Hydrogen Production Progress Update

November 9, 2011
22.033 Fall

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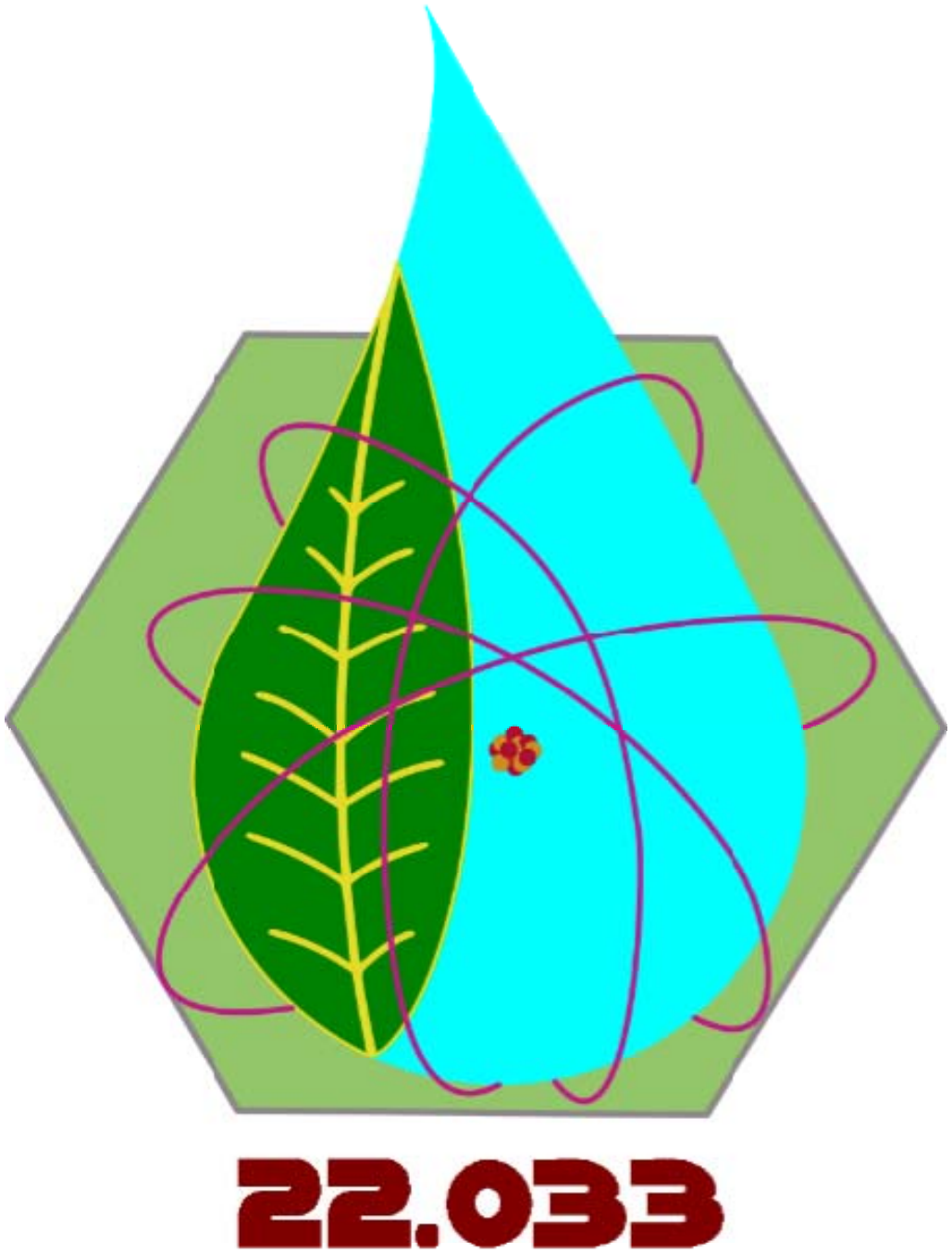


Presentation Outline

- review of UT-3 process
- block diagram & iterations
- components
  - hydrogen separator membrane
  - oxygen separator membrane
  - calcium reagent structure
  - hydrogen storage system
- next steps

UT-3 Process Overview

- The UT-3 process consists of four reactions proceeding at the indicated desired temperatures.[1]

$$CaBr_2(s) + H_2O(g) \rightarrow CaO(s) + 2HBr(g)\ (760\,C)$$

$$CaO(s) + Br_2(g) \rightarrow CaBr_2(s) + 0.5O(g)\ (571\,C)$$

$$Fe_3O_4(s) + 8HBr(g) \rightarrow 3FeBr_2(s) + 4H_2O(g) + Br_2(g)\ (220\,C)$$

$$3FeBr_2(s) + 4H_2O(g) \rightarrow Fe_3O_4(s) + 6HBr(g) + H_2(g)\ (560\,C)$$

[1]H. Kameyama and K. Yoshida. Br-ca-fe water decomposition cycles for hydrogen production. Proc. 2nd, WHEC., pages 829–850, 1978.

Block Diagram - Forward

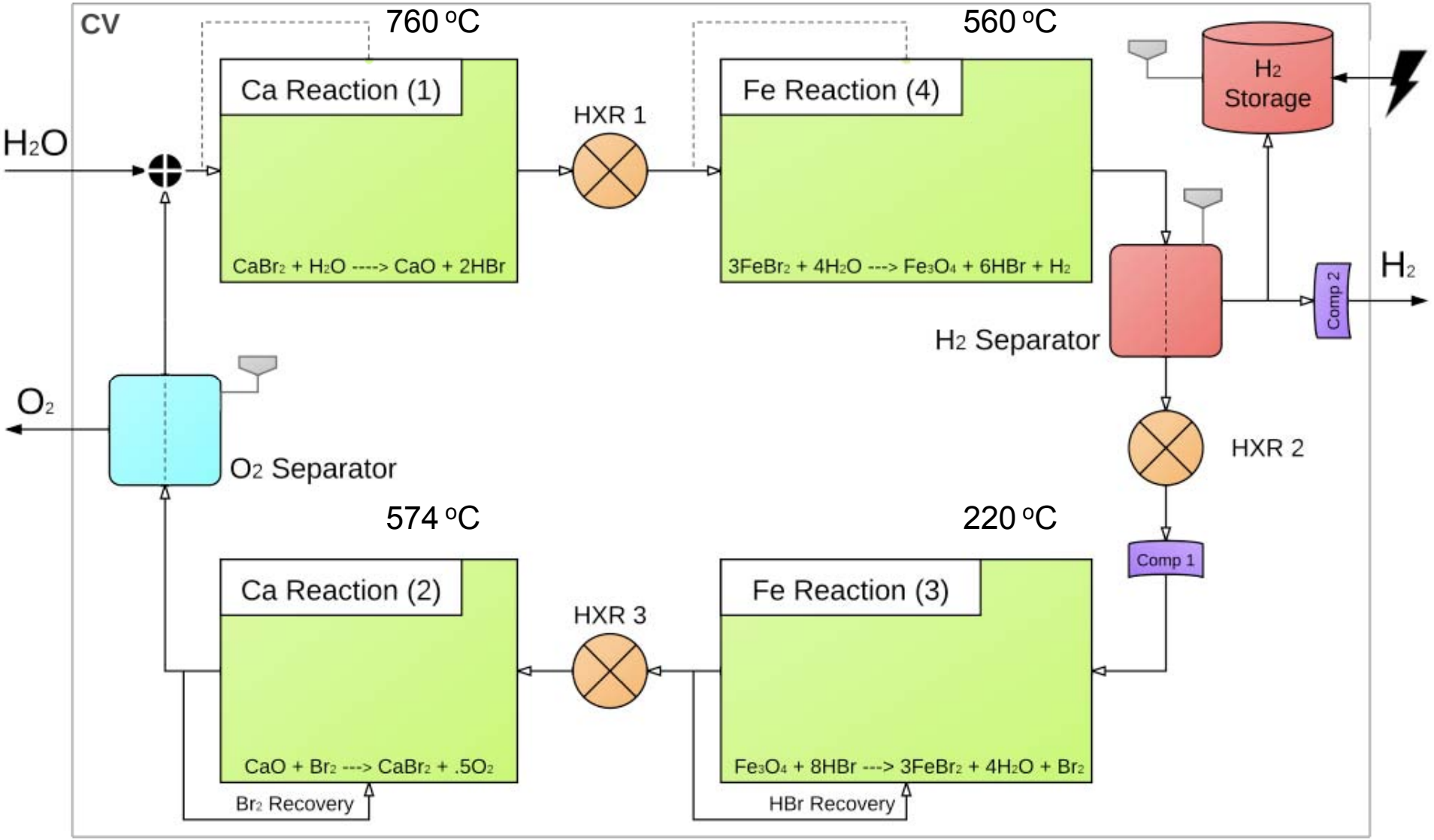


Image adapted from: Sakurai, M. *et al*. "Adiabatic UT-3 Thermochemical Process for Hydrogen Production". *International Journal of Hydrogen* Energy. **2**(10), 865-870 (1996).

Block Diagram - Backwards

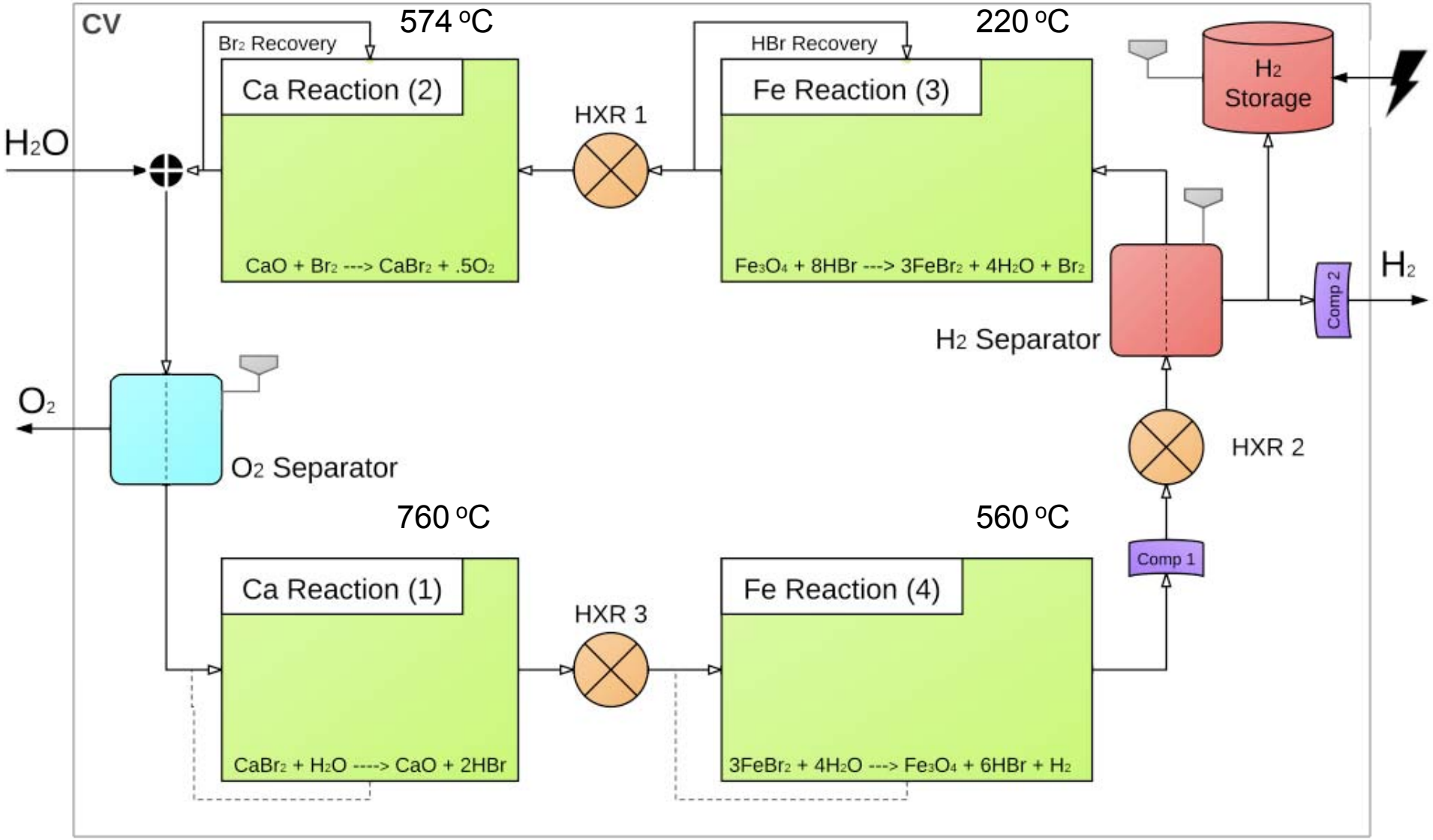
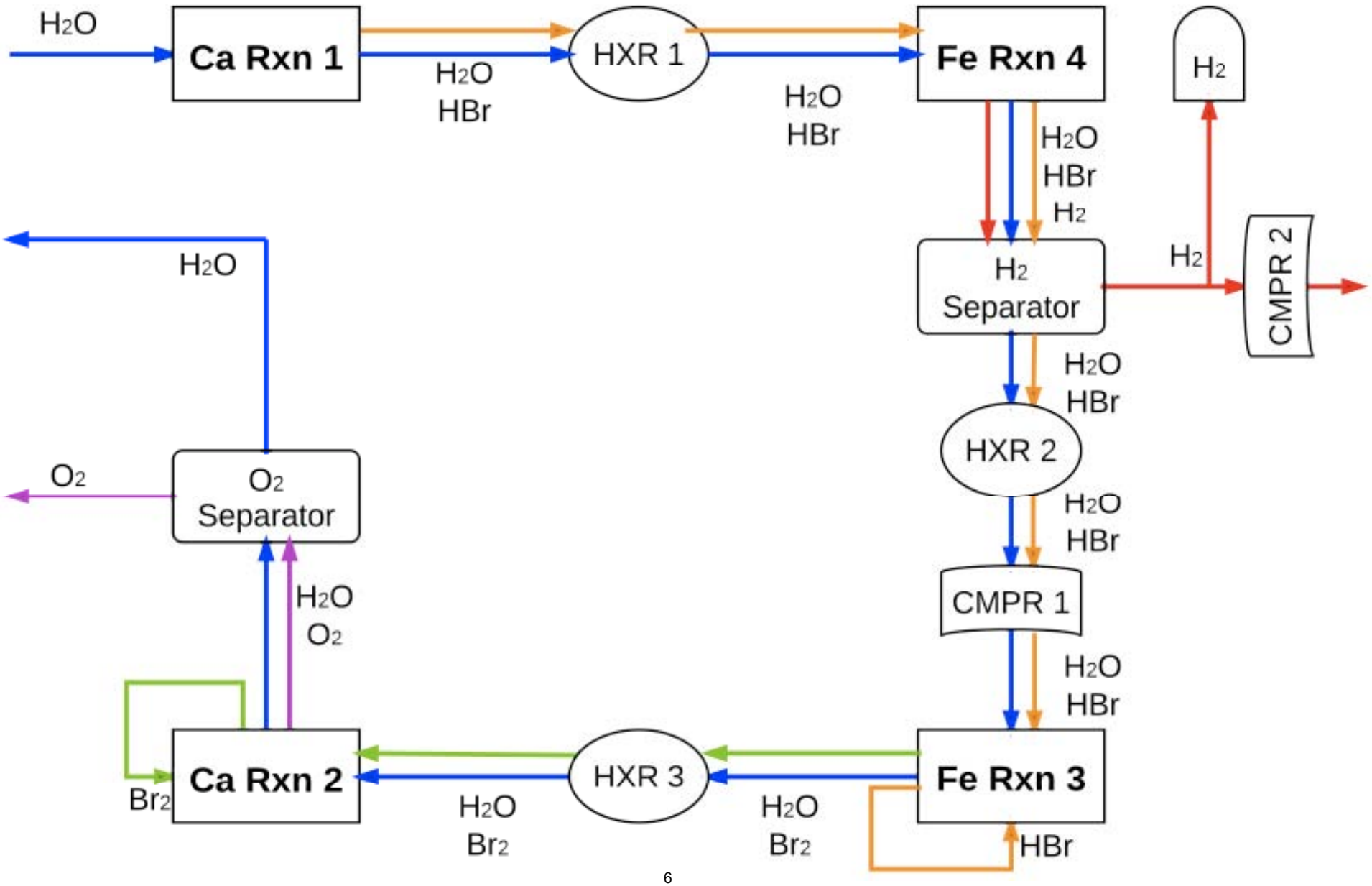
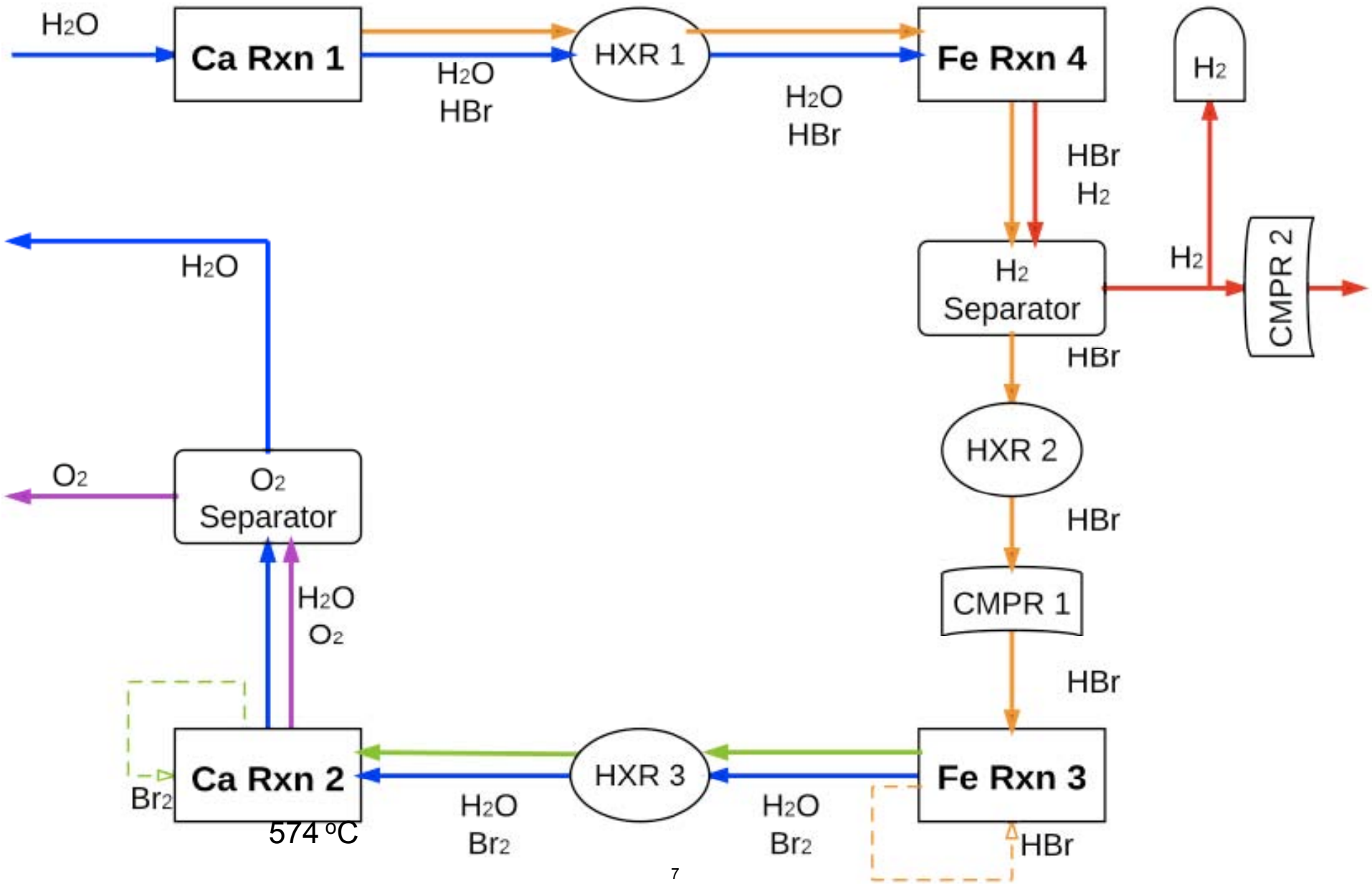


Image adapted from: Sakurai, M. *et al*. "Adiabatic UT-3 Thermochemical Process for Hydrogen Production". *International Journal of Hydrogen* Energy. **2**(10), 865-870 (1996).

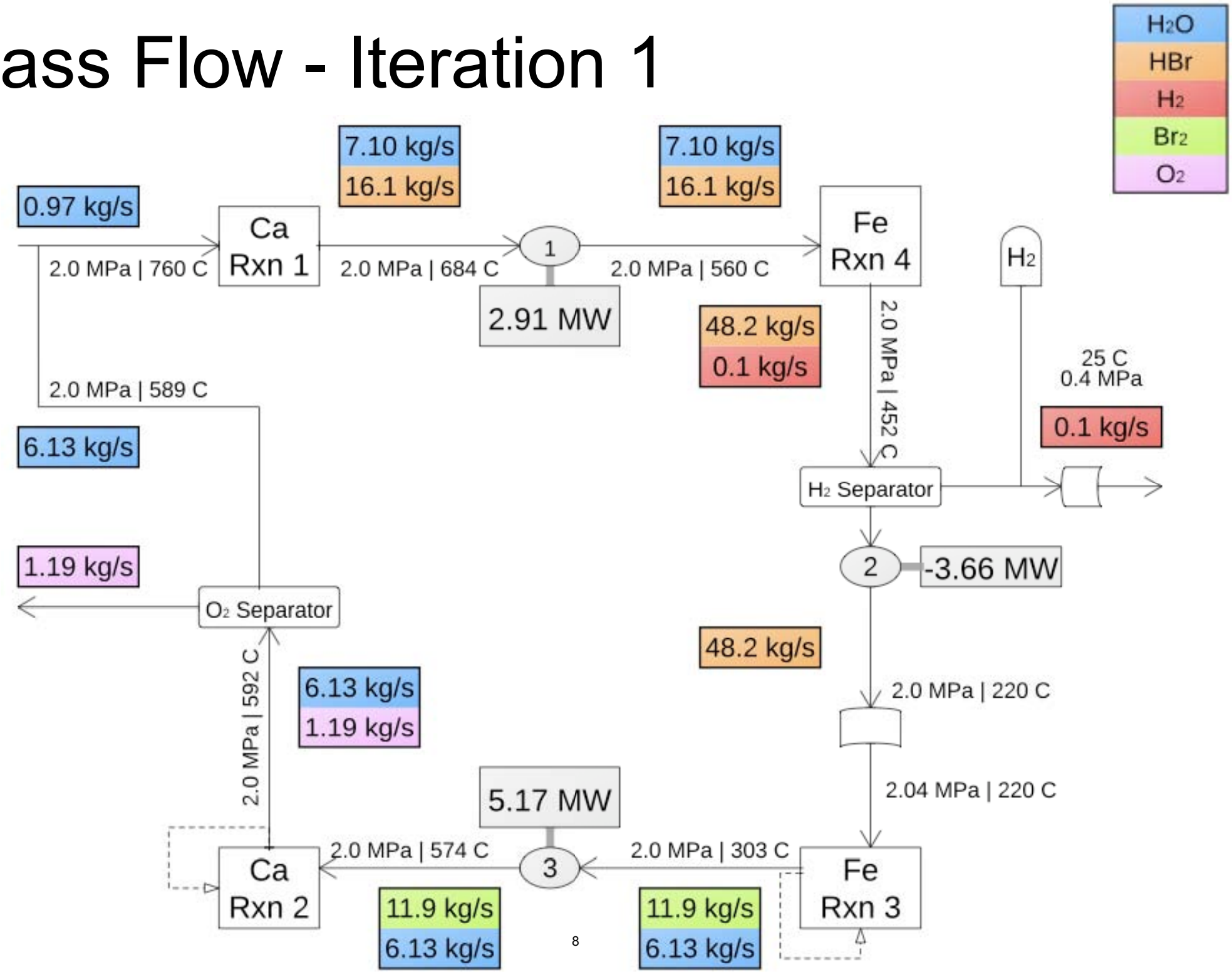
Forward Mass Flow (Realistic)



Forward Mass Flow (Idealized)



Mass Flow - Iteration 1



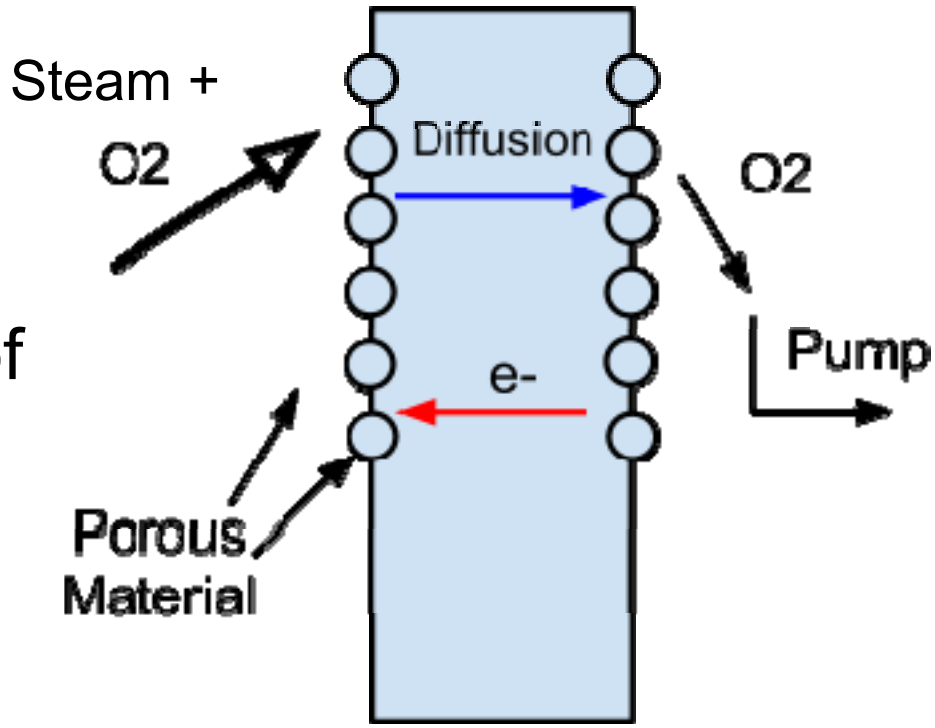
Hydrogen Separator Membrane

	CVD (TEOS)	**Zr silica**
Diffusion	Solution-diffusion	Solution-diffusion
Permeance [mol m^{-2} s^{-1} Pa^{-1}]	4.0×10^{-8} *(stated)*	10.0×10^{-8} *(extrapolated from fig. 6)*
Pressure	2.0 MPa	2.0 MPa
Area Needed [m^2]	1240	496
Concerns?	Stability issues: phase transition Poisoning issues: H_2S, HCl, Co	Stability issues: phase transition Poisoning issues: H_2S, HCl, Co

[1] http://cat.inist.fr/?aModele=afficheN&cpsidt=3202655
[2] http://www.sciencedirect.com/science/article/pii/036031999490006X

Oxygen Separator Membrane

- Electrons create negatively charged oxygen-ions.
- Electrodes, temperature and the differential partial pressure of O2 can be used for transport
- Combination of oxygen-ion conducting material and electronic conducting material
- Doped CeO2
  - 0.1 S/cm



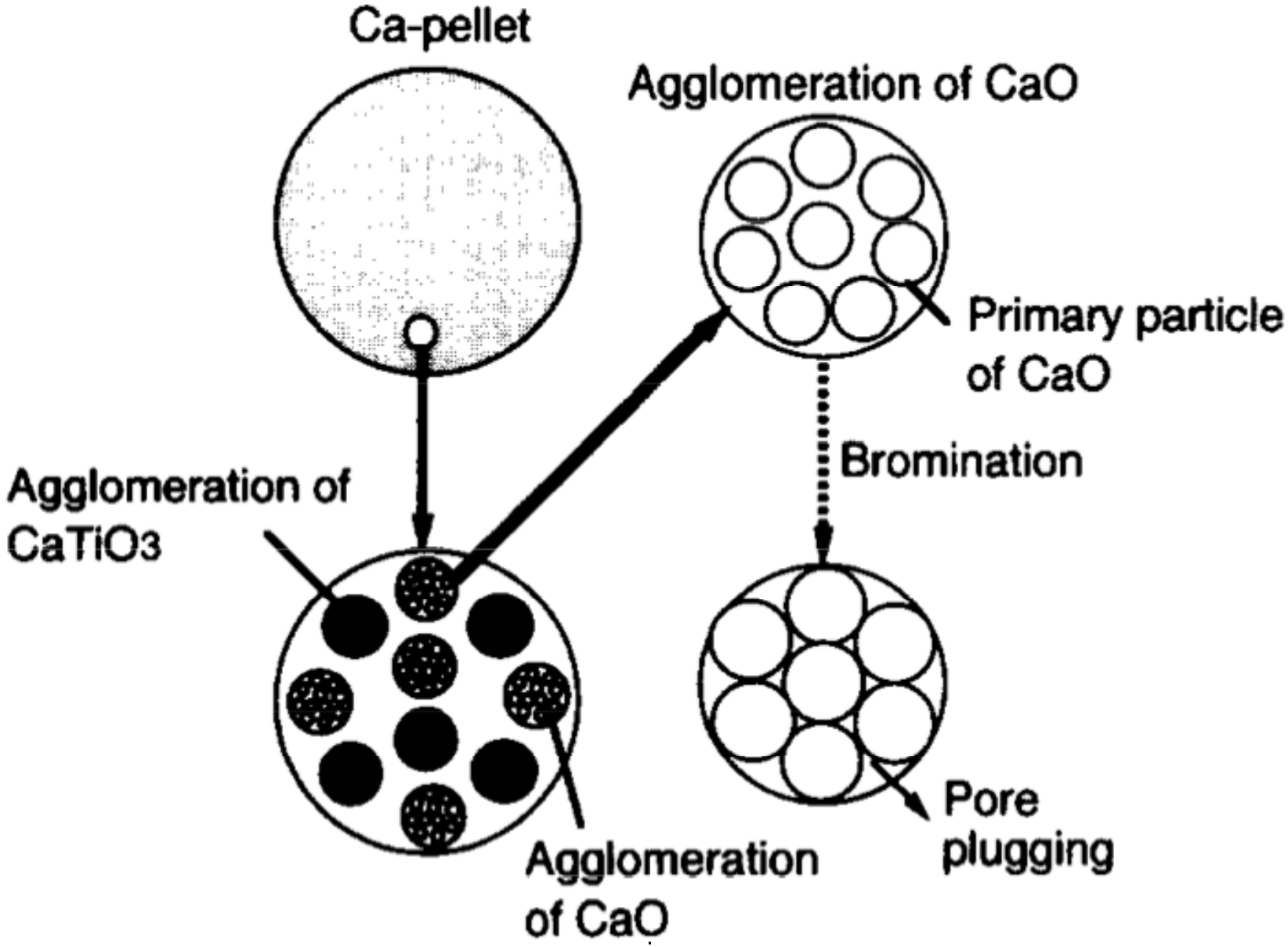
Materials for separation membranes in hydrogen and oxygen production and future power generation <http://iopscience.iop.org/1468-6996/7/8/A06>

Calcium Reagent Structure

- 76% volumetric difference between CaO and $CaBr_2$.[1]
- Fines can form which may lead to product sintering after substantial cycling.
- $CaTiO_3$ is used as a binder to maintain the overall structural integrity of the calcium pellet.
- CaO is distributed as to allow room for expansion and contraction.

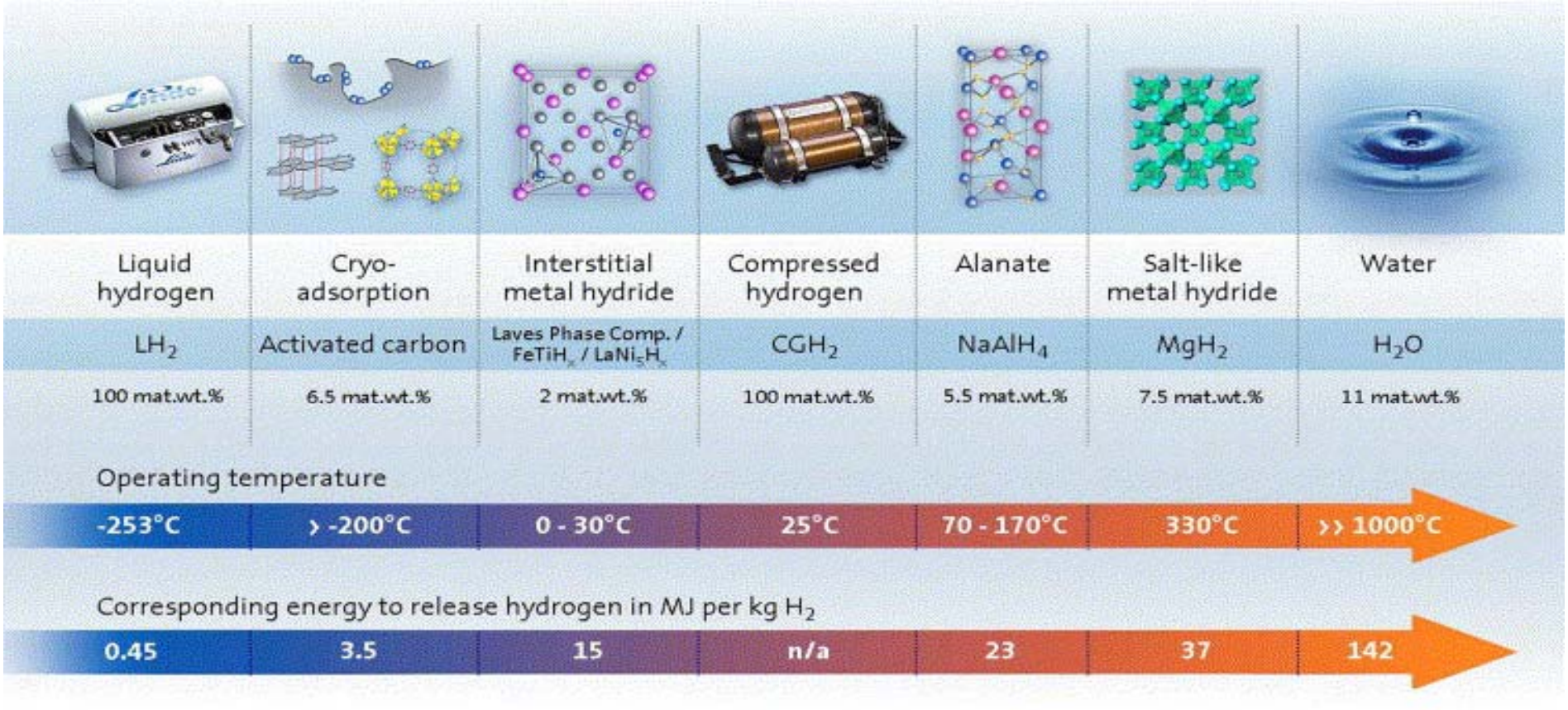
[1]Michele A. Lewis, Manuela Serban, and John K. Basco, **Hydrogen Production at <550°C Using a Low Temperature Thermochemical Cycle,** *Argonne National Laboratory.*

Calcium Reagent Structure



Hydrogen Storage

- want to store 1 day's worth = 9000 kg
- 130 m^3 of liquid hydrogen



Refueling/Bio Fuels Down/Power Down

- if something goes wrong within hydrogen
  - use stored hydrogen for 1 day
  - shut down if needed for longer

- if biofuels shuts down
  - hydrogen also shuts down

Next Steps

- Analysis using EES, ASPEN
- Individual components
  - heat exchangers
  - compressors
- Timing of flow switch
- Chemical reactors
  - physical size
  - solid reactants consumption rate
- Recovery of Br_2 and HBr

Questions?

22.033 / 22.33 Nuclear Systems Design Project

Fall 2011