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The third life of CSP : Solar high temperature processes

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Developed in the 80's to produce electricity, Concentrated Solar Power (CSP) is today more expensive than photovoltaic panels (PV) for direct production during sunny hours. CSP keeps a competitive advantage if coupled with thermal storage that permits to meet daily electricity production and user needs. The third step of CSP is chemical storage from high temperature processes. Produced solar fuels present a great energetic density and allow to tackle solar spatial heterogeneity and temporal variation.

Candidate reactions for high temperature solar processes

High temperatures reachable by concentrated solar processes, above 800°C, permit to carry out endothermic reactions which are presented in Figure 1. The energy is stored in the products of the reaction : materials, (CaO, Fe, ...), materials for energy (Zn/O₂ batteries...), fuel (syngas, hydrogen...). Some of these reactions produces both fuels and materials (i.e. metal oxide methano-reduction)

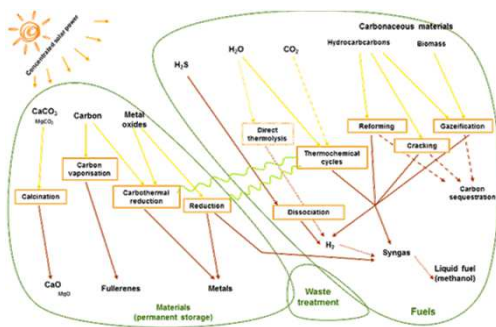


Figure 1 : recapitulative scheme of candidate for high temperature processes (Bizeau, O.)

Because of the variability of solar energy, it's possible to hybridize the process: during the night or a cloudy day, the energy is provided by combustion of fossil fuel or carbonaceous material.

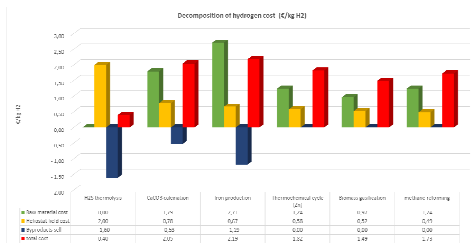


Figure 2 : Decomposition of hydrogen cost produced by different high temperature processes. Red blocks shows the total cost of hydrogen production. It is based on the energy needs of reaction, assuming that thermodynamic equilibrium is achieved, and considering thermal losses and ideal product separation.

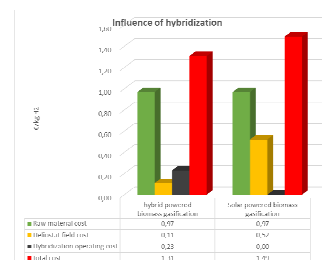


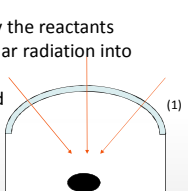
Figure 3 : Influence of hybridization on the cost of hydrogen production by gasification of biomass. Hybridization is managed by combustion of CH₄.

Solar reactor technology overview

Radiative transfer

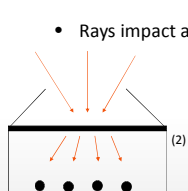
Direct:

- Rays impact directly the reactants
- Good transfer of solar radiation into reaction zone
- Window is required to prevent from loss of product



Indirect:

- Rays impact an absorber which releases the energy on the reactant
- Window not required
- More thermal losses (absorber overheated)

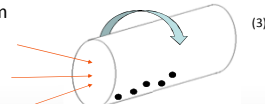


The window is a major problem, because even if it leads to good performances, it's a sensible part of the reactor and needs to be cooled and cleaned.

Mobile parts

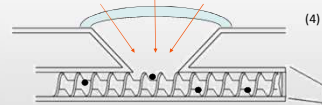
Rotating kiln:

- Good repartition of mass and energy ensured by the rotation
- High complexity from rotating parts and seals at high temperature



Feeder screw:

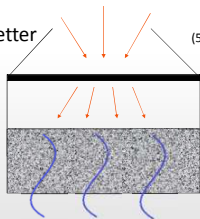
- Reactant is transferred through the irradiated zone by a heated screw.
- Complex design and mechanically challenging.



Mass distribution

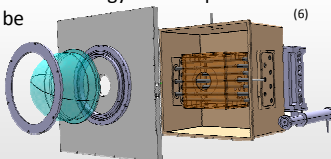
Fixed/fluidized bed:

- The solid reactant is packed in the reaction zone.
- There can be a fluid passing through to fluidize the bed.
- A fluidized bed presents a better mass/energy transfer but operability under variable solar flux is challenging.



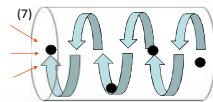
Tubular reactor:

- All the reactants are passing through one or several heated tubes.
- The tube can be transparent, so the reactant are heated directly.
- Good mass distribution and energy transfer provided that turbulent flow can be achieved
- The tubes can be obstructed by condensed byproducts.



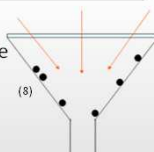
Vortex flow:

- Particles of reactant are injected with a gas in a tangential direction.
- Good mass and heat transfer, complex flow.



Gravity distribution:

- Particles go down through the reaction zone by gravity.
- Simple construction.
- Short residence time



How to maximize the solar energy amount in the products: reactor design key points

- Minimize thermal loss, reducing the reaction zone's and absorber's temperature,
- maximize heat transfer to the reactants.
- Ensure good temperature distribution in reaction zone.
- Lead a free-flowing transport of reactant in the reaction zone (avoid fouling).
- Allow a good product separation and avoid product losses.
- Reduce construction cost with a optimized design matching the mechanical needs.
- Ensure reliable process and materials to reduce operating cost.

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