Nanofilms for Solar-thermochemical redox

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Energy/Water Grand Challenge

$M_xFe_{3-x}O_4$: M=Co, Ni

Fe^{3+}

H_2

<1200 to 1500 °C

H_2O

Fe^{2+}

Heat

>1200 to 1500 °C

O_2

Seawater

Distillation Process

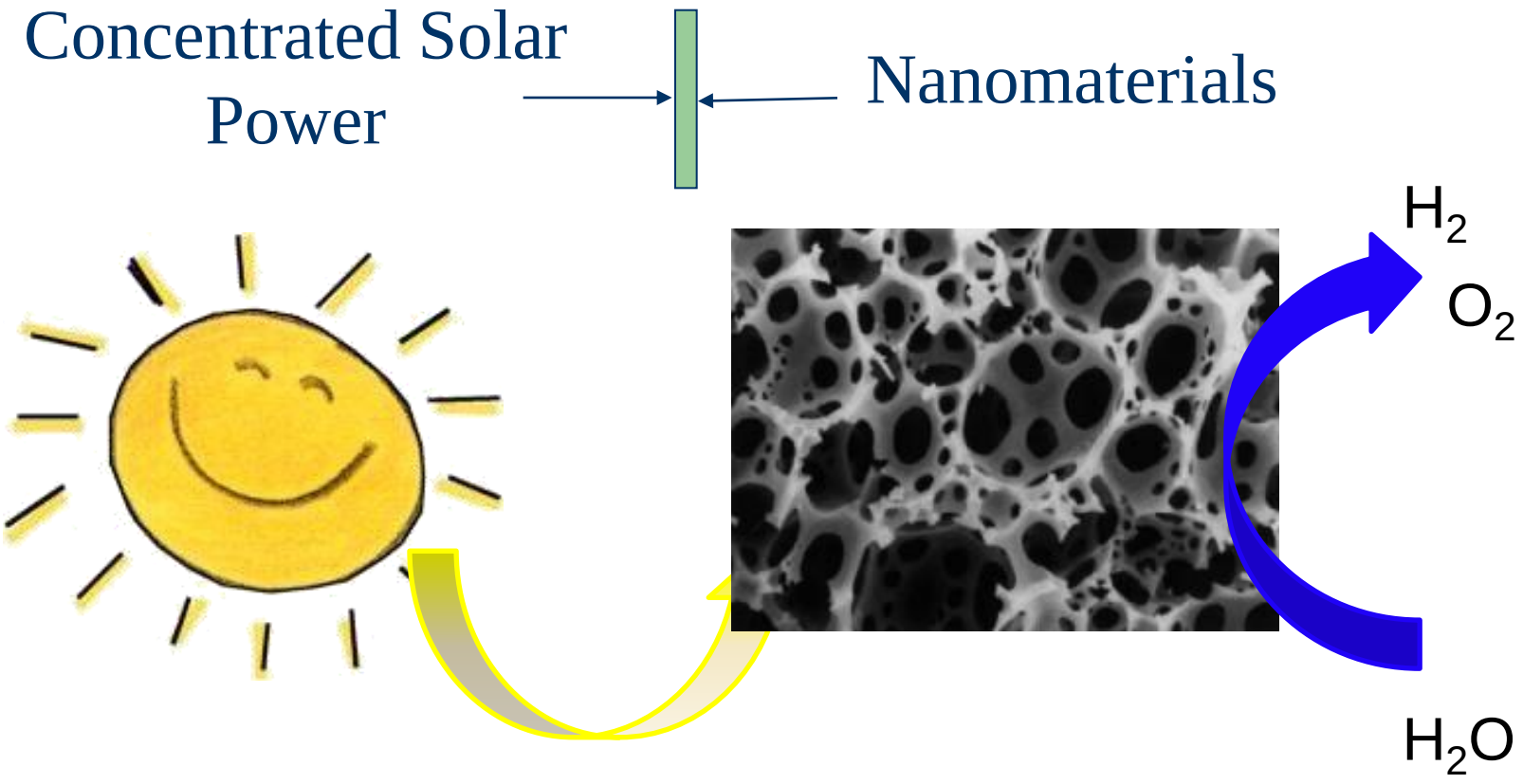
Potable Water

Salt

Triple Play

1. Sustainable H_2
2. Reduced GHG
3. Sustainable H_2O

Directing Energy and Matter



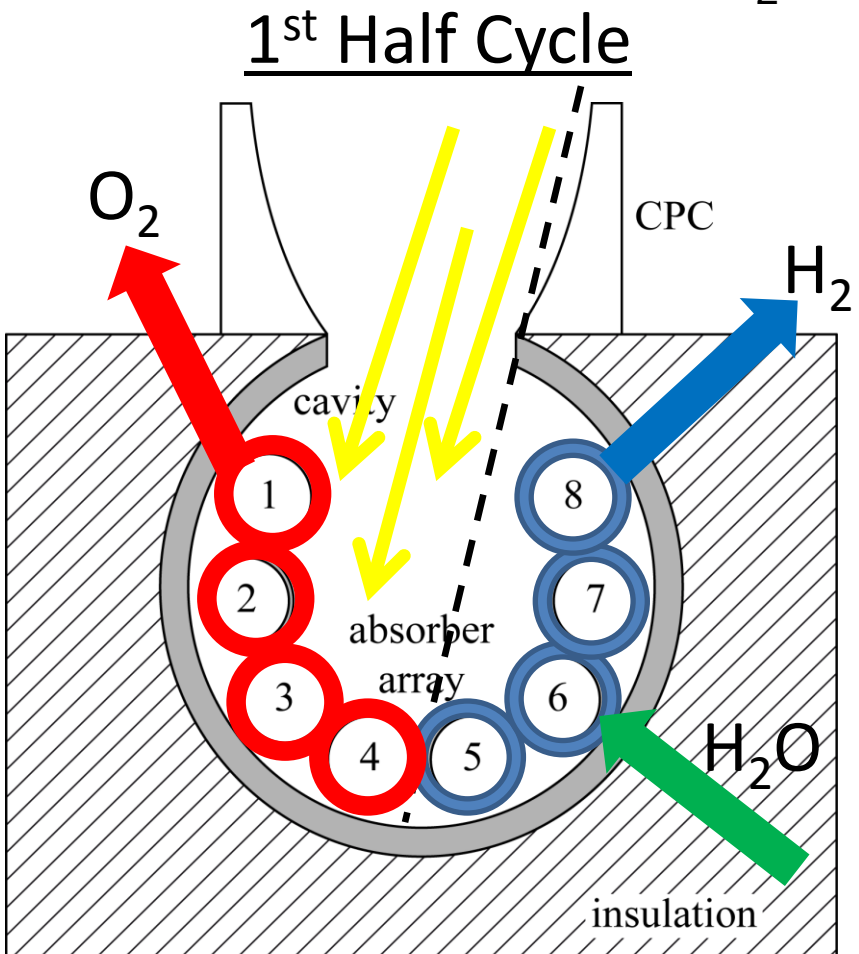
Significant innovation is often realized at the interface of technologies

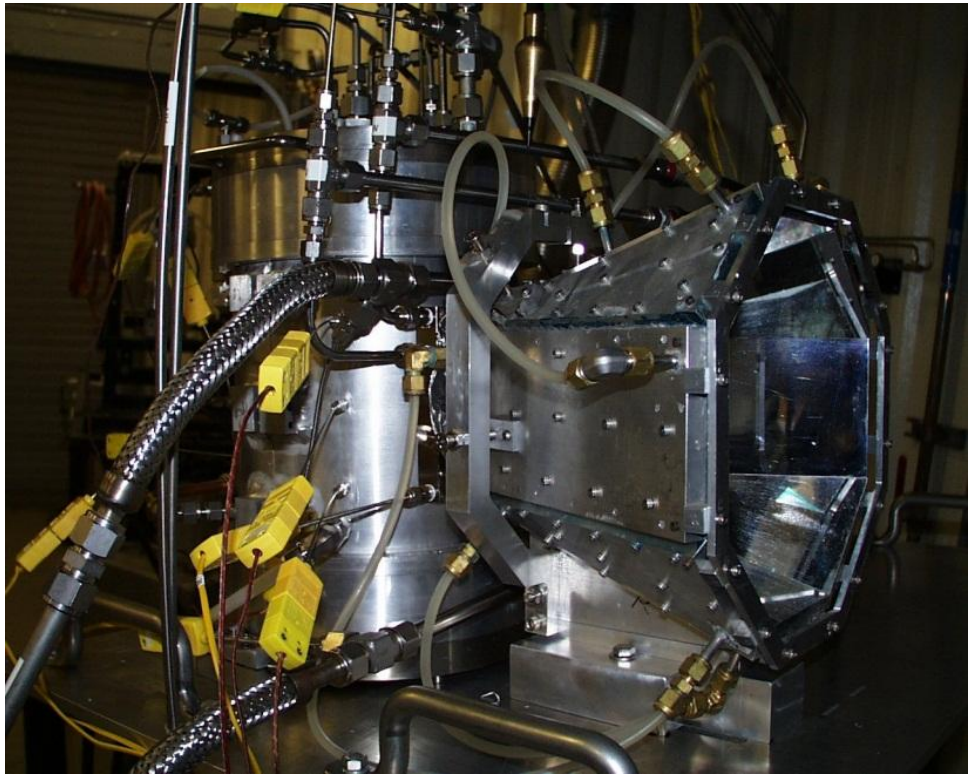
SurroundSun™ Multi-tubular Switching Redox Reactor/Receiver

$CoFe_2O_4 + 3\ Al_2O_3 \rightarrow [CoAl2O4{:}2Fe2AlO4] + 1/2O_2$

$[CoAl_2O_4{:}2Fe_2AlO_4] + H_2O \rightarrow CoFe_2O_4 + 3\ Al_2O_3 + H_2$

$H_2O \rightarrow H_2 + 1/2O_2$





University of Colorado
Multi-tube Solar Receiver/Reactor

SurroundSun™ Multi-tubular Switching Redox Reactor/Receiver

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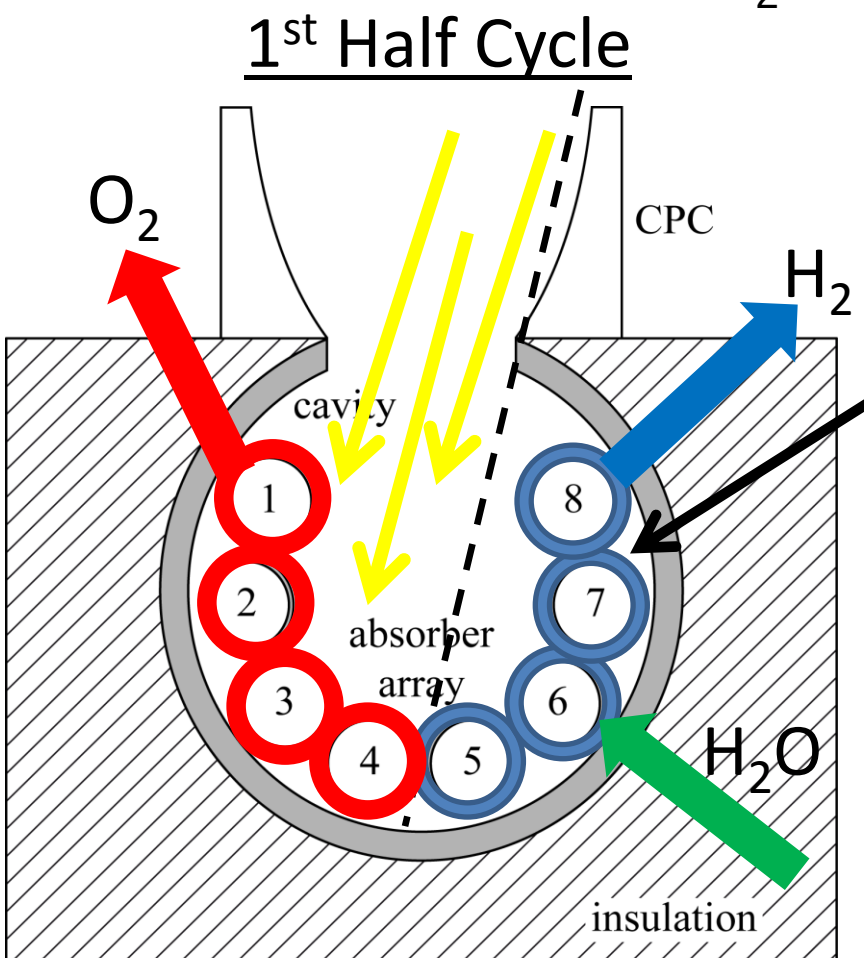
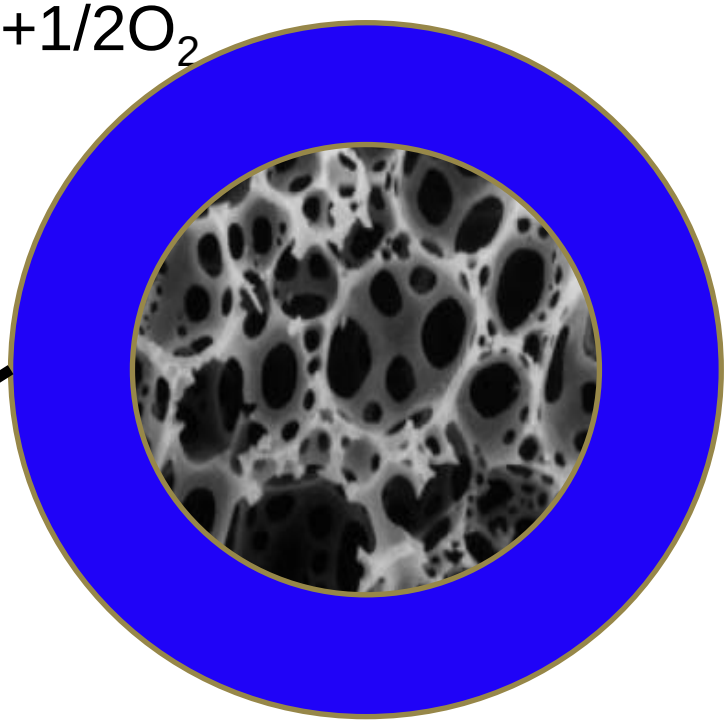
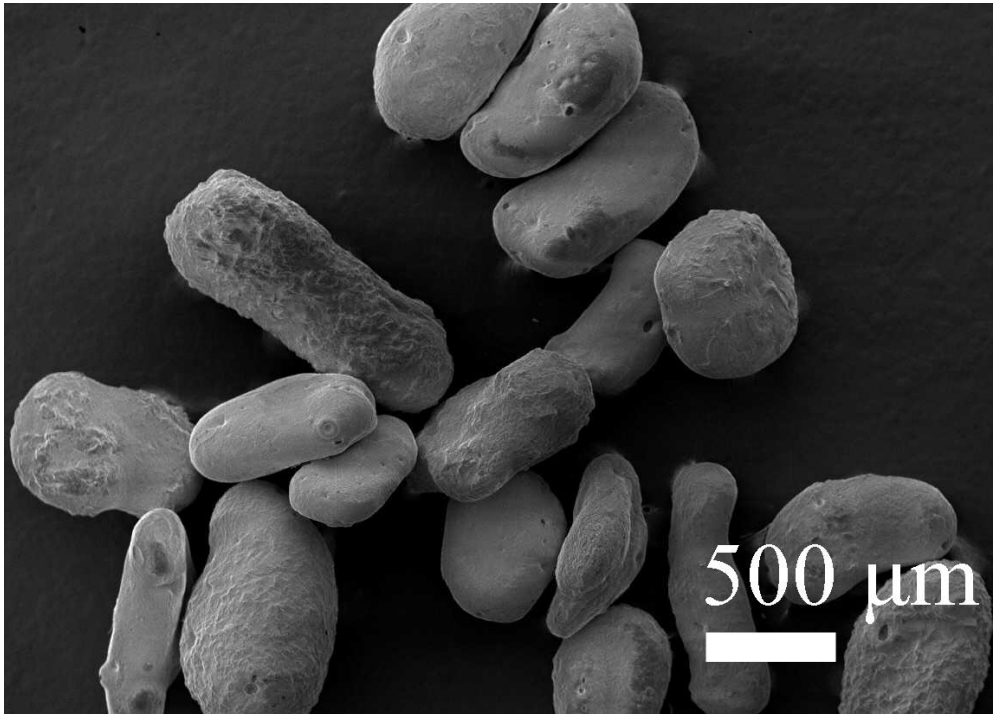
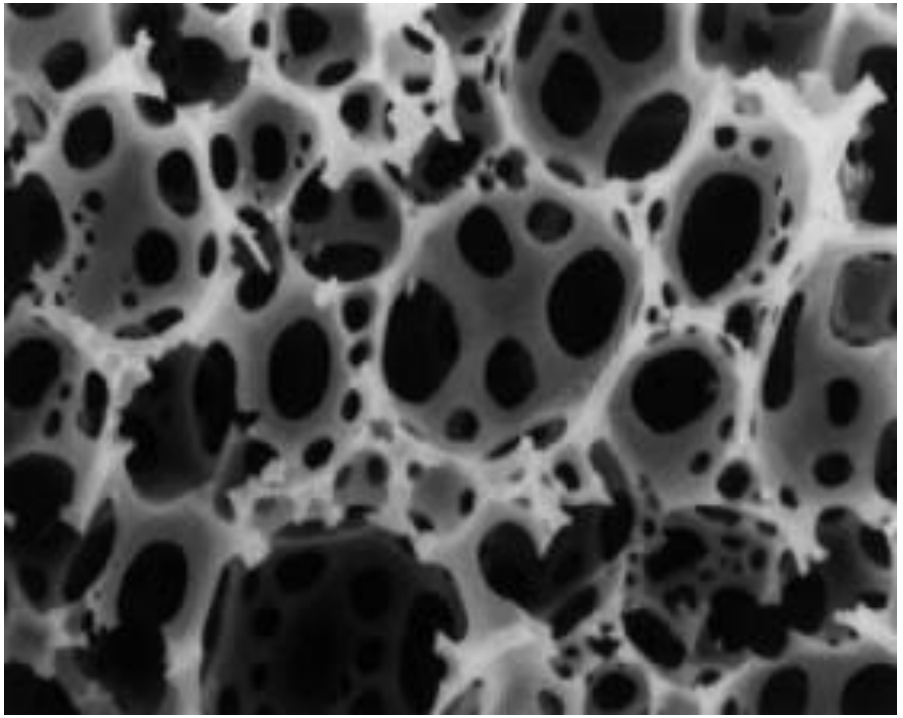




- Fast radiative heat transport
- Fast mass flow (large pores & porosity)
- Ultrathin walls to limit sensible heat loss
- Ultrathin active films to eliminate diffusional resistances (i.e. fast kinetics)

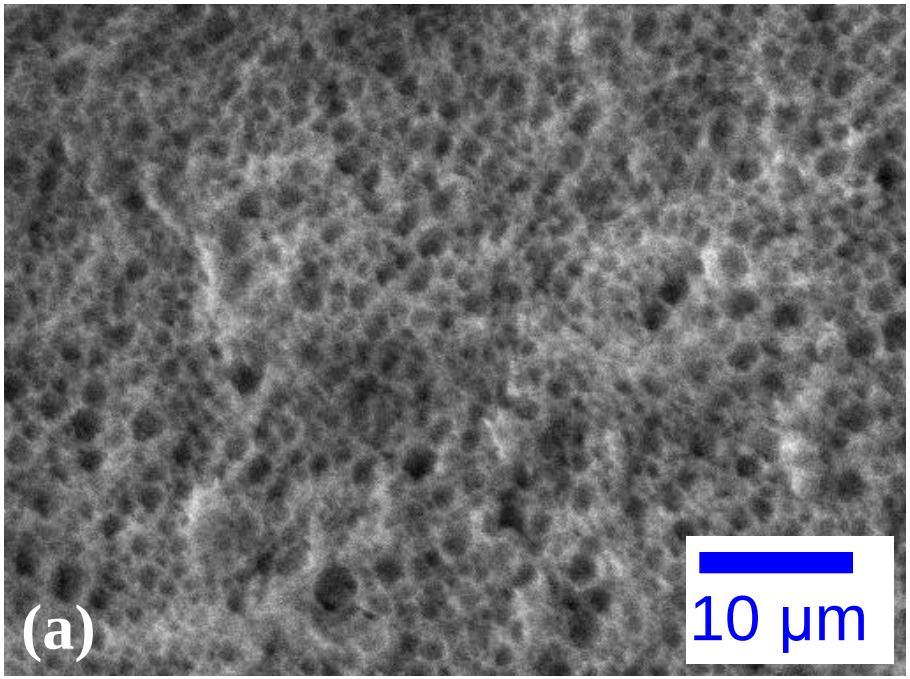
Uncoated poly(styrene-divinylbenzene) particles (Dowex™ or Cavilink™)

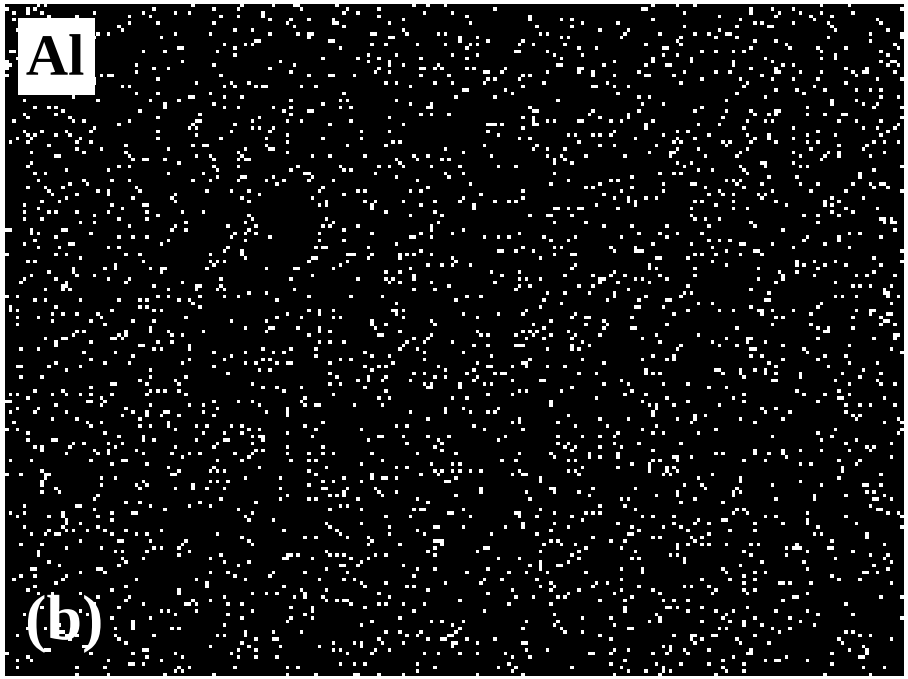




Particle size of ~600 µm, a porosity of 85%, a pore volume of 8-10 cm^3/g, a surface area of 43.5 m^2/g, and a density of 70 kg/m^3

Alumina films were coated throughout the inner surface of the particles

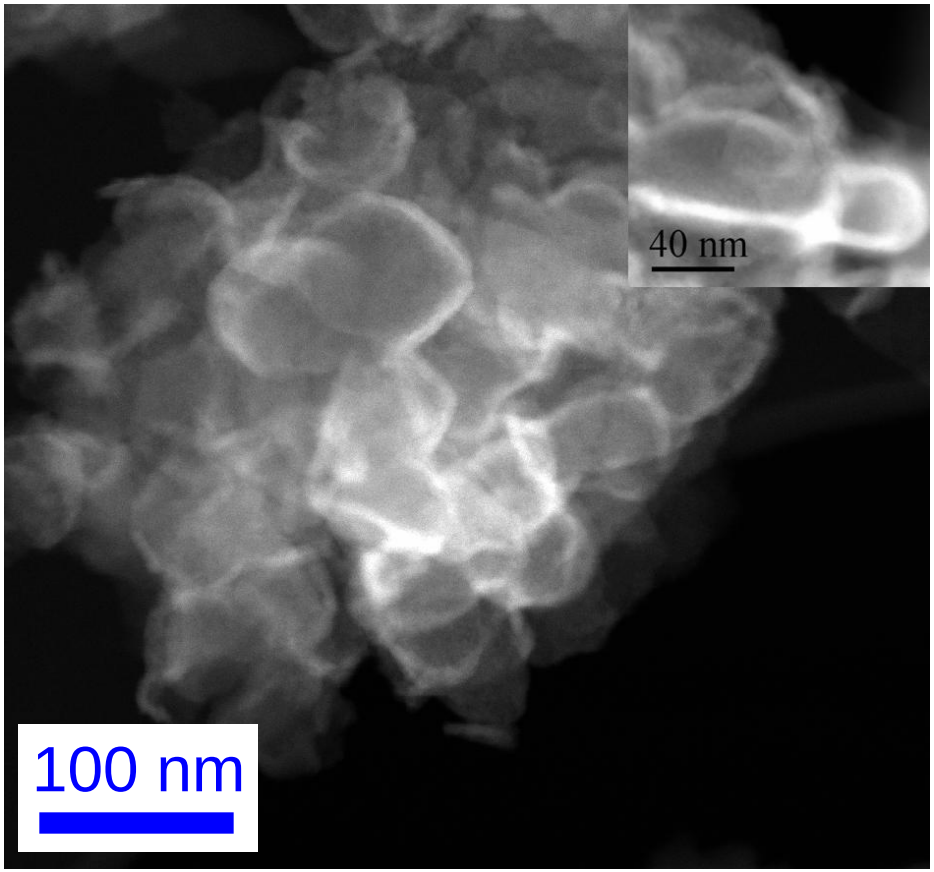


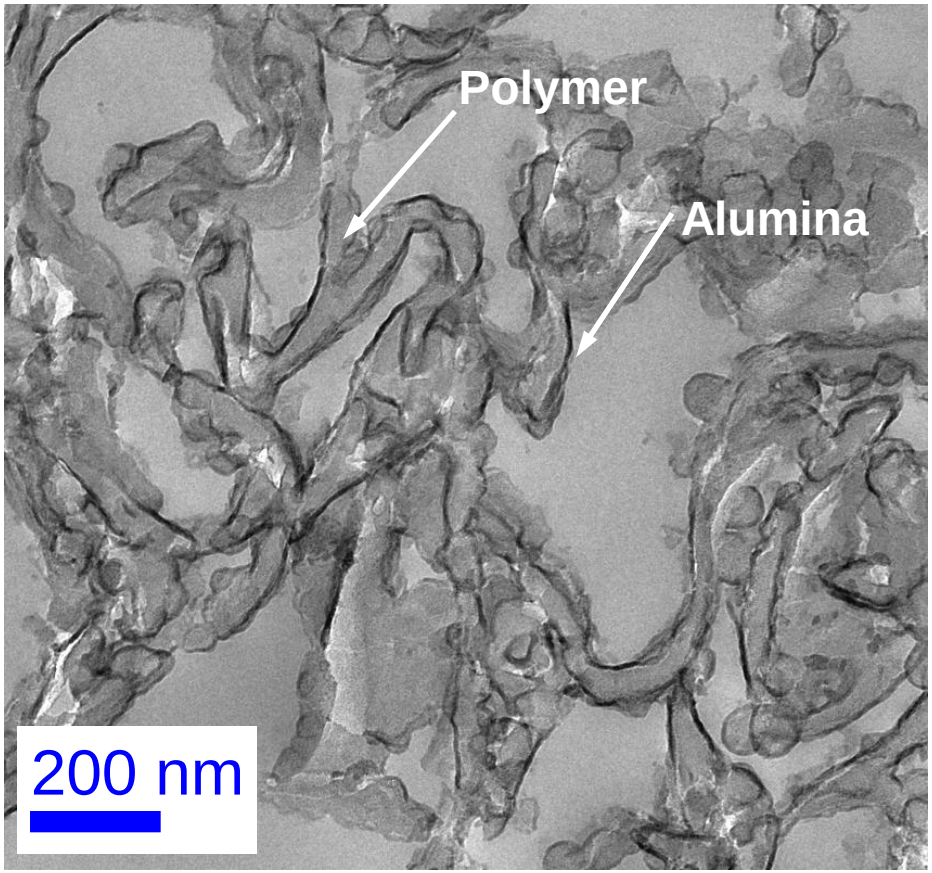


FESEM of cross sectional surface after 25 cycles of Al_2O_3 coating

Al EDS mapping

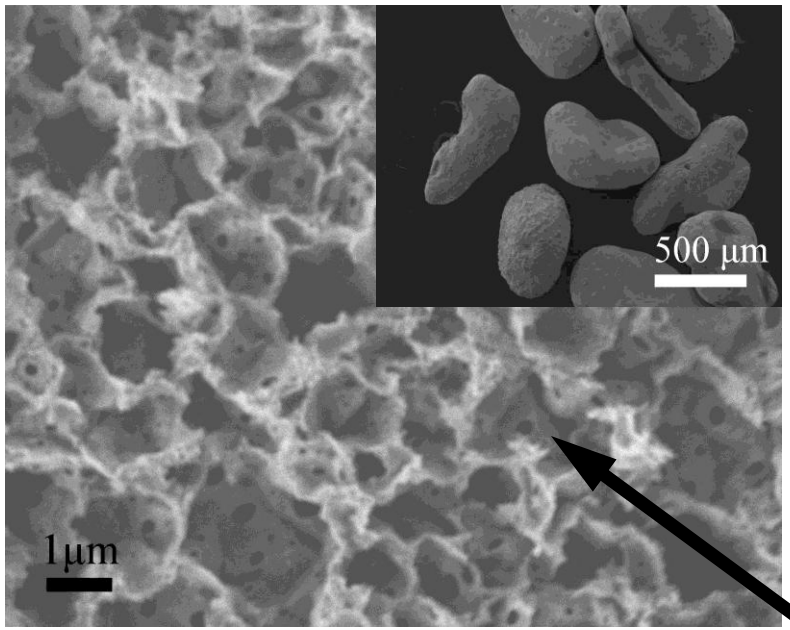
Conformal Al_2O_3 films coated on porous PS-DVB particles



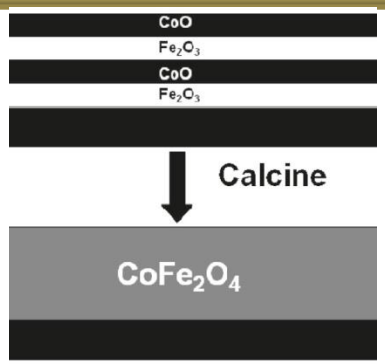


Liang XH, et al., ***Chem. Mater.*** 19: 5388-5394, 2007

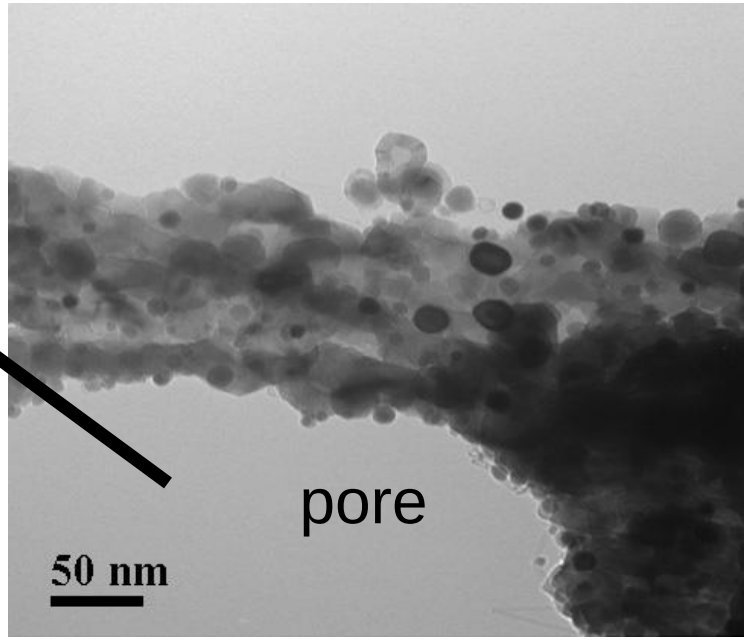
Porous Al_2O_3 particles after calcination, then subsequently coated with $CoFe_2O_4$



Skeletal γ-Al_2O_3
(80 m^2/g; 1 cm^3/g pore volume);
inset image shows the size of
the porous γ-Al_2O_3 particles



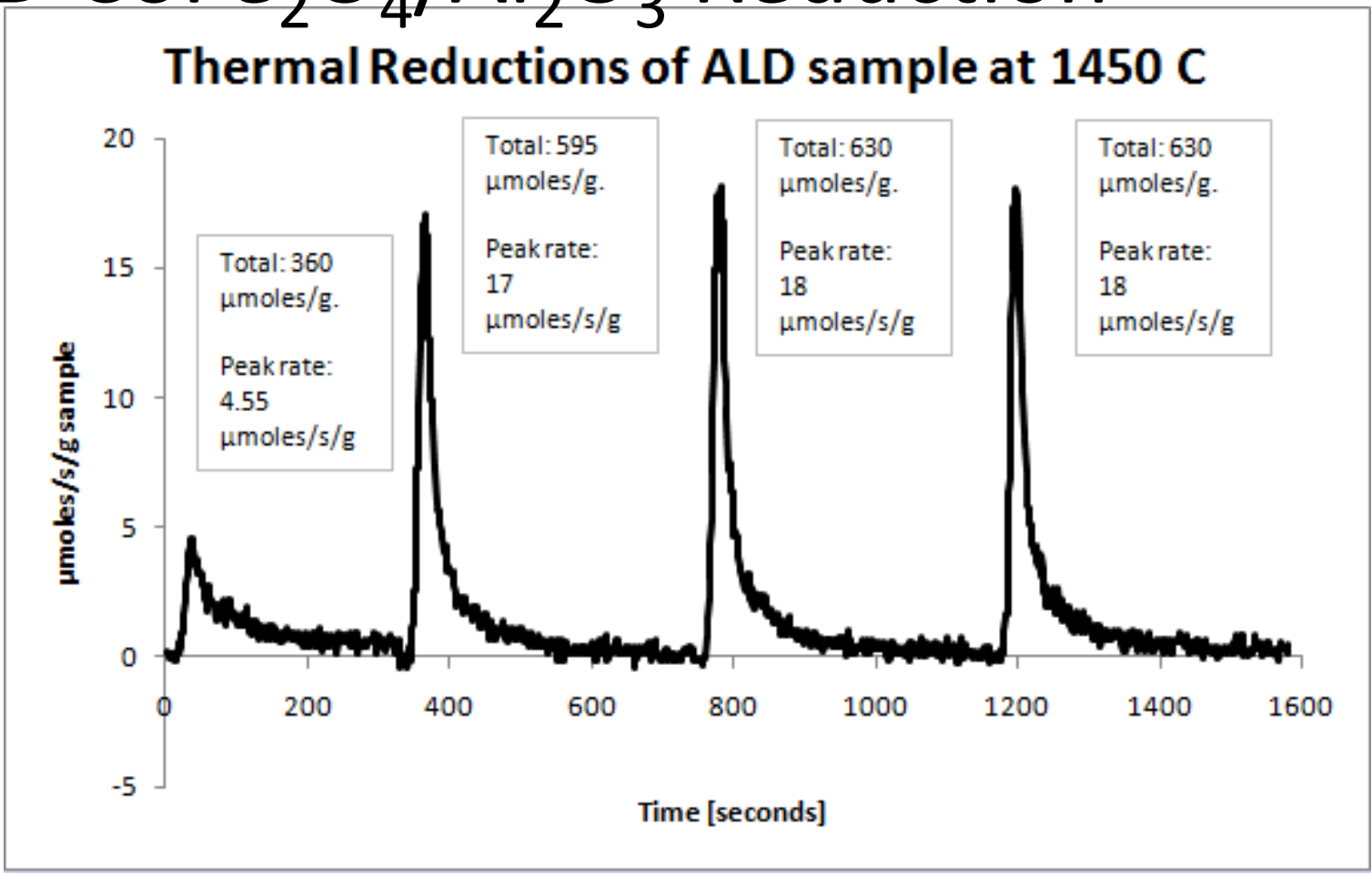
Scheffe et al.,
International Journal of Hydrogen Energy, 35 (2010), 3333-3340



~ 20 wt% $CoFe_2O_4/Al_2O_3$
(after 1450 ˚C reduction)

ALD $CoFe_2O_4/Al_2O_3$ Reduction

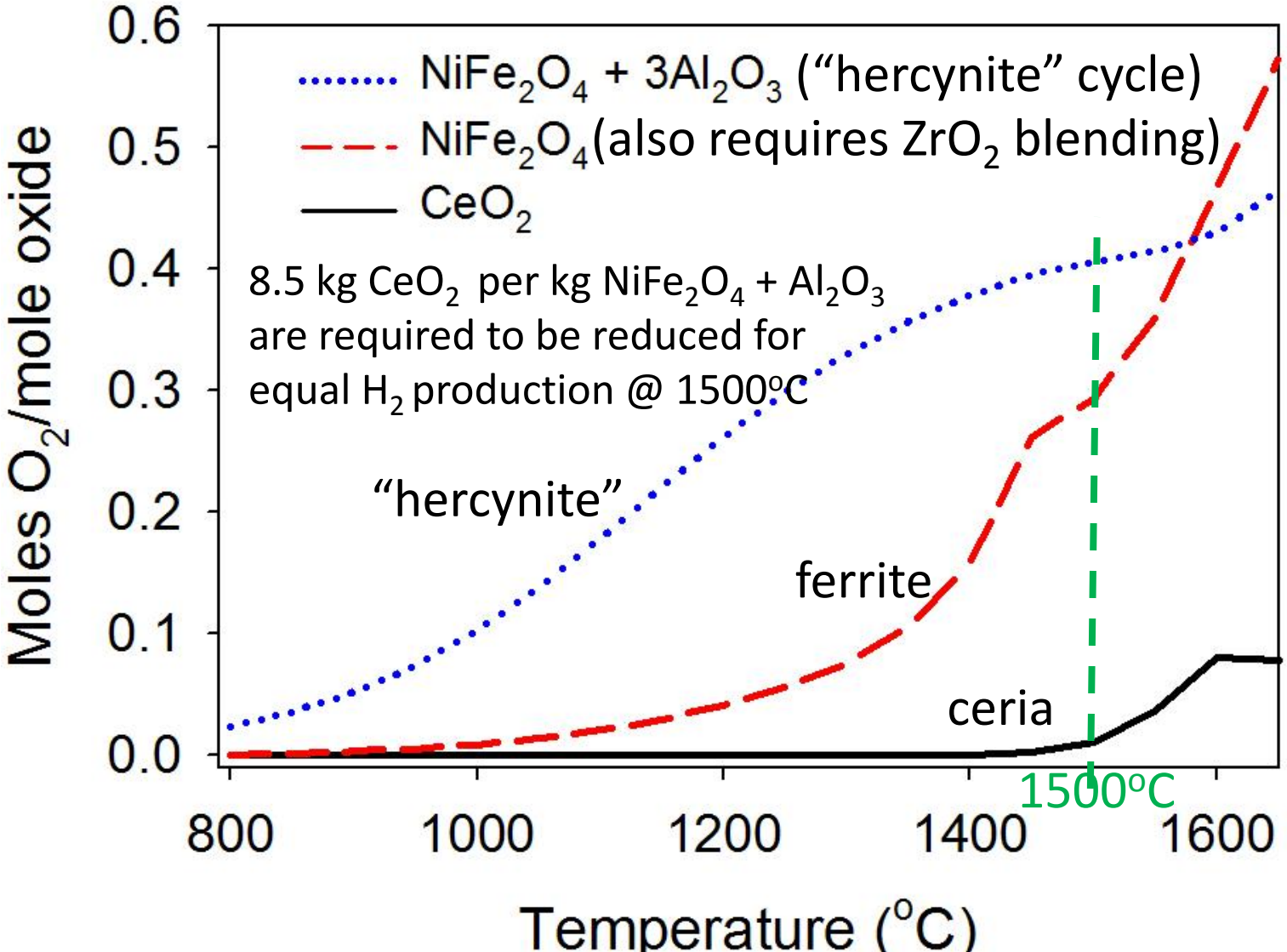
Rapid Laser Heating at SNL



1450°C Thermal Reduction; 17.7 µmole/s/g; 618 µmole/g

1300°C Thermal Reduction; 12.7 µmole/s/g; 417 µmole/g

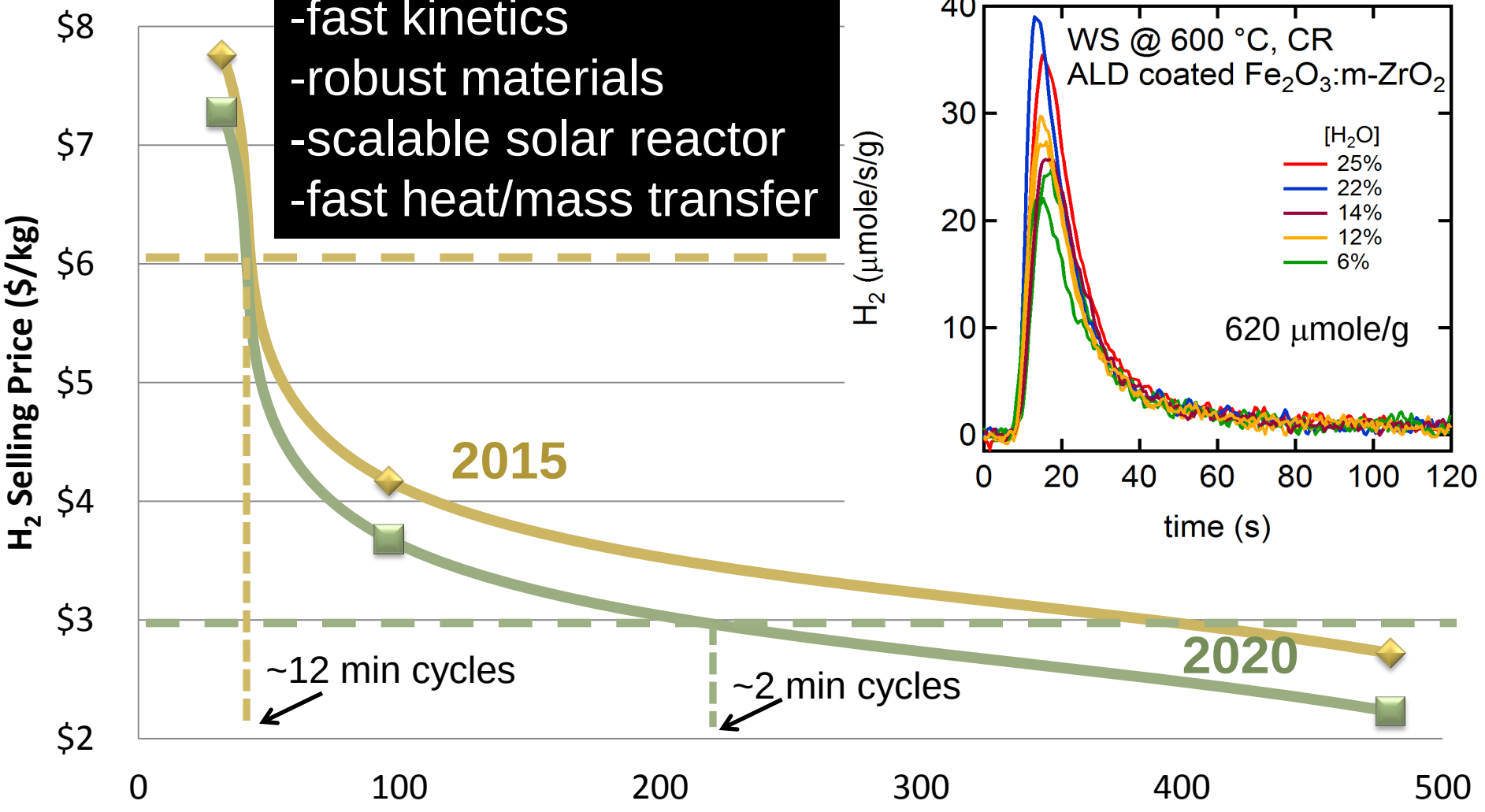
Comparative Reduction Step from FACTSage™ Free Energy Minimization Results



Economic Results – 100,000 kg H_2/day (central receiver facility)

Key Requirements

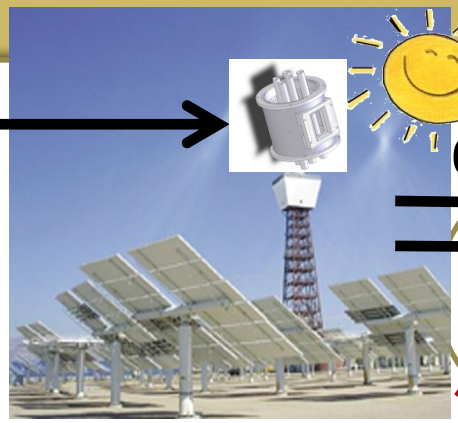
-fast kinetics
-robust materials
-scalable solar reactor
-fast heat/mass transfer



(TIAX, LLC: DE-DT0000951)

Hybrid Solarthermal Process

Renewable H_2 & Desalinated H_2O



900,000 kg H_2O/day

698 GWhr/yr

800,000 kg O_2/day
(for water purification)

100,000 kg H_2/day

2332 GWhr/yr

Distilled
H_2O

Steam
(loop)

Sea/brackish
Water Feed

Potable

Condensate (loop)

to multiple-effects;
2.1 M gal H_2O/day
(8 M kg/day)

Salt Concentrate

A2

A1

B2

B1

2nd Effect

1st Effect

Triple-effect Evaporator

0.35 kg steam/kg water evaporated

Solarthermal Conclusions

- Thin film “hercynite” cycle has potential significant advantages in terms of reduced temperatures, expanded operating window, fast cycling and lower cost
  - Sustainable H2
  - Sustainable H2O
  - Sustainable energy/environment

Acknowledgements