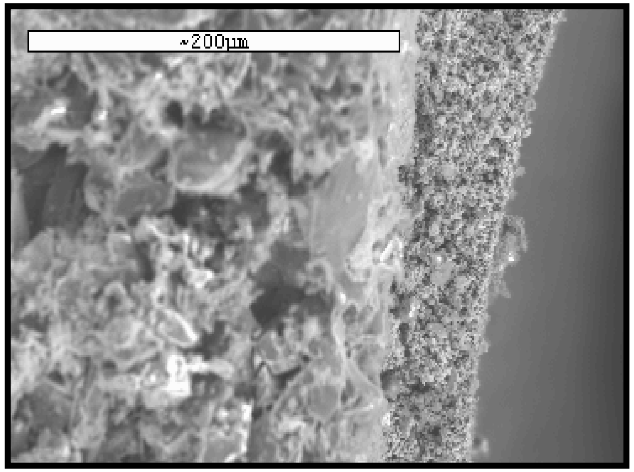
500-2000 C



650 - 2250 C

Functions of a
Solar Thermochemical Reactor

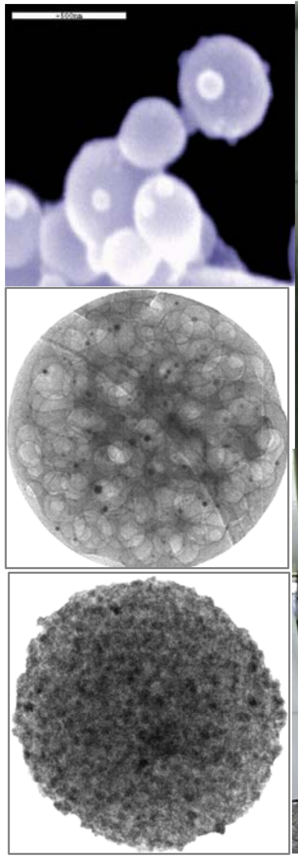




- **Volumetric Receiver:** Absorption of solar radiation/conversion into heat
- **Heterogeneous reactor:** Gas solid reactions/Catalytic reactions

Common Development Path

Particle Synthesis



Shaping of structured reactors

Coating of monoliths

Application Specific Testing

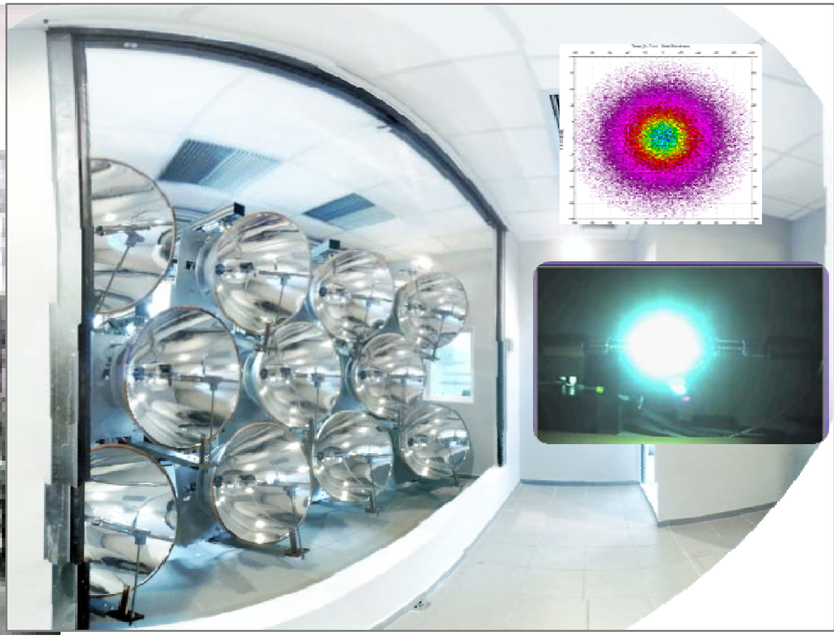
Lab side-stream reactor

Engine test cell

Field Testing

Lab fixed bed reactor

Solar Simulator

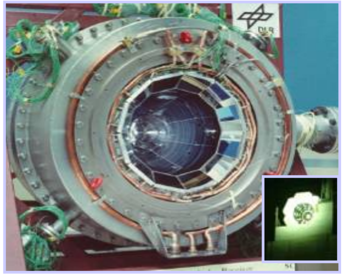


Field Testing

Solar Thermochemical Reactor Research at APTL (2000-today)

Solar Volumetric Receiver

Solar H_2 from H_2O splitting

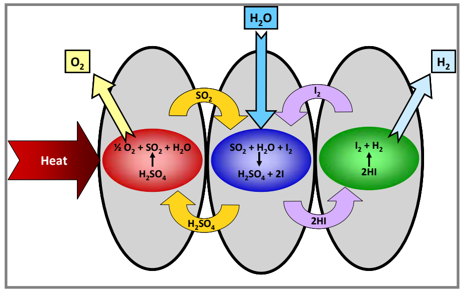


Solar CH_4 Reforming

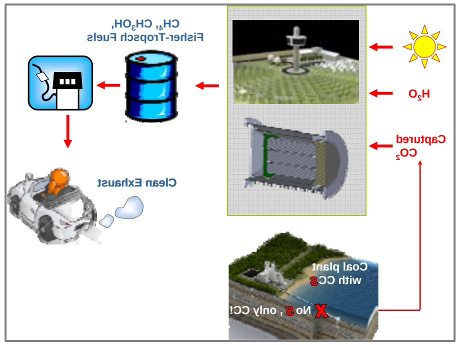
CH_4 Solar Cracking

Solar Reactor manufacturing

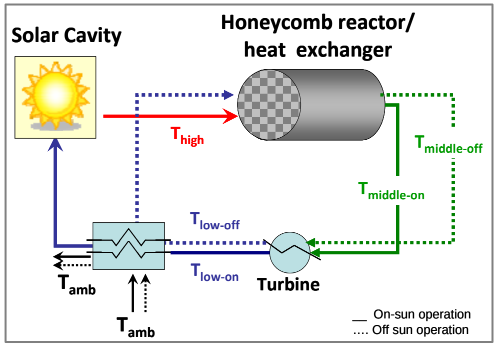
Solar H_2 Plant Design



Solar Sulfur-Iodine Cycle



Carbon Neutral Solar Fuels



Thermochemical Storage of Solar Energy

Solar Thermochemical Reactor Research at APTL

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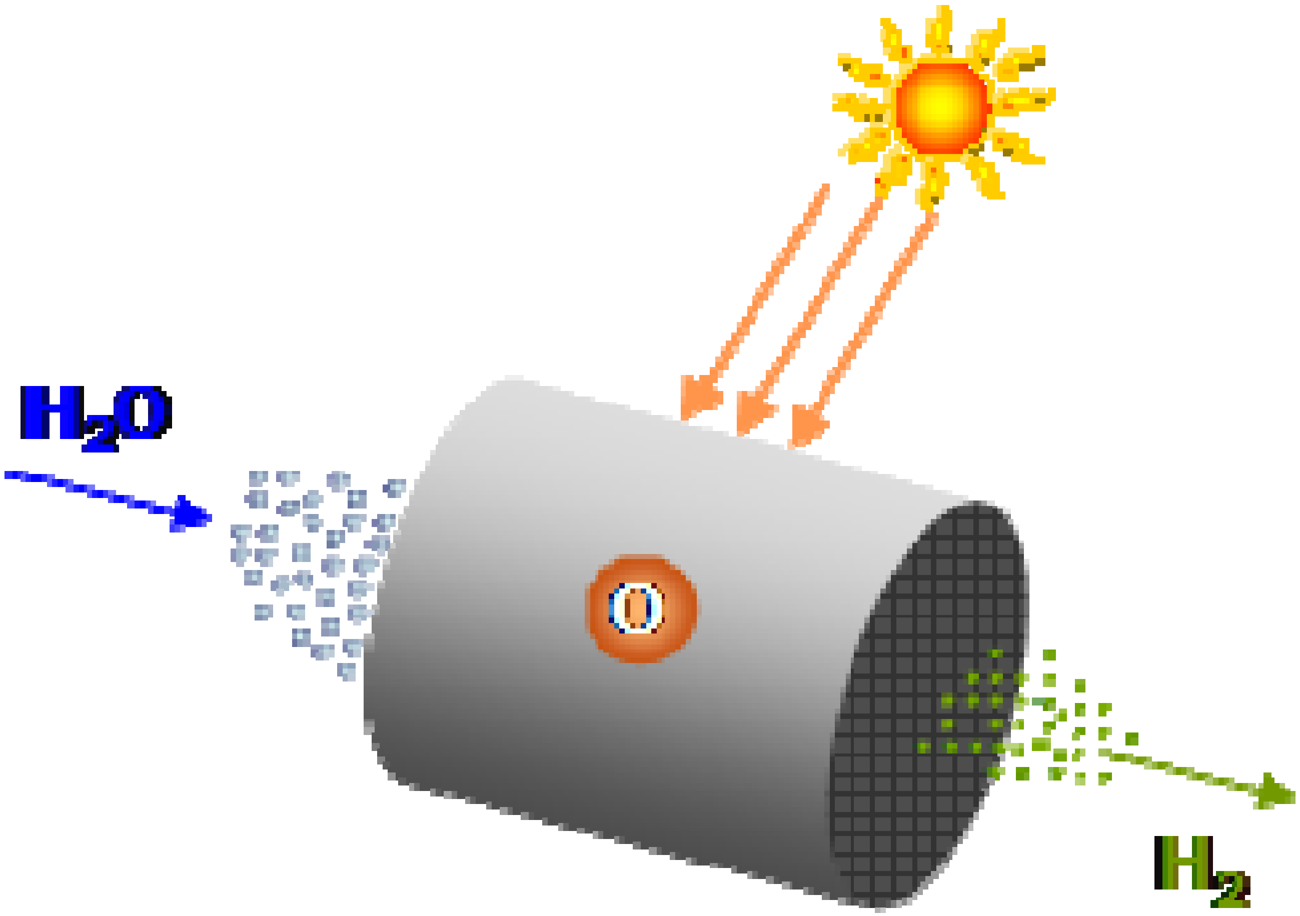
Solar Hydrogen: The HYDROSOL Process



- Renewable energy sources and raw materials
- Zero greenhouse gas emissions
- Long-term potential

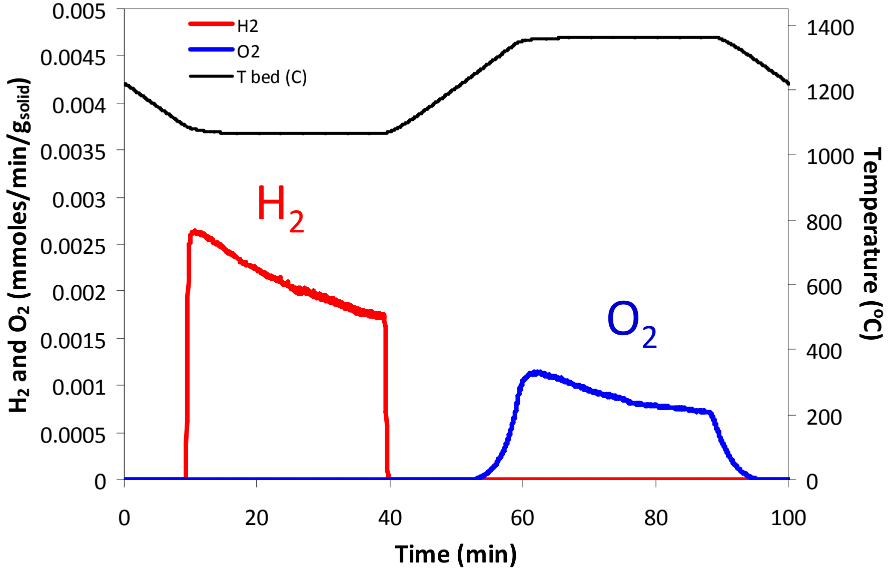
HYDROSOL Principle of Operation: Redox Cycle

Water-splitting (oxidation step)

$$MO_{x-1} + H_2O \rightarrow MO_x + H_2$$

Regeneration (reduction step)

$$MO_x \rightarrow MO_{x-1} + \frac{1}{2}O_2$$

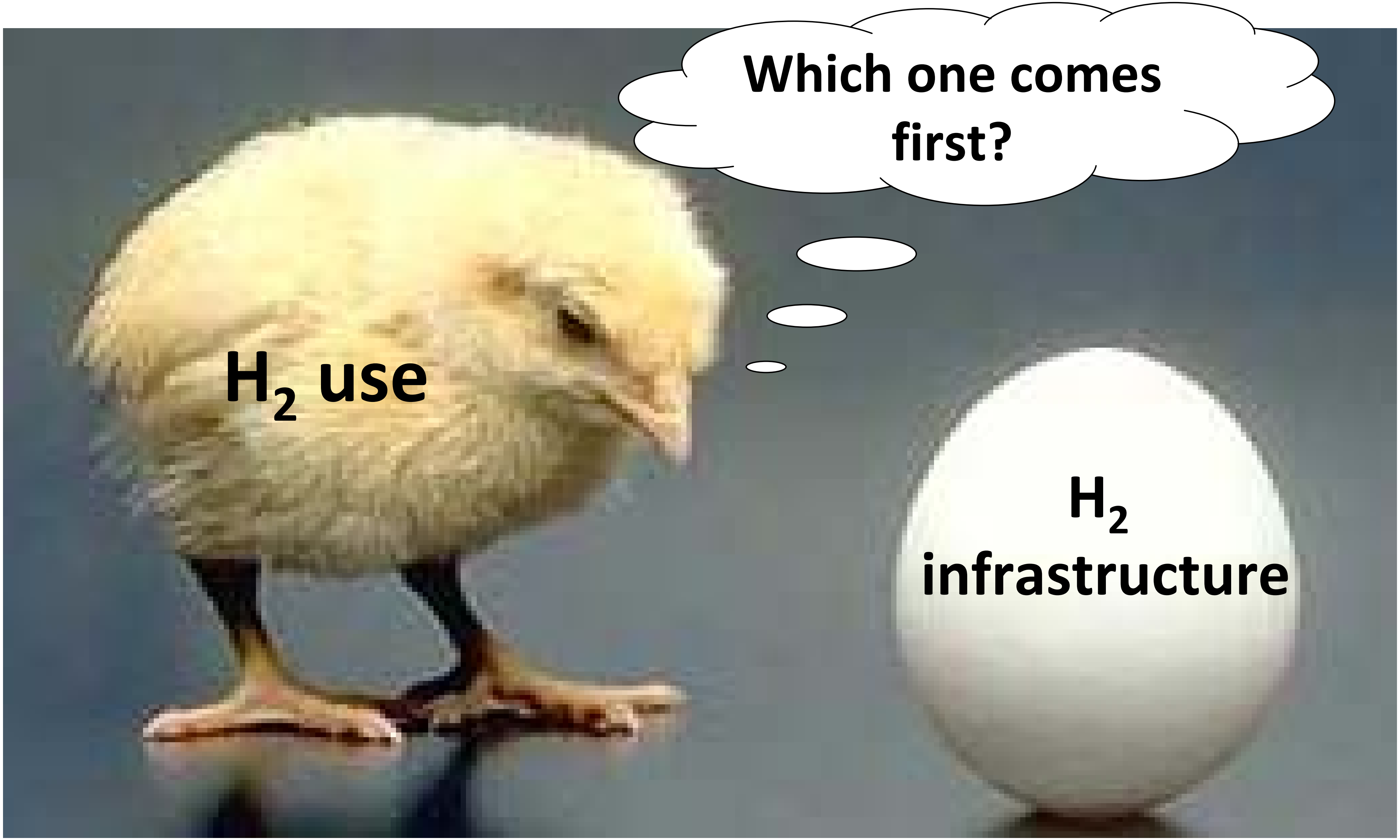


MO_x : Metal oxides

- **Single Oxides of Fe, Mn, Zn, …**
- **Mixed Oxides Fe, Mn, Ni, Zn, Co, rare earths (Ce, Pr, La), etc**

HYDROSOL Technology Scale-Up

Why we do not already have a H_2 economy?



Carbon Neutral Solar Fuels from CO_2 and H_2O

H_2O and CO_2 splitting (oxidation step)

$$MO_{x-1} + H_2O \rightarrow MO_x + H_2$$

$$MO_{x-1} + CO_2 \rightarrow MO_x + CO$$

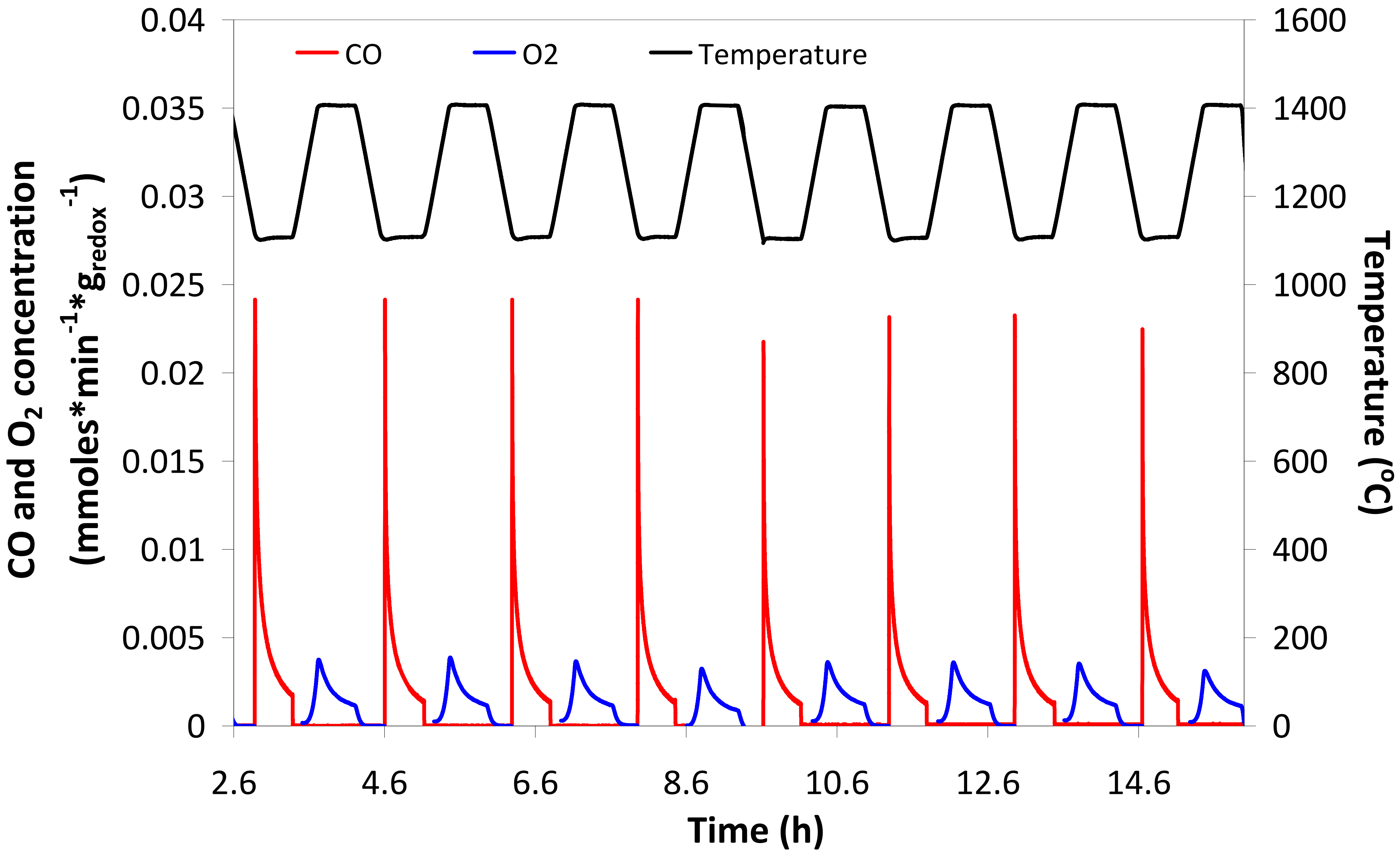
Regeneration (reduction step)

$$MO_x \rightarrow MO_{x-1} + \frac{1}{2}O_2$$

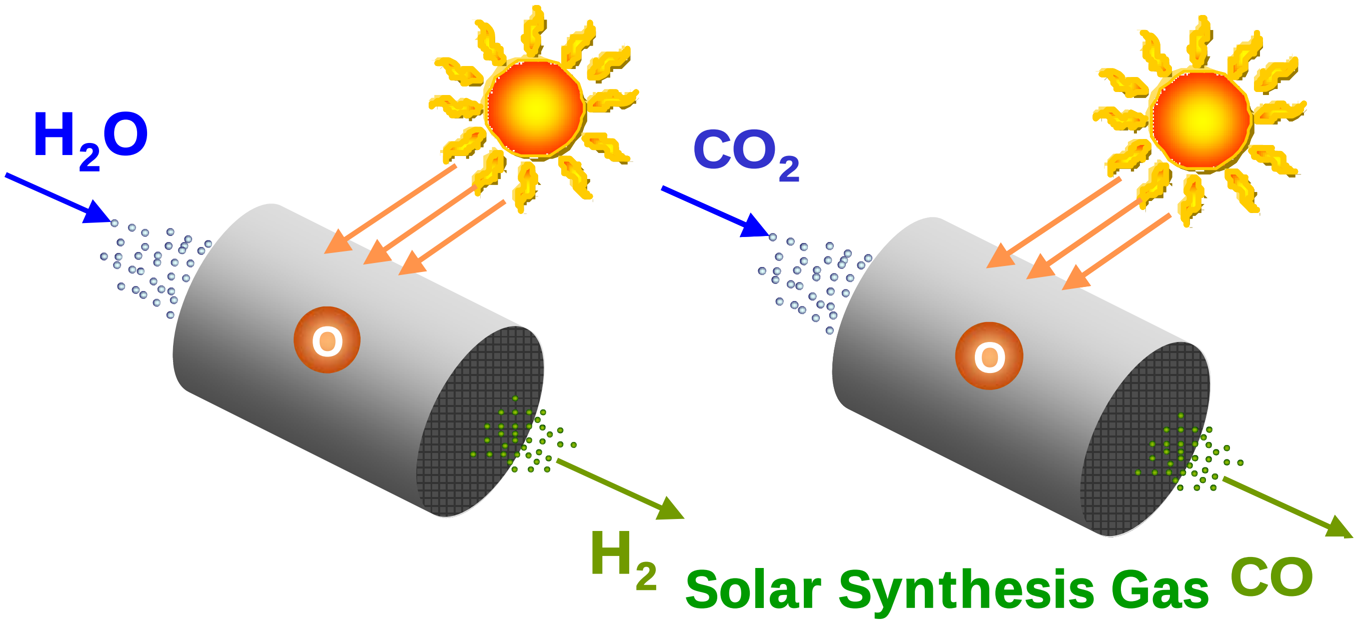
MO_x : Metal oxide

Cycling Process

Reactant gas concentration: 100% CO_2



Sustainable Energy & Materials from Sun, H_2O & CO_2



$H_2 + CO \rightarrow C_xH_y$ (Liquid Fuels/Fischer-Tropsch process)

$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$ (Gas fuels, methane/Sabatier process)

$H_2 + CO \rightarrow C_xH_y$ (Plastics)

Sustainable Storage of Carbon AND Hydrogen!

Carbon Neutral Solar Fuel Plant

Clean Energy and Green Mobility

H_2O →

CO_2 →

→ H_2

→ Electric Energy

→ CH_4, C_xH_y
Fuels & Chemicals

→ Waste Heat for Solar Desalination H_2O

EXPO 2005

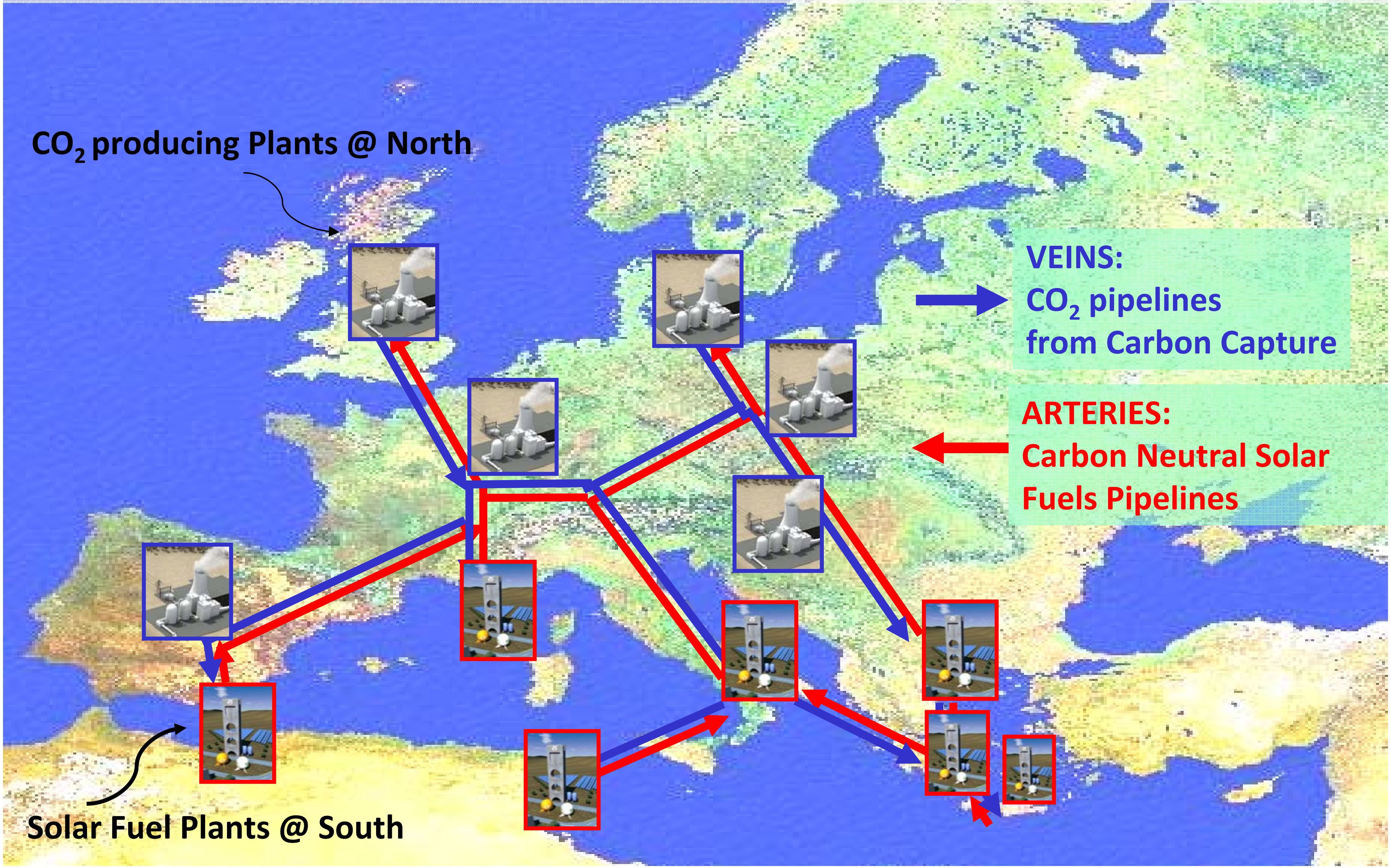
IPHE 2006

Descartes Prize 2007

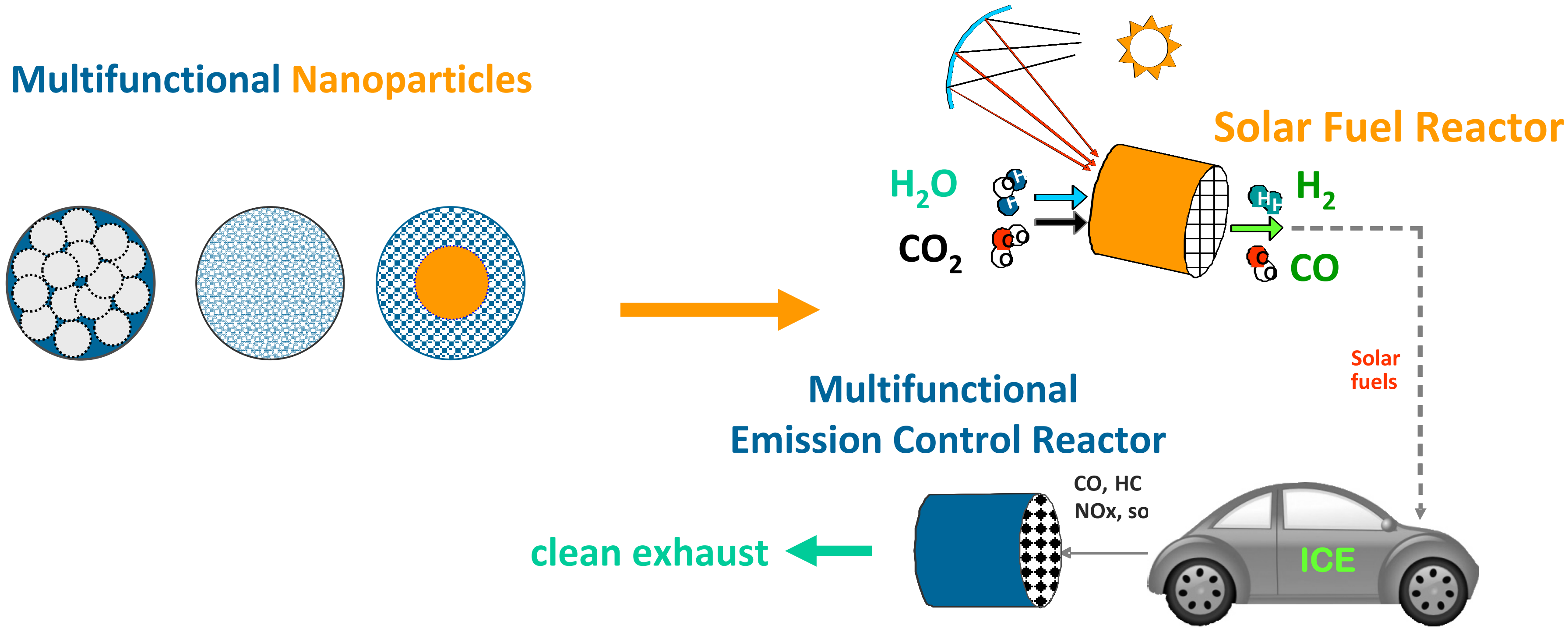
EU IDEAS Award 2010

European Research Council
Advanced Grant
erc

Biomimetic Integration of North and South



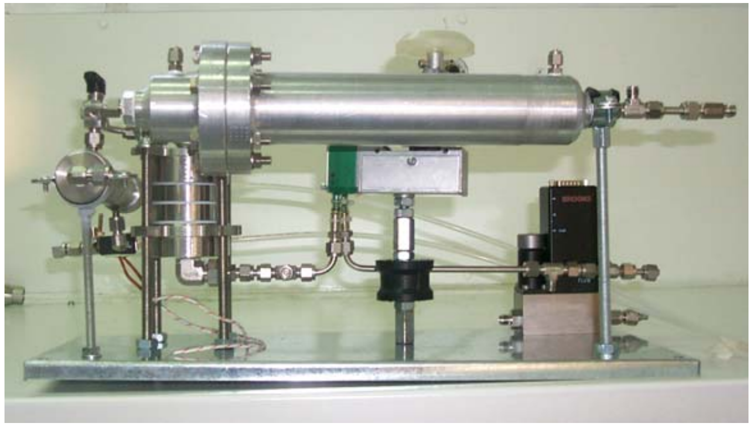
Green Mobility and Clean Energy for the Future



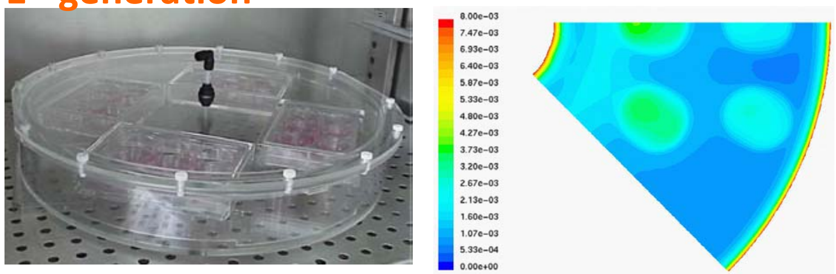
- Eco-responsible Aerosol Based Nanotechnology
- Solar Reactors/Carbon Neutral Solar Fuels
- Compact multifunctional emission control reactors

Size Specific Nanoparticle Biological Responses

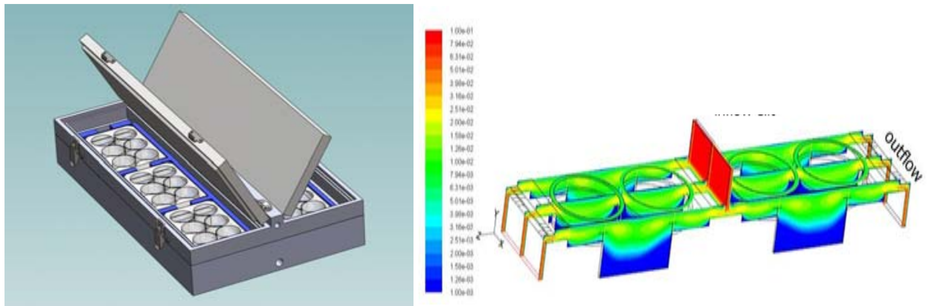
Size Specific Particle Sampler (SPS)



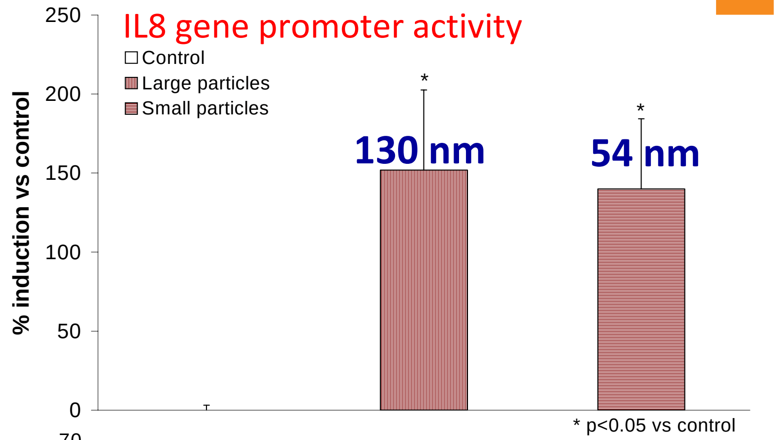
1st generation

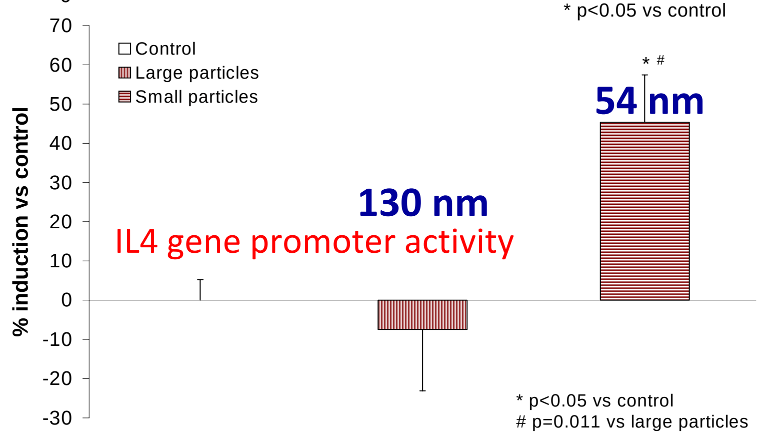


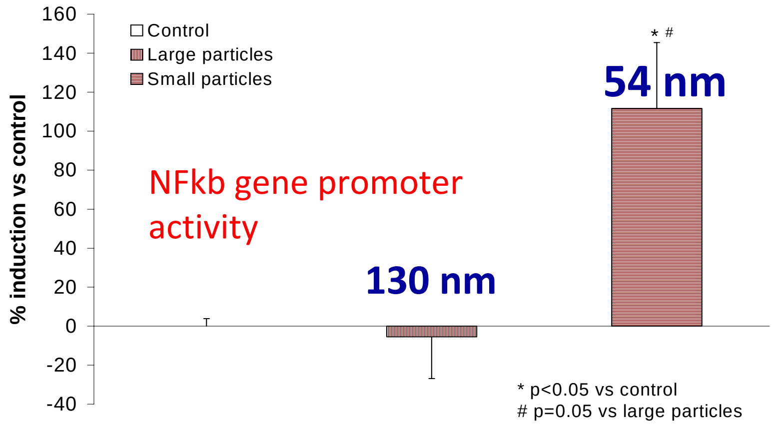
2nd generation



End Points







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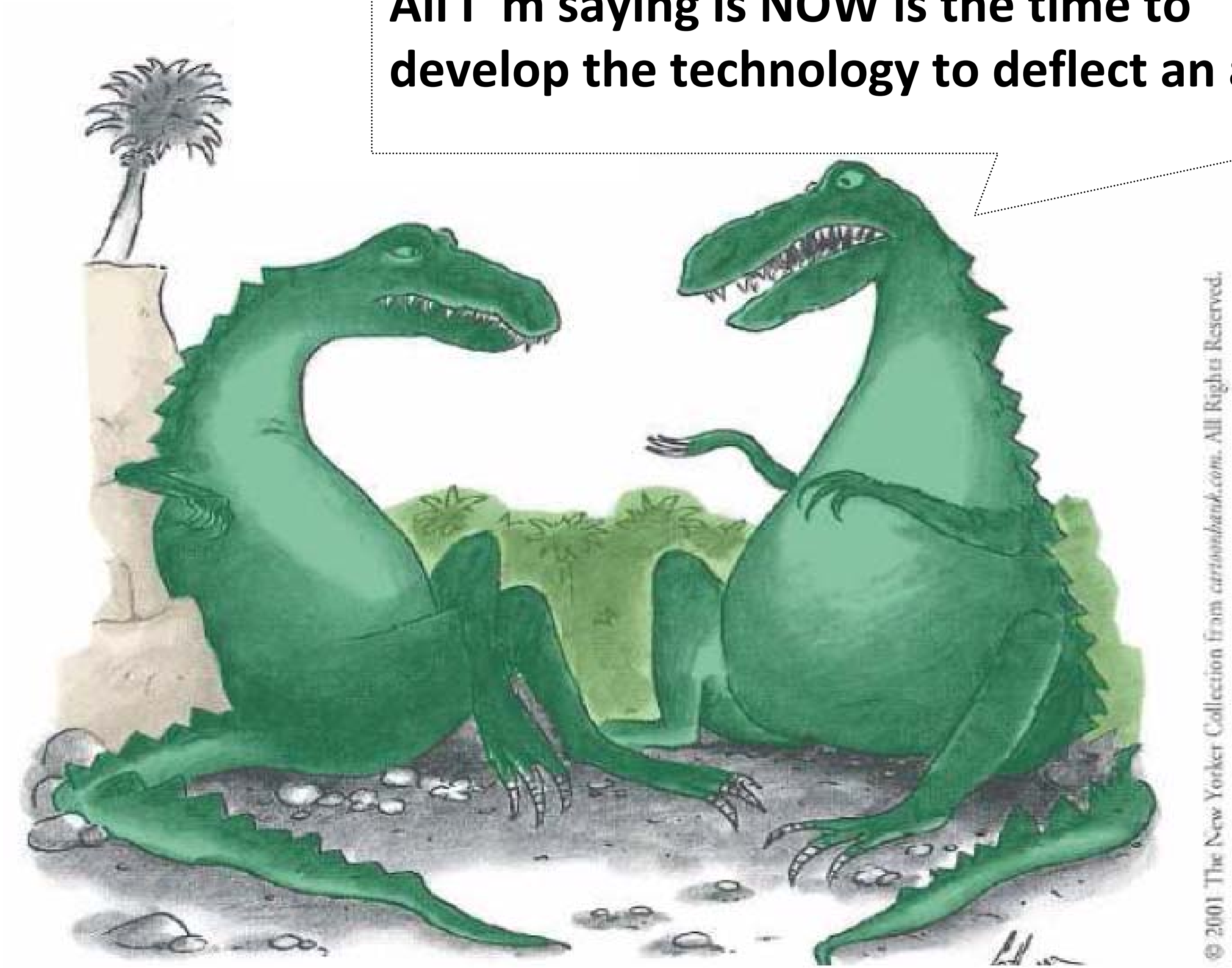
Conclusion…

All I' m saying is NOW is the time to develop the technology to deflect an asteroid



Acknowledgments

- **The European Commission for supporting our research in combustion engines and their emissions** through >24 projects over the last 17 years including projects APT-STEP, CLEANER-D, HCV and our partners in these projects.
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- **The Greek Secretariat for Research and Technology** for supporting our research through projects HYDROSOL+ and NANOREDSOL.
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