



# Reactor Technologies for Carbon-Neutral Solar Fuels and Clean Vehicles

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# Functionalized Structured Reactors

## Emission Control Reactors

Soot nanoparticles, CO, HC, NO<sub>x</sub>



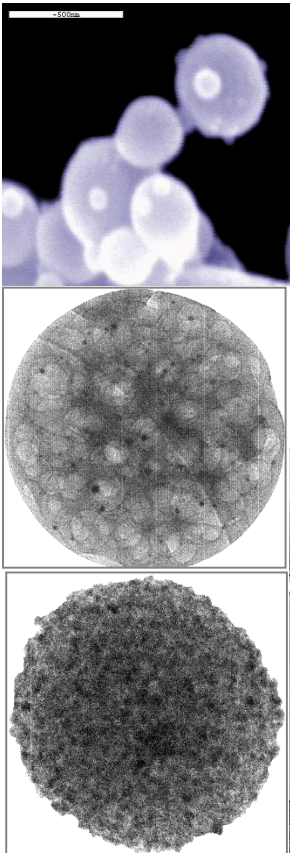
## Solar Reactors

Thermochemical processes for energy production

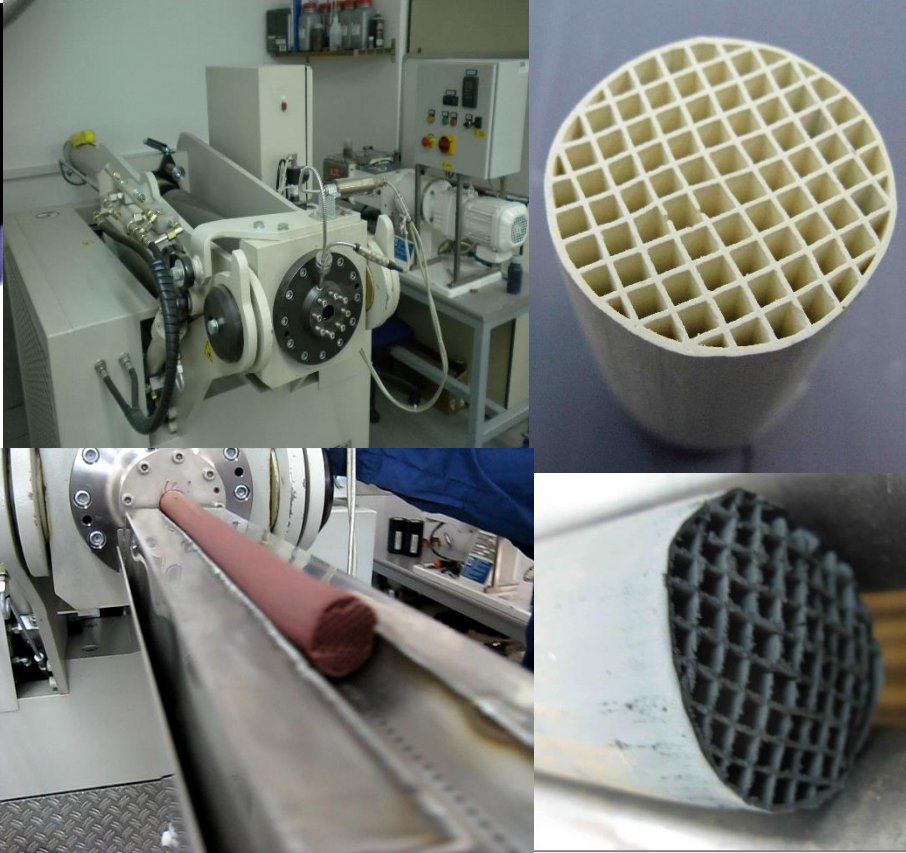


# Functionalized Structured Reactor Development

## (Nano)-Particle Synthesis



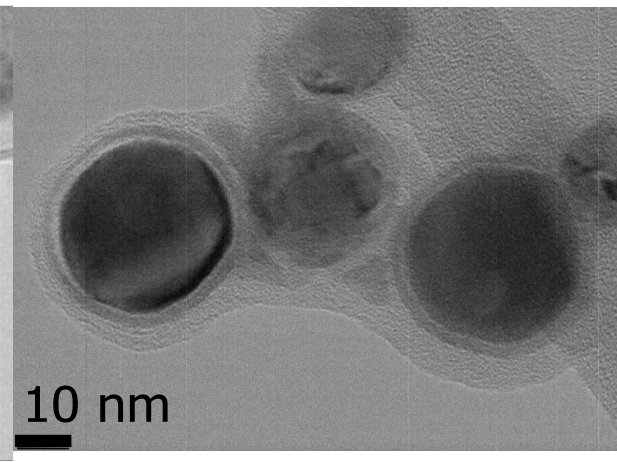
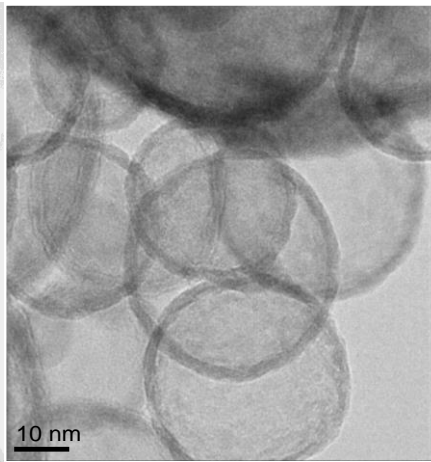
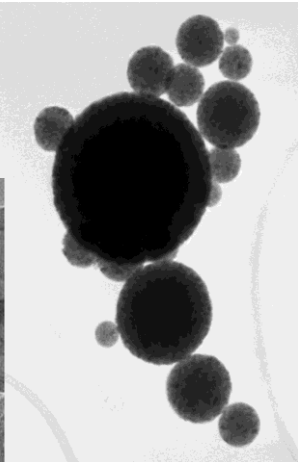
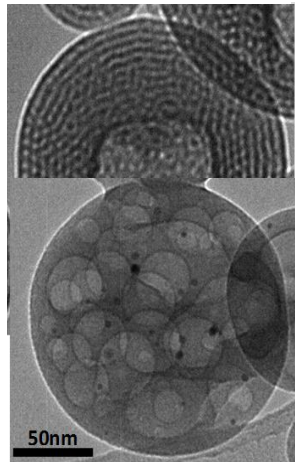
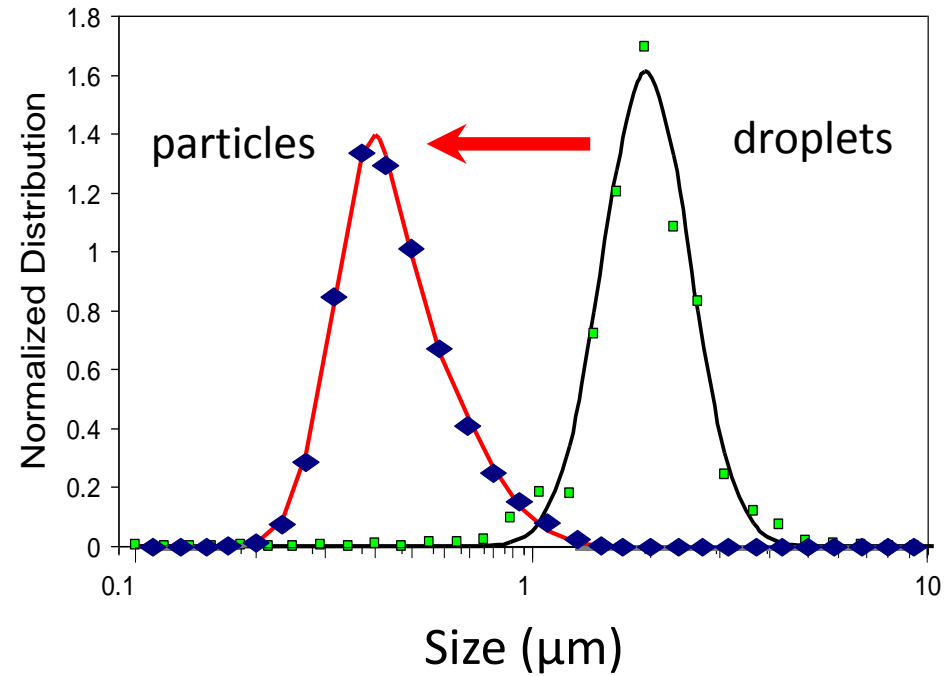
## Shaping of structured reactor bodies



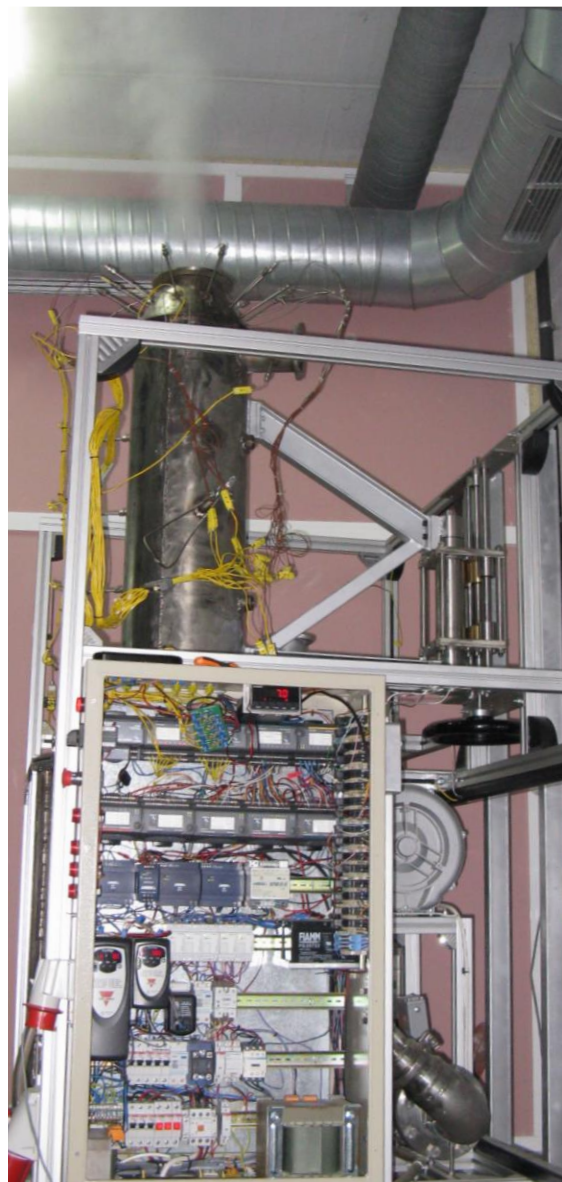
## Coating/Functionalization of structured reactors



# From Droplets to Particles with Different Morphologies/Nanostructures



# Aerosol Based Manufacturing Pilot Plant



deposition

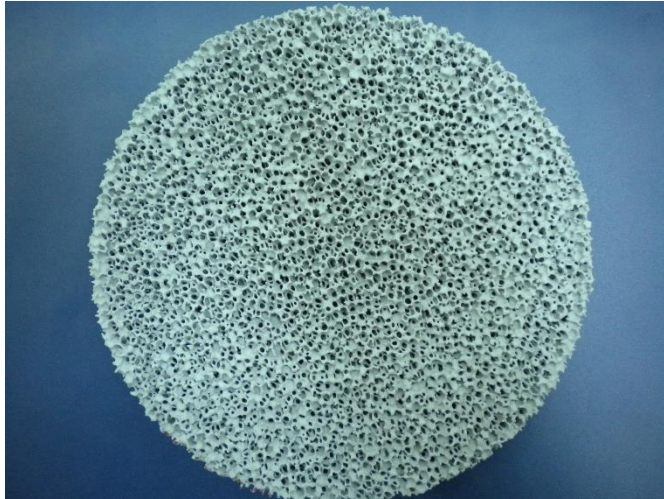
synthesis



# Functionalizing/Coating Porous Supports



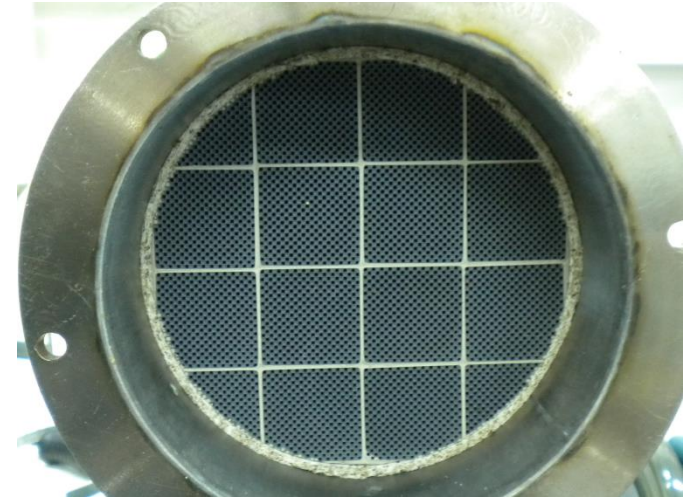
## Ceramic Foam



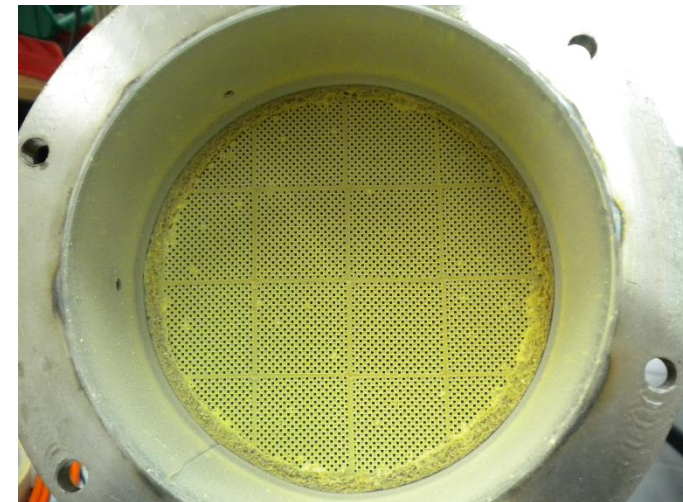
## Fibrous metal



## Ceramic Honeycomb

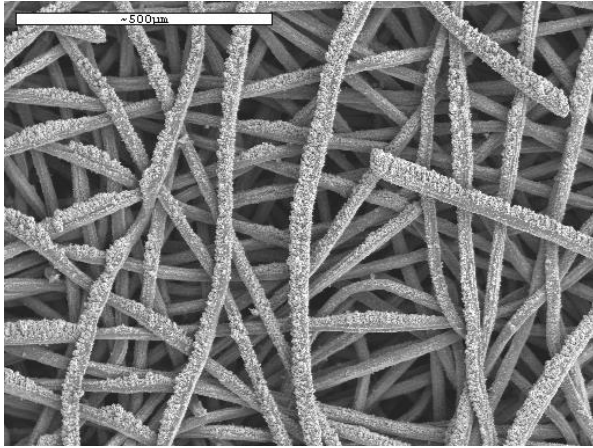


## Functionalized/Coated samples

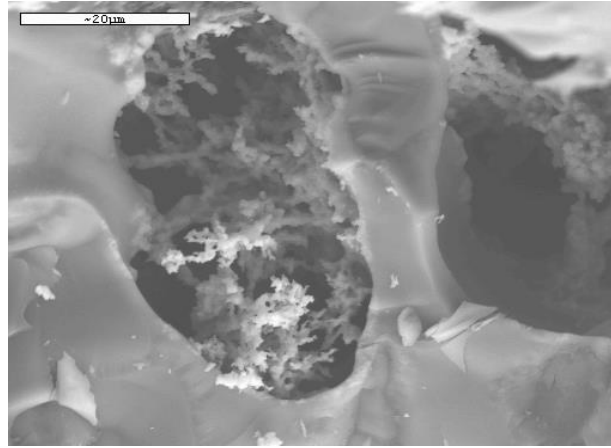


# Flexibility in Deposition Mode

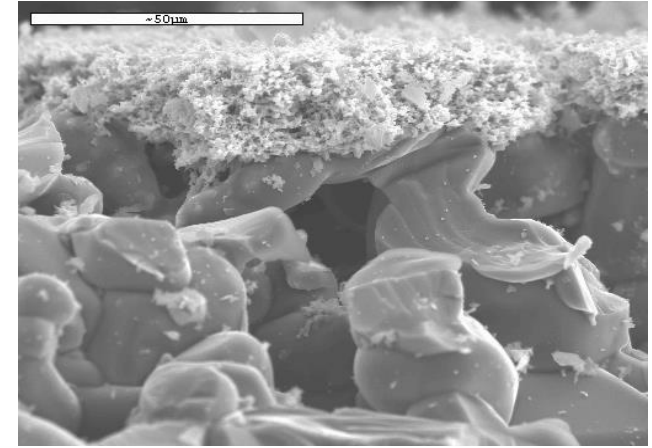
On Surface



Inside the Pores

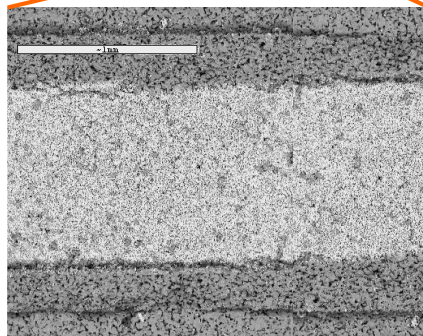


Layer

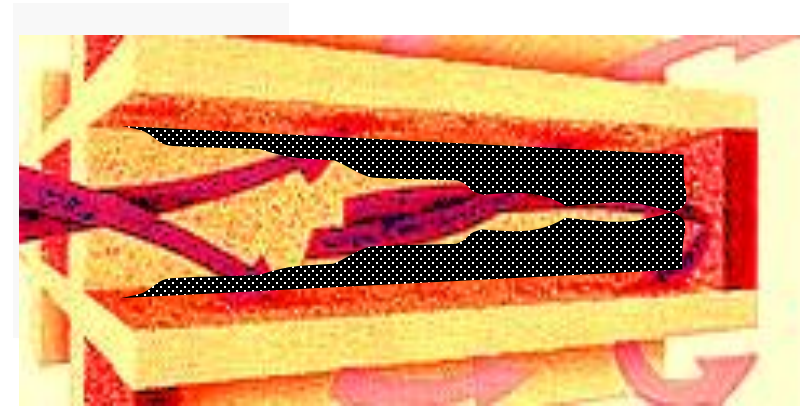
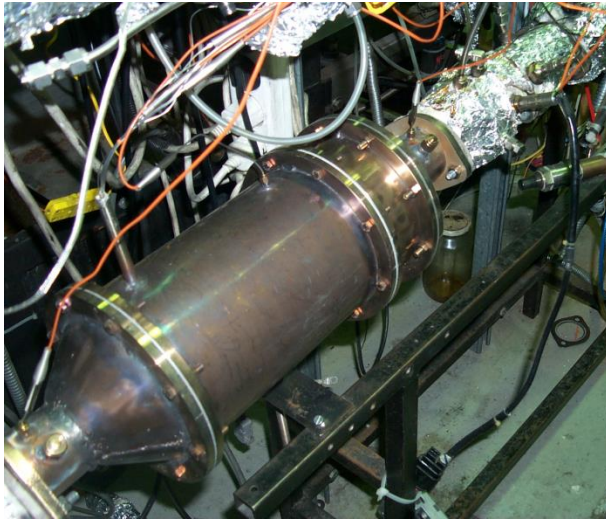


Inside Microchannels

1.5 x 150 mm



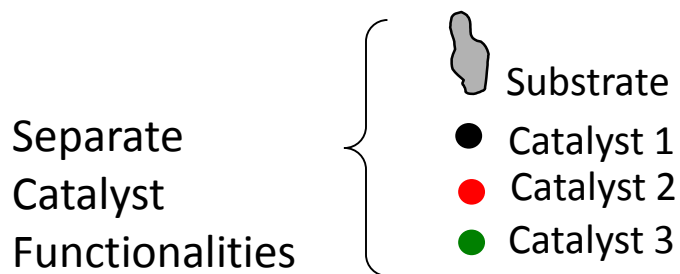
# Functions of an Emission Control Reactor (4WC)



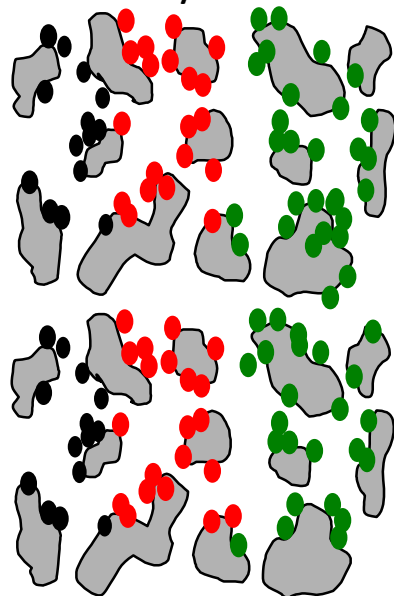
- **Nanoparticle Separation:** Filtration & Pressure Drop
- **Reactor:** Soot, CO/HC/NO oxidation, NO<sub>x</sub> reduction
- **Ash Accumulator:** Aging performance



# Adding Multiple Catalytic Functions to a Porous Wall

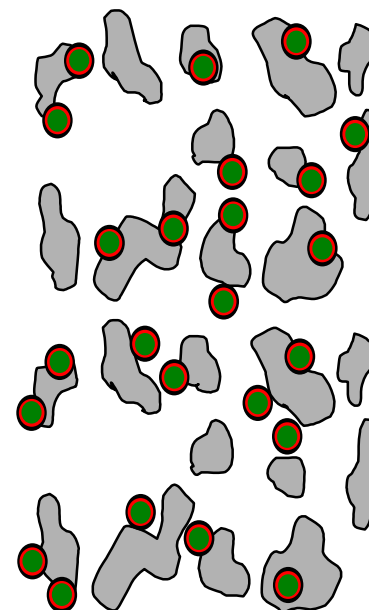


Different Catalyst Particles

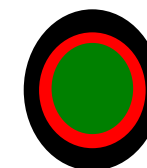
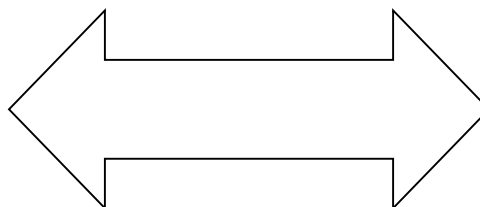


High  $\Delta P$

Multi-Functional Particles



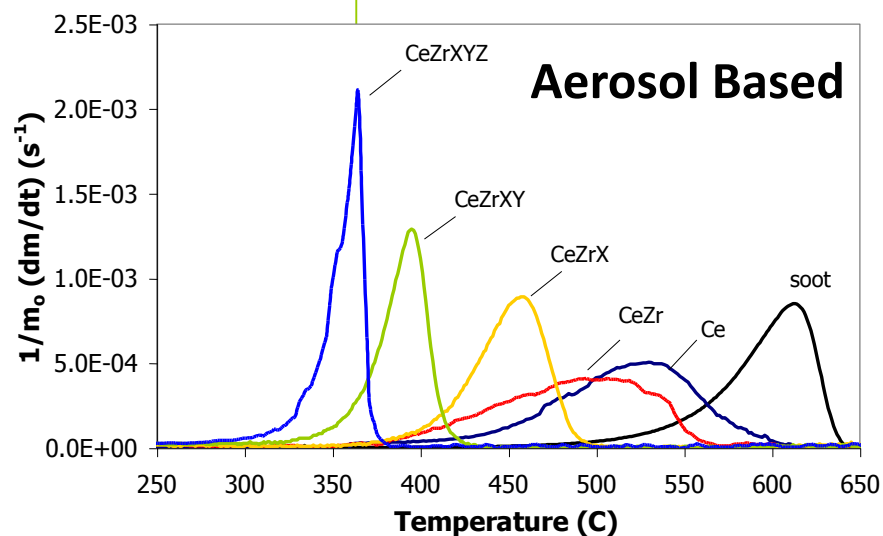
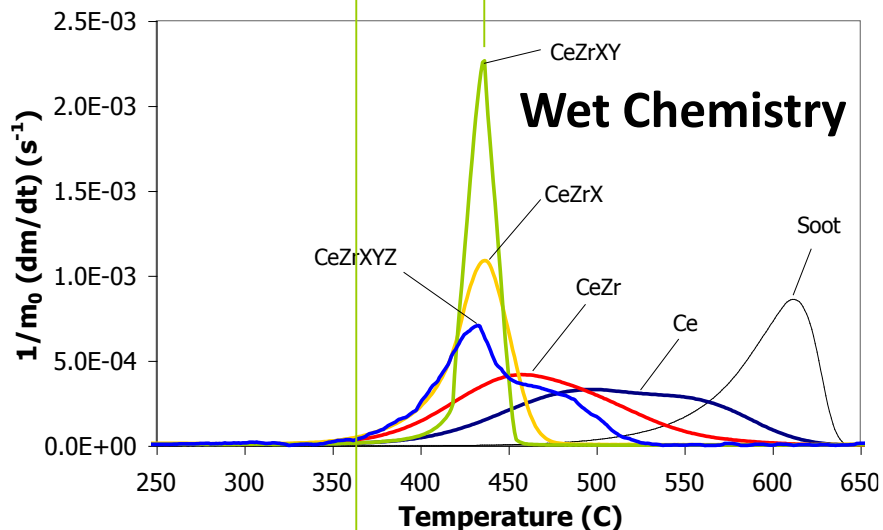
Low  $\Delta P$



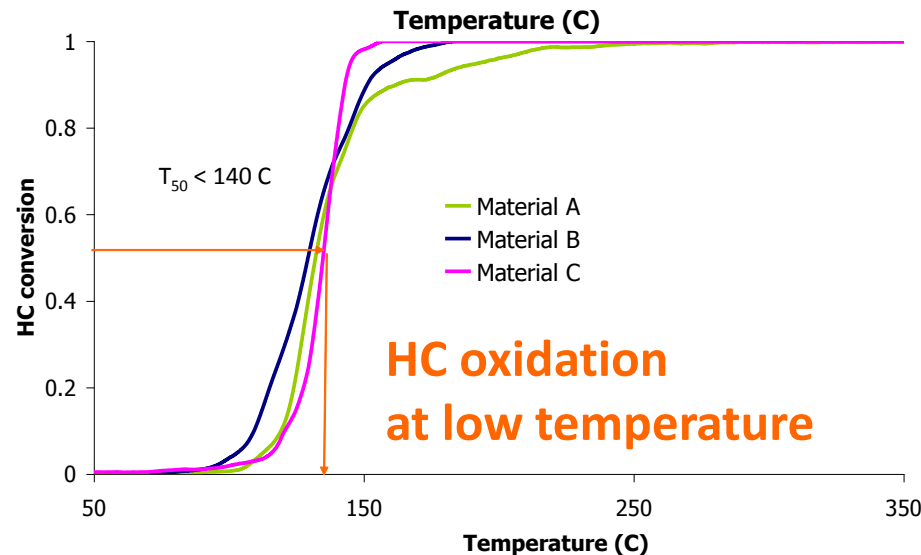
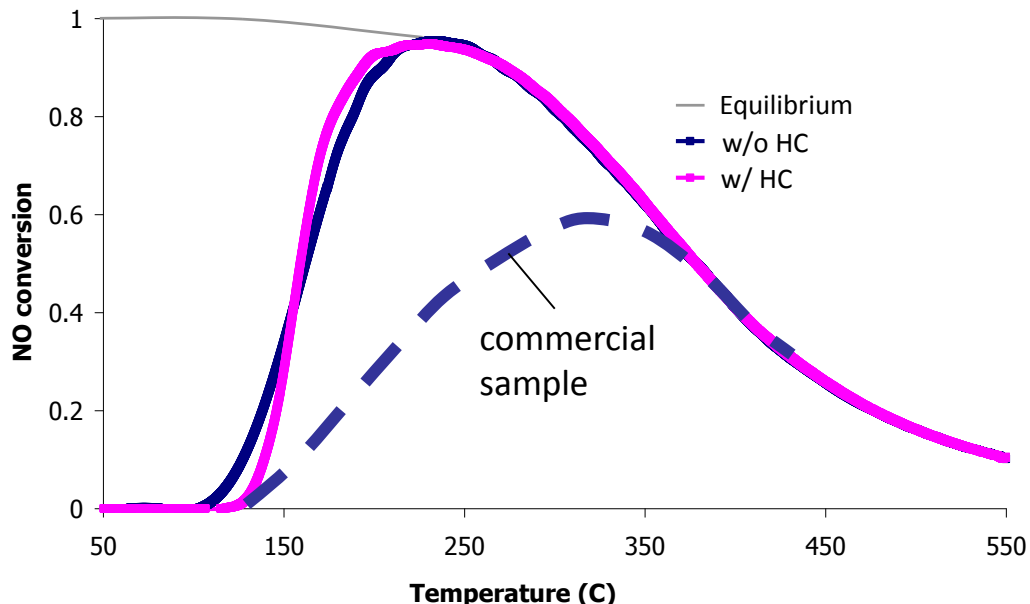
# Aerosol Synthesis of Diesel Emission Control Catalysts



## Improvement in soot oxidation

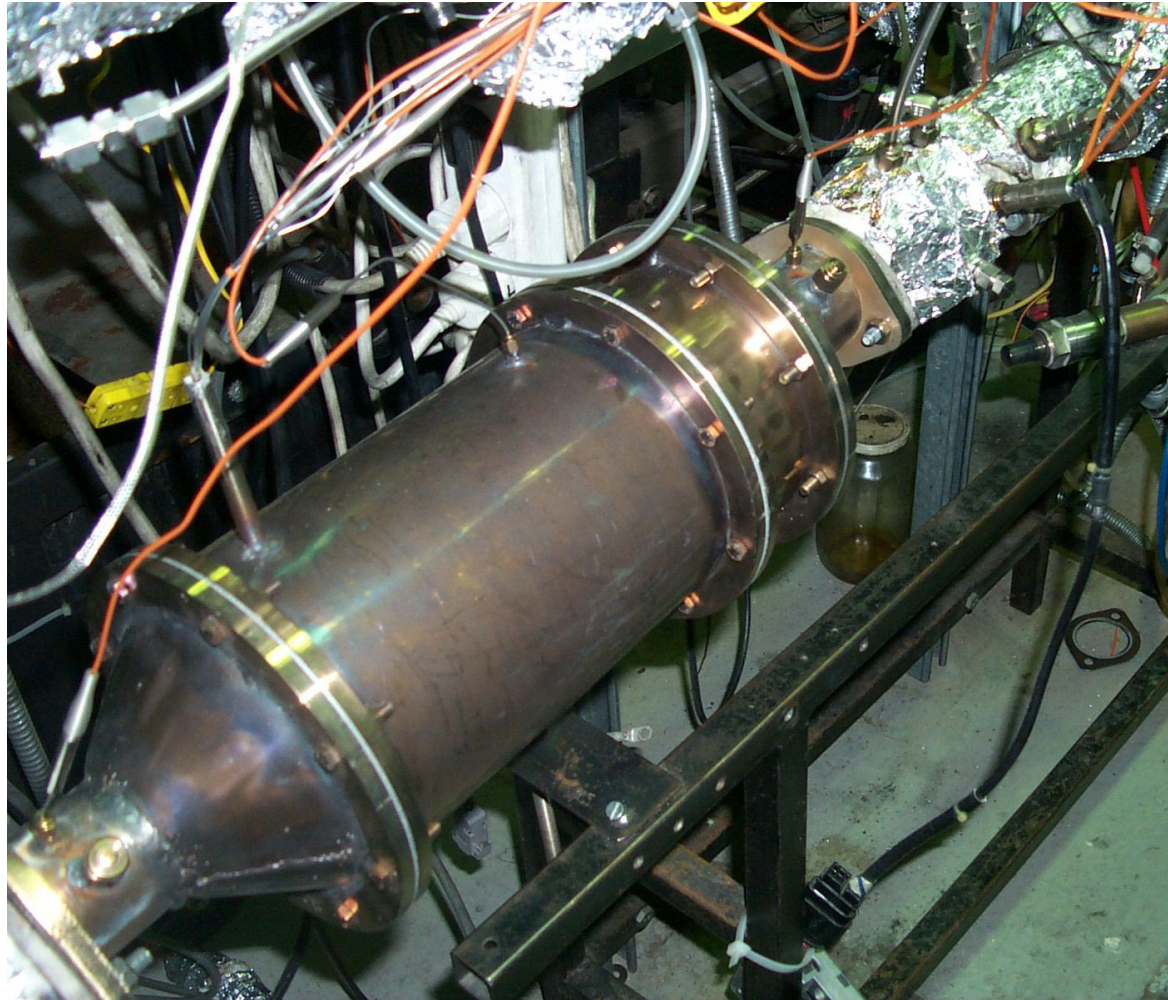


## NO to NO<sub>2</sub> oxidation unaffected by HC



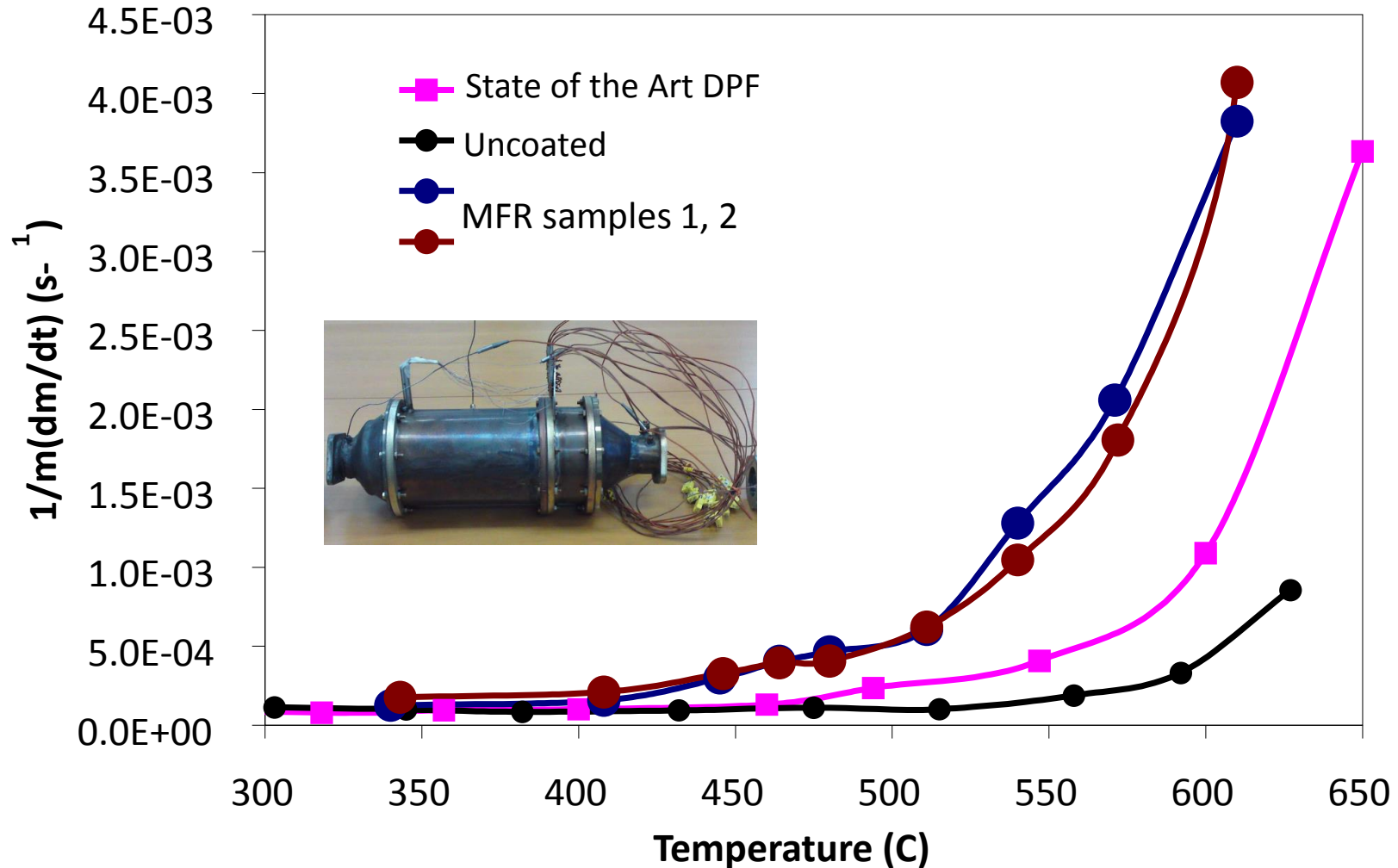
# Multi-Functional Filter-Reactor (MFR)

The MFR is a 4-way converter solution for soot nanoparticle removal and oxidation, CO and HC oxidation and NO<sub>x</sub> removal.



# MFR Assessment

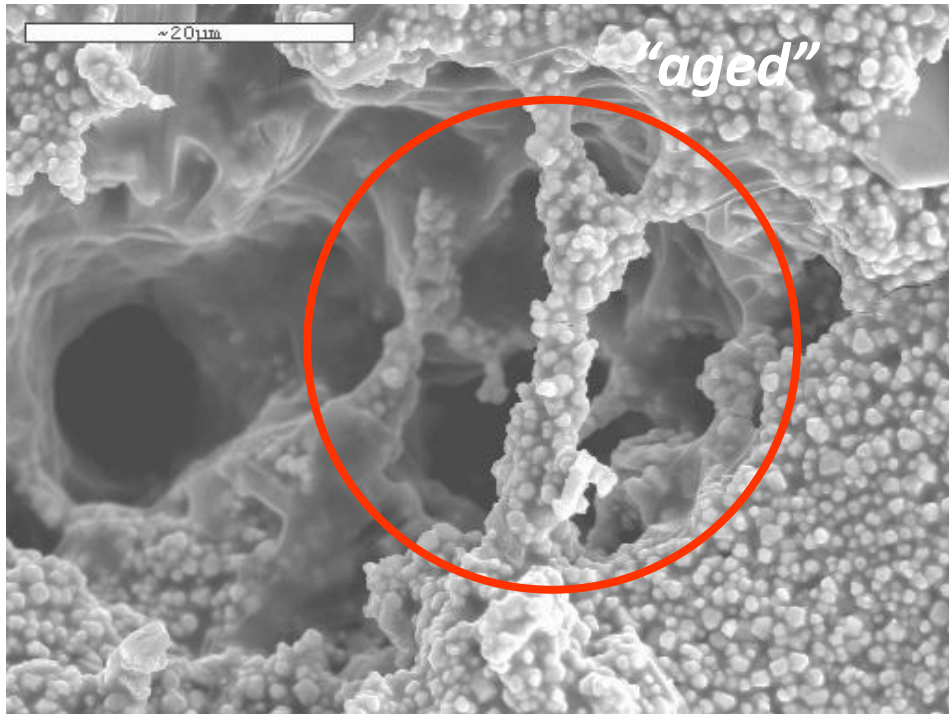
4 times higher soot oxidation rate at 550 C compared to a State of the Art DPF



# Doping for Thermal Resistance to Sintering



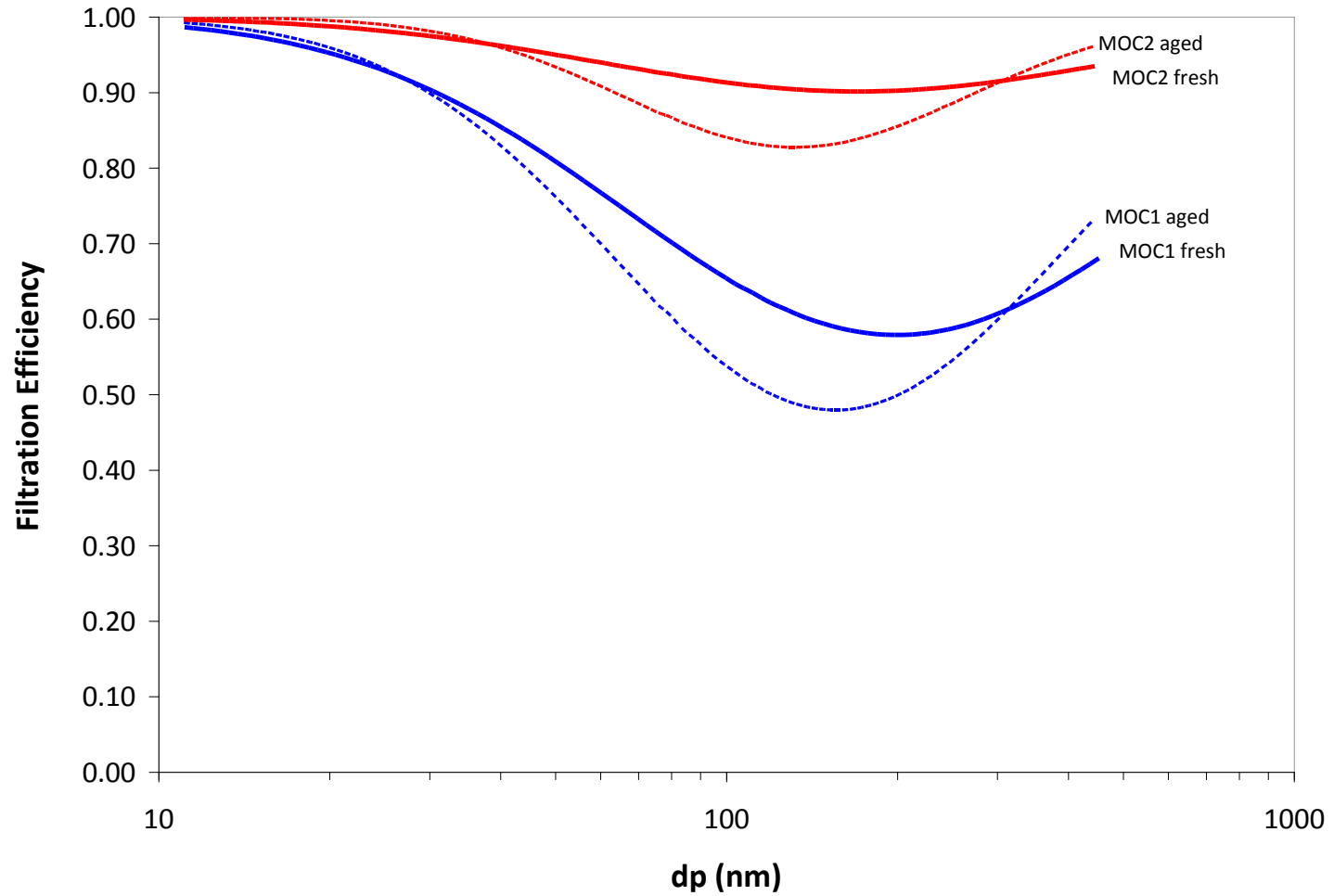
Mixed Oxide Catalyst MOC 1



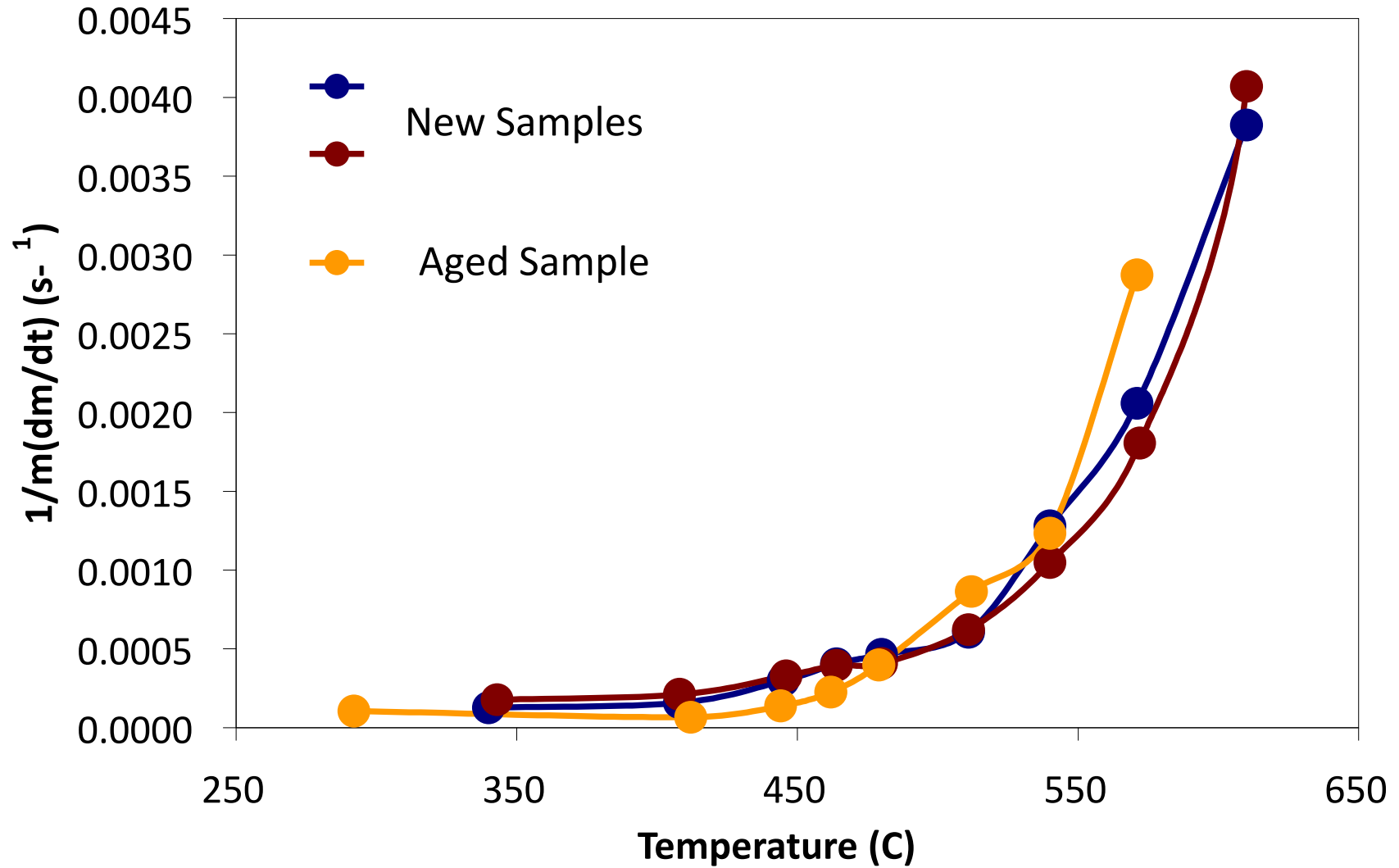
Mixed Oxide Catalyst MOC 2



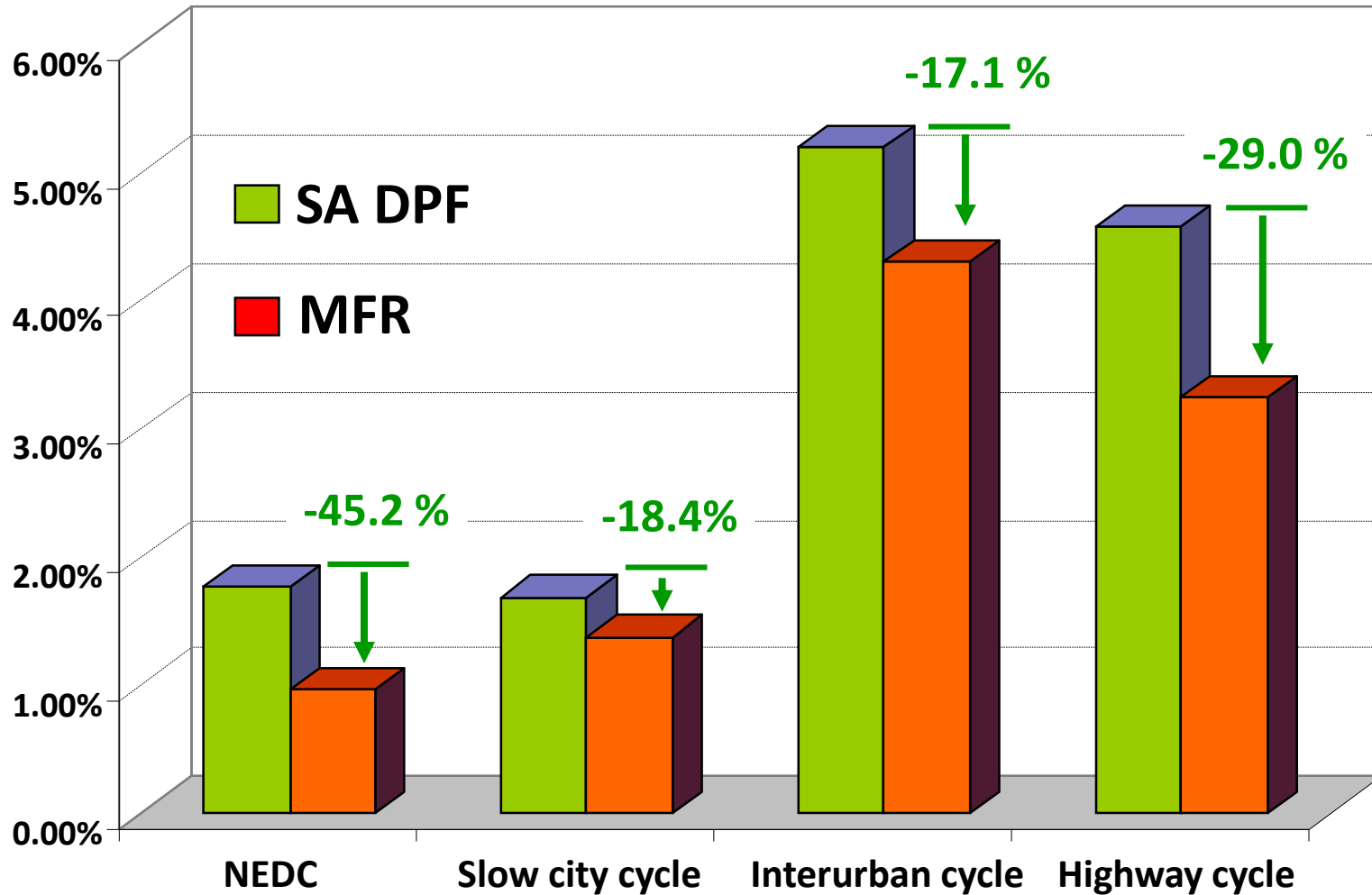
# Size specific clean filtration efficiency



# MFR Aging (equivalent to 100,000 km)



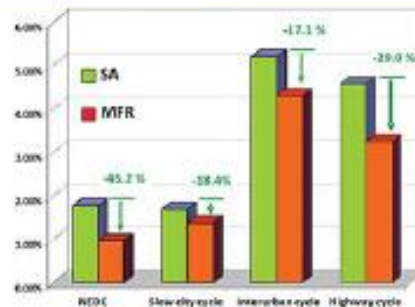
# Fuel penalty comparison for different driving cycles





# Emission Control Science & Technology

An International Journal



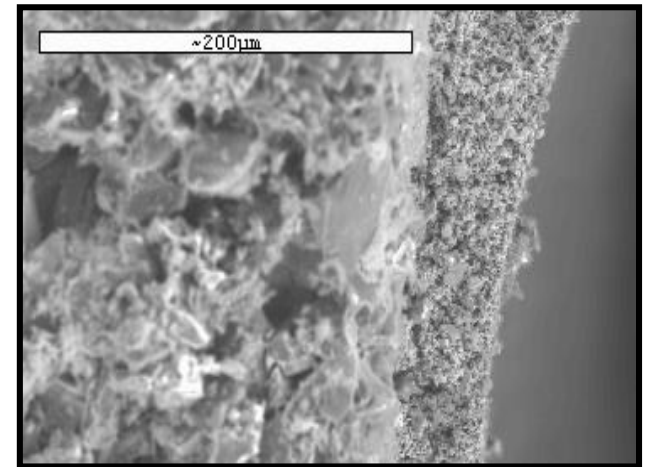
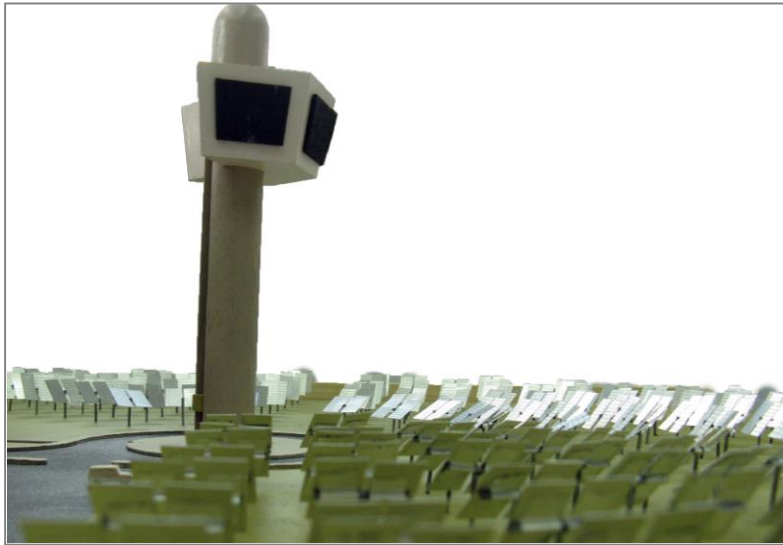
‘Emission Control Science and Technology’ is the single, authoritative outlet for all areas of emission control research, development and application related to mobile (automotive-land/air/sea transport) and stationary sources in the energy, chemical process and manufacturing industries where combustion technologies are employed.

Editors-In-Chief:

Athanasios G. Konstandopoulos

Mansour Masoudi

# Functions of a Solar Thermochemical Reactor

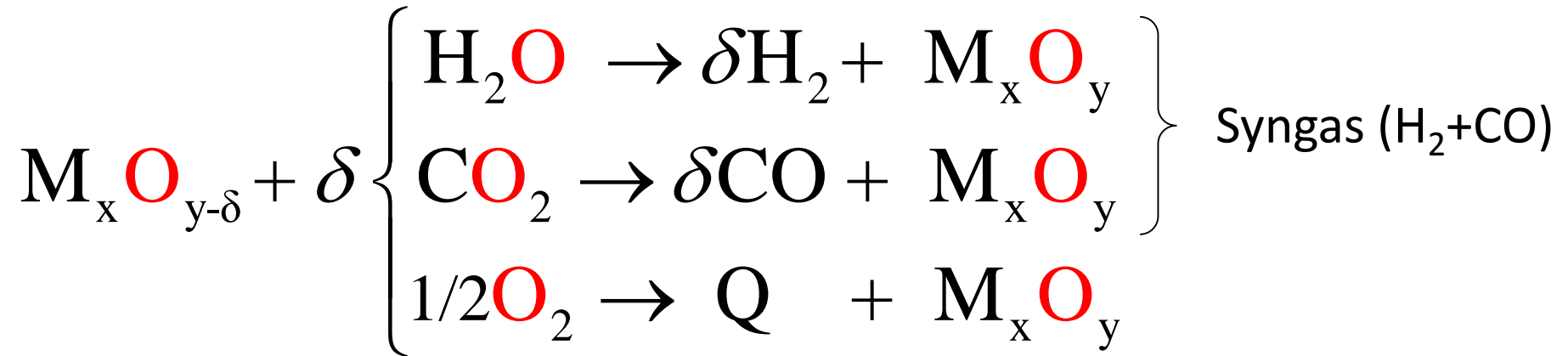


- **Volumetric Receiver:** Absorption of solar radiation/conversion into heat
- **Heterogeneous reactor:** Gas solid reactions/Catalytic reactions

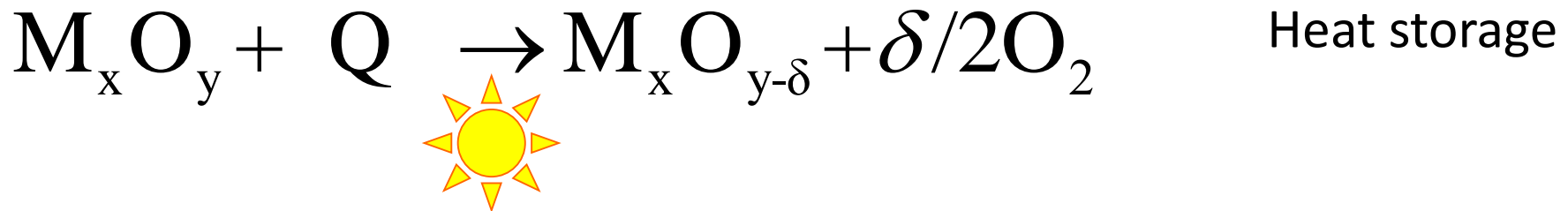
# Key Enabling Technology: Redox Materials



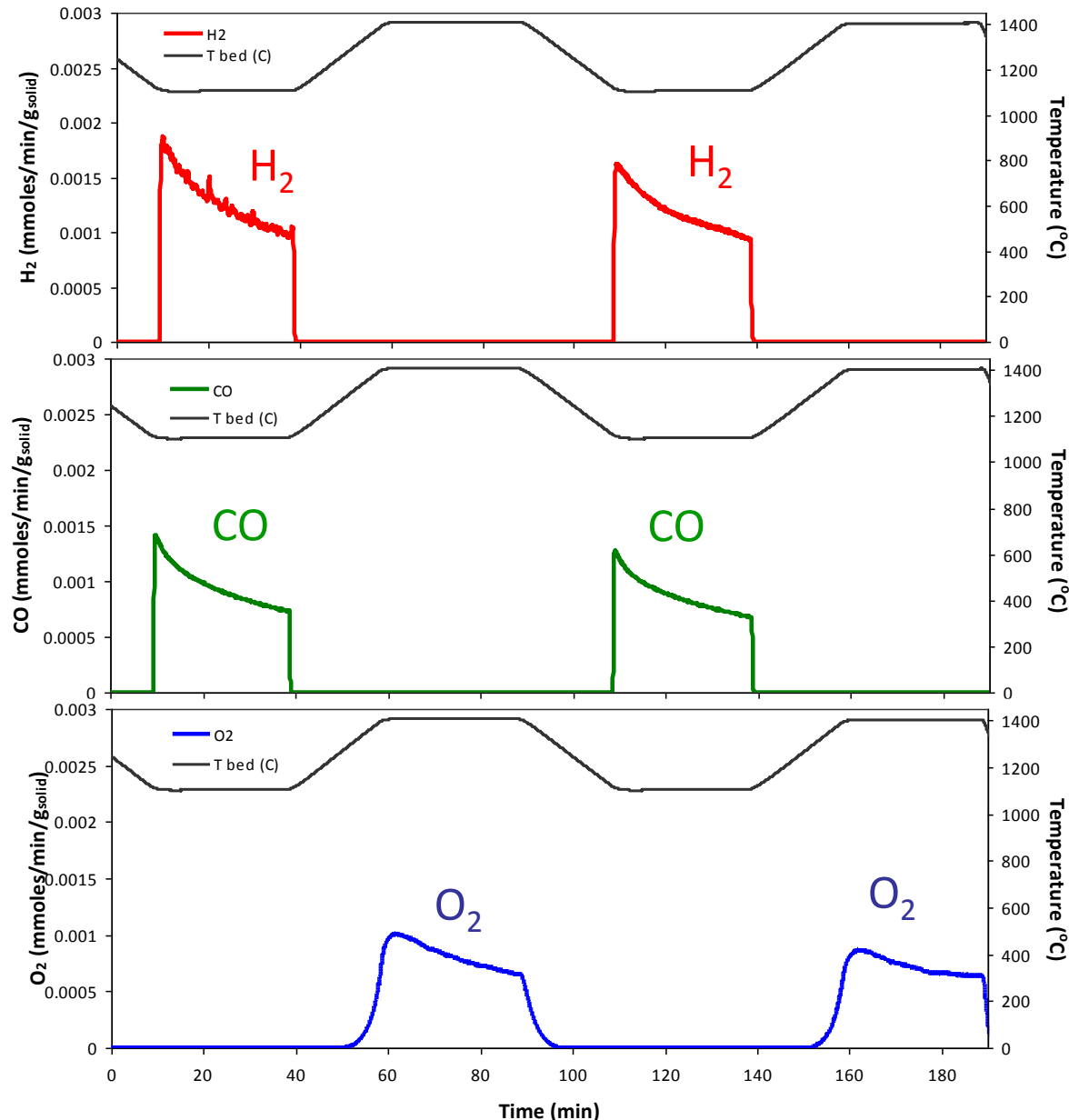
## Oxidation of reduced oxide



## Thermal reduction of oxide



# Simultaneous H<sub>2</sub>O & CO<sub>2</sub> splitting over a redox material



H<sub>2</sub>O splitting

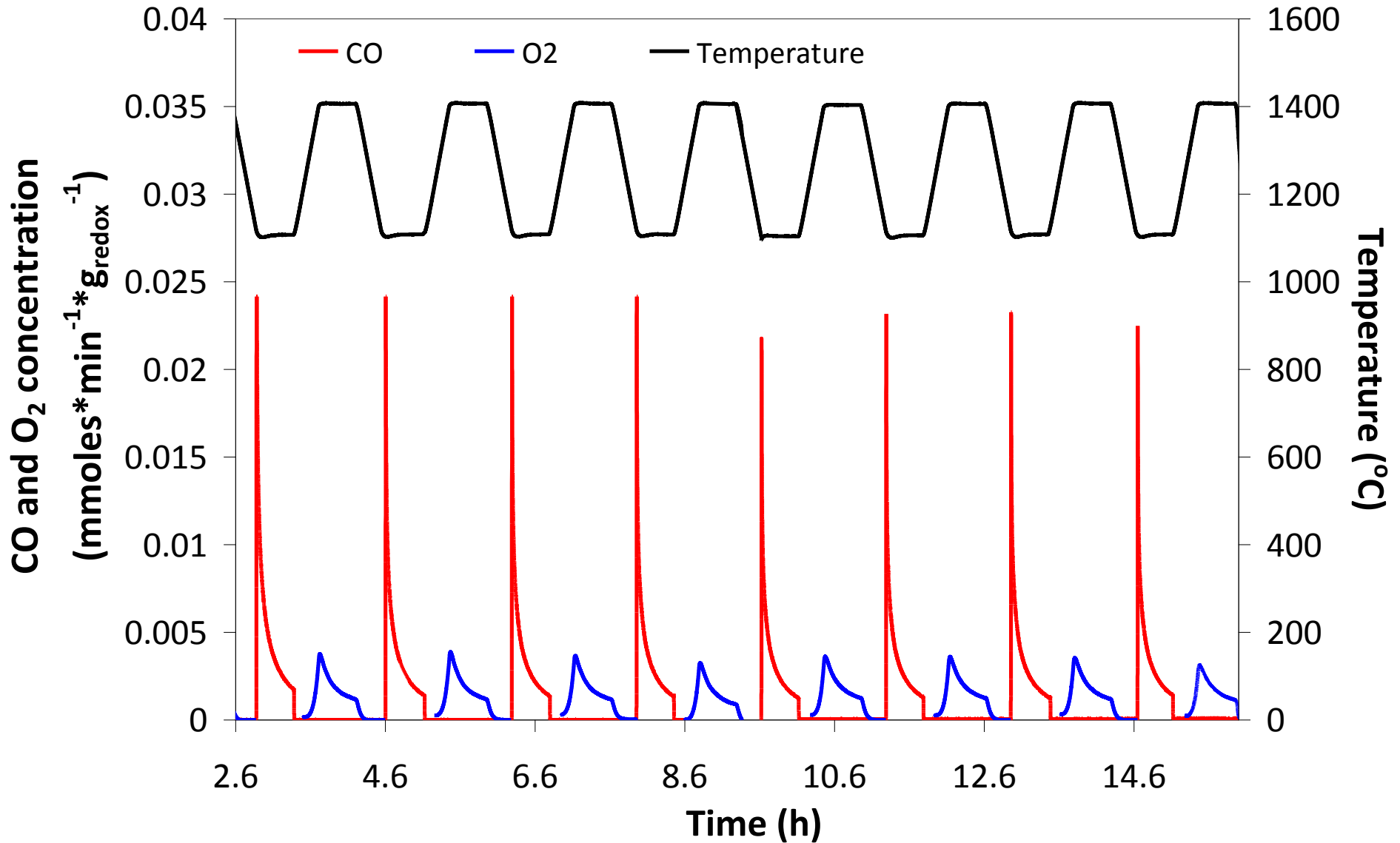
CO<sub>2</sub> splitting

thermal reduction

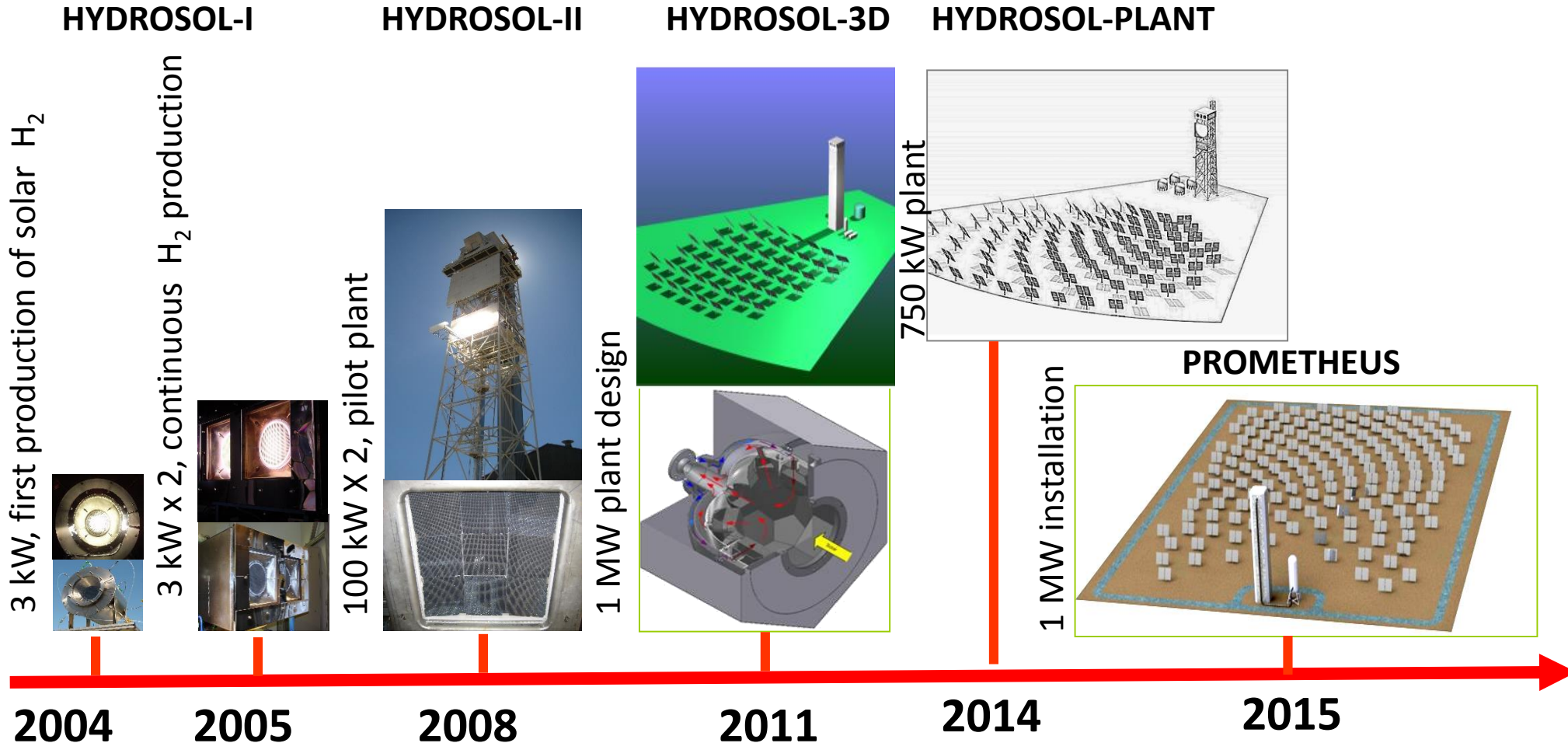
# Cycling Process



Reactant gas concentration: 100% CO<sub>2</sub>



# Solar Fuels Technology Evolution



EXPO 2005



IPHE 2006



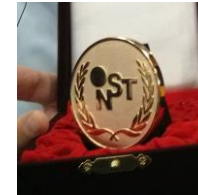
Descartes Prize 2007



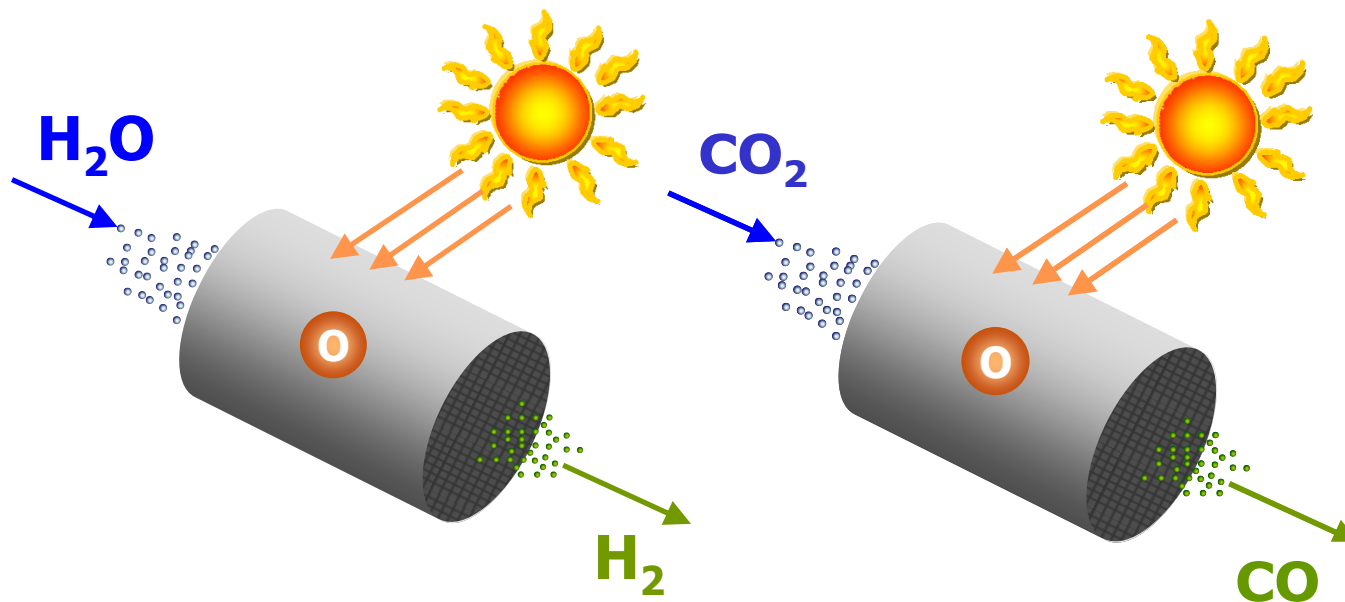
EU IDEAS Award 2010



Taipei Inv. Tech. 2014



# Clean Energy & Materials from Sun, H<sub>2</sub>O & CO<sub>2</sub>



## Solar Synthesis Gas

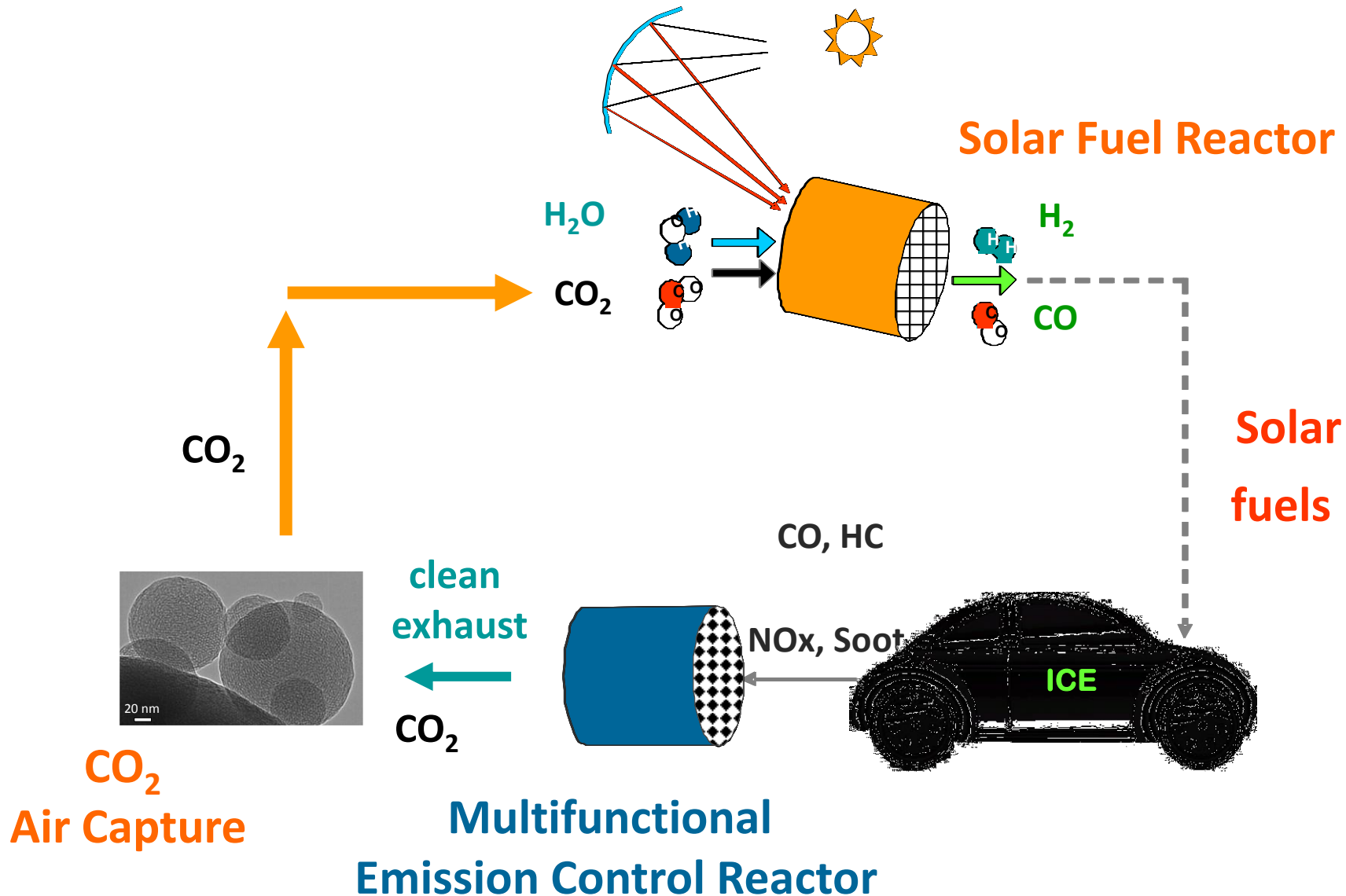


**Sustainable Storage of Carbon AND Hydrogen!**



# Vision: Sustainable Mobility and Clean Energy

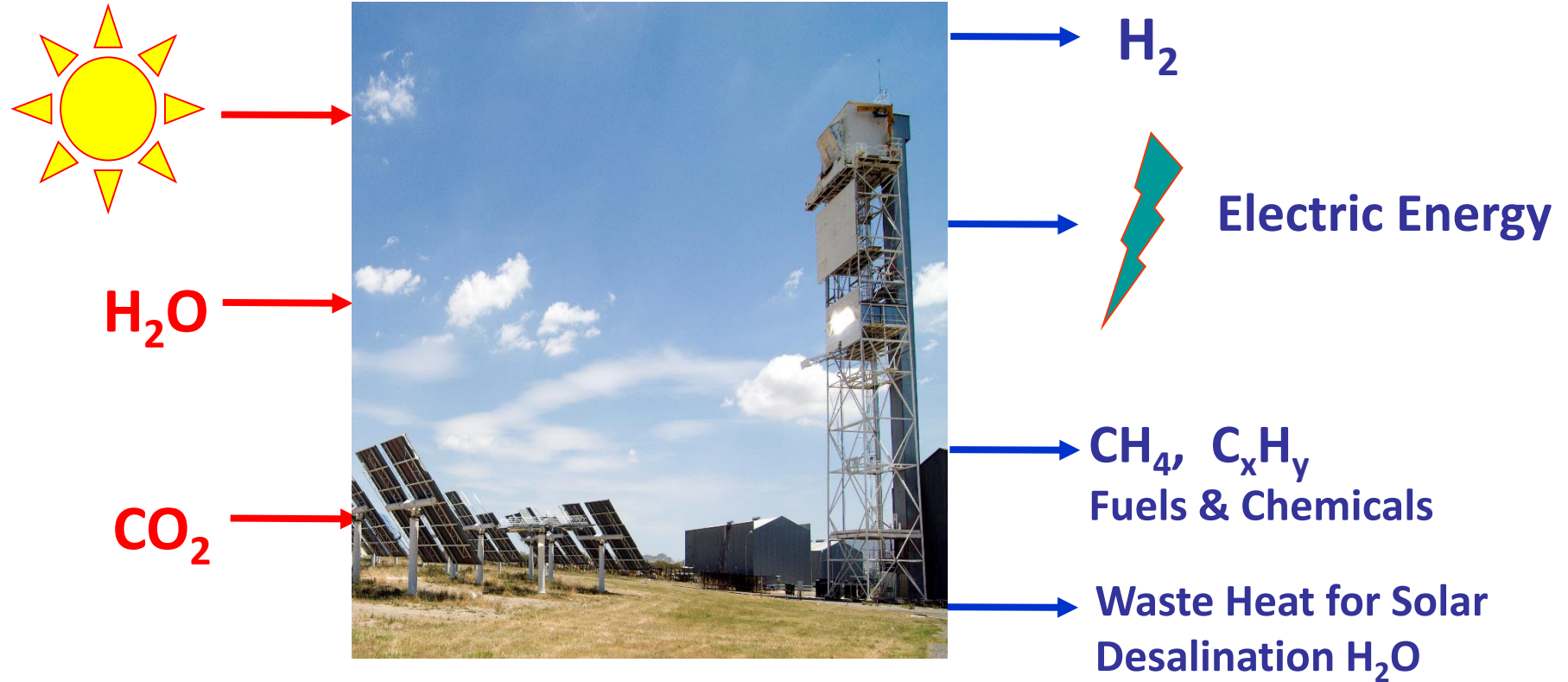
## Enabler: Aerosol Based Manufacturing



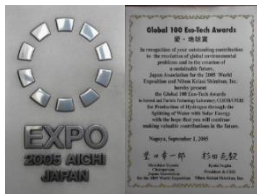


# Carbon Neutral Solar Fuel Plant

## Clean Energy and Green Mobility



EXPO 2005



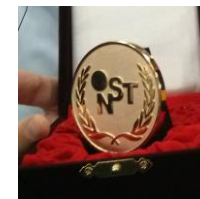
IPHE 2006 Descartes Prize 2007



EU IDEAS Award 2010



Taipei Inv. Tech. 2014



# Helionomics – Solar to Liquid (STL) Fuels

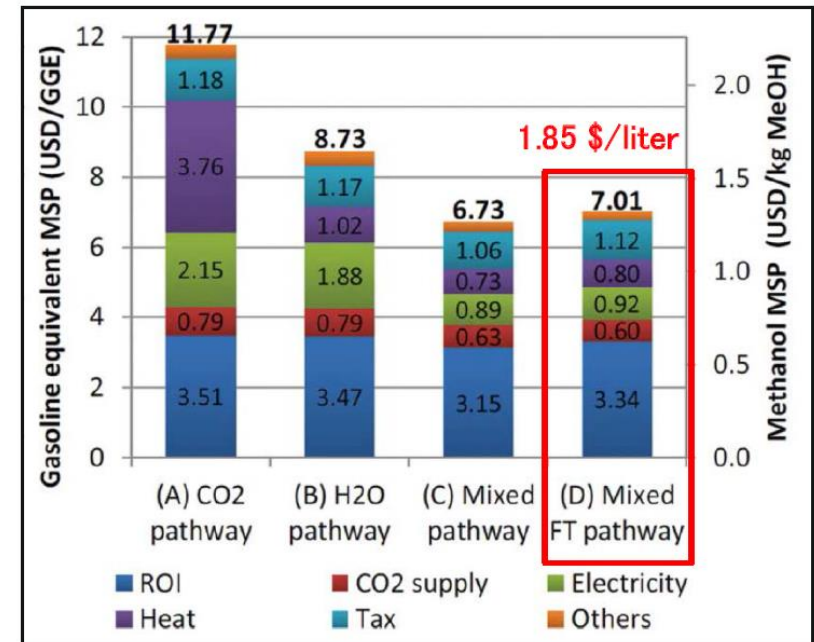


ICAO UNITING AVIATION



## STL - Economics

- Economics dominated by large investment cost and cost of capital
  - Mainly due to collection of solar energy and interest
  - =>Thermochemical efficiency decisive
- A path efficiency of ~10% is assumed to be required for economic viability
- Own calculations: Production costs of 1.3-2.9 \$/l (publicly owned facility)



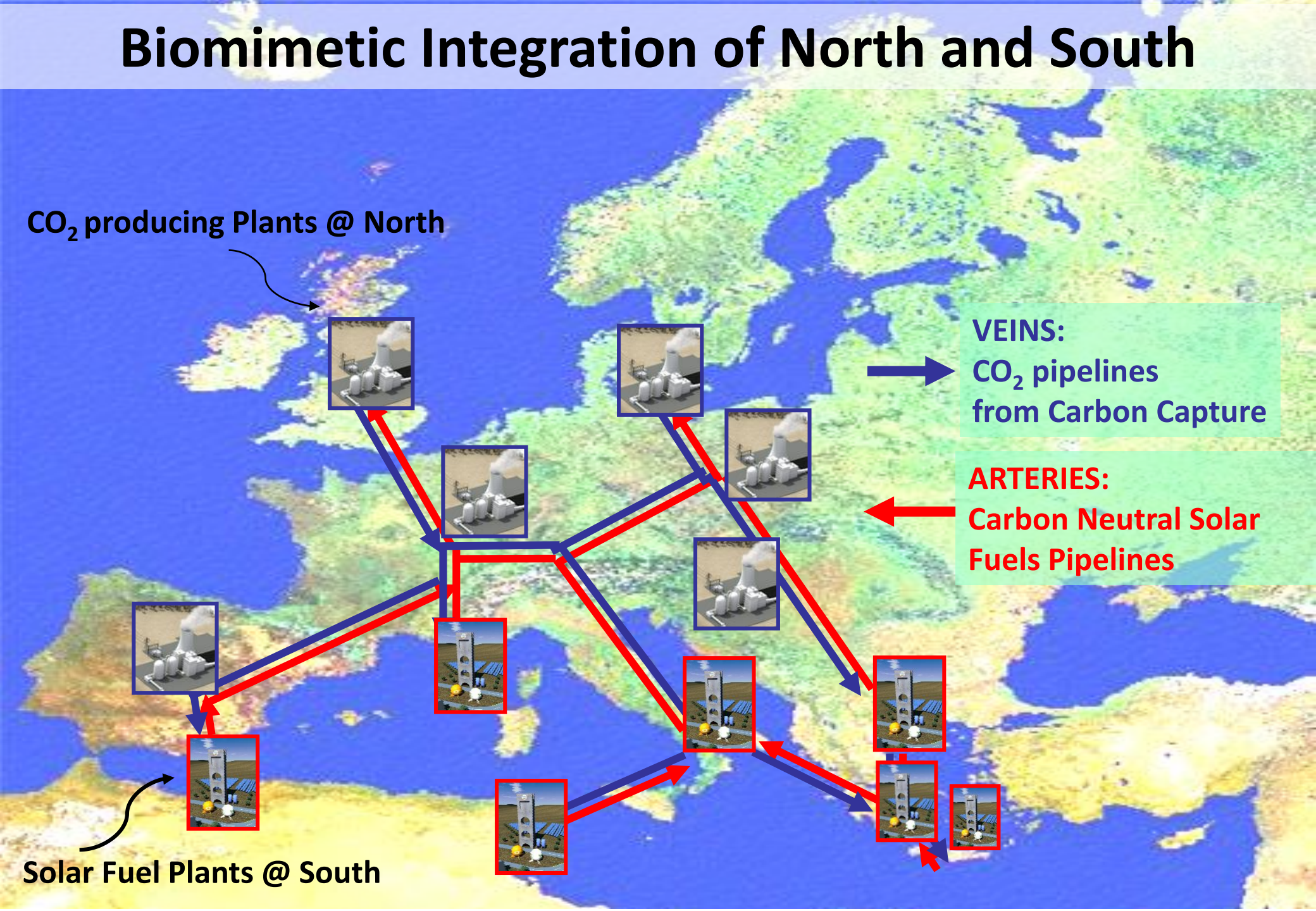
# Biomimetic Integration of North and South

CO<sub>2</sub> producing Plants @ North

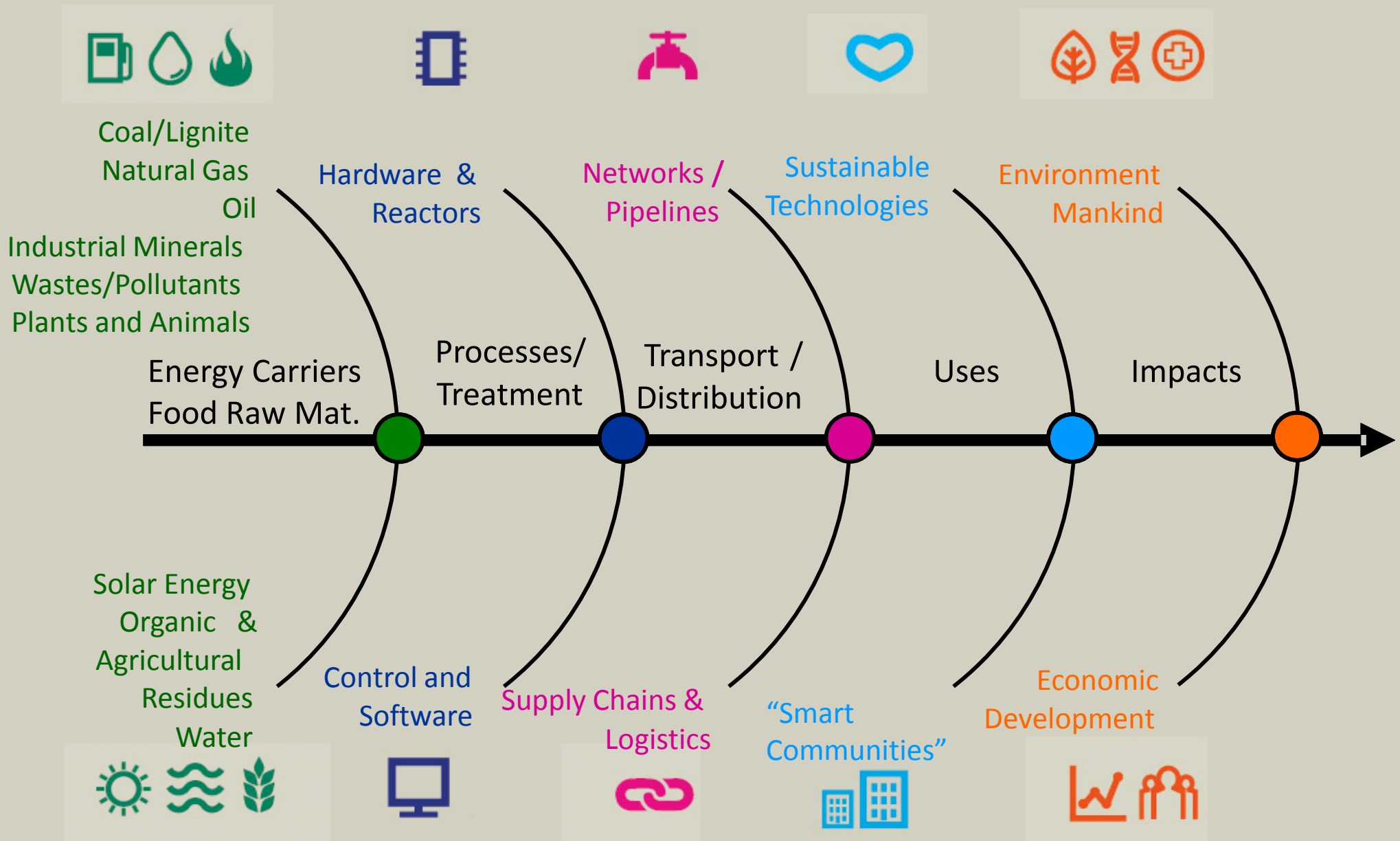
**VEINS:**  
CO<sub>2</sub> pipelines  
from Carbon Capture

**ARTERIES:**  
Carbon Neutral Solar  
Fuels Pipelines

Solar Fuel Plants @ South

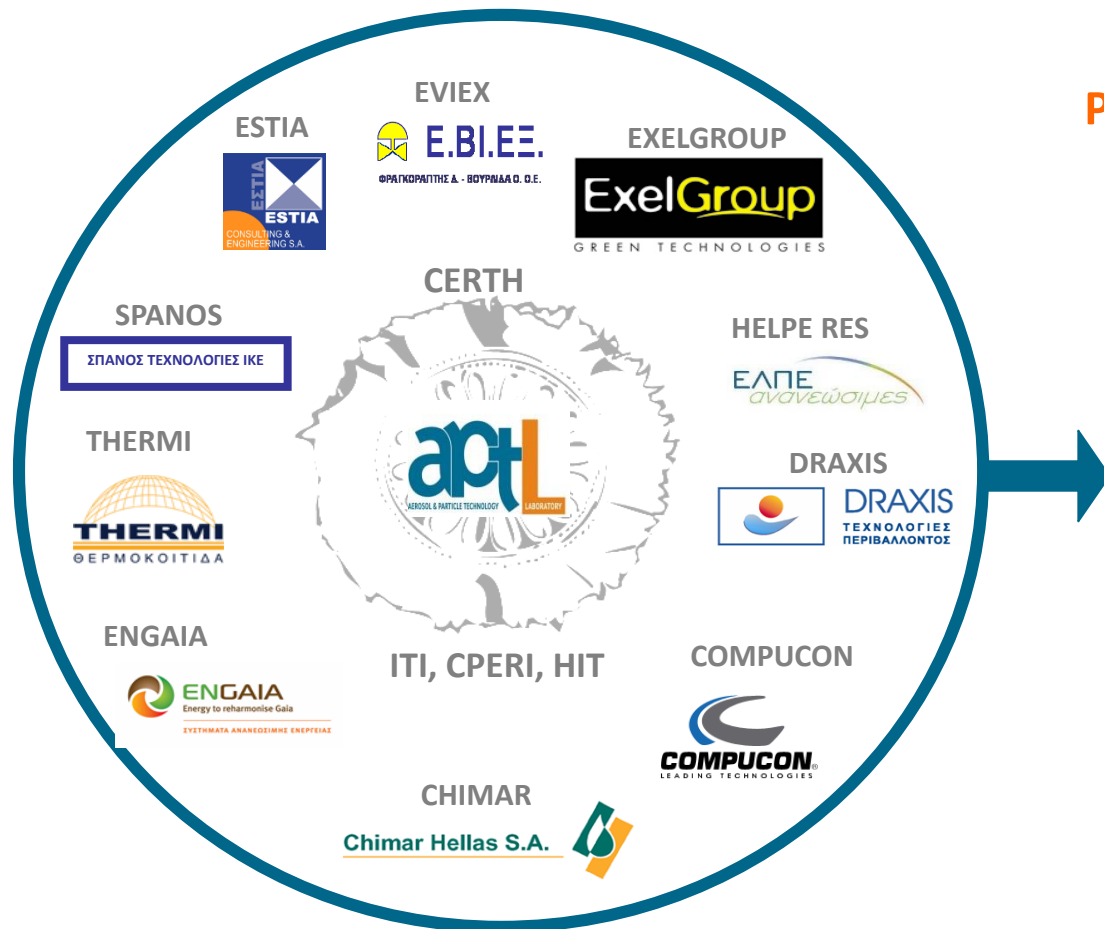


# PROMETHEUS Energy Corridor: A Holistic Approach to Sustainability





## KNOWLEDGE CREATION & TRANSFER



## NOVEL PRODUCTS & MARKETS



**RENEWABLES / LOW CARBON ENERGY SOURCES**

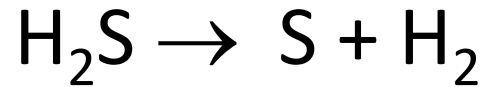
**ENERGY EFFICIENCY/EMISSION CONTROL**

# Regional Innovation and Smart Specialization

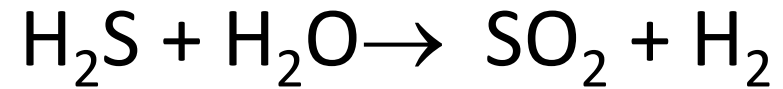


# A Solar Thermochemical Proposal for the Black Sea's life-threatening H<sub>2</sub>S

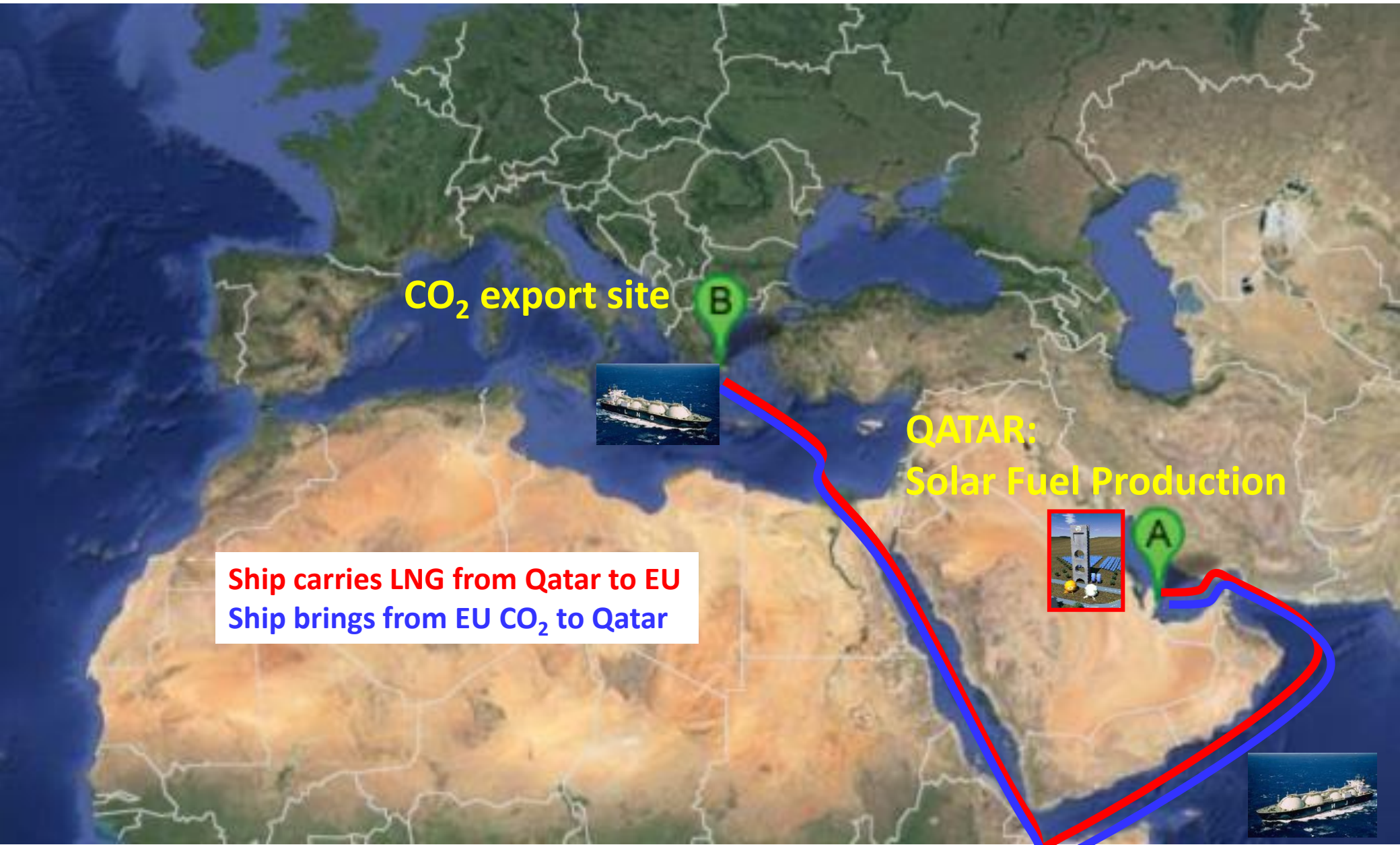
## Solar Cracking of H<sub>2</sub>S



## Solar Steam Reforming of H<sub>2</sub>S



# Energy Corridor between Emirates-EU





# Acknowledgments

- **The European Commission for supporting our research in combustion engines and their emissions** through >24 projects over the last 18 years including projects APT-STEP, CLEANER-D, HCV and our partners in these projects.
- **The European Commission for supporting our Hydrogen and Solar Fuels research** with >16 projects including projects ARMOS, RESTRUCTURE, STORRE, NEMESIS2+, ARTIPHYCTION, BIOROBUR, EU-SOLARIS, HYDROSOL-3D and our partners in these projects
- **The Greek Secretariat for Research and Technology** for supporting our research through projects HYDROSOL+ and NANOREDSOL.
- **Past and Current Industrial Partners including** Molycorp, Tenneco, Ividen, Honda, CR Fiat, AVL
- **Our colleagues at APTL**

