



Centrales solaires et stockage de chaleur



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Plan

Introduction

Stockage d'énergie

Centrales solaires et stockage thermique

Conclusion



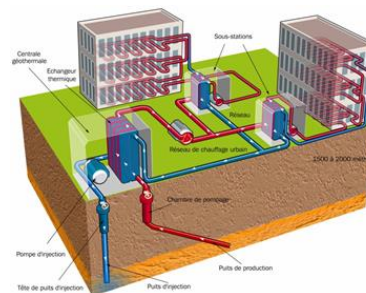
Introduction :

Gestion de l'énergie

Énergie de stock/énergie de flux

Vecteur énergétique :

- ➔ Production centralisée/décentralisée
- ➔ *Stockage*
- ➔ Transport : réseau et infrastructure

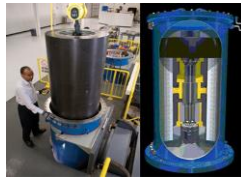


Stockage d'énergie :

Les différents modes de stockage

stockage
mécanique

potentiel
cinétique



stockage
électrique

électrostatique
magnétique



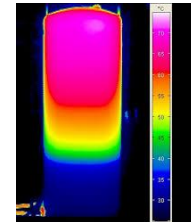
stockage
chimique

électrochimique
biofuels



stockage
thermique

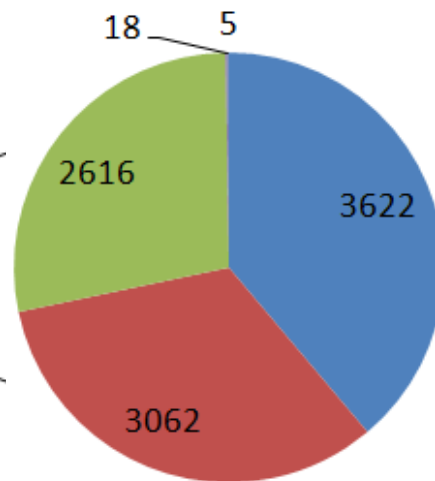
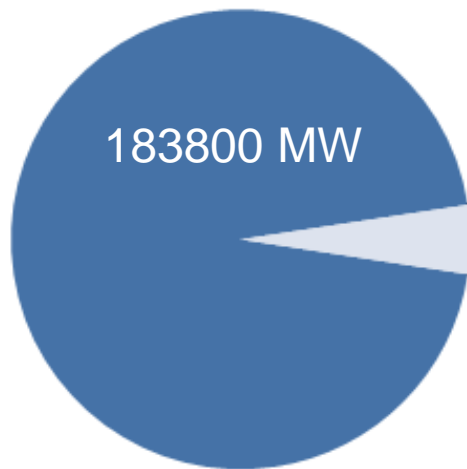
thermochimique
chaleur latente
chaleur sensible



Stockage massif de l'énergie électrique :

Capacité installée dans le monde (MW)

■ pumped hydro storage



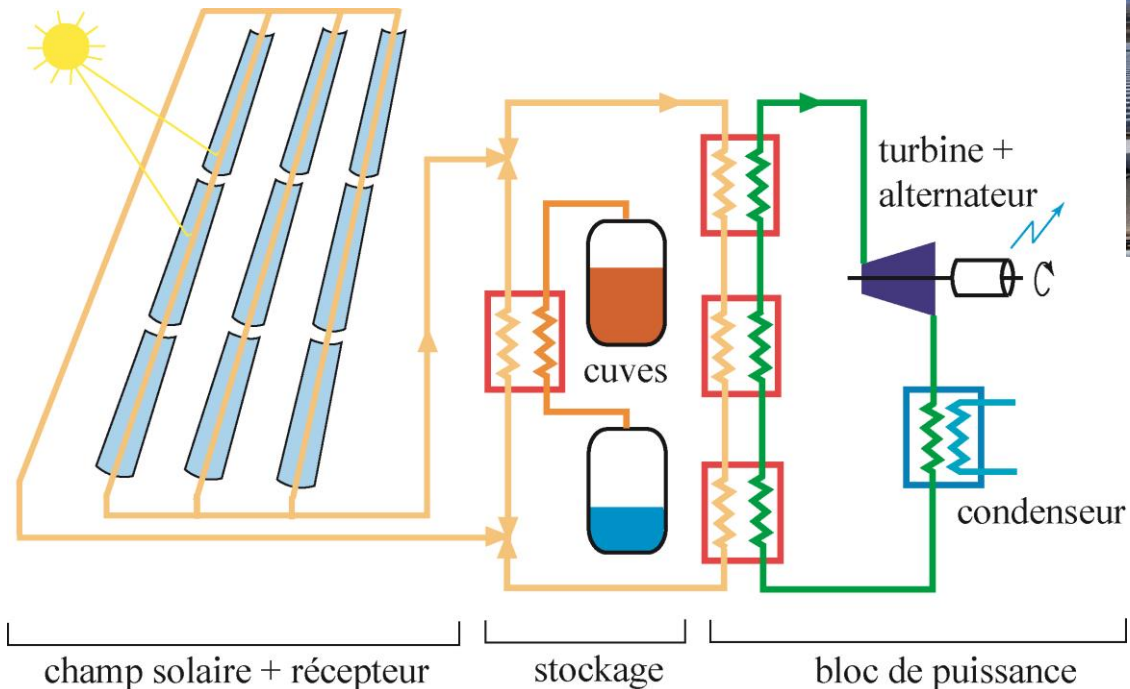
- thermal storage
- electro-chemical
- electro-mechanical
- hydrogen storage
- liquid air energy storage

Centrales solaires à concentration



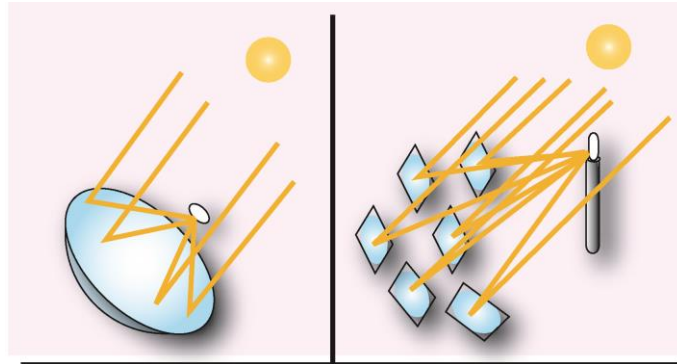
Centrale solaire à concentrateurs cylindro-paraboliques d'Andasol 1,2 et 3 (Espagne)
150 MW, 180 GWh

Centrales solaires à concentration d'Andasol

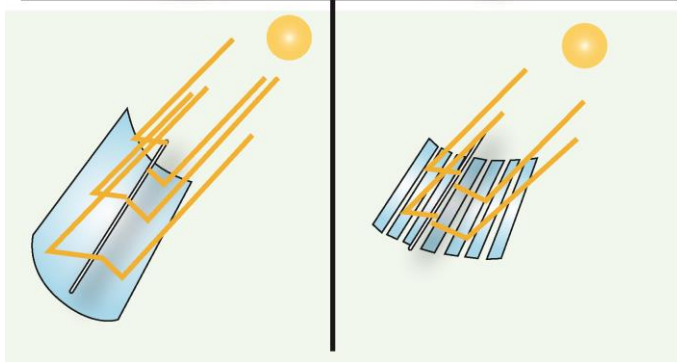


Centrales solaires à concentration

Parabole Stirling



Centrale à concentrateurs cylindro-paraboliques



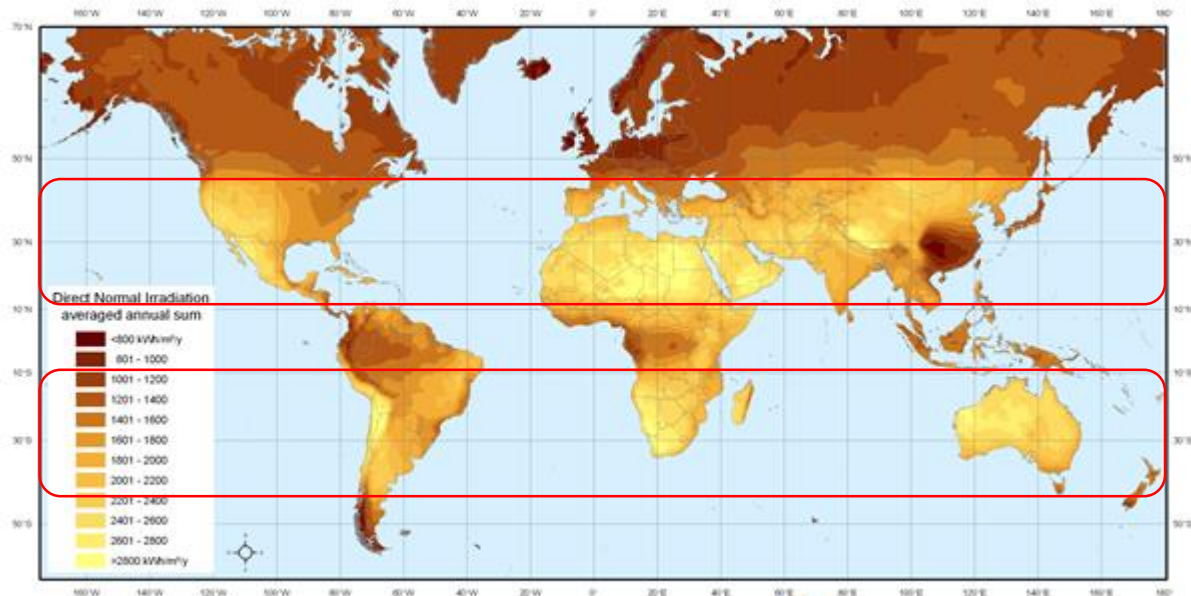
Centrale à tour



Centrale à concentrateurs linéaires de Fresnel

Ressource solaire

Direct Normal Irradiation (DNI)

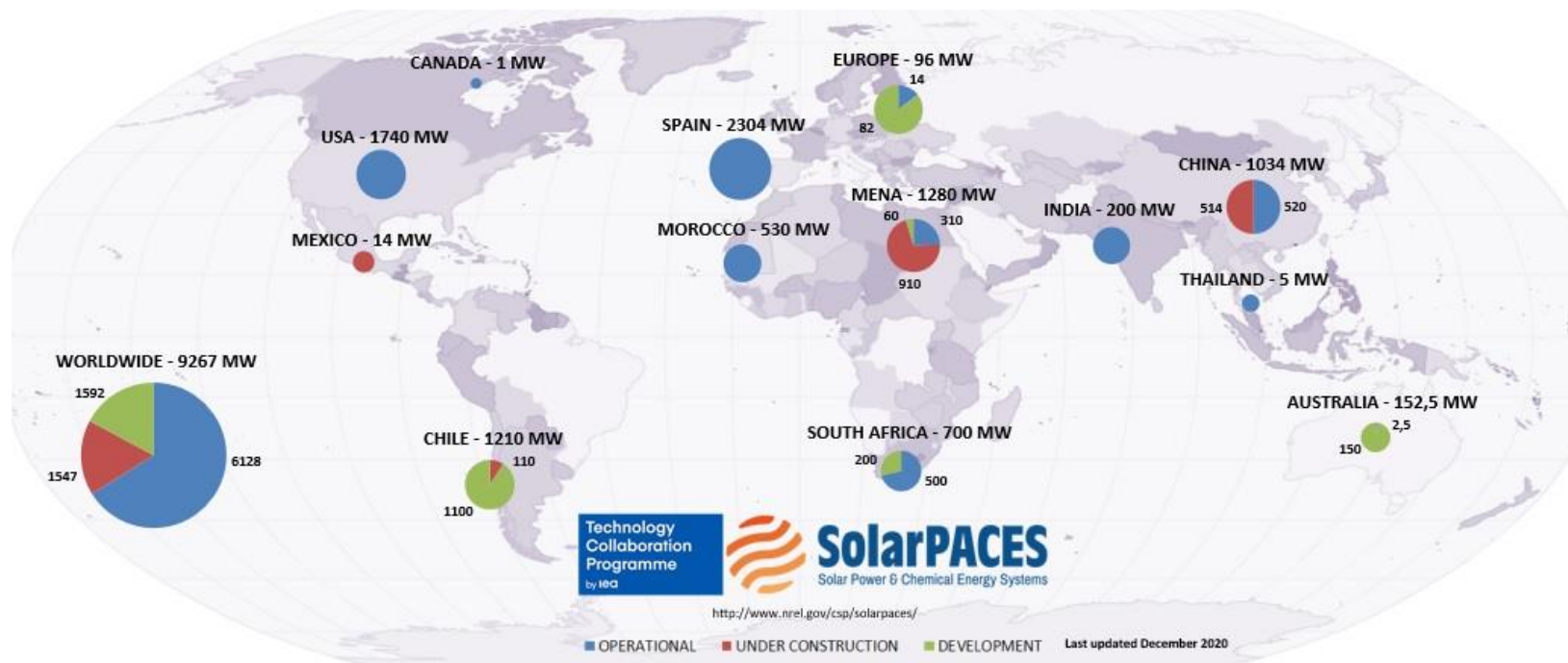


Date based on SSE 6.0 dataset for a 22-year period (July 1983 - June 2005)
(<http://eosweb.larc.nasa.gov/sse/>)

Map created and map layout by 2008
(<http://www.dlr.de/>)

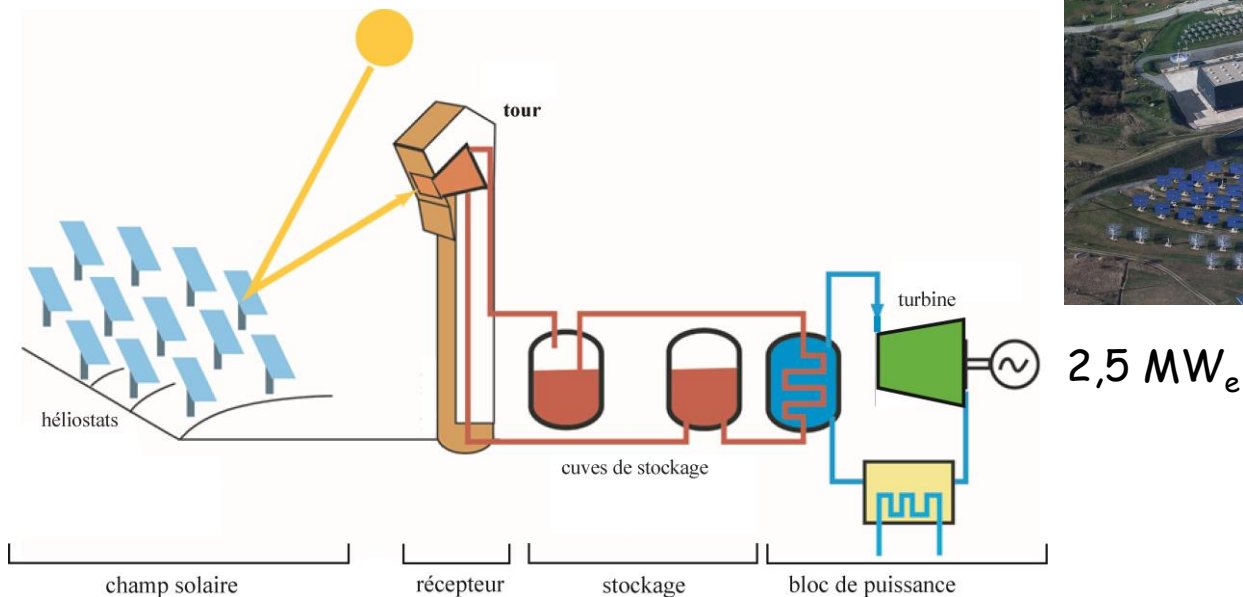
Centrales solaires à concentration :

Puissances installées



Centrales solaires et stockage :

Centrale solaire de Thémis (1983-1986), Targasonne, France



Capacité de stockage : $40\,000 \text{ kWh}_{th}$
550 t de sel fondu (mélange de nitrite et nitrate de sodium et de potassium)

Centrales solaires et stockage :

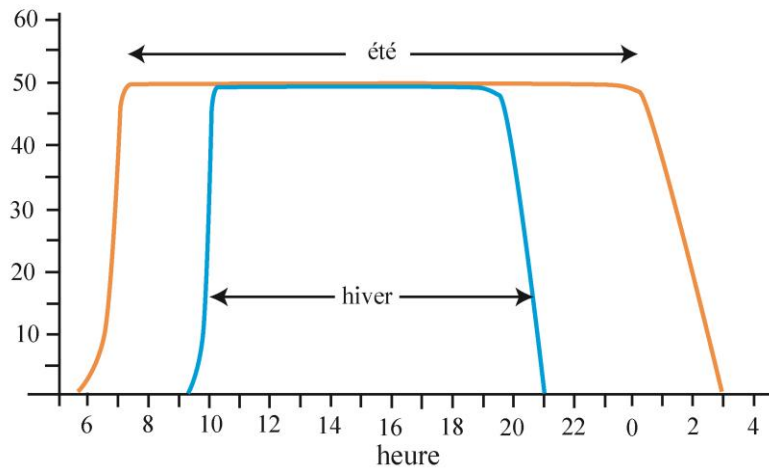
Exemple de la centrale d'Andasol (Espagne)



3850 h/an à 50 MW_e (7,5 h/jour)
1010 MWh_{th}
28 000 t
 $\Delta T=100$ K

$\text{NaNO}_3/\text{KNO}_3$: 0,41 Wh/kg/K

Puissance (MW)



Centrales solaires et stockage :

Exemple des centrales d'Andasol et de Gemasolar (Espagne)



3850 h/an à 50 MW_e (7,5 h/jour)
1010 MWh_{th}
28 000 t
 $\Delta T=100$ K



6450 h/an à 19,9 MW_e (15 h/jour)
670 MWh_{th}
8 500 t
 $\Delta T= 275$ K

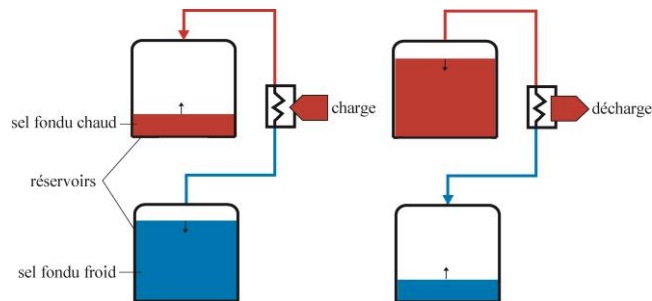
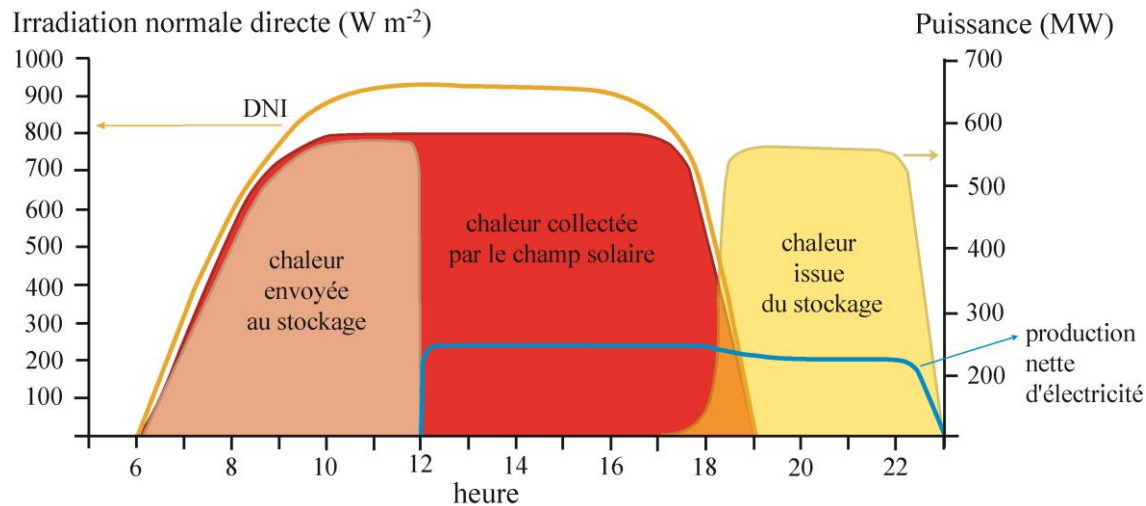
$\text{NaNO}_3/\text{KNO}_3 : 0,41 \text{ Wh/kg/K}$



30 – 80 Wh/kg

Fonctionnalités du stockage

Production différée :



- + Protection thermique
- + Régulation
- + Efficacité de conversion

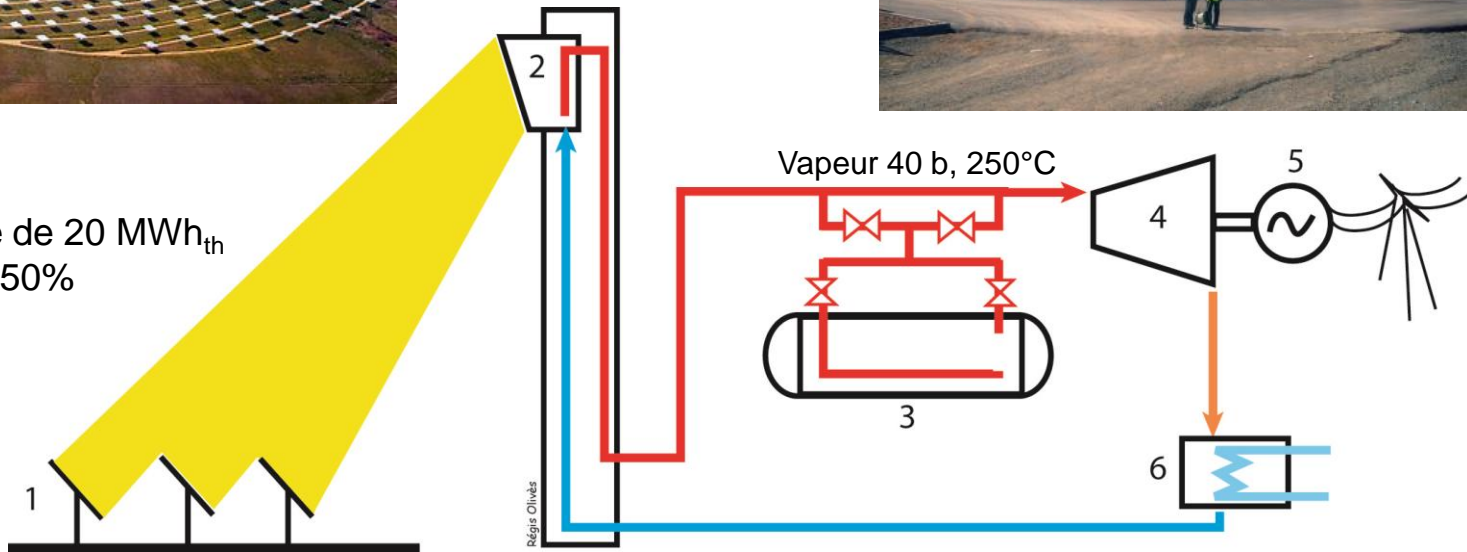
Autres technologies de stockage pour centrales solaires



PS10, Séville



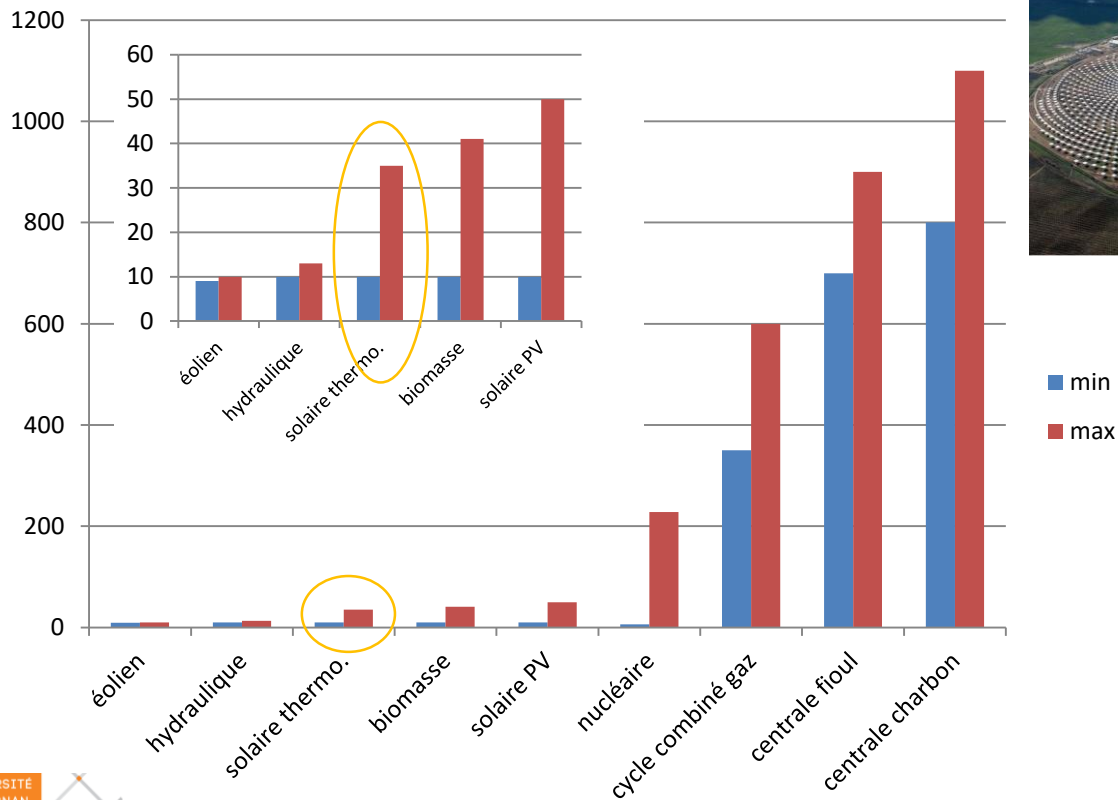
11 MW_e
Stockage de 20 MWh_{th}
50 min à 50%



Impacts environnementaux des centrales solaires :

Contenu CO₂ de l'électricité produite

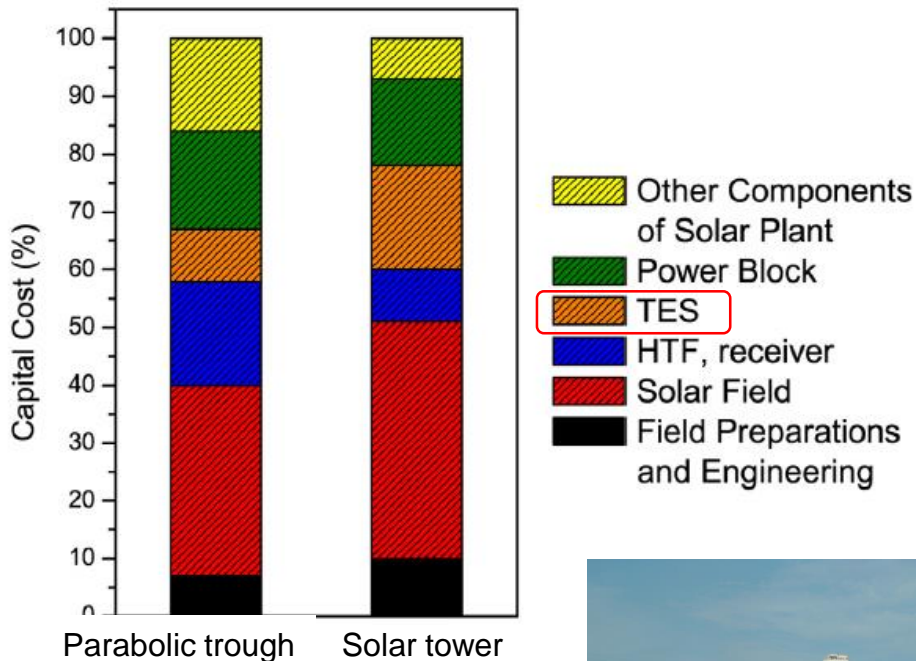
gCO₂/kWh



Aspect économique des centrales solaires :

Répartition des coûts

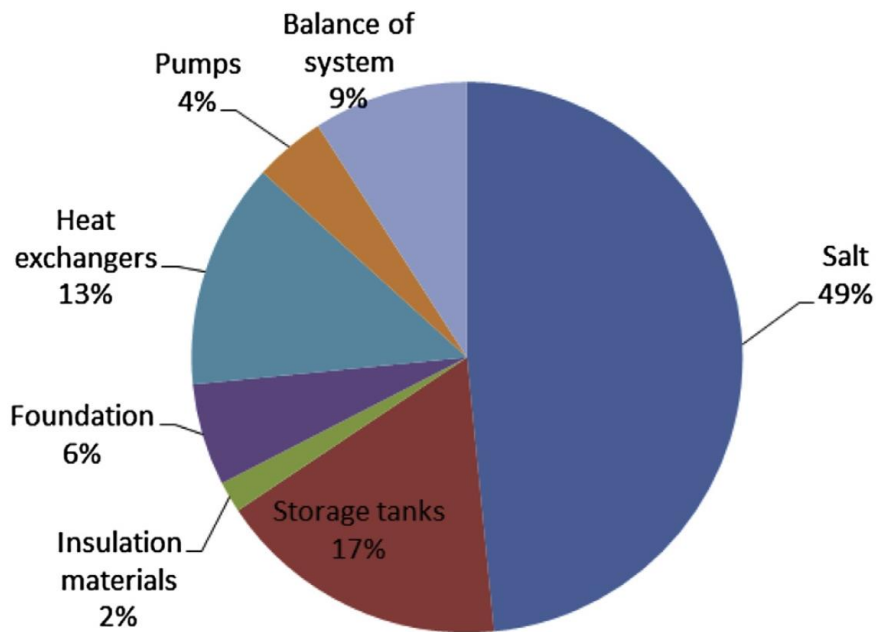
Coût de l'électricité produite : ~0,10 €/kWh



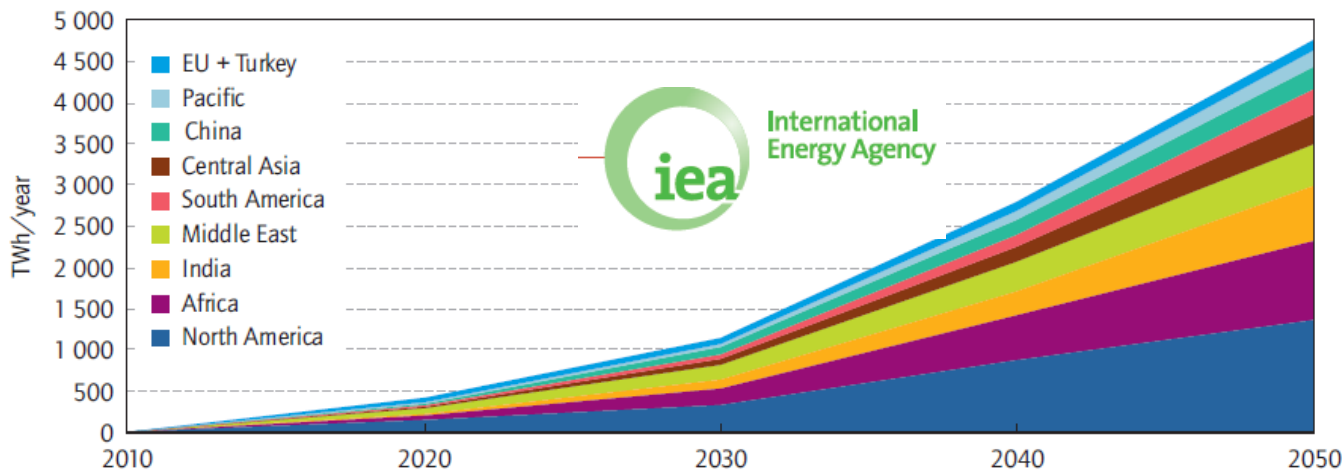
Aspect économique du stockage :

Répartition des coûts

Coût du stockage : 20-50 €/kWh



Perspectives du solaire à concentration



~1 000 GW

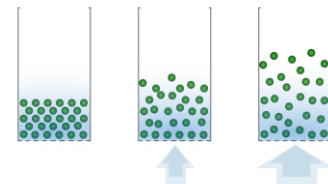
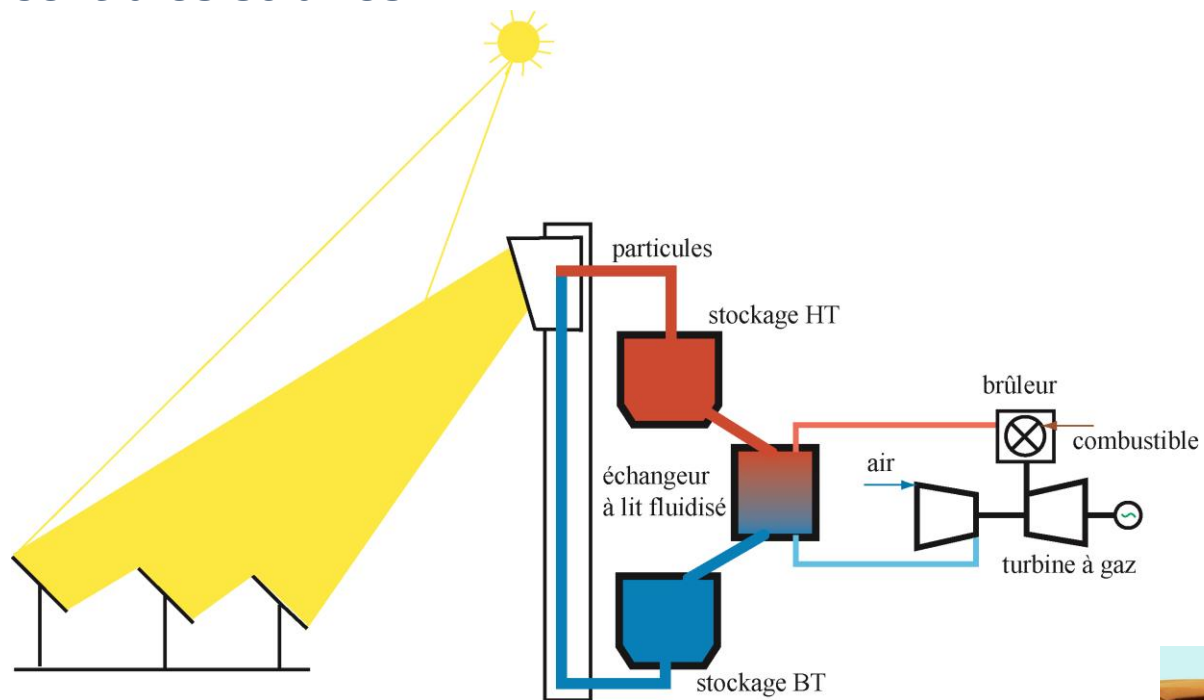


9 à 21 Mt/an de nitrates ! (production mondiale 0,8 Mt/an)

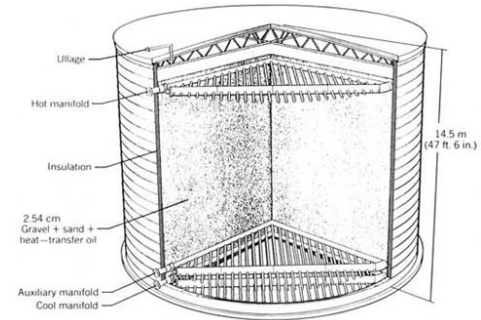
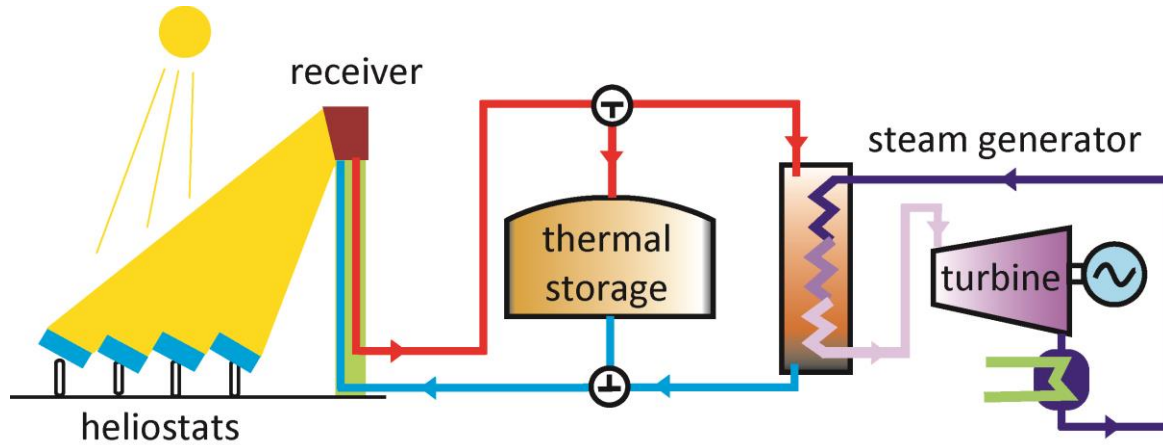


Disponibilité de la matière première

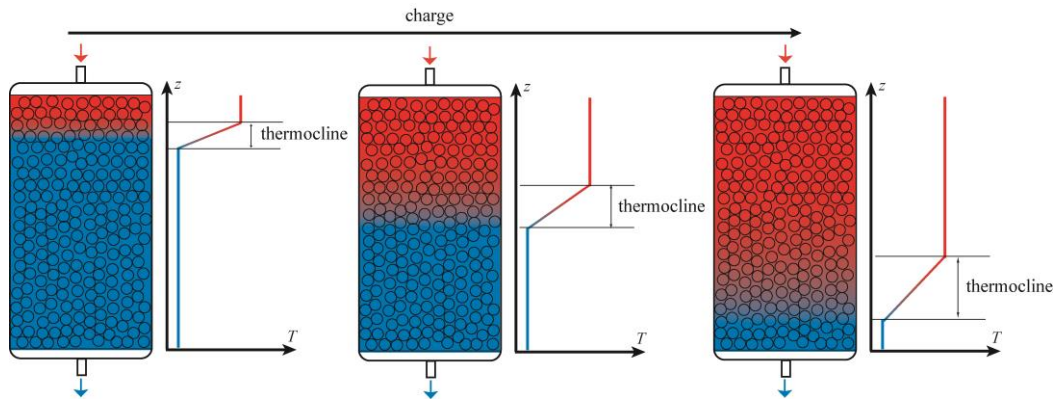
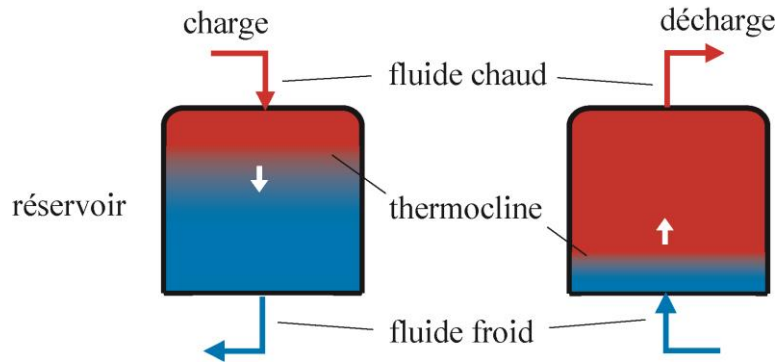
Autres technologies de stockage pour centrales solaires



Autres technologies de stockage pour centrales solaires



Stockage de type thermocline



Matériaux de stockage

Inertage et valorisation de déchets

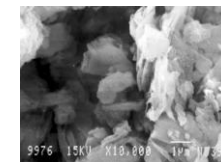
Déchets Amiantés (ACW) :

174 Mt d'amiante utilisées au XX^{ième} siècle dans le monde
250 000 t/an d'ACW produites in France



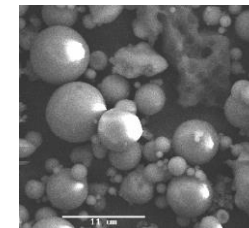
Cendres volantes d'incinérateur (MSWI Fly Ashes) :

UE(15) : 1,6 Mt/an
UIOM : 3 à 5% des MSW



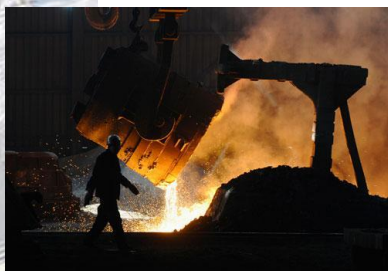
Cendres volantes (Coal Fly Ashes) :

750 Mt/an Mondial
UE(15) 42 Mt/an



Metallurgical slag :

> 411 Mt/an Mondial



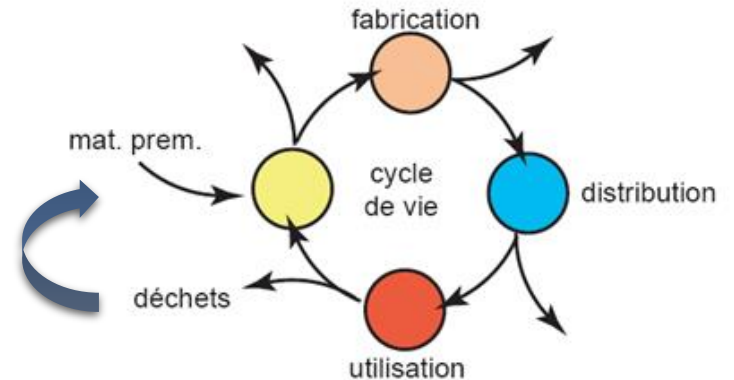
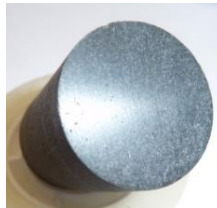
Analyse de cycle de vie et empreinte écologique du stockage

Temps de retour énergétique : < 1 an

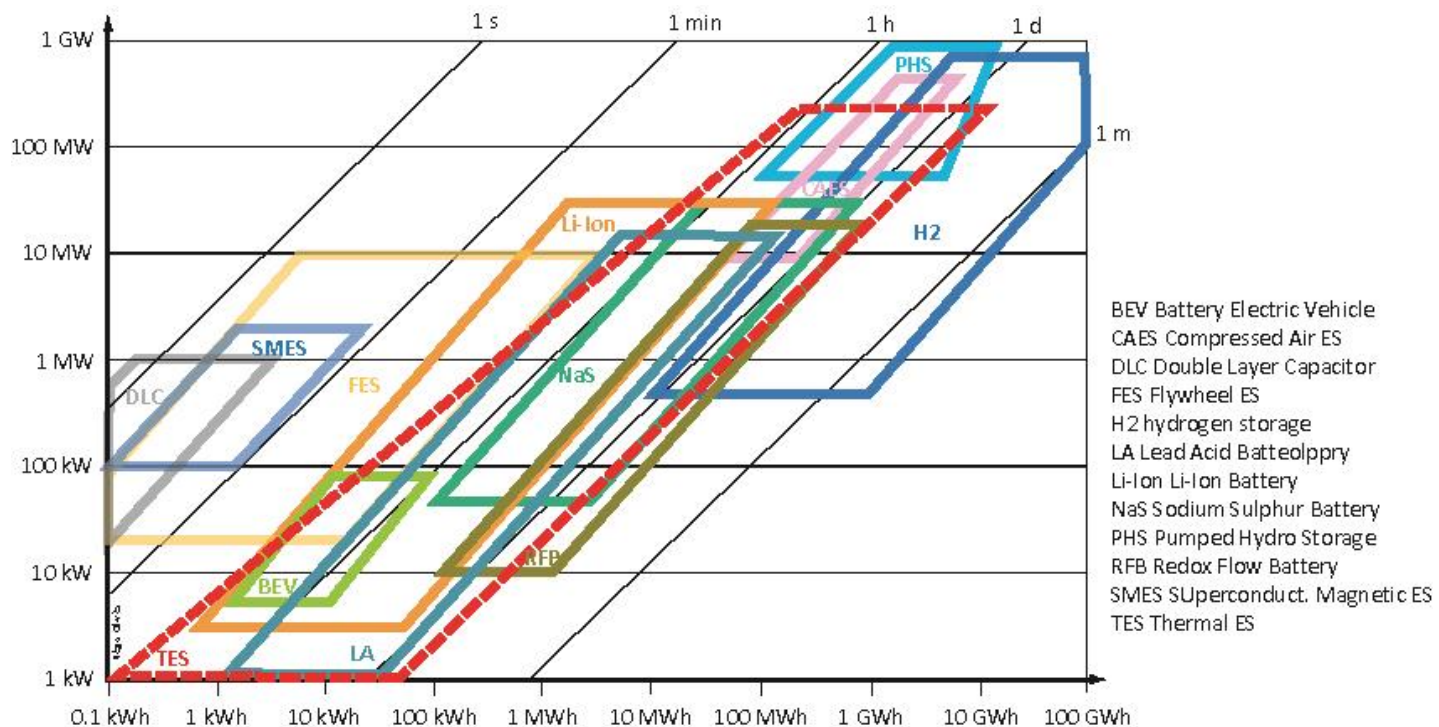
Impact CO_2 : TES < 5 gCO_2/kWh (centrale : 20-30 gCO_2/kWh)

Valorisation de déchets : utilisation d'une matière première « secondaire »

Éco-toxicité

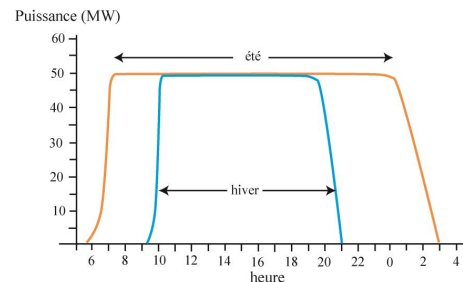
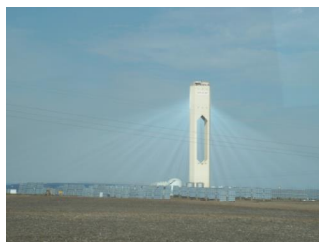
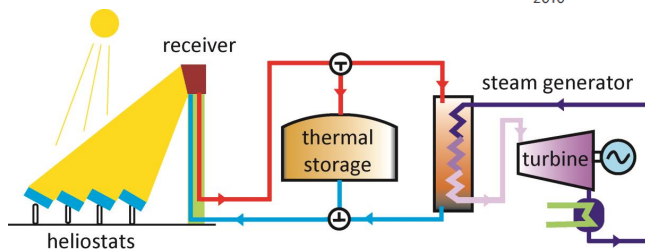
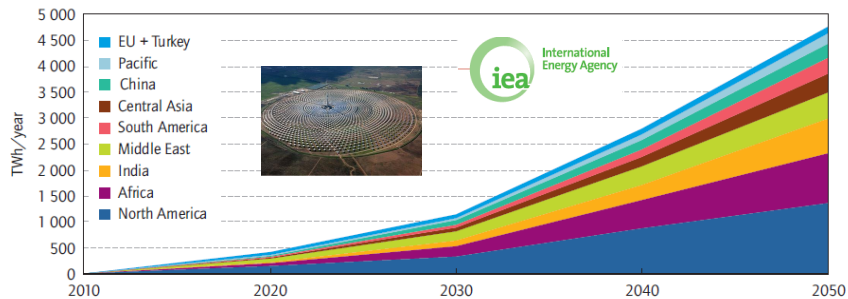
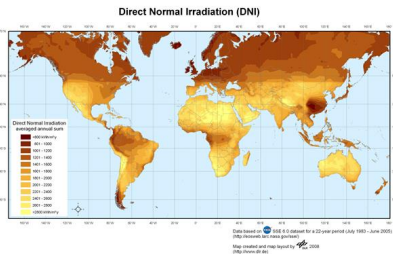


Le stockage thermique parmi les autres technologies



- BEV Battery Electric Vehicle
- CAES Compressed Air ES
- DLC Double Layer Capacitor
- FES Flywheel ES
- H2 hydrogen storage
- LA Lead Acid Batterie
- Li-Ion Li-Ion Battery
- NaS Sodium Sulphur Battery
- PHS Pumped Hydro Storage
- RFB Redox Flow Battery
- SMES Superconduct. Magnetic ES
- TES Thermal ES

En conclusion





Merci

www.promes.cnrs.fr

<https://sup-enr.univ-perp.fr/>

www.cnrs.fr

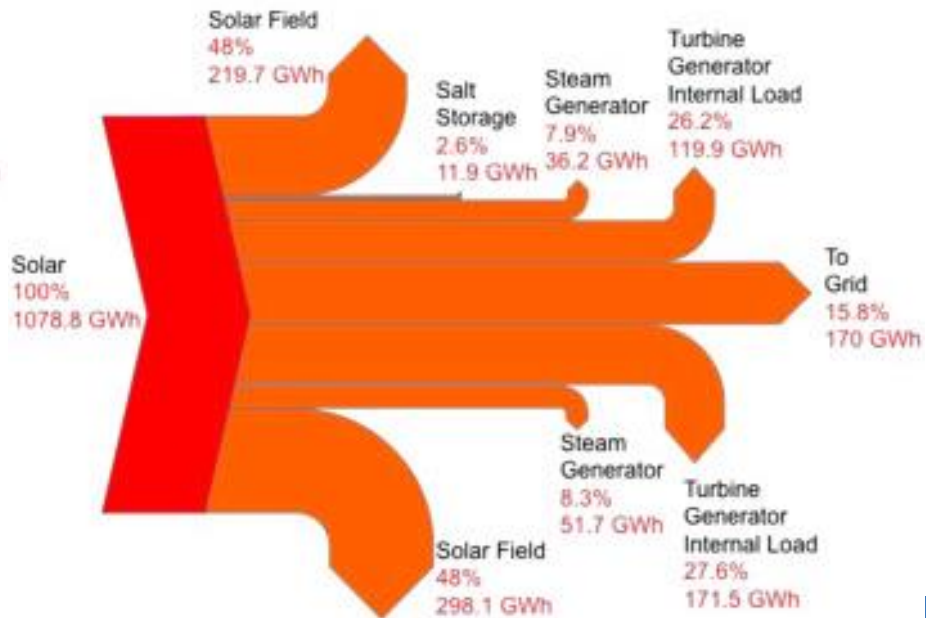


Rendement d'une centrale solaire à concentration avec ou sans stockage

Sankey diagram - Solar

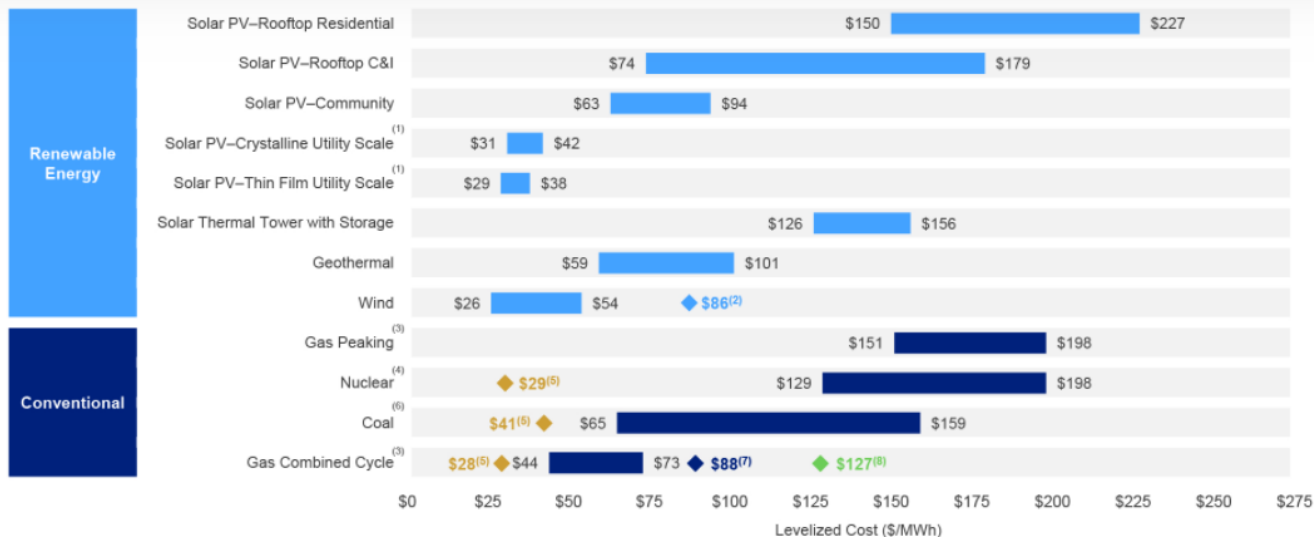


Sankey diagram – Solar + storage



Coût de l'électricité produite

Selected renewable energy generation technologies are cost-competitive with conventional generation technologies under certain circumstances



Source: Lazard estimates.

Note: Here and throughout this presentation, unless otherwise indicated, the analysis assumes 60% debt at 8% interest rate and 40% equity at 12% cost. Please see page titled "Levelized Cost of Energy Comparison—Sensitivity to Cost of Capital" for cost of capital sensitivities. These results are not intended to represent any particular geography. Please see page titled "Solar PV versus Gas Peaking and Wind versus CCGT—Global Markets" for regional sensitivities to selected technologies.

(1) Unless otherwise indicated herein, the low case represents a single-axis tracking system and the high case represents a fixed-tilt system.

(2) Represents the estimated implied midpoint of the LCOE of offshore wind, assuming a capital cost range of approximately \$2,600 – \$3,675/kW.

(3) The fuel cost assumption for Lazard's global, unsubsidized analysis for gas-fired generation resources is \$3.45/MMBTU.

(4) Unless otherwise indicated, the analysis herein does not reflect decommissioning costs, ongoing maintenance-related capital expenditures or the potential economic impacts of federal loan guarantees or other subsidies.

(5) Represents the midpoint of the marginal cost of operating fully depreciated gas combined cycle, coal and nuclear facilities, inclusive of decommissioning costs for nuclear facilities. Analysis assumes that the salvage value for a decommissioned gas combined cycle or coal asset is equivalent to its decommissioning and site restoration costs. Inputs are derived from a benchmark of operating gas combined cycle, coal and nuclear assets across the U.S. Capacity factors, fuel, variable and fixed operating expenses are based on upper- and lower-quartile estimates derived from Lazard's research. Please see page titled "Levelized Cost of Energy Comparison—Renewable Energy versus Marginal Cost of Selected Existing Conventional Generation" for additional details.

(6) High and incorporates 90% carbon capture and storage. Does not include cost of transportation and storage.

(7) Represents the LCOE of the observed high case gas combined cycle inputs using a 20% blend of "Blue" hydrogen, (i.e., hydrogen produced from a steam-methane reformer, using natural gas as a feedstock, and sequestering the resulting CO₂ in a nearby saline aquifer). No plant modifications are assumed beyond a 2% adjustment to the plant's heat rate. The corresponding fuel cost is \$5.20/MMBTU.

(8) Represents the LCOE of the observed high case gas combined cycle inputs using a 20% blend of "Green" hydrogen, (i.e., hydrogen produced from an electrolyzer powered by a mix of wind and solar generation and stored in a nearby salt cavern). No plant modifications are assumed beyond a 2% adjustment to the plant's heat rate. The corresponding fuel cost is \$10.65/MMBTU.