Energy Transport Compounds

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Overview of presentation

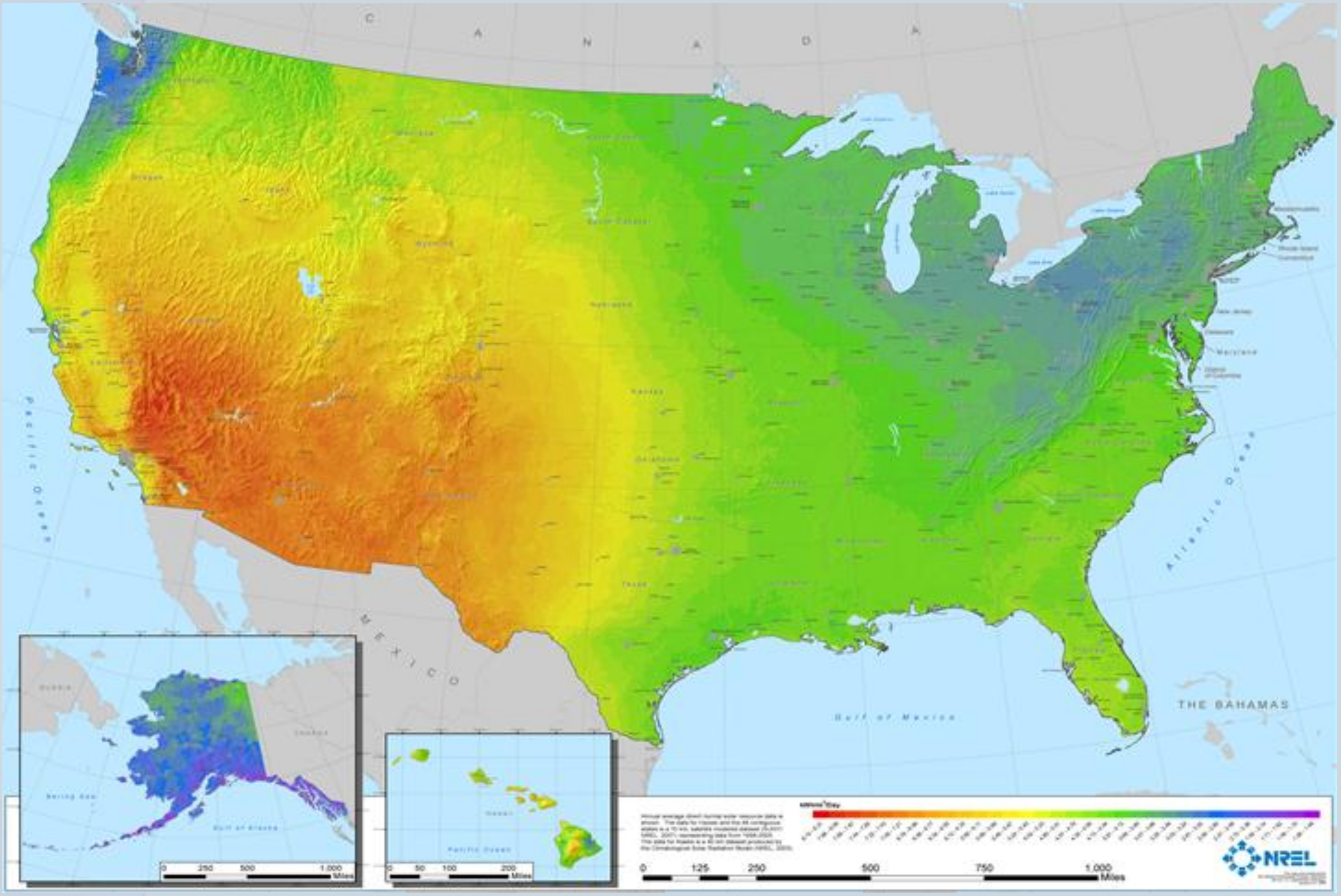
- Introduction-Renewable energy sources
- Why local power production is desired.
- Concentrated solar power production storage and transport
  - Solar tower concept
  - Solar kiln deisgn
  - Over-all process efficiency
  - Economic analysis of the process
- Carbon dioxide mitigation strategy
- Conclusion

Introduction

- CO_2 emissions- green house effect.
- Deminishing fossil fuels.

DESERTEC concept

Introduction



Why transport is required

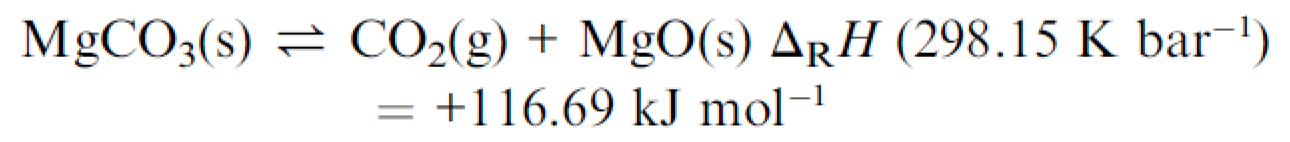
Local production is encourged for the following reasons

- High thermodynamic efficiency is possible

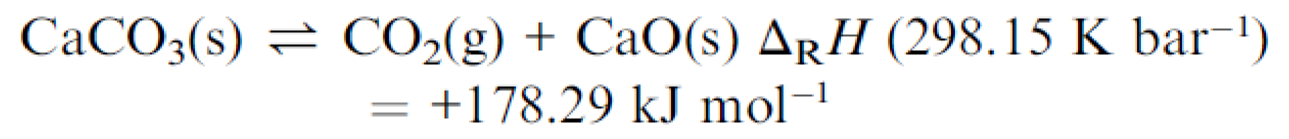
$$\eta_C = 1 - \frac{T_L}{T_H}$$

- Use of low grade energy is possible(domestic heating)
- Transmission losses due to HVDC can be avoided.

Solid Compounds for Energy Storage and Transport



$$MgCO_3(s) \rightleftharpoons CO_2(g) + MgO(s)\ \Delta_R H\ (298.15\ \mathrm{K\ bar^{-1}}) = +116.69\ \mathrm{kJ\ mol^{-1}}$$



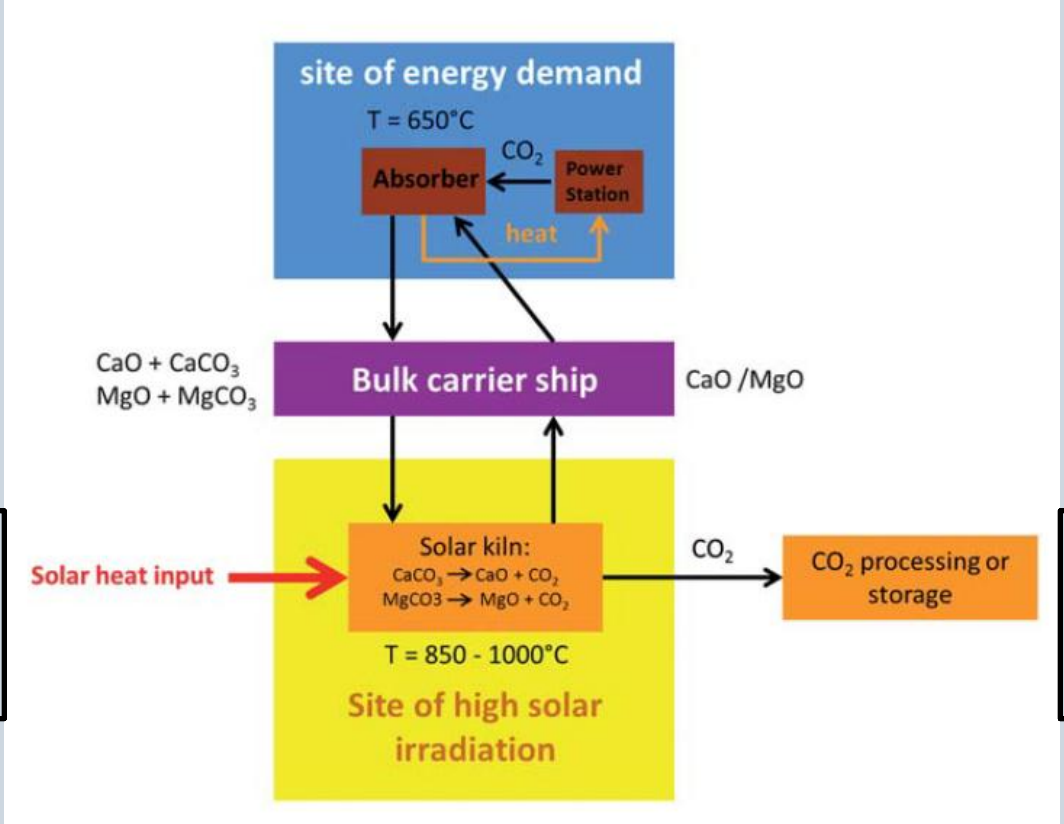
$$CaCO_3(s) \rightleftharpoons CO_2(g) + CaO(s)\ \Delta_R H\ (298.15\ \mathrm{K\ bar^{-1}}) = +178.29\ \mathrm{kJ\ mol^{-1}}$$

Solid Compounds for Energy Storage and Transport

$CaCO_3$ is preffered over $MgCO_3$.

- Vast availbility of material in energy lean state.
- Low tendency of leakage or degradation.
- High mass related energy capacity.
- Ideal for high quality steam production.
- Favorable toxicity and ecotoxicity.

Thermal performance analysis
Comparision with exsiting technologies

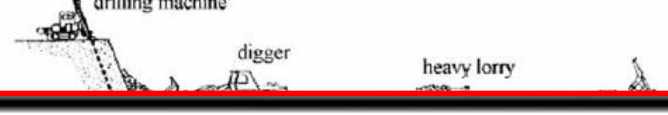


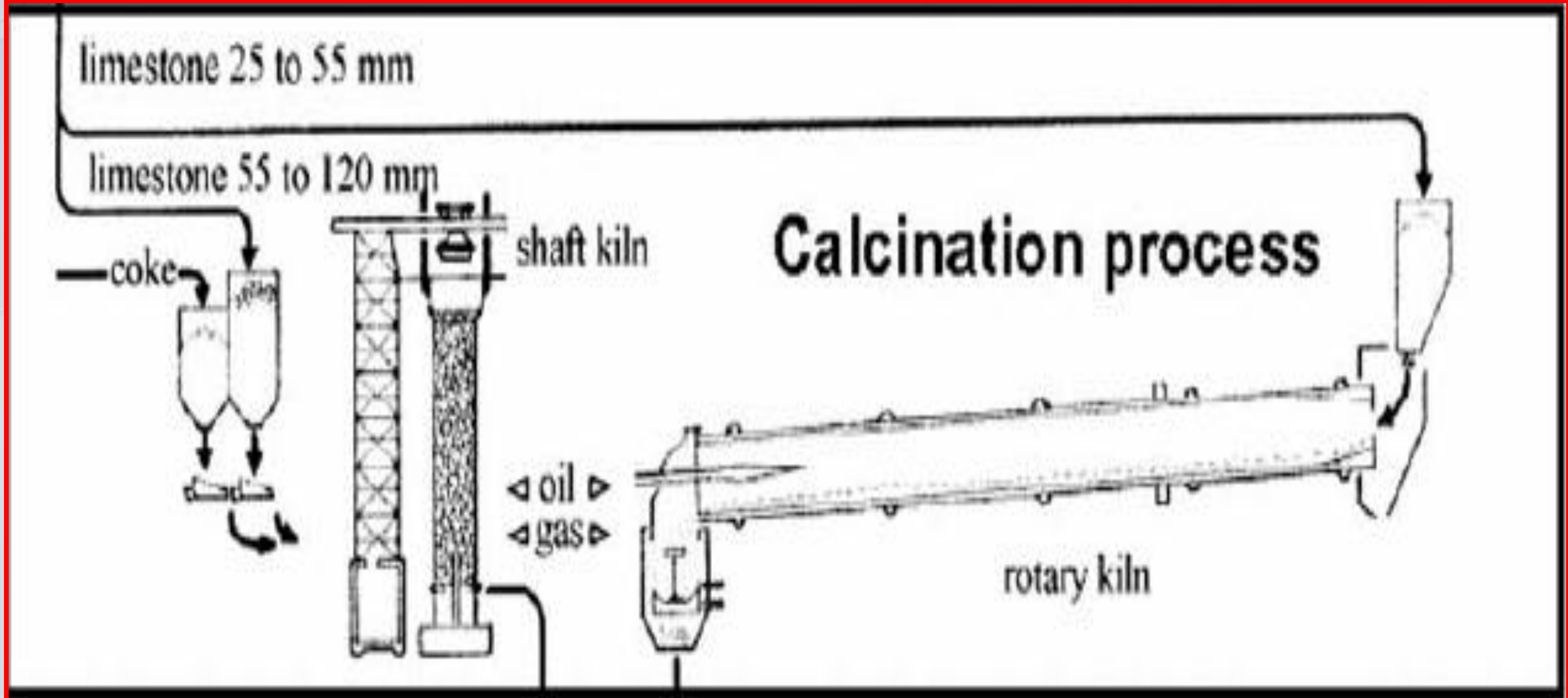
Concentrated solar tower concept for solar heat input

Carbon capture and squaring

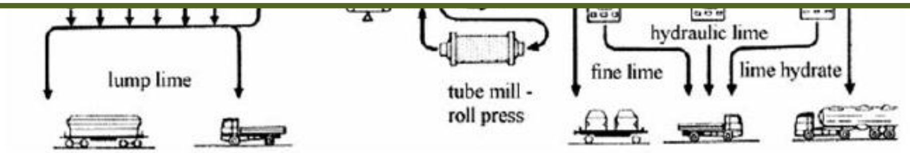
Kiln design and Reaction kinetics for lime production

Economic analysis of the process

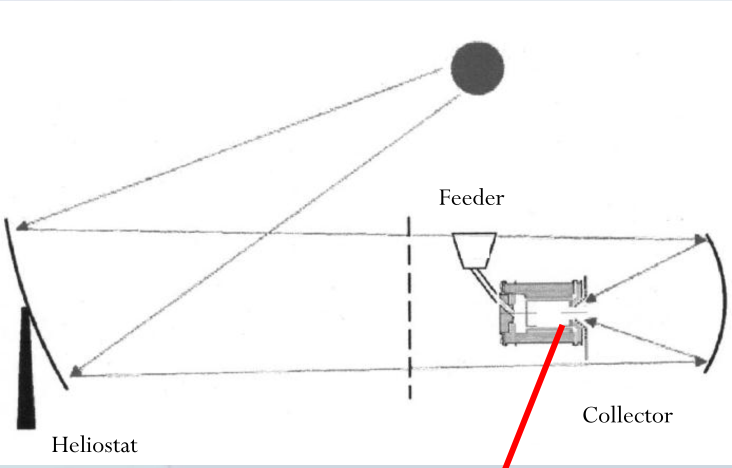


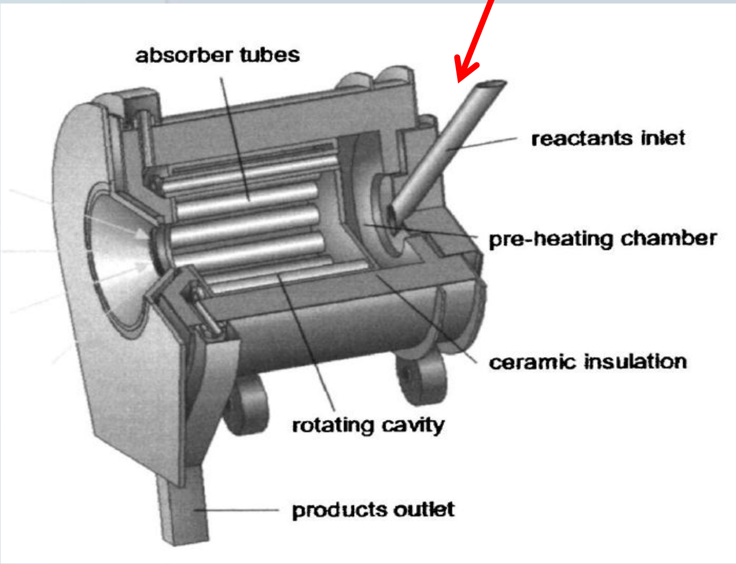


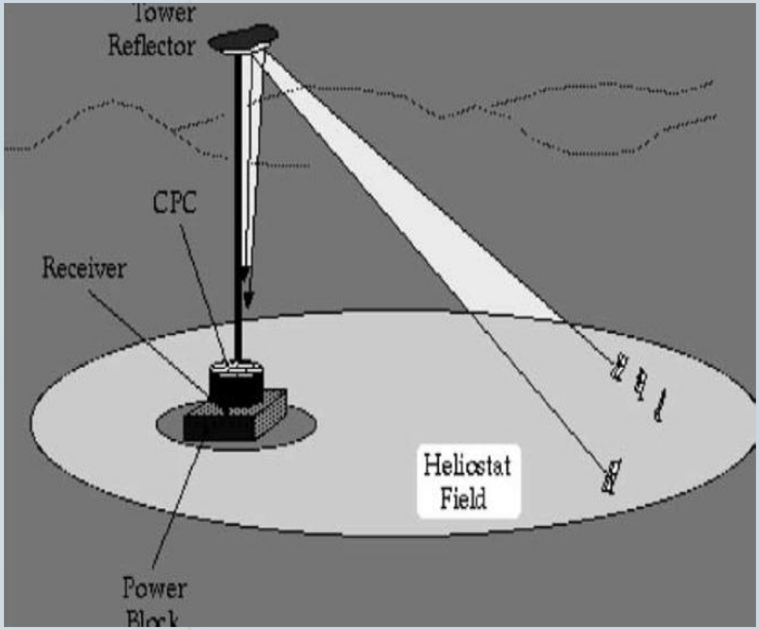
$$\mathrm{CaCO_3(s)} \rightleftharpoons \mathrm{CO_2(g)} + \mathrm{CaO(s)}\ \Delta_R H\ (298.15\ \mathrm{K\ bar^{-1}}) = +178.29\ \mathrm{kJ\ mol^{-1}}$$



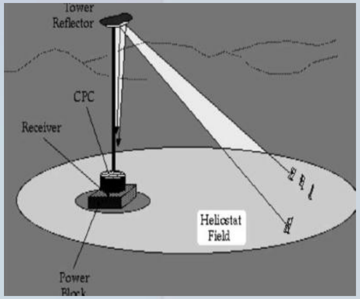
Kiln design for lime production

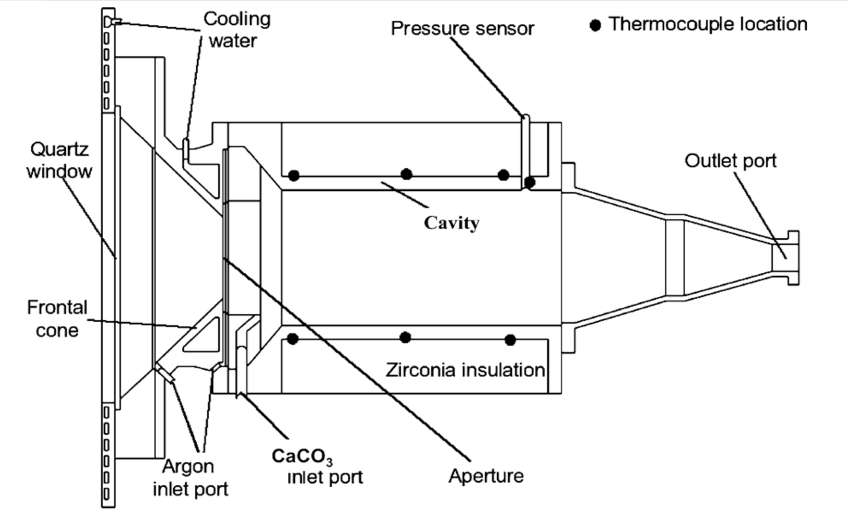


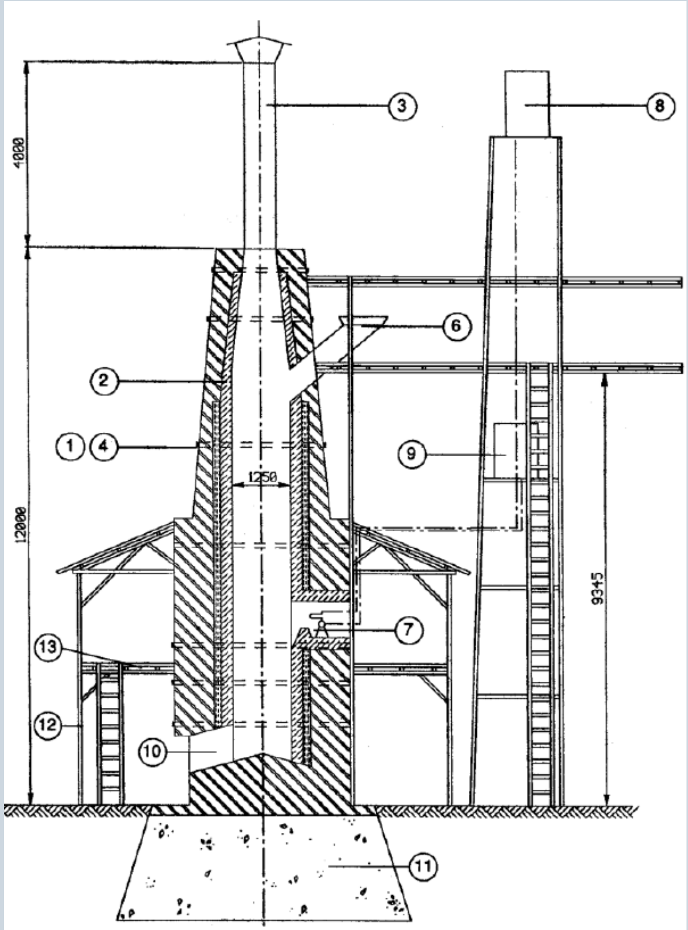



Tower
Reflector
CPC
Receiver
Heliostat
Field
Power
Block

Kiln design and Reaction kinetics for lime production



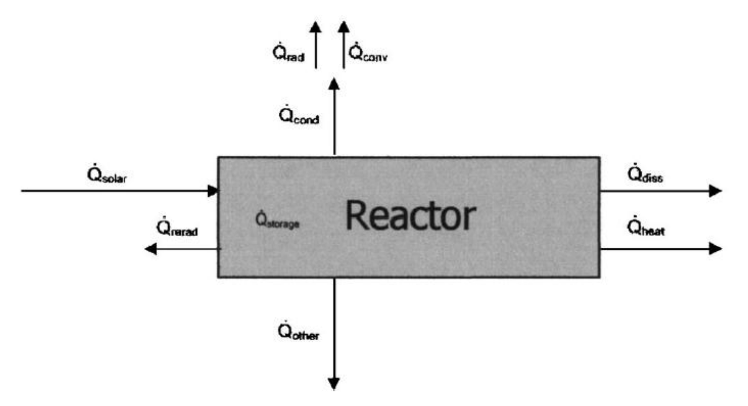




2-Burning zone 6-Inlet 7-Burner 10-Outlet

Kiln design- Solar reactor efficiency

$$\eta = \frac{Q_0}{Q_{solar}} = \frac{m_{CaO}.\Delta\dot{H}_0}{Q_{solar}}$$



$$Q_{solar} = Q_0 + Q_{product} + Q_{rerad} + Q_{cond} + Q_{others}$$

Kiln design- Loss of ignition (LOI)

$$LOI = \frac{m_{in} - m_{out}}{m_{in}} = 1 - \frac{m_{out}}{m_{in}} = \frac{m_{CO_2}}{m_{in}}$$

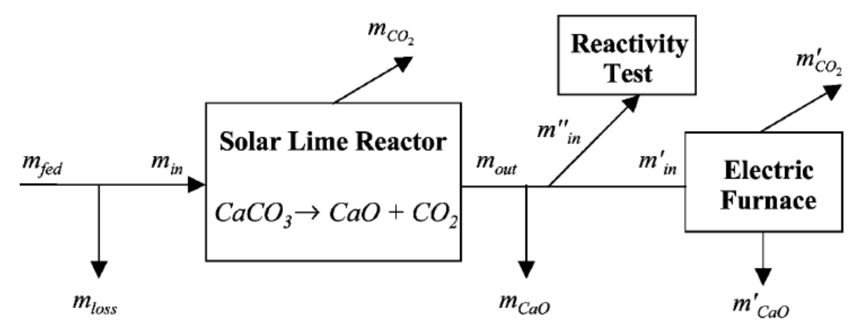
$$\acute{m}_{\ CaO} = \acute{m}_{\ in} - \acute{m}_{\ CO_2}$$

$$\acute{m}_{\ in} \leq m_{out}$$

$$\acute{m}_{\ CaCO_3} = {\acute{m}_{\ CaO}}/{0.5608}$$

$$LOI = 1 - \frac{0.5608\acute{m}_{\ in}}{\acute{m}_{\ CaO}}$$

ASTM C25.19



Kiln design- Degree of calcination

$$\alpha = \frac{LOI}{x_{CO_2}}$$

$$x_{CO_2} = stoichiometric\ fraction\ of\ CO_2$$

$$m_{in} = \frac{m_{out}}{1 - \alpha x_{CO_2}}$$

Over-all Process Efficiency

- Electric transmission losses are 10 % over 3000 km.
- Mirror efficiency is 0.61.
- Kiln efficiency is 0.45.
- 30 % of CaO remains active for about 20 cycles.
- Energy required to transport material over 6000 km is about 0.28 $\mathrm{MJ_{th}}$

Over-all Process Efficiency

$$\eta_{total}^{CSP} = \eta_{PP}\eta_{T} = 0.108$$

$$\eta_{total}^{ETS} = \frac{E_{electric}}{E_{Q_{solar}} + E_{transport}}$$

$$\eta_{S-C} = \eta_{mirror}\eta_{kiln} = 0.27$$

$$E_{th,solar} = \frac{E_{electric}}{\eta_{PP}} = \frac{1\ MJ}{0.45} = 2.22\ MJ$$

$$n_{th,solar} = \frac{E_{th,electric}}{\Delta H} = \frac{2.22\ MJ}{0.171\ MJ/mol} = 13.0\ mol\ CaO$$

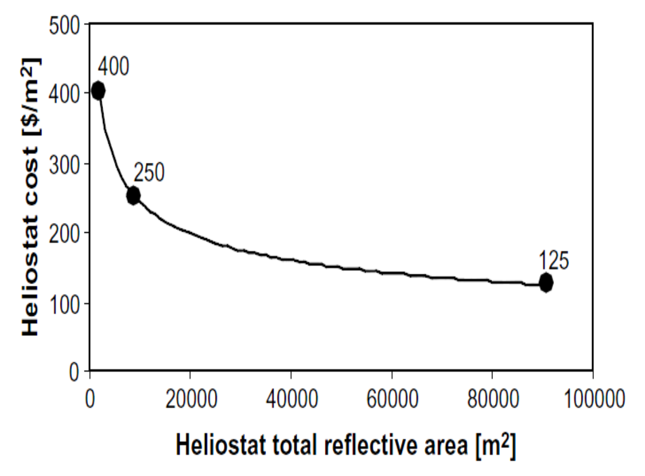
Over-all Process Efficiency

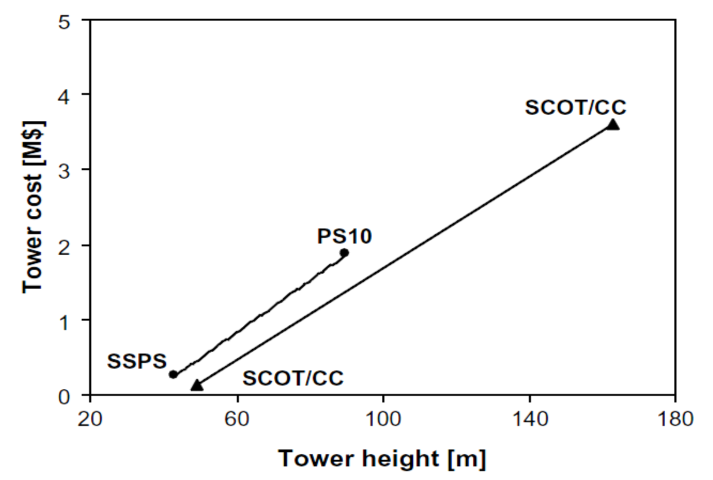
$$n_{req} = \frac{n_{th,solar}}{X_{max}} = \frac{13.0\ mol}{0.3} = 43.33\ mol\ CaO$$

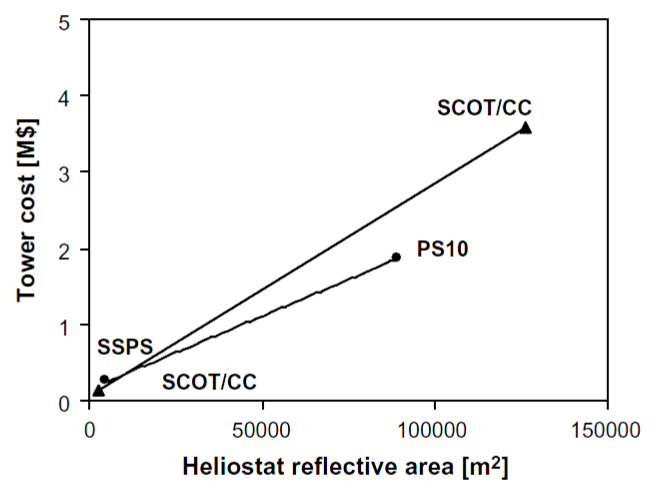
$$E_{Q_{solar}} = \frac{1}{\eta_{S-C}}\left(n_{th,solar} \times \Delta H\right) = \frac{1}{0.27}\left(13\ mol \times 0.168\,\frac{MJ}{mol}\right) = 8.09\ MJ$$

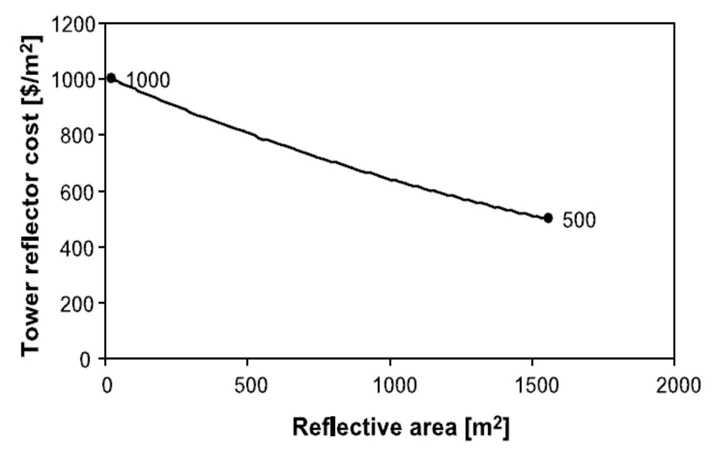
$$\eta_{total}^{ETS} = \frac{1\ MJ}{8.09\ MJ + 0.28\ MJ} = 0.119$$

Economic Evaluation

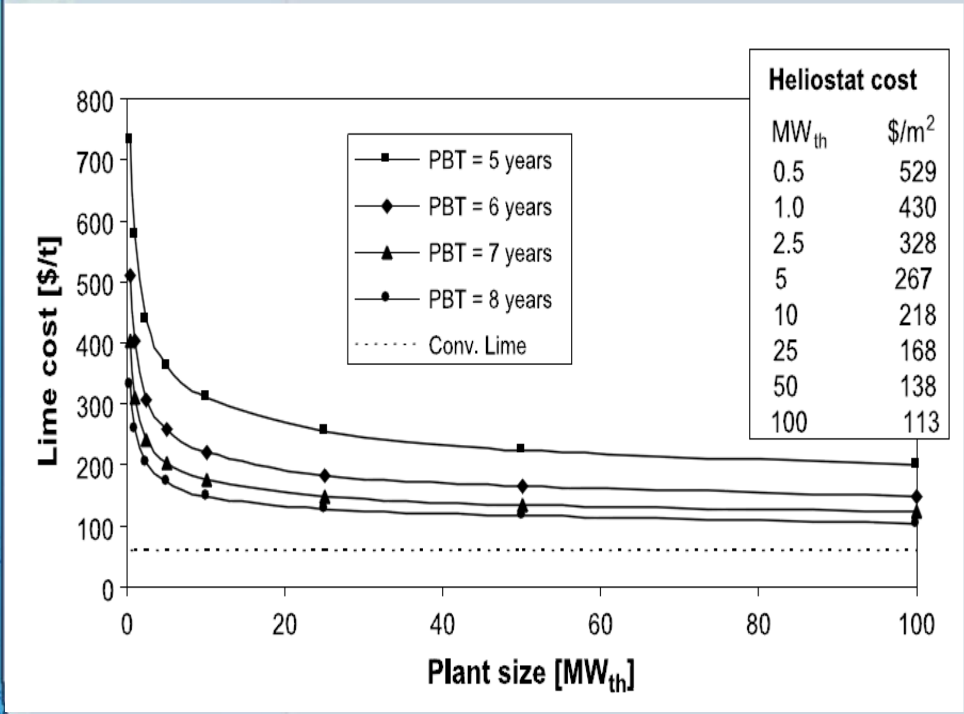






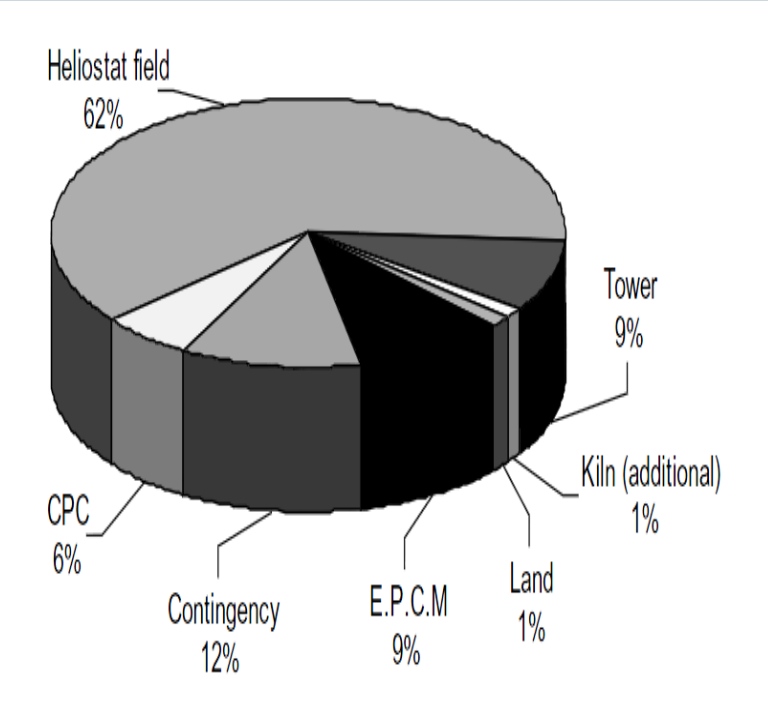


Economic Evaluation



Heliostat cost

MW$_{th}$	$/m^2
0.5	529
1.0	430
2.5	328
5	267
10	218
25	168
50	138
100	113

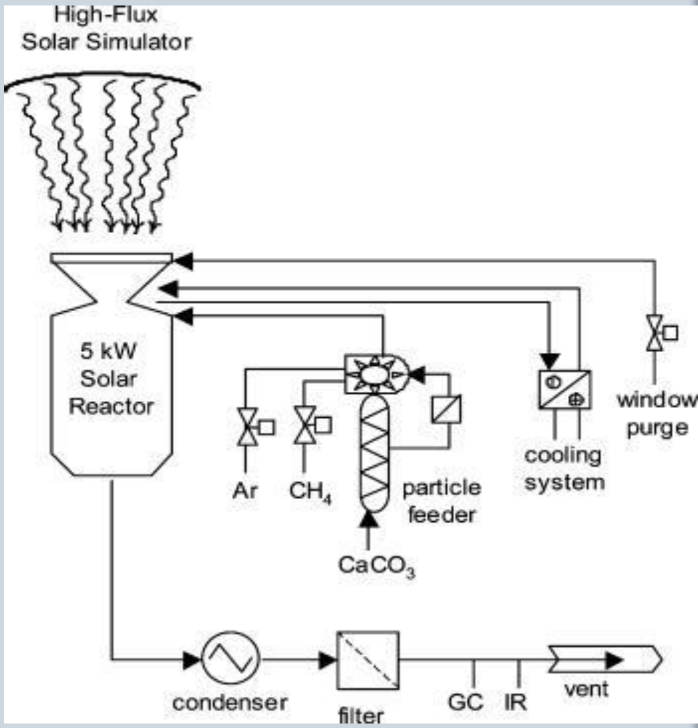


Improvement of Process
Co-generation of Lime and Synthetic Gas

$$CaCO_3 = CaO + CO_2 \quad \Delta H_{298K}{}^{\circ} = 164.9\ \mathrm{kJ\ mol^{-1}}$$

$$CH_4 + CO_2 = 2CO + 2H_2 \quad \Delta H_{298K}{}^{\circ} = 247\ \mathrm{kJ\ mol^{-1}}$$

$$CaCO_3 + CH_4 = CaO + 2CO + 2H_2 \quad \Delta H_{298K}{}^{\circ} = 425.2\ \mathrm{kJ\ mol^{-1}}$$



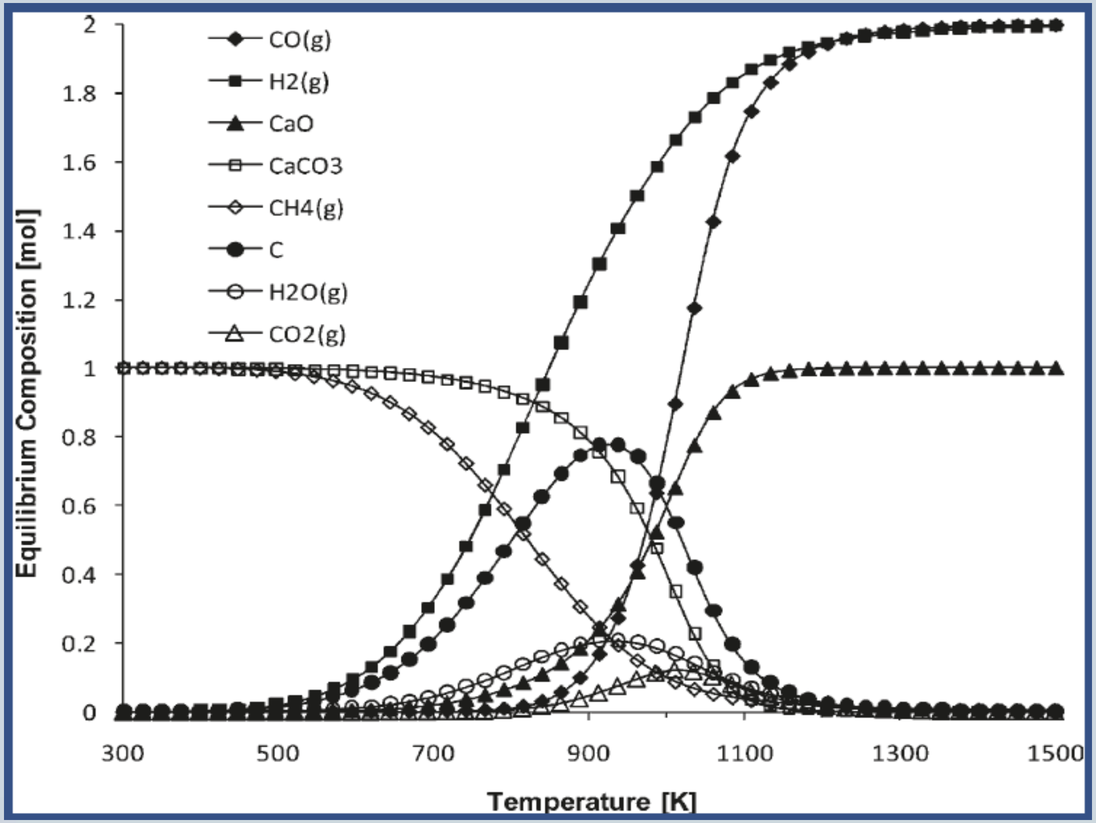
Improvement of Process
Co-generation of Lime and Synthetic Gas

Water – gas shift $H_2 + CO_2 \rightarrow H_2O + CO$

Boudoudard $2CO \rightarrow CO_2 + C$

CH_4 Decomposition $CH_4 \rightarrow 2H_2 + C$

C Gasification $C + H_2O \rightarrow H_2 + CO$



Limitation and disadvantages

- Large amount of $CaCO_3$ is required for the feasible process.
- CaO gets deactivated when used for multiple cycle for CO2 absorption.
- Transportation of CaO to power production unit and $CaCO_3$ back to solar production site an issue to be considered.
- CO_2 produced during calcination requires efficient mitigation strategy.

Advantages

- Better efficiency can be achieved for the power production unit.(Efficiency 0.43-0.46)
- Better heat utilization is possible(heat utilization factor 0.8-0.9)
- CO_2 produced during calcination can be used to produce synthetic gas.

References

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Thank you